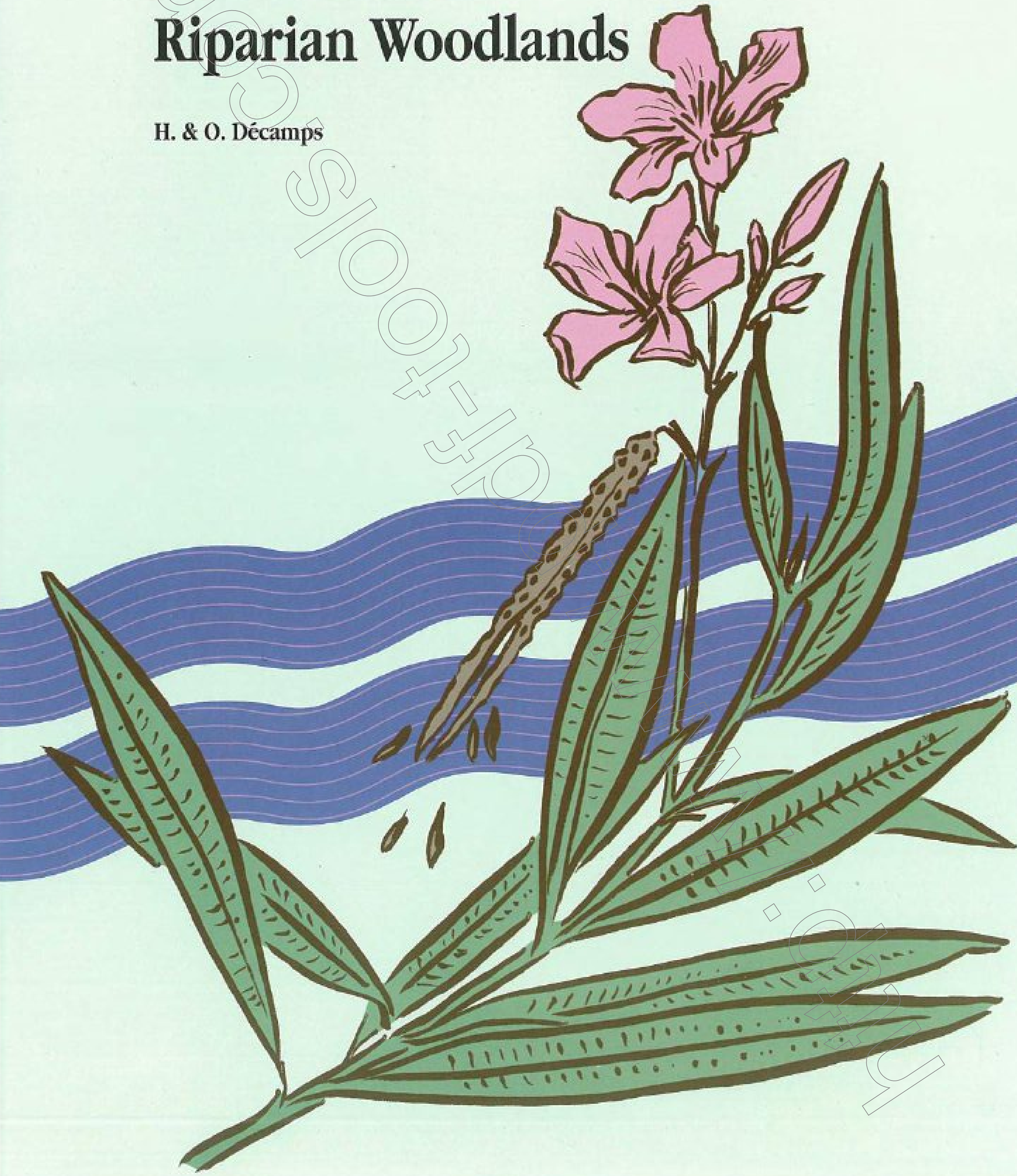
MedWet

Conservation of Mediterranean Wetlands

Mediterranean Riparian Woodlands

H. & O. Décamps



MedWet

The MedWet initiative

The Mediterranean basin is rich in wetlands of great ecological, social and economic value. Yet these important natural assets have been considerably degraded or destroyed, mainly during the 20th century. MedWet is a concerted long-term collaborative action, launched in Grado, Italy in 1991, to stop and reverse this loss and to ensure the wise use of wetlands throughout the Mediterranean.

The MedWet initiative is guided by the Mediterranean Wetlands Committee (MedCom), under the umbrella of the Ramsar Convention on Wetlands, which brings together 25 governments from the region, the European Commission, the Barcelona and Bern Conventions and international NGOs. It seeks partners and funds for implementing the Mediterranean Wetland Strategy, which includes conservation actions in wetlands of major importance in the region (especially Ramsar sites) and the promotion of national wetland policies, which take account of wetland values during the planning process. MedWet also provides a forum for regional exchange of experience at a technical level and publishes a range of wetland management tools with financial support from the European Union.

The concept of MedWet and its importance for promoting wise use of Mediterranean wetlands has been unanimously endorsed by the Contracting Parties to the Ramsar Convention on Wetlands.

The MedWet publication series

Wetlands are complex ecosystems, which increasingly require to be managed in order to maintain their wide range of functions and values. The central aim of the MedWet publication series is to improve the understanding of Mediterranean wetlands and the policy issues that surround them, and to make sound scientific and technical information available to those involved in their management.

Henri and Odile Décamps
Mediterranean Riparian Woodlands
Conservation of mediterranean wetlands - number 12
Tour du Valat, Arles (France), 140 p.

Titles of the collection:

1. Characteristics of Mediterranean Wetlands
2. Functions and Values of Mediterranean Wetlands
3. Aquaculture in Lagoon and Marine Environments
4. Management of nest sites for Colonial Waterbirds
5. Wetlands and Water resources
6. Aquatic emergent Vegetation, Ecology and Management
7. Conservation of Freshwater Fish
8. Vegetation of temporary Marshes, Ecology and Management
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12. Mediterranean Riparian Woodlands

Conservation of Mediterranean Wetlands
MedWet

Mediterranean Riparian Woodlands

Henri and Odile Décamps

Number 12

Series edited by A.J. Crivelli and J. Jalbert

Preface

Over the past decade or so, watercourses with a torrential regime around the Mediterranean Sea have experienced numerous devastating floods with serious consequences in many countries. In France alone, there was the Ouvèze at Vaison la Romaine and the Aude near Carcassonne; there have been similar events in Italy, Spain and, more recently, Algeria.

Obviously these are not new phenomena but, occurring as they do after a long period of neglect of watercourses, and in an age that no longer tolerates the unexpected, they have triggered a broad awareness on the part of the public authorities in several countries. Scientific research has helped to further understanding of the functioning of these watercourses, which are prone to rare but violent flooding, making them all the more dangerous.

Today, experts have reached important practical conclusions: it is imperative that flood-prevention measures respect the natural functioning of watercourses. It is now clear that the "flow" of sediments, coarse or fine, must not be impeded (sediment transport) and that the natural vegetation of river banks (riparian woodland) plays an important role, both under normal conditions and during periods of flooding. This booklet will easily convince its readers of this.

We now know that it is vital to preserve natural riverside habitats, especially riparian woodlands. Yet in most cases, in France as in many Mediterranean countries, these rich, dynamic plant communities are in private hands. They are in the safekeeping of property owners who do not necessarily have adequate knowledge for a proper understanding of their responsibilities. So it is important to inform them of the necessity of keeping riparian woodlands in good, functional condition. It is also important to encourage the necessary rehabilitation of riparian woodlands or even their restoration if these woodlands are no longer present, which is sadly all too often the case.

It is with this aim in mind that the Conseil Général du Vaucluse, with the collaboration of the Conservatoire Botanique National Méditerranéen de Porquerolles, has initiated various research projects into the reproduction of riparian plants. On the banks of the River Ouvèze, at Beauregard, an experimental area has been set up containing an arboretum of the plants of the local riparian woodland. The Conseil Général would like the experiments carried out there in the years to come to be useful for all those wishing to rehabilitate or restore riparian woodlands: riverside property owners along Mediterranean rivers; public authorities in charge of the protection of populations against the risks of flooding or in charge of the protection of natural habitats.

The plants used in these experiments are all obtained from seeds or cuttings from plants of strictly local origin, with a great genetic diversity within each species. The long-term aim is to obtain entirely natural woodlands, so that these very valuable habitats can be restored.

These will be important contributions to the defence of "ordinary nature" i.e. non-protected habitats; as well as to the defence of local populations against flooding.

I would like to praise the quality and tremendous scientific rigour of the work of Henri and Odile Décamps, as well as the recognised competence of the Tour du Valat and the Conservatoire Botanique Méditerranéen de Porquerolles which have enabled this timely booklet to be produced.
I congratulate and thank them most sincerely.

I hope that their work will contribute to the improvement of management of Mediterranean watercourses, in France and in all other countries on the shores of the Mediterranean.

Claude Haut
President of the Conseil Général,
Senator for Vaucluse
France

Mr Haut was mayor of Vaison la Romaine during the catastrophic flood of 1992.

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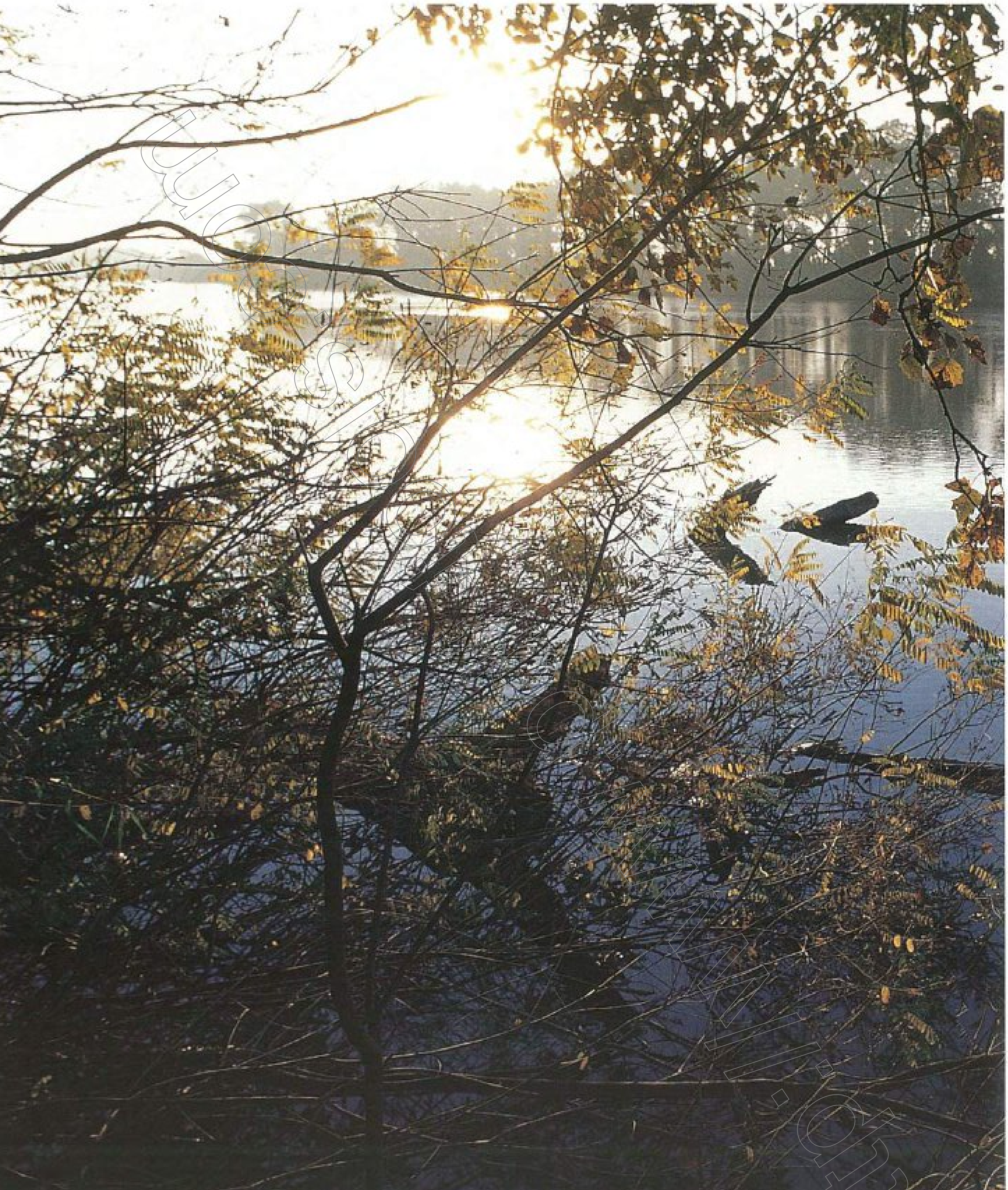


Daniel Heuclin/Bios

Introduction

Riparian woodlands are distinctive components of Mediterranean landscapes. As natural forests of riverbanks, they form major linear features along hydrographic networks and spread out to a greater or lesser extent at various points along their courses: they form sometimes modest bankside woodlands bordering minor watercourses, while in other locations they form genuine alluvial forests, complex and diverse. Their existence depends on the presence of groundwater not very far below the surface and on periodic flooding.

The distinctive character of riparian woodlands derives from the fact that their dynamics are regulated principally by the hydrological regimes of watercourses. Flooding modifies riverbanks, with varying

Fluvial landscape

frequency, creating changing mosaics of interlinked plant communities. Each of these communities represents one of many stages of vegetation development, from pioneer through to maturity, which constitute riparian vegetational succession.

The schematic model shown in figure p. 11 describes how this dynamic can be represented. Pioneer communities, dominated by herbaceous species whose height is dependent on the richness of the soil, develop on alluvium recently deposited by flooding. Gradually, as the conditions become less aquatic through sedimentation, they give way to communities of early and late pioneer species as well as later successional species, passing from willows and alders to poplars, then to oak-ash, and finally to mixed oak woodlands which are not affected by flooding. This sequence can take some thirty years, over which time the ground level is raised by sedimentation depending on water levels in the watercourse. At any time, but with decreasing frequency as the sequence progresses, further flooding may, through erosion, return any given stage – pioneer or later successional stages – to the starting point.

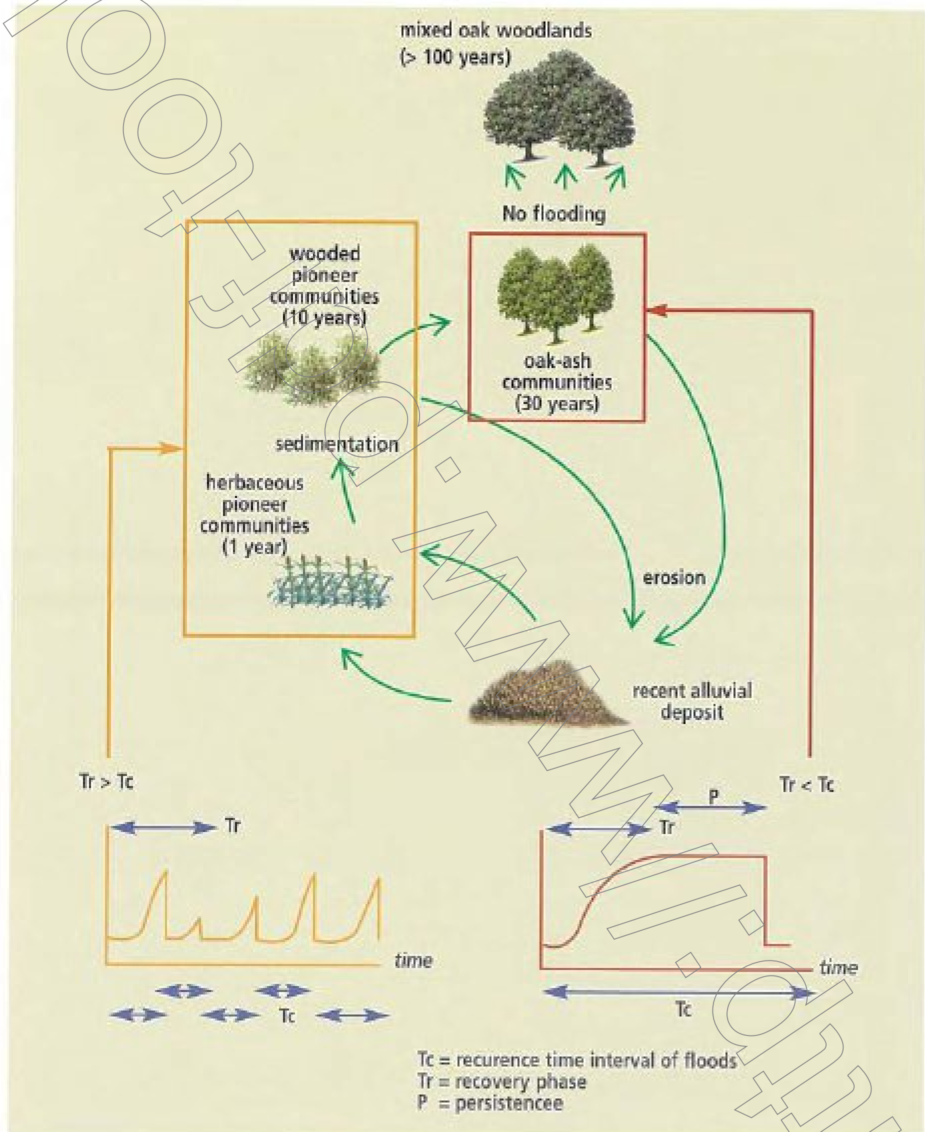
Two notable characteristics of this sequence may be highlighted here. Firstly, this periodic "rejuvenation" depends principally on existing hydrological regimes. Frequent floods will maintain a community at the pioneer stages; infrequent flooding allows the sequence to reach its end point, namely a dominance by later successional species. Secondly, different stages of the sequence coexist, forming mosaics of juxtaposed and changing components. This heterogeneity of riparian systems accounts to a great extent for their biodiversity.

The development of human activities has of course, over a long period, considerably reduced the areas in which riparian woodland dynamics are played out. Nevertheless, some of these areas have been conserved and sometimes restored. Moreover, the Mediterranean riparian woods merit all the more attention in that, from the point of view of biodiversity, they represent hotspots in a region – the Mediterranean – which has itself been identified as one of the 25 biodiversity* hotspots on the scale of the entire planet[1].

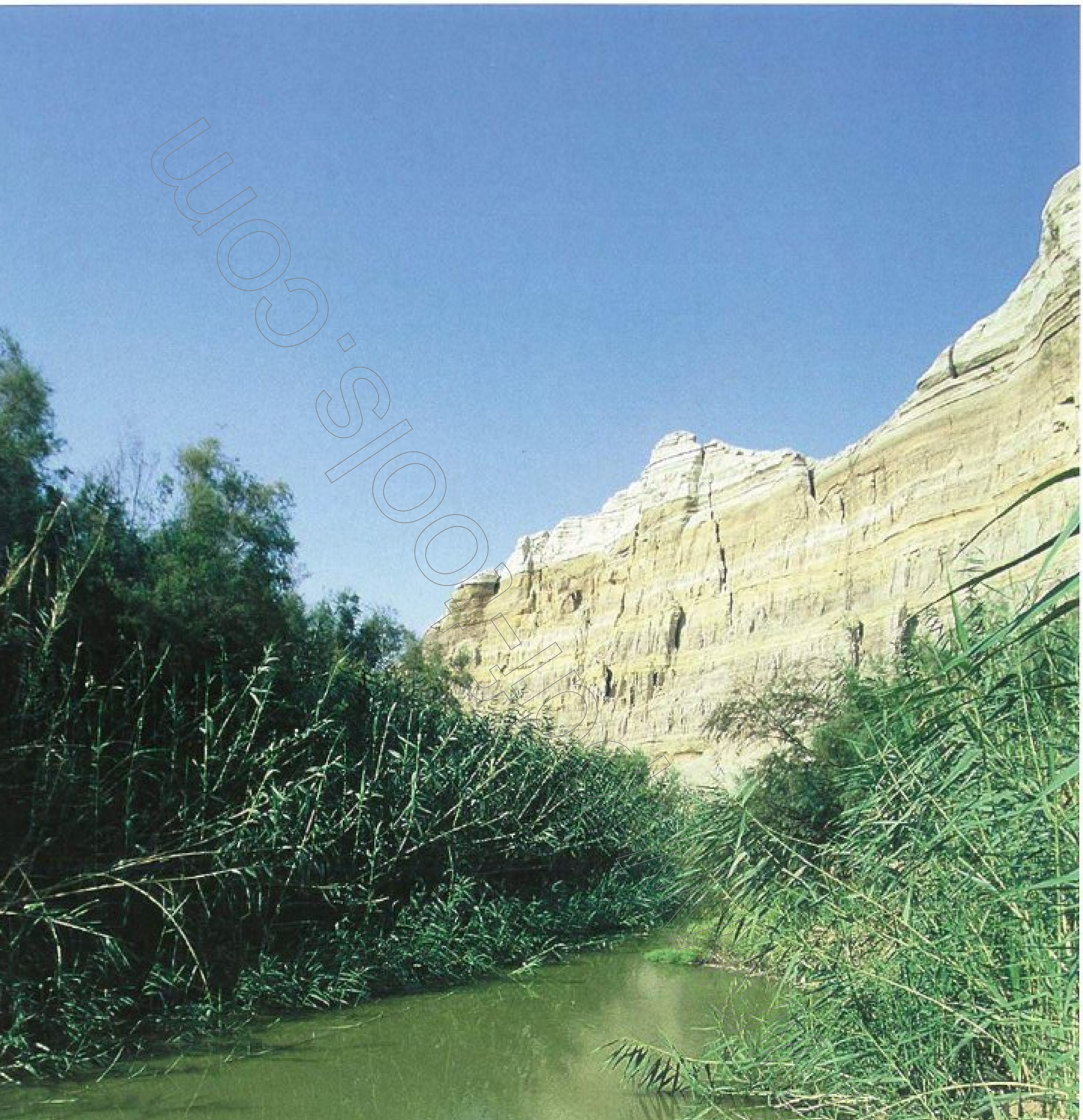
In this publication, Mediterranean riparian woods are firstly placed in their regional bioclimatic context (chapter 2). They are then considered from the point of view of their heritage interest (chapter 3), their ecological aspects (chapter 4), their integration into the landscape (chapter 5), and finally their restoration and upkeep (chapter 6). The conclusion returns to the subject of these Mediterranean riparian woodlands' distinctive character in the context of the management of water, land and landscapes.

1 - Myers et al. (2000)

This work has benefited greatly from the advice and recommendations of Nadia Barsoum, François Boillot, Alain Crivelli, Maurice Desagher, Jean-Pierre Roux and Robert J. Naiman. In addition, Maya Abboud, Maurice Desagher, Serife Gunduz, Jala Makhzoumi, Jean-Pierre Roux, Kostas Vitoris and Reuven Ortal prepared some of the boxes. They are all warmly thanked.



Vegetational successions on riverbanks as a function of hydrological perturbation regimes along the watercourses. The pioneer communities, frequently perturbed by floods, exhibit a greater instability than later successional communities, which are less frequently perturbed (after Décamps & Tabacchi 1994).



Doron Nisim

The Mediterranean context

At first sight, the definition appears straightforward: Mediterranean riparian woods run alongside watercourses which flow directly or indirectly into the Mediterranean sea. However, these watercourses arise mainly in the mountain ranges which encircle the Mediterranean Basin. Some of them even originate outside the region. This is true of the three largest: the Ebro River, originating in the Pyrenees, and the Po and Rhône Rivers flowing from the Alps (see table p. 14) (the Nile, which is more African than Mediterranean is not included). It is necessary then, in the first place, to define the Mediterranean region.

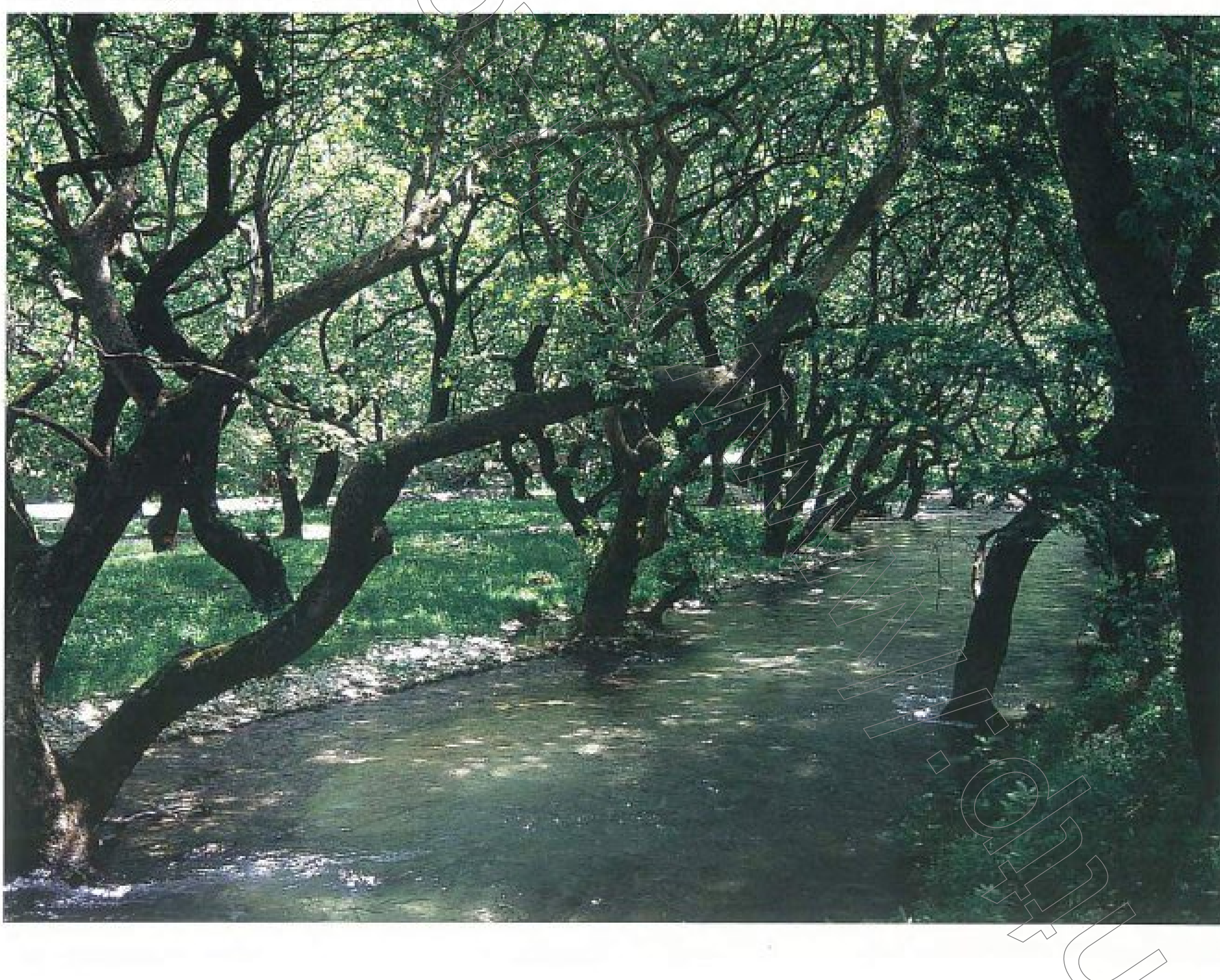
The Jordan River

	Ebro	Po	Rhône
area of basin	82 593 km²	76 987 km²	100 531 km²
population density	38/km²	215/km²	97/km²
large cities (1)	5	12	12
Ramsar sites	4	9	4
forests	10 %	14 %	11 %
cultivation	57 %	48 %	61 %
developed areas	16 %	22 %	21 %
shrub	14 %	8 %	3 %
grassland	2 %	3 %	2 %
eroded areas	8 %	5 %	5 %
large dams (2)	1	8	10

(1) > 100,000 inhabitants in built-up area ; (2) dams > 15 m high or reservoirs > 1 km^3.

Characteristics of the three largest Mediterranean river basins, excluding the Nile (after Revenga *et al.* 1998).

Gallery forest along the river Louros, south-west Greece



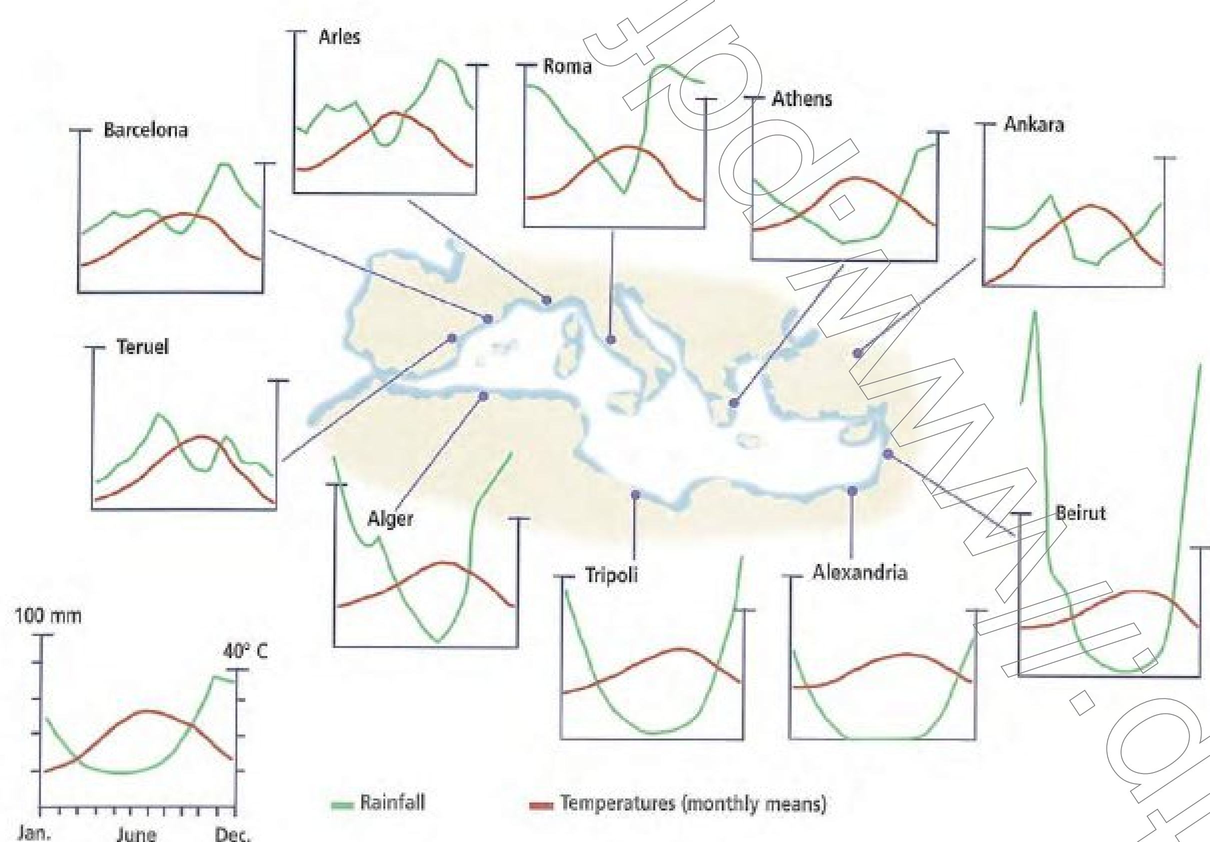
Jean Roché

A bioclimatic approach

Various methods have been proposed to define the Mediterranean region. The one best suited to our purposes calls for a bioclimatic approach; that is to say a combination of climatic conditions and species composition of vegetation.

With regards to climate, pluviothermic diagrams clearly demonstrate the temperature and rainfall regimes of the Mediterranean region see figure below Rainfall distribution is characterised by a summer low, with dry months when rainfall is, according to convention, less than twice the air temperature (Pmm < 2T). The Mediterranean flora therefore include thermophilic* species, which tolerate only mild winters and are adapted to summer droughts as a result of features allowing for lowered transpiration rates; i.e. no or fewer leaves, a thickened cuticle*, or distinctly glaborous. The leaves of some perennial species are shed at the beginning of summer and reappear in September. Annuals spend the summer at the seed stage.

Some ombrothermic diagrams of the Mediterranean Basin (after Grenon & Batisse 1988, modified).

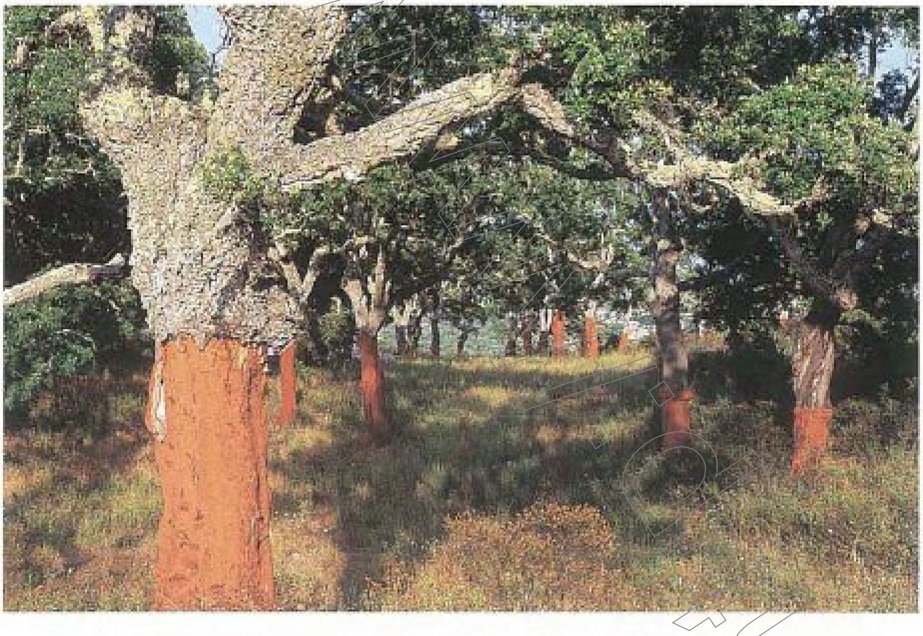


Regarding the vegetation, there are a number of zones which encompass the Mediterranean region, varying in altitude and latitude. These may be characterised by a number of indicator tree and shrub species[2].

• The infra-mediterranean zone occurs at the lowest altitudes and latitudes, in the hottest regions, for example in south-west Morocco where an endemic Acacia *Acacia gummifera* is found.

• The thermo-mediterranean zone lies in close proximity to the coasts. Characterised by the Wild Olive *Olea europea* var. *sylvestris*, the Locust tree or Carob *Ceratonia siliqua* and the Dwarf Fan Palm *Chamaerops humilis*, it may be found in the Nice area and, in general, to the south of a line between Barcelona and Smyrna (Izmir).

• The meso-mediterranean zone is predominantly situated to the north of the Barcelona-Izmir line. In theory, the Evergreen or Holm Oak *Quercus ilex* community is dominant here; this species may be replaced by other oaks *Quercus rotundifolia, Q. calliprinus*, for example in Spain and Greece. In reality, this vegetation has been highly degraded by fire and human exploitation. High forest is the exception here and coppice woodland is most common, often being replaced by maquis* or garrigue*. In the western basin, the Holm Oak is replaced by Cork Oak *Quercus suber* on siliceous soils; in the hotter regions human activities have favoured the development of Aleppo Pine *Pinus halepensis* and, in deeper soils, Stone Pine *Pinus pinea*. Olive tree *Olea europaea* var. *europaea*, Figs trees *Ficus carica* and vines *Vitis vinifera* are grown here.



Hugues Fougère/Bios

Cork oak

2 - Ozenda (1994) ; Blondel & Aronson (1999)

• The sub-mediterranean or supra-mediterranean zone is characterised by deciduous oaks, of which the main species is the Downy Oak *Quercus pubescens*, with which Maples *Acer* spp., Ashes *Fraxinus* spp. and, sometimes, Scots Pine *Pinus sylvestris* are associated. Although Olive trees are no longer cultivated, vines are still present on open slopes.

• The oro-mediterranean zone, corresponding to a highland zone, is characterised by various tree species: Scots Pine *Pinus sylvestris* and Juniper *Juniperus thurifera* in central Spain, Beeches *Fagus* spp. in Calabria and Sicily, Grecian Fir *Abies cephalonica* in Greece, and Cedars *Cedrus* spp. in North Africa. The Corsican Pine *Pinus laricio* grows on south-facing hillsides.

• The lower alti-imediterranean, corresponding to a subalpine zone, lies above the oro-mediterranean, with, among other communities, characteristic moorlands of spiny xerophytes.

• The upper alti-mediterranean, corresponding to an alpine zone, supports herbaceous communities, reminiscent of alpine meadows, in the higher parts of the Sierra Nevada in Spain and in the Moroccan High Atlas.

• At the very highest altitudes, a cryo-mediterranean flora may develop in areas virtually devoid of vegetation apart from a few species such as saxifrages growing amongst the rocks.

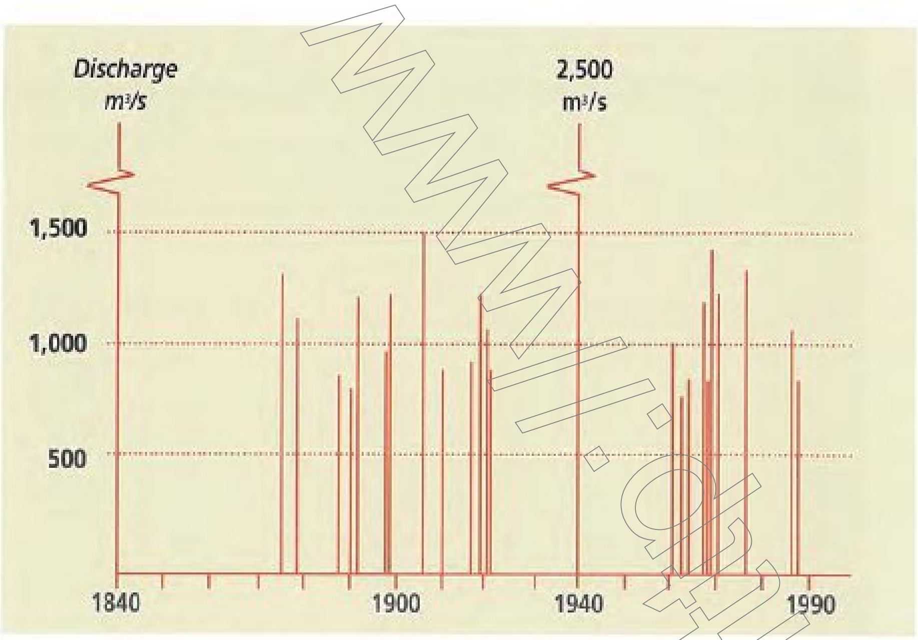
Mediterranean riparian woods cut across these vegetation zones. They grow, similarly to the other vegetation, in a climate characterised by dry summers and mild winters although since they lie along watercourses, they are partly shielded from the surrounding dry conditions. Similar woodlands develop under the same climatic conditions in other parts of the world: in California, Chile, Australia and South Africa. There is the possibility therefore of using results obtained in these areas to understand the characteristics of Mediterranean riparian woodlands.

Hydrological variability

The rivers around the Mediterranean perimeter are characterised by wide variability. The Tech provides a typical example.

This small coastal river rises at an altitude of 2400 metres in the Pyrenean massif of the Canigou and, after flowing for 83 km, reaches the sea south of the town of Perpignan. There is significant within-year variation between the extreme monthly flow rates: 15.4 m^3/s in May and 1.6 m^3/s in September, that is a ratio of 9.6:1, in the Roussillon Plain just upstream of the river mouth. The minimum flow rate can decline further to 0.10 m^3/s, that is a specific flow rate of 0.13 $l/s/km^2$ over consecutive five-day periods in August, again in the Roussillon plain.

However it is the history of flooding which best illustrates the variability of flow in the Tech. A history which has witnessed an exceptionally severe flood in October 1940 (see figure below). After a series of major floods around the turn of the 20^{th} century, the 1940 flood came at the end of a dry period which had prevailed since 1922. It was marked by water depths of over 12 to 13 metres, by average speeds of 8 m/s and by flow rates of 2500 m^3/s at the level of the village of Céret, at an altitude of around 150 metres (this for a catchment area of 487 km^2). Scouring, landslides and erosion led to sediment deposition: parts of the middle reaches growing to heights of 5 to 15 metres, and at one point up to 21 metres.



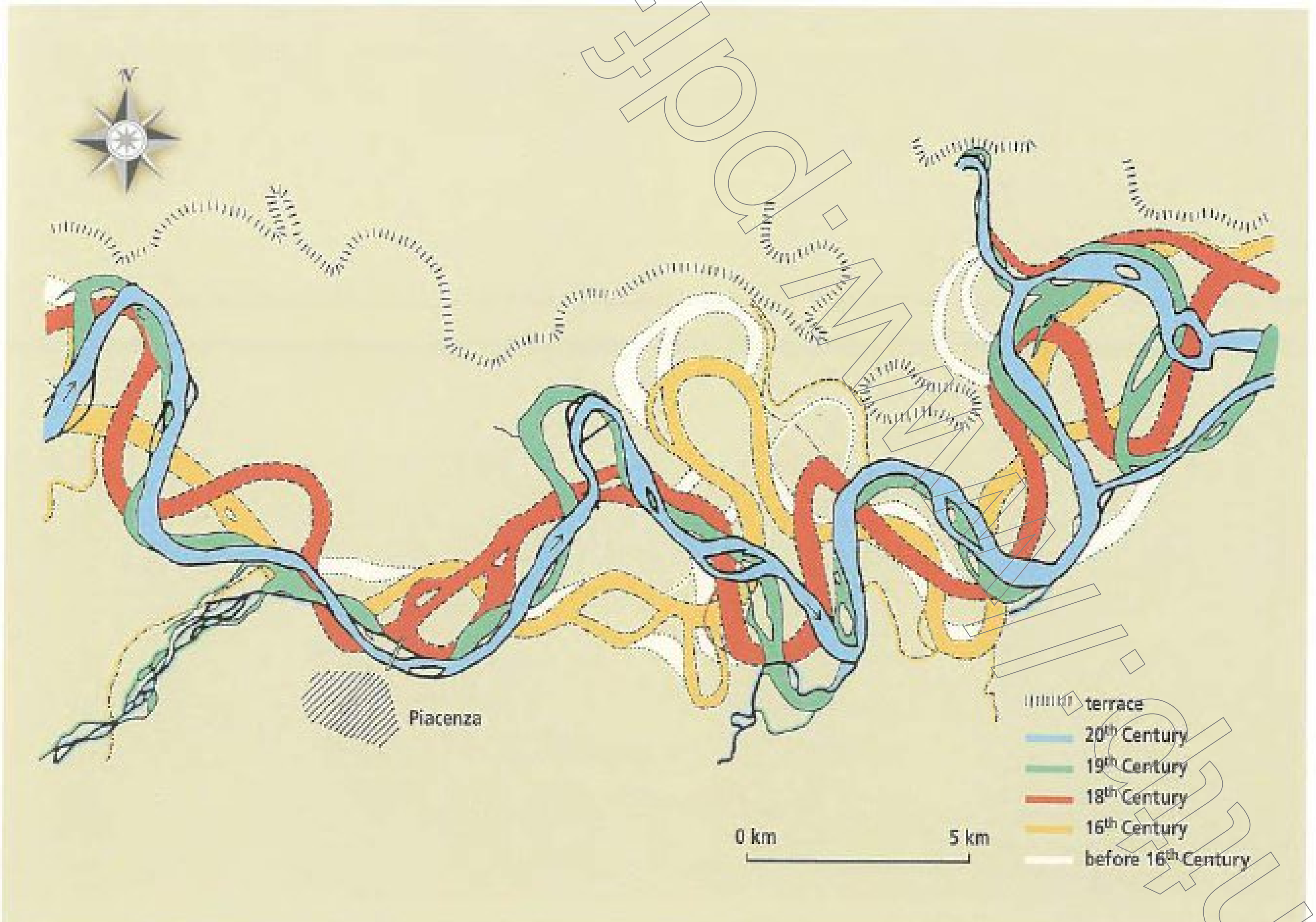
The Tech: history of floods observed at the Pont du Diable at Céret between 1840 and 1990 (floods of more than 700 m^3/s) (after Lalanne-Berdouticq 1990, modified).

Edwards/Still Pictu/Bios

The Po River

As a result of this hydrological variability there is a corresponding variability in the courses of the rivers, as is shown for example by the Po River, whose changes have been reconstructed very precisely, with downstream displacement of loops, repositioning of meanders, decreases in the radii of curves, and migrations of tributary confluences (fig. below).

Evolution of the Po River course in the Piacenza region between the 16th and 20th centuries (after Braga & Gervasoni 1983, modified).

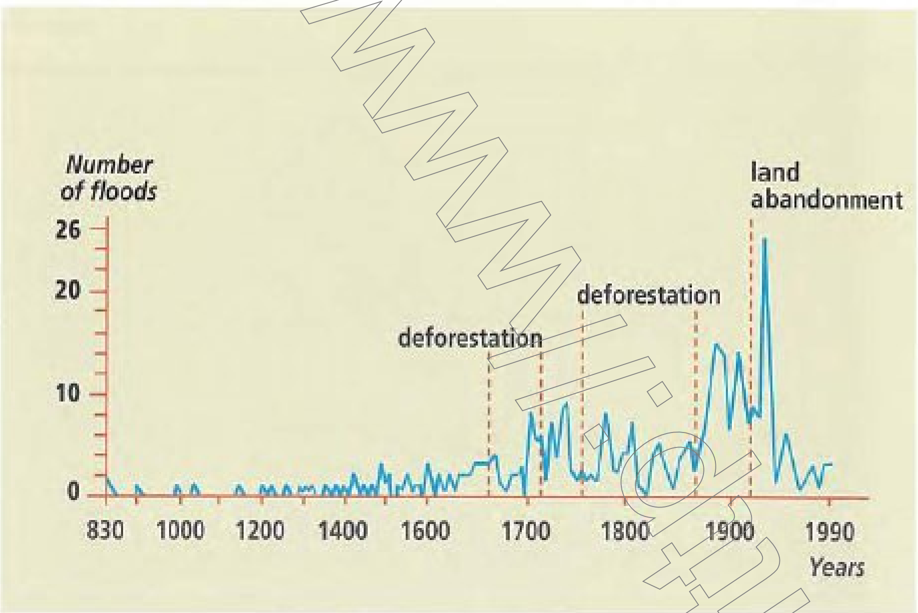


Soil erosion

It must be emphasised from the start that erosion is a natural process, sporadic and variable in space and time. It increases at certain times, as is revealed by dating of layers of sediment deposits in terraces and deltas, and this probably is a consequence of torrential rains associated with climatic variations, as in the 13th and 19th centuries[3].

Over the course of the second half of the 20th century, the scale of erosion has increased, as bulldozers shift sediment for the purposes of re-forming cultivated land, road-building, and various earthworks. This increase in erosion affects all the Mediterranean regions. Rain often arrives when the ground is dry, causing scouring, landslides and mud flows. These phenomena are all the more destructive in that they affect soils which are poor in organic matter, and have been transformed by deforestation, agricultural practices, fire and/or overgrazing.

Scouring (gully erosion) is a major process leading to the degradation of Mediterranean soils. It is largely to blame for the silting up and infilling of reservoirs. In addition to scouring other sources of erosion include: ploughing, trampling by livestock and earthworks. In some regions deforestation coincides with an increase in the frequency of floods, for example in the Segura Basin in Spain (see figure below).

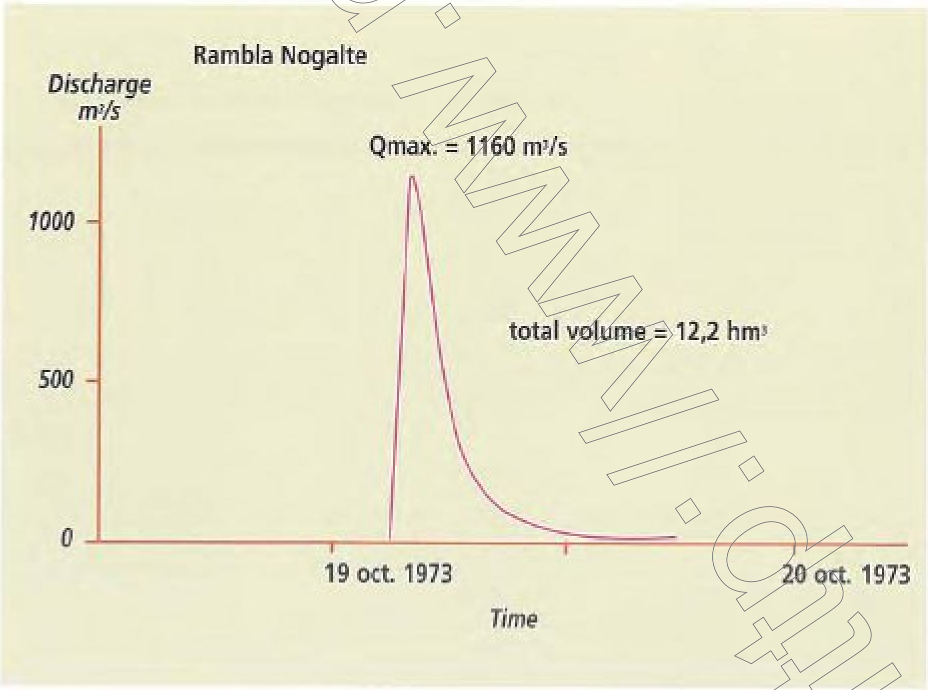


Changing frequency of floods on the River Segura in south-east Spain (after Molina Sempere *et al.* 1994, in Poesen & Hooke 1997).

3 - Grove & Rackham (2001)

Mediterranean floods are sudden and brief (see figure below). They transport enormous quantities of sediment in a few hours: concentrations can be 10 to 100 times greater than in wetter regions[4]. Thus, movements of sludge have characterised all the catastrophic floods of recent years: in Catalonia in 1940, in Florence in 1966, in south-east Spain in 1973, at Almeria 1980, at Vaison la Romaine in 1992, at Biescas in 1996, at Algiers in 2001. Under the impact of these floods, the channels become braided, banks unrecognisable, and some islands disappear while others are created where there are accumulations of gravel, especially in the middle catchment reaches.

In general, the severest bank erosion occurs during the most violent floods, but the effects vary according to the way in which hydrological events succeed one another in time. Thus, a high-intensity flood may simply destabilise a bank without eroding it, while subsequent floods of lesser intensity may activate the process of erosion. The presence of a top layer of bankside vegetation may have the effect of facilitating the deposition of sediments.



Change in flow through the course of a Mediterranean flood: the example of Rambla Nogalte, south-east Spain (after Navarro Hervás 1991, in Poesen & Hooke 1997).

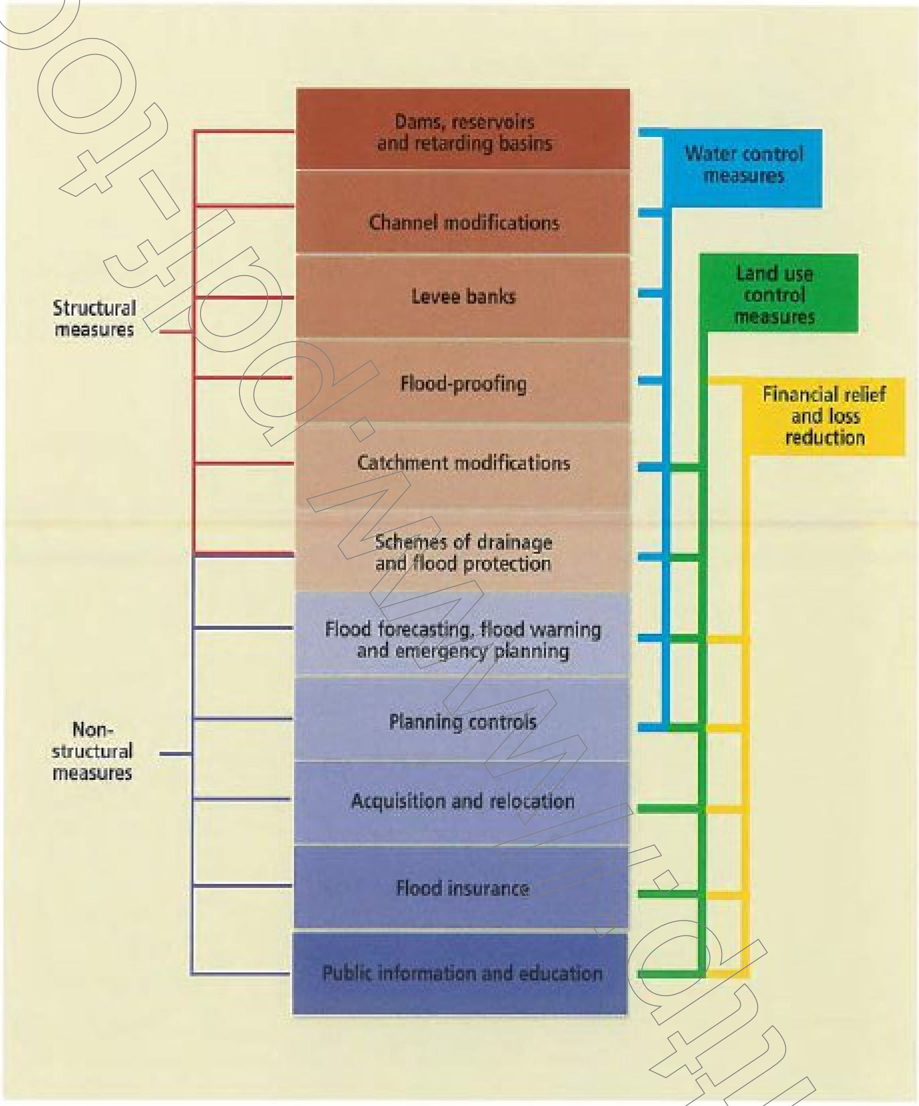
4 - Laronne & Reid (1993)

Flood control

At any time, but above all in autumn and spring, sudden rainfall in Mediterranean regions will lead to a swelling of dried-out rivers, sweeping away of sediment from river beds and banks, causing damage to infrastructure (e.g. bridges, embankments) all the way to the sea.

The control of floods has always preoccupied humans, giving rise to two types of solution[5]; those involving modification of the structure of rivers, and those that do not (see figure below).

Measures affecting river structure (construction of reservoirs, balancing lakes, creation of flood-banks etc.) pose particular problems in the



Methods of controlling floods, either involving or not involving change to the structure of rivers (after Poesen & Hooke 1997).

5 - Poesen & Hooke (1997)

Flood of the Golo Ponte Leccia River, Corsica

J.J. Alcalay/Bios

Mediterranean region. The accumulation of sediments actually accelerates the filling-in of reservoirs, sometimes in a spectacular way. It may also increase the erosive power of floods, deprive downstream areas of sediment, and leave estuaries open to the influence of the sea. In the Ebro Basin, the rate of transport of sediments to the sea is now only 1% of what it used to be before the construction of dams[6].

The other measures not involving changes to the structure of rivers rely on prediction, impact evaluation, public perception, communication and information. These measures are currently finding greatest favour among managers as they appear to respect the environment and are likely to be sustainable in the long term. They utilise the capacity of rivers to adjust to hydrological events which they have created. This is what managers mean by the expression "working with nature" as opposed to "working against nature". However, in the Mediterranean region another dimension has to be taken into account: managers must also learn to "work with culture" in order to conform both with the natural and cultural character of landscapes created through several centuries of history.

It is clear that the two different types of measure are not mutually exclusive. In some high-risk situations, dams are the only way of protecting people and property. What is essential is to also take alternative solutions into consideration; this requires a deep understanding of basic information encorporating rainfall data, soil dynamics, the effects of vegetation cover and the public perception of

6 - Guillen & Palanques (1992)

riparian landscapes. In the Mediterranean region, rivers have become ever more channelised and lands ever drier, more irrigated and increasingly urbanised. An integrated and holistic approach to flood control is therefore required. This approach must, as far as possible, promote solutions which do not affect the structure of rivers and which make use of comprehensive historical information to evaluate risks and mitigate impacts. Greater account must be taken of the strong spatio-temporal variability of flood impacts: for example, along a single watercourse, excess sediment loads upstream can lead to accelerated silting-up of reservoirs, while at the same time a downstream deficit can stimulate further erosion. To gain control over floods it is first necessary to understand the whole range of possible extreme events which may occur and probability of occurrence.

Ebro River at Sastago, Spain

Jean Roche

"Hydrogeoecological" partition

We have seen that the Mediterranean has its own characteristic hydrology, deriving primarily from specific climatic conditions, intermediate between those of the more temperate north and those of the drier south.

The hydrology of the Mediterranean is characterised by drought and heat in the summer, and by heavy rains in the autumn and, to a lesser extent, in the spring; rains are irregular, concentrated over a few days, and liable to cause catastrophic flooding. The hydrology of the Mediterranean also owes its character to the small or medium size of many of the river basins (see table below) : those of less than 10,000 km^2 make up almost 60% of the whole of the Mediterranean Basin[7]. This fragmentation is further accentuated by the presence of numerous islands.

Hydrographic fragmentation also affects subterranean, karstic and alluvial waters (see figure p. 26). The karstic aquifers* of calcareous massifs give rise to many springs, often with high flow rates. Alluvial aquifers are replenished both from adjacent karstic aquifers and from the rivers themselves. These two types of aquifer may discharge their waters directly into the sea via coastal or submarine springs. The sediment loads carried by rivers lead to the formation of deltas whose mosaic of aquatic and wetland environments is being constantly modified in response to changes in the river-borne supply regime.

Mediterranean river basins having an area greater than 10,000 km^2, excluding the Nile (after Margat 1992, modified).

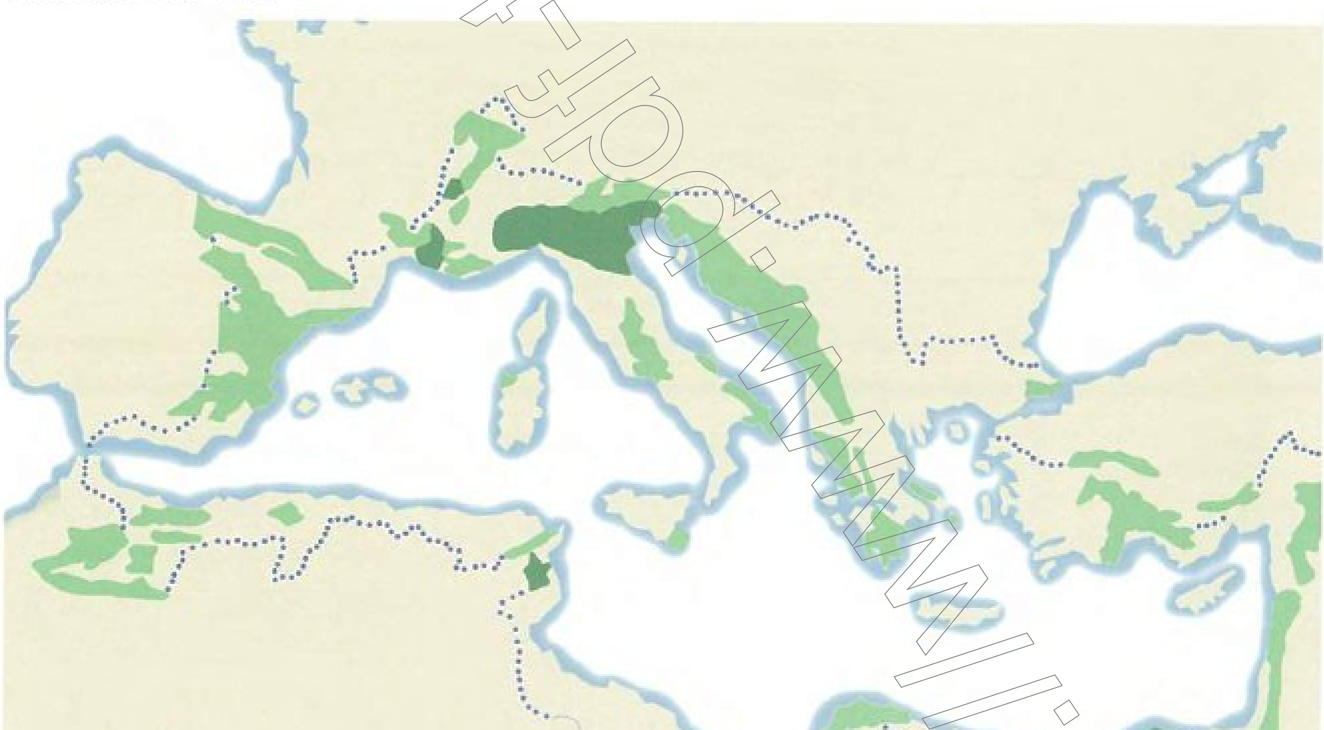
River	Catchment area (km^2)	Length (km)	Country
Rhône	98 845	812	France, Switzerland
Ebro	86 000	930	Spain
Po	70 090	676	Italy
Moulouya	53 700	450	Morocco, Algeria
Meric-Evros/Ergrenne	52 450	490	Bulgaria, Greece, Turkey
Cheliff	45 000	700	Algeria
Büyück Menderes	24 976	450	Turkey
Axios Vardar	24 662	388	Macedonia, Greece
Asi-Orontes	23 933	570	Syria, Lebanon, Turkey
Medjerda	23 700	484	Tunisia, Algeria
Ceyhan	21 982	509	Turkey
Seyhan	20 450	500	Turkey
Gediz	18 000	270	Turkey
Jucar	17 876	506	Spain
Tiber	17 169	405	Italy
Strymon-Strouma	16 533	430	Bulgaria, Greece, Macedonia
Segura	14 925	240	Spain
Neretva	12 750	275	Bosnia-Herzegovina, Croatia
Drin	12 368	151	Albania, Serbia and Montenegro
Adige	12 200	415	Italy

7 - *Margat (1992)*


Bruno Pambour/Bios

The river Sorgue downstream of Fontaine de Vaucluse

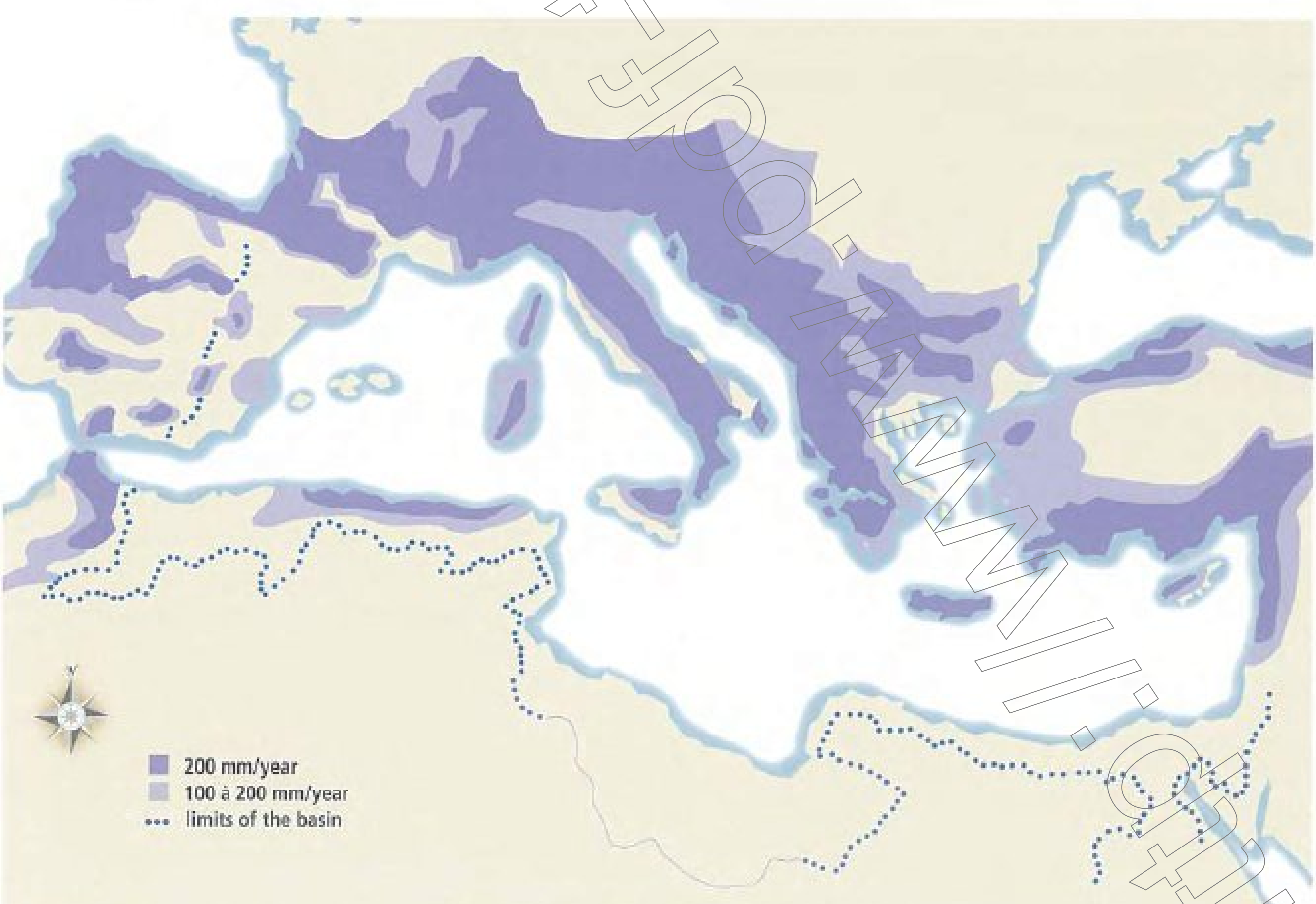
Subterranean waters in the Mediterranean Basin.
1: principal alluvial aquifers;
2: karstic carbonated aquifers
(after Margat 1992, modified).



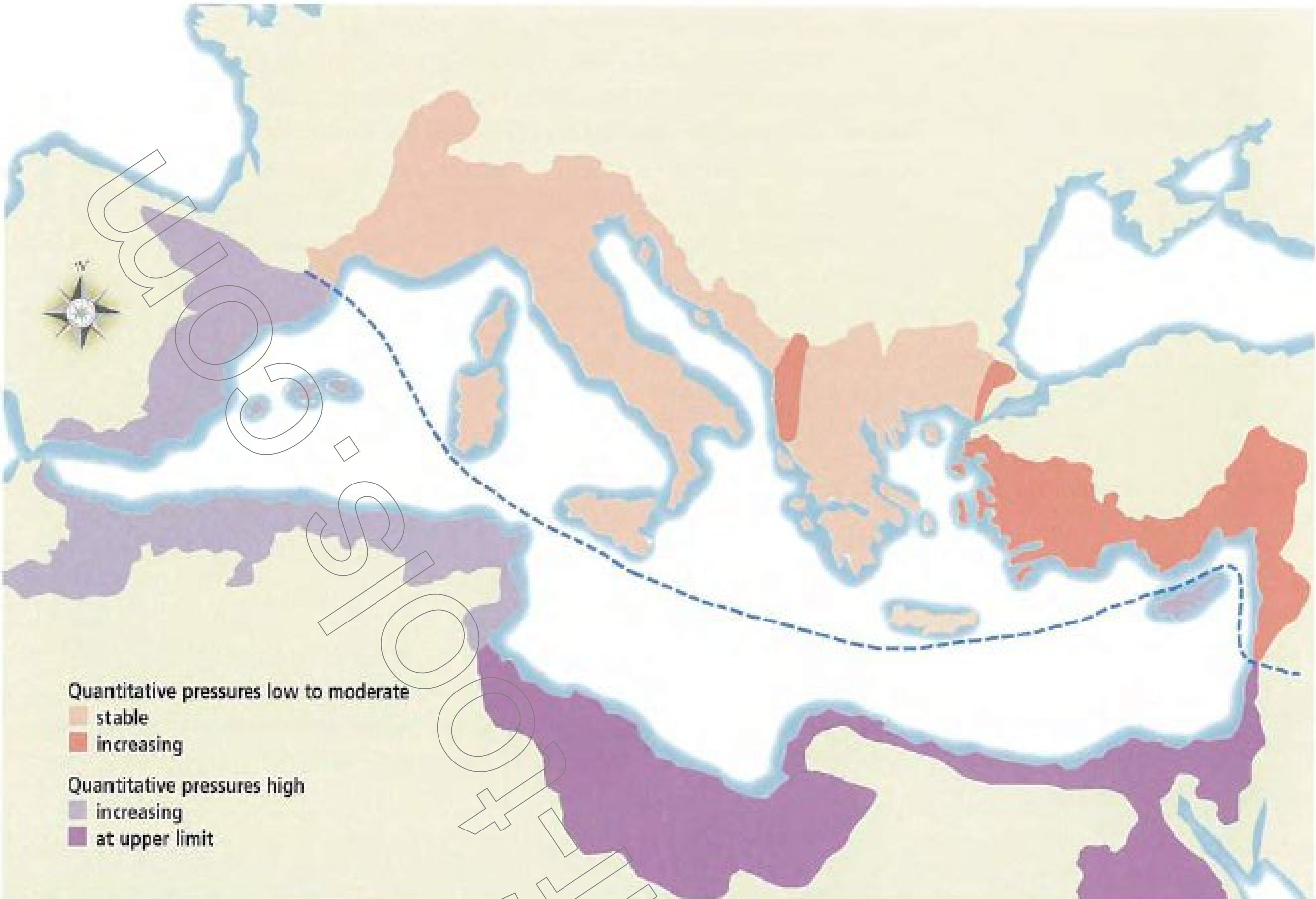
Although the whole Mediterranean region generally has similar hydrological characteristics, there are some strong contrasts, particularly between the north and the south of the Mediterranean Basin. These contrasts markedly affect discharge distribution. The figure below shows that the contrasts are more marked in the east, that desertic conditions extend up to the sea in the south-east, and that inputs of water decrease from the coast towards the interior in the Maghreb, the Levant and Anatolia, whereas on the other hand they increase in Spain, France, Italy and the Balkans. As a result there are very significant differences between the volumes of water received by the different countries.

These differences, as well as demographic and economic disparities, have implications for water basin management. They have allowed a "hydrogeoecological" partition of the Mediterranean Basin to be defined (see figure p. 28).

• In the north, needs are moderate in relation to the quantities present and, although local scarcity can always arise, it is hardly possible to imagine any real shortages occurring before 2025. Apart from security considerations, the priorities here lie more with the maintenance and



Distribution of mean annual potential discharge in the Mediterranean Basin (after Margat 1992, modified).



"Hydrogeoecological" partition of the Mediterranean Basin, comparing the north, where quantitative pressures on continental waters are low to moderate, with the south, where these pressures are high : the interrupted line separates northern and southern countries (after Margat 1992, modified).

restoration of water quality. However it is possible to distinguish between countries such as France, Italy, the former Yugoslavia and Greece, where water requirements are stable, and those such as Albania, Turkey, Lebanon and Syria, where requirements are increasing.

• In the south, needs are high in relation to the quantities present. They can still be met up to 2025 in Spain, Cyprus and the countries of the Maghreb provided that the infrastructure can be developed, but are no longer able to be satisfied by conventional means in Egypt, Israel, Libya, Malta and Tunisia. Here the priorities lie with saving water, imports of water, and making use of unconventional resources. The question of preserving water quality is a minor one compared with the problem of water quantity.

Subterranean waters: two-speed flows

Subterranean waters play an essential role in supporting rivers and riparian vegetation in the Mediterranean region. The underground movements of these waters have long been a mystery, giving rise to many myths and legends. We now know that subterranean waters flow at very different speeds according to whether they are running through calcareous massifs or sedimentary basins.

Calcareous massifs contain fissures which are enlarged by the process of karstification. Water from atmospheric precipitation seeps rapidly through from the surface before being discharged via numerous exits. The Fontaine de Vaucluse provides a well-known example. It forms the outlet of a vast underground karstified network, fed by precipitation distributed over an impluvium* of 1,100 km² which includes the massif of Mont Ventoux, the Lure mountain, the Albion Plateau and the mountains of the Vaucluse. The spring delivers on average 700 million m³ per year[8]. Experiments with dyes have provided an idea of the extent of water movements from different points in the massif and of the speed of these movements: the greatest distance travelled by a dye was 46 km (with a 25-day delay before emergence at the Fontaine de Vaucluse); the shortest time taken for water to emerge was 6 days, over a distance of 30 km.

Conversely, groundwater in sedimentary basins moves very slowly: it soaks through as if being absorbed by a sponge. The component materials of these basins are actually only slightly or very slightly permeable. The input of water takes place mainly at the edges, where permeable layers commonly outcrop. Infiltration is thus favoured by any realignment of these layers, and rainwater already present is forced towards the centre of the basins by new precipitation. The water-bearing layer is structured in accordance with the precipitation: the age of the water infiltrating from the edges increases towards the centre of any given basin. Carbon-14 dating shows that throughput is extremely slow, so much so that the water sampled from some deep drilling could have fallen as rain during the era of prehistoric man.

8 - Truc (1991)

Jacques Blondel

Woodlands of heritage interest

For some years riparian woodlands have aroused the interest of the scientific community and increasingly of the wider public. They are habitats worthy of investment in a broad sense, including financial. They are now considered to be of interest from the cultural heritage point of view, a concept which allows us to "qualify" species, to "prioritise" them in order to define conservation priorities, and to "communicate" amongst participants in the world of nature, with the overall goal of a rational management of the environment[9].

The heritage interest of riparian woodlands often provides an argument for taking these woods into account where river and flood plain management activities occur. It is necessary first of all, however, to take stock.

White poplar

9 - Delavigne (2001)

Overview of riparian plant communities

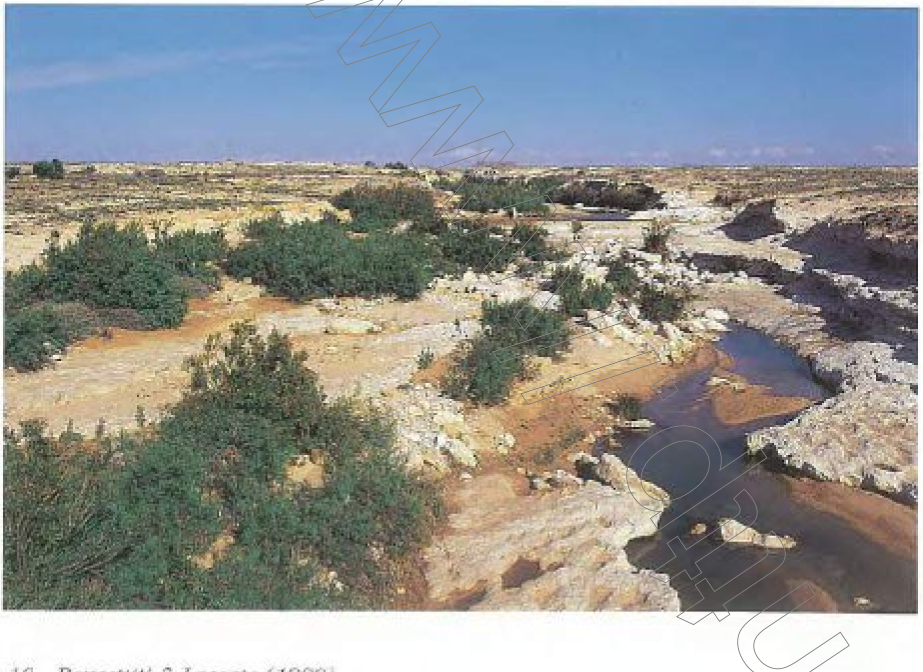
Riparian woodlands have a very special role in the vegetation of the Mediterranean. Dependent on the courses of river systems, they cross different vegetational zones from the mountains to the sea while retaining at the same time a distinctive character. Their plant communities are many and varied, among the best known in the world thanks to phytosociological studies carried out around a large proportion of the Mediterranean perimeter.

Southern Mediterranean

The data available for Algeria[10] reveal the existence of relic riparian woodlands, modified by felling, fires, grazing and urbanisation. Different types of river communities, unequally represented, interpenetrate here according to flooding and soil conditions, and levels of dryness.

1. Willow communities consisting of *Salix purpurea*, at the southern limit of its range, are rare here. The banks of the wadis offer only limited possibilities for the establishment of scrubby willow woods which, when they survive, resemble those of north-west Spain.

Willow communities with Common Alder *Alnus glutinosa*, but impoverished of northern species, occupy marshy areas which are flooded for several months of the year in eastern Algeria and in



Michel Gunther/Bios

Wadi in Morocco

10 - Bensettiti & Lacoste (1999)

Tunisia. They include some characteristic species of Alder woods with ferns: Royal Fern *Osmunda regalis*, Lady Fern *Athyrium felix-femina*, Enchanter's Nightshade *Circaea lutetiana*, and Yellow Flag Iris *Iris pseudacorus*. The North African endemic Bellflower *Campanula alata* is the principal indicator species in these woods.

3. The White Poplar communities of the Maghreb are clearly distinguished from their homologues in the northern Mediterranean: Alder and Beech communities are replaced here by Mediterranean Oak communities. The Clematis *Clematis cirrhosa* (Virgin's Bower) achieves its optimum development here.

These poplar communities form the typical plains woodlands of northern Algeria. They include White Poplar *Populus alba* and Black Poplar *P. nigra*, Narrow-leaved Ash *Fraxinus angustifolia*, the Elm *Ulmus minor*, and more rarely Common Alder and White Willow *Salix alba*. Creepers are well represented, with Virgin's Bower and Fragrant Clematis *C. flammula*, Ivy *Hedera helix*, Common Smilax *Smilax* aspera, the Birthwort *Aristolochia sempervirens* and the Rose *Rosa sempervirens*. Mediterranean Buckthorn *Rhamnus alaternus*, Hawthorn *Crataegus monogyna*, the Bramble *Rubus ulmifolius*, Giant Reed *Arundo donax*, Olive *Olea europaea*, Plum *Prunus domestica*, and the Fig *Ficus carica* appear in the shrub and tree layers, and in the herb layer the Asparagus *Asparagus acutifolius*, Herb Robert *Geranium robertianum*, False Brome *Brachypodium sylvaticum*, Three-cornered Garlic *Allium triquetrum*, Rice *Millet Piptatherum* miliaceum, Friar's Cowl *Arisarum vulgare*, the Dock *Rumex conglomeratus* and the horsetail *Equisetum ramosissimum*, are found amongst very common Large Cuckoo-pint *Arum italicum*.

Higher up, for example along the wadis of the Tellian Atlas, White Poplar stands are replaced by willow-oak communities characterised by Mediterranean Willow *Salix pedicellata*, Holm Oak *Quercus ilex*, Garlic Mustard *Alliara petiolata*, Wild Cherry *Prunus avium*, Holly *Ilex aquifolium* and Dead-Nettle *Lamium flexuosum*.

4. Tamarisk communities with Oleander *Nerium oleander* extend along wadis, replacing the White Poplar community wherever conditions become significantly drier. They appear to play a pioneer role similar to that of the northern willow communities and are characterised by the tamarisks *Tamarix gallica* and *T. africana*, together with Oleander, Giant Reed, Rice Millet, *Ampelodesmos mauritanicus*, Stranglewort *Cynanchum acutum*, and *Dittrichia viscosa*.

Northern Mediterranean

From Spain to the Balkans, White Poplar stands in the northern reaches of the Mediterranean differ from those in the south, notably by a high proportion of Euro-Siberian species such as the Bramble *Rubus caesius*, Black Poplar *Populus nigra*, Hedge Bedstraw *Galium mollugo*, the Willows *Salix alba*, *S. triandra*, *S. atrocinerea* and *S. fragilis*, and especially the Soapwort *Saponaria officinalis*.

The White Poplar woods of the plains of the Languedoc provide one of the better-known examples of this type of community[11], characterised by the Poplar *Populus alba*, the Elm *Ulmus campestris*, Ash *Fraxinus angustifolia*, Stinking Iris *Iris foetidissima*, Sweet Violet *Viola odorata*, Berry Catchfly *Cucubalus baccifer* and Tuberous Comfrey *Symphytum tuberosum*. The poplar woods described from Provence and the Southern Alps have proven to be fairly similar[12]; those in Spain have diversified to form associations with, for example, the Bramble *Rubus ulmifolius* by the Ebro, the Willow *Salix atrocinerea* in Extremadura and the Oleander *Nerium oleander* in Andalusia[13]. As a whole, the Mediterranean poplar woods occur in the area between the coast and the foothills, occupying deep, rather basic, alluvial soils.

Other species may dominate the upper layer, depending on flooding regime, soil type, and climatic conditions. Other types of riparian woodland are now considered, which also occur from Spain to the Balkans:

– Common Alder communities of *Alnus glutinosa*, often accompanied by Narrow-leaved Ash *Fraxinus angustifolia*, Silver Birch *Betula pendula* and, in the understorey, Royal Fern *Osmunda regalis*;

– Communities of *Alnus glutinosa* and *Fraxinus angustifolia* spp. *oxycarpa*, notably in the Cévennes ;

– Ash-elm communities with *Fraxinus angustifolia* and *Ulmus minor*, when periods of flooding are infrequent.

Records from Spain as well as from France and Italy reveal a strong link between poplar and willow communities. Willows form thickets on stony banks, poor in organic material. They are dominated by *Salix purpurea*, *S. triandra*, *S. viminalis* and *S. elaeagnos*, fast-growing species reproducing vegetatively from major shoots and which are, as a result, able to colonise new areas rapidly following flooding events.

In southern Spain, the willow communities are replaced by tamarisk communities with Oleander which are able to tolerate dry conditions

11 - Tchou (1948-1949))
12 - Loisel (1976)
13 - Rivas Martinez (1964)

The riparian forests of Greece: in urgent need of protection

At one time, riparian forests extended in broad bands along almost every watercourse in Greece. They have since been reduced to narrow strips by agriculture and forestry. Only the most inaccessible areas, and a few rare sites by large rivers and some lakes, have retained their original woodlands. Further reduced and transformed by the channelisation of rivers, overgrazing and felling, these forests nevertheless still have an ecological role which is surprising in view of their size, due as much to their functioning as a buffer zone as to the rich and varied natural habitat they form[14].

In the north of Greece, reasonably wide wooded zones remain along rivers such as the Strymon and the Nestos. The Strymon woodlands have a complex and heterogeneous structure with numerous transitional stages, from populations of *Salix alba* at the lowest elevations to those of *Populus alba* at the highest altitudes and furthest from the water. All of these stages have *Salix alba, Alnus glutinosa* and *Populus nigra* as the most common species. Their understorey becomes richer in woodland species as one ascends, with abundant creepers including *Humulus lupulus, Periploca graeca* – a characteristic southern species – and *Vitis vinifera* spp. *sylvestris.* At Kerkini, the riparian forest ecosystem has been severely affected by artificially raised water levels.

The riparian forest of the Nestos has also been reduced, by overgrazing, deforestation, agriculture and the planting of poplar. *Salix alba, Populus alba, P. nigra, Fraxinus angustifolia* spp. *oxycarpa, Alnus glutinosa, Quercus penduculiflora* and *Ulmus minor* are the most abundant trees here, accompanied by a wide range of creepers. At the lowest levels intensive drainage, combined with long periods of drought, have lowered the water table, leading to the infiltration of brackish water. The ancient Great Forest (Kodja Orman), reduced to some thirty hectares of unique alluvial woodland, remains under threat from illegal exploitation.

In the south of Greece, the riparian forests and the valleys take on a more markedly Mediterranean structure, characterised, as for example on the River Pinios, by an abundance of *Platanus orientalis,* along with species such as *Salix alba, S. fragilis, Populus alba* and *P. nigra* which are still predominant. These communities extend along the whole length of the river, including the river delta; *Alnus glutinosa* and *Fraxinus angustifolia* inhabit the wetter sites, in association with a mosaic of herbs.

These ecosystems can attract many leisure activities and, as part of the development of tourism, may become a resource for the local economy. However, this requires protection measures which will not succeed unless the hydrological regimes of the watercourses are taken into consideration.

By Kostas Vitoris,
University of Thessaloniki, Greece.

14 - Vitoris (2000)

with high salinity similar to those in the Maghreb; here the watercourses are bordered with thickets of Tamarisk, Oleander, Giant Reed and Rice Millet.

Further east, White Poplar communities are enriched with oriental and drought-tolerant species in southern Italy or with elements recalling the oak-elm communities of Central Europe in Albania. In southern Italy, including Sicily, the tree layer may also include the Plane tree *Platanus orientalis* alongside White Poplar, the Ash and White Willow, with thickets of Oleander and Tamarisk[15]. In Albania, the species in White Poplar communities may be enhanced by the Elm *Ulmus procera*, Pedunculate Oak *Quercus robur*, Common Alder, White Willow and Plane trees[16]. The Narrow-leaved Ash community supports the Elm *Ulmus minor*, Judas trees *Cercis siliquastrum*, Pedunculate Oak, and Kermes Oak *Q. coccifera*. The willow community, includes, besides White Willows, the widespread species Common Alder, Oleander and *Tamarix africana*.

Well represented in Greece, notably in the Hodja Oman forest of Macedonia, White Poplar communities also include many species typically found in Central and Eastern Europe, the White Poplars being increasingly replaced by Plane trees as one moves from west to east. Ash communities of *Fraxinus angustifolia* spp. *oxycarpa* are present around the Ionian and Aegean coasts, and Alder woods with *Alnus glutinosa* on the coasts of Thessaly, Macedonia and Thrace. Oleander and Tamarisks are present, together with the Chaste Tree *Vitex agnus-castus*, wherever dry conditions are prevalent, particularly in the Peloponnese.

Eastern Mediterranean

A number of notable communities have been described from Turkey[17]. The River Delaman in south-west Anatolia is, for example, fringed by woodlands of Oriental Sweet Gum *Liquidambar orientalis*, the Alder *Alnus orientalis*, the Plane tree *Platanus orientalis*, Elms *Ulmus* spp., Larger Smilax *Smilax excelsa*, the Asclepiad *Periploca graeca* (Silk-vine), and Vine *Vitis vinifera*. The River Ergene, close to the Greek border, has poplar woods of *Populus alba* with *Ulmus minor* and *Salix alba*, while the Sakarya in northern Anatolia has ash-dominated communities with *Fraxinus angustifolia* spp. *oxycarpa*, *Ulmus carpinifolia*, *Carpinus betulus*, *Alnus glutinosa*, and *Acer campestre*.

However, many riparian woodlands in Turkey are dominated by the Plane tree *Platanus orientalis*, with which are associated sometimes species of Central Europe such as *Ulmus minor*, *Salix alba* and *Sambucus nigra*, and occasionally Mediterranean species such as *Nerium oleander*. Tamarisk thickets are also common along Anatolian watercourses[18].

15 - Gentile (1968)
16 - Karpati & Karpati (1961)
17 - Yaltirik (1973), Akman et al. (1979), Yon & Tendron (1981)
18 - Zohary (1973)

Riparian vegetational succession

Riparian vegetational succession is relatively well-known north of the Mediterranean[19]. In accordance with the process shown in figure p.11, pioneer herbaceous communities become established on banks which have been denuded by flooding; they open the way to shrub and early tree stage communities, followed by post-pioneer and late successional trees.

Pioneer herbaceous communities

The recently deposited coarse alluvia of the main channels support a community comprising Yellow Horned-poppy *Glaucium flavum*, French Figwort *Scrofularia canina*, Sticky Goosefoot *Chenopodium botrys*, Branched Plantain *Plantago indica*, Evening Primrose *Oenothera biennis*, the Willowherb *Epilobium dodonaei*, and Hairy Rocket *Erucastrum nasturtiifolium*.

On the other hand, silty or clayey soils partly dried out in summer will promote the development of a nitrophilous community, with Trifid Bur-marigold *Bidens tripartita*, Beggarticks *B. frondosa*, the knotgrasses *Polygonum lapathifolium*, *P. mite* and *P. minus* and the potentilla *Potentilla supina*, or otherwise another community of small Cyperaceae such as the galingales *Cyperus fuscus* (Brown Galingale) and *C. flavescens*.

Finally, large perennial herbs establish themselves as alluvial banks are transformed into raised areas of alluvial deposits; communities of umbellifers and reedbeds arise, with Common Reed *Phragmites australis* or Reed Canary-grass *Phalaris arundinacea*.

Pioneer shrub and tree communities

This category includes shrubby willows, woods of willow and poplar trees and Black Poplar woods.

• Shrub willows include various willows bed communities on one hand and *Salix purpurea* and *Saponaria officinalis* communities on the other.

Various willow bed communities occur on sandy, gravelly or silty/clayey deposits as well as simple alluvial soils which are regularly disturbed, in the middle and lower reaches of watercourses. A very wide variety of willows is found, with *Salix elaeagnos*, *S. fragilis*, and osiers *S. purpurea*, *S. triandra*, *S. viminalis*. The community is typified

19 - Roux (1998)

by the presence of Stinging Nettle *Urtica dioica*, Ground-ivy *Glechoma hederacea* and Common Hemp-nettle *Galeopsis tetrahit*. *Salix alba* and *Populus nigra* are rare here. Communities with Purple Willow and Soapwort occupy damp sand and gravel immediately adjacent to swift rivers as well as simple alluvial soils, regularly disturbed by strong floods. The willows *Salix purpurea* and *S. elaeagnos* are common here, as well as Soapwort *Saponaria officinalis*, Purple Toothwort *Lathraea clandestina* and Berry Catchfly *Cucubalus baccifer*. *Salix alba*, *Populus nigra* and *P. alba* are all rare.

• Tree willows and poplars can form several types of community: White Willow communities, Crack Willow communities, Willow-Poplar communities *with Phalaris arundinaca*, and White Willow communities with Grey Alder.

White willow communities develop on very varied substrates, prone to severe flooding, in the piedmont. *Salix alba* and *Populus nigra* are characteristic here, as well as *Salix fragilis*, *S. purpurea* and *S. viminalis*.

Crack Willow communities grow on siliceous deposits poor in minerals in conditions similar to the previous type. They are characterised by *Salix fragilis* and *S. alba*.

Willow-poplar communities with *Phalaris arundinacea* develop on calcareous deposits. Characteristic species include *Populus nigra*, *P. alba*, *Salix alba*, *S. purpurea*, *S. eleagnos* and *Alnus incana*, as well as Reed Canary-grass *Phalaris arundinacea* and Soapwort *Saponaria officinalis*.

White Willow communities with *Alnus incana* grow on predominantly calcareous deposits, forming a transition stage towards climax woodland. Characteristic species here are *Salix alba*, *Alnus incana* and *A. glutinosa*, with *Carex pendula*, *C. acutiformis*, *Iris pseudacorus* and *Lysimachia vulgaris*.

• Black Poplar communities on shingly banks include communities with Hazel when there is permanent contact with the water table and communities with *Brachypodium phoenicoides* in drier situations.

Mesophytic Black Poplar communities with Hazel contain, in addition to *Populus nigra* and *Corylus avellana*, species such as *Populus alba*, *Euonymus europaeus*, *Arum italicum*, *Brachypodium sylvaticum*, *Viola reichenbachiana* and *Hedera helix*.

Black Poplar communities with *Brachypodium phoenicoides*, in drier conditions, include *Populus nigra* and herbs such as *Brachypodium* *phoenicoides, Rosmarinus officinalis, Aphyllanthes monspeliensis, Echium vulgare.*

Post-pioneer tree communities

These comprise woods of White Poplar, alders and oaks.

• White Poplar communities constitute the typical post-pioneer community of Mediterranean and supra-Mediterranean regions. They develop on silty or sandy substrates which overlie gravel and shingle in medium to large rivers. Characteristic species are *Populus alba, P. nigra, Ulmus minor, Fraxinus angustifolia* spp. *Oxycarpa* and *Acer negundo*, as well as Stinking Iris *Iris foetidissima*, Sweet Violet *Viola odorata*, Berry Catchfly *Cucubalus baccifer*, Tuberous Comfrey *Symphytum tuberosum*, Pendulous Sedge *Carex pendula* and Wood Spurge *Euphorbia amygdaloides*.

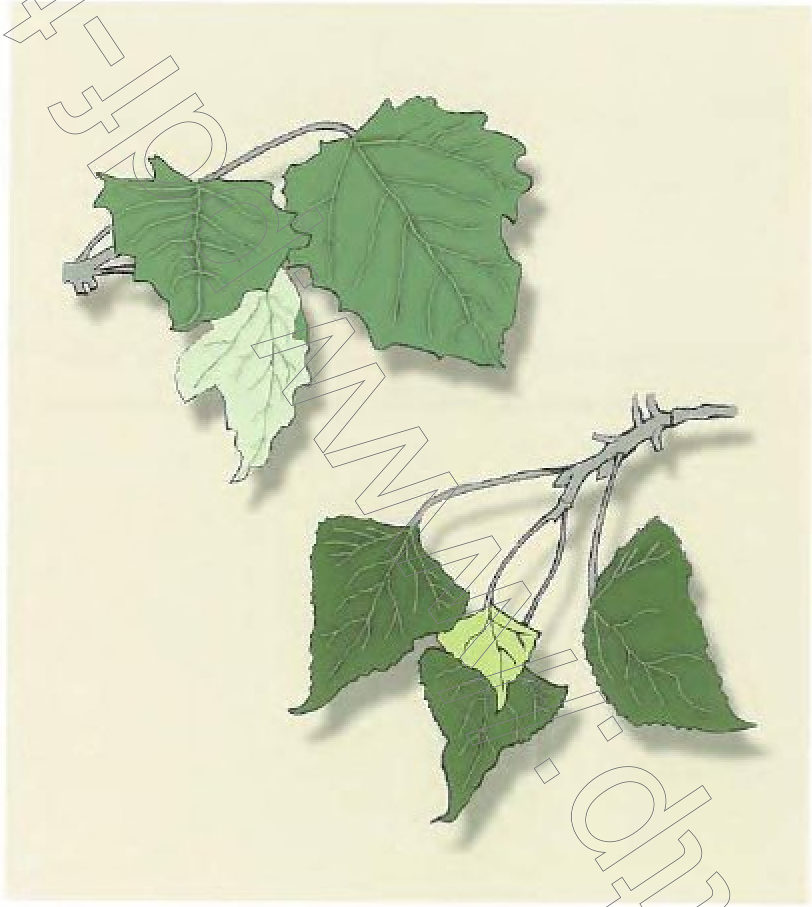
• Alder woods can take on various forms depending on soil and climatic conditions. Alder woods with Narrow-leaved Ash *Fraxinus angustifolia* grow on sandy/silty and shingly banks subject to temporary floods in wet Mediterranean climates. Following the edges of watercourses in the Cévennes, they are characterised by *Alnus glutinosa, Fraxinus angustifolia* spp. *oxycarpa, Salix alba, S. elaeagnos, Populus alba* and *P. nigra*, as well as *Carex pendula, Angelica sylvestris, Circaea lutetiana, Scrophularia nodosa* etc. They are replaced by alder woods with *Alnus glutinosa* and Small-leaved Lime *Tilia cordata* in the cold, steep-sided valleys of the Maures and Estérel massifs, on gravel and silt substrates formed from siliceous rocks, whereas woodland with *Alnus glutinosa* and Hop Hornbeam *Ostrya carpinifolia* develops on mainly sandy, permanently damp substrates, for example in the bottoms of the valleys of some of the tributaries of the Var.

• Downy Oak woodland with Elm and Pedunculate Oak woodland with Elm, occupy very fine substrates, undisturbed by severe floods, in the great river systems. The oaks *Quercus pubescens* and *Q. robur* are accompanied here by *Ulmus minor, Fraxinus angustifolia* spp. *oxycarpa, Alnus incana* and, more rarely, *Populus alba*. The herb layer here is very well developed.

Poplars: White and Black

Black Poplars *Populus nigra* and White *P. alba* are characteristic of many Mediterranean riparian woodlands. Both species are dioecious*: their sexual reproduction is effected by cross-pollination. White Poplars generally flower from the end of February to the beginning of March, Black Poplars from late March to early April. The seeds are mature after six to eight weeks. They are small, light, surrounded by cotton, and are easily dispersed by wind and by water. However, these seeds only remain viable for four to eight weeks. The seeds colonise bare and damp banks, where they can germinate in 24 hours and form seedlings in two to three days. Vegetative reproduction is possible via regrowth from roots and stems following disturbance to an already established plant.

The Black Poplar, native to the Mediterranean regions, ranges as far as China and to the shores of the North Sea and the Baltic. A pioneer tree, it accompanies willows in colonising riparian zones recently denuded by floods. It grows to a height of over 30 metres during a lifespan of 150 to 200 years. In plantations it is often replaced by American black poplars, with which it hybridises. The wild populations of Black Poplars interact with these hybrids, exchanging genes and parasites. The species



Leaves of White Poplar (above) and Black Poplar (below), (after Quartier & Bauer-Bovet 1973, modified).

is an important source of revenue in several Mediterranean countries: 63% of poplar cultivars listed worldwide have Populus nigra as part of their parentage, and it is included in 45% of poplar plantations intended for wood production in Turkey[20]. The Lombardy Poplar, a cultivar of *Populus nigra*, characterises many lowland landscapes.

The White Poplar is also thought to have originated from Mediterranean shores. Its natural range extends from southern Europe and North Africa to Asia, and from Turkey to India. *Populus alba* can live for 200 to 300 years and can grow to a height of 40 metres and a diameter of a metre; hence its value as a landscape feature. It grows in combination with willows, alders and other poplars. White Poplar communities are characteristic of the Mediterranean region. The tree layer is typically dominated by White and Black Poplars, with White Bryony and Berry Catchfly, Field Maple, Narrow-leaved Ash, Downy and Pedunculate Oaks, and Small-leaved Lime. The shrub layer includes *Evonymus europaeus* and *Hypericum androsaemum*. The herb layer, which is very lush, supports among other species *Arum italicum, Iris foetidissima, Carex alba, C. pendula, Brachypodium sylvaticum, Lathraea clandestina, Euphorbia amygdaloides, Buglossoides purpurocaerulea, Galium verum, Lapsana communis, Primula eliator, Saponaria officinalis, Stachys sylvatica* and *Vinca minor*[21].

Some authors discourage the use of Black Poplars, for bank management programmes: these very tall trees with relatively shallow roots are easily exposed by the wind and the banks become destabilised.

Thunderstorm along the river Rhône

Emmanuel Vialet/Bios

20 - *Frison et al. (1995)*
21 - *Rameau et al. (1989)*

Some notable species of Mediterranean riparian woodlands

Natural populations of the Plane tree, *Platanus orientalis*, occur along watercourses of the north-east Mediterranean, from Sicily to Iraq, including some extremely arid environments such as along the River Barada in Damascus (Syria)[22]. The species has been introduced outside its natural range as an ornamental tree commonly lining avenues. It may be grown in irrigated plantations to produce wood for commercial purposes.

Plane trees may grow 30 to 40 metres in height and live for 500 to 2000 years. They reproduce readily from seed. They are monoecious*, with flowers grouped in spherical, pendulous, single-sex catkins. The achenes* are covered with hairs at the base, and are dispersed by the wind and sometimes by ants. In the Near East they are found from sea level up to 1500 metres, where the rainfall patterns are typically Mediterranean; that is very dry summers and with mean annual rainfall varying from 200 mm (eg. in Damascus) to over 1200 mm (eg. at Shaukaran in Syria and at Bikfya in Lebanon)[23].

Denis Bringard/Bios

Plane tree

In the riparian woods of Turkey, Cyprus, Syria and Lebanon, Plane trees are nearly always associated with *Alnus orientalis*, these two species being typically accompanied by *Salix alba* and *Rubus ulmifolius* spp. *anatolicus* in the Mediterranean zone[24].

The Oriental Sweet Gum *Liquidambar orientalis* is originally from Turkey, more precisely from south-west Anatolia. Populations extend from the coast up to almost 900 metres. Widespread in the plains, they follow streams and rivers, forming regular, generally monospecific stands which are flooded in winter. *Liquidambar orientalis* may grow to 35 metres in height and 3 metres in circumference – with a shallow, horizontal root system. It can send up vigorous shoots and suckers, while at the same time fruiting abundantly on almost an annual basis. It is a monoecious tree whose fruits are capsules which release seed in autumn to germinate in April-May. Growth is rapid: in four years individuals in plantations can attain on average a height of 3 metres and a circumference of 15 cm[25].

Sweet Gums are balsamic trees which, in spring, release a pleasant scent during wet

22 - *Nabal & Rahme (1990)*
23 - *Nabal & Rahme (1990)*
24 - *Barbero & Quézel (1976)*
25 - *Efe & Dirik (1992)*

Oleander

weather. If damaged, they exude a balsam which was formerly exported as a fixative for the perfume industry. This balsam is a well-known antiseptic, used in the treatment of asthma and bronchitis, as well as of mycosis and galls, skin diseases caused by parasitic organisms. The residue obtained after extraction may be used as an incense.

The Oleander, *Nerium oleander*, grows all round the Mediterranean close to watercourses, including those which regularly dry out in summer. It grows vigorously and abundantly for example along the wadis of North Africa. The species withstands oceanic winds well. It is commonly planted in ornamental shrubberies and avenues.

A bushy shrub, with the stem dividing fairly low down, the Oleander can grow to a height of five metres or even more. The flowers, in familiar shades of pink, are grouped in terminal cymes. They produce beautiful rotate corollas, funnel-shaped at the base, reminiscent of the flowers of the Periwinkle, a species from the same family (Apocynaceae). The fruits, in the form of long follicles, contain plumed seeds which are readily dispersed by the wind.

All parts of the Oleander are very toxic, especially the milky sap, as noted by Pliny in the 1st Century AD.

Tamarisks are shrubs whose form is often contorted, with long spindly branches and very light foliage. The abundant flowers, of a more or less bright pink colour, are all the more remarkable in that they appear before the leaves. The very small flowers form long terminal spikes, or panicles. The fruits, which are capsules, contain large numbers of seeds with terminal plumes to facilitate dispersal by the wind. Tamarisks grow well in poor, freely-draining soils as well as sands where salinity is high. They are used to stabilise sand dunes and to form windbreaks. Shoots develop readily from the bases of branches if they are cut back. Both species, *Tamarix africana* and *T. gallica*, are vulnerable to frosts.

Tamarix africana occurs, from west to east, from northern Africa to Arabia, Iran and northern India. Its habit is very straggly and it does not grow taller than three metres. It flowers from May onwards.

Tamarix gallica is larger, growing up to eight metres tall. It occurs near the coast, including North Africa and the Canaries. Its flowers come out from June to August. Together with *Salix eleagnos*, Oleander and the Chaste-tree, it forms a community which takes over from a herbaceous stage and precedes alder-poplar communities on sandy river deposits.

The Vaucluse: well known for its diversity

By virtue of its geographical location, the Vaucluse *Département* of France has some riparian woodlands whose richness is being increasingly appreciated, as much from the floristic as from the faunistic point of view, for example along some sections of the Calavon, the Durance, the Rhône and the Sorgues Rivers[26].

The Calavon

For fifty kilometres or so upstream of its confluence with the Durance, this river supports poplar communities containing a wide range of willow species. Their shrub layer is diverse while the herbaceous layer is made up of shade-tolerant species such as Wood False-brome. In places, oak, lime, maple and ash infiltrate, producing mixed mesophytic oak-dominated woodland. These woodlands support more than 130 species of birds, with breeding Cetti's Warblers *Cettia cetti*, Grey Wagtails *Motacilla cinerea*, Kingfishers *Alcedo atthis*, Moorhens *Gallinula chloropus*, Little Grebes *Podiceps ruficolis*, Mallard *Anas platyrhynchos* and Black Kites *Milvus migrans*. The following have also been recorded: 29 species of mammals, of which three – the Beaver *Castor fiber* and the bats *Rhinolophus hipposiredos* and *Myotis daubentoni* – are protected under the Habitats Directive; 9 species of amphibians, including *Pelobates cultripes*, *Alytes obstetricans*, *Bufo calamita* and *Hyla meridionalis* which are also cited in the Habitats Directive; approximately ten reptiles, including the terrapin *Emys orbicularis*; up to 40 molluscs, up to 30 dragonflies, around 300 species of Coleoptera including the giant longhorn beetle *Cerambyx cerdo* and 200 species of Macrolepidoptera.

The Durance

This river has several habitats of great ecological interest, in spite of some profound modifications. Seven dams have been built here since the Serre-Ponçon dam was completed in 1959 and a whole network of artificial channels has been constructed for agricultural and industrial purposes; natural riparian areas have been much reduced. Nevertheless, some 100 species of birds have been recorded along the Durance, compared with 174 for the ornithologically rich area of western Provence, including the Camargue.

Pioneer herb communities are found in the centre of the river bed, with annual and biennial species such as Purple Loosestrife *Lythrum salicaria*, Redshank *Polygonum persicaria*, White Melilot *Melilotus albus*, Hemp-agrimony *Eupatorium cannabinum*, Common Fleabane

26 - Roux (1998)

Cetti's warbler

Pulicaria dysenterica, Yellow Loosestrife *Lysimachia vulgaris*, Evening Primrose *Oenothera biennis*, Cocklebur *Xanthium italicum*, Early Goldenrod *Solidago gigantea*, the Butterfly Bust *Buddleja davidii* etc. A specialised avifauna is found here including Common Sandpiper *Actitis hypoleucos*, Little Ringed Plover *Charadrius dubius*, Common Tern *Sterna hirundo*, Black-headed Gull *Larus ridibundus* etc. Shrubby communities with Sea-buckthorn *Hippophae rhamnoides*, Hawthorn *Crataegus monogyna* and the clematis *Clematis recta* in particular, provide habitat for large numbers of Wild Rabbit.

The tree communities include various species of willow, poplar and alder, to which may be added creepers and herbs including Wild Angelica *Angelica sylvestris* and Common Gromwell *Lithospermum officinale*. Many birds occur in the taller trees: Golden Oriole *Oriolus oriolus*, Night Heron *Nycticorax nycticorax*, Grey Heron *Ardea cinerea*, Little Egret *Egretta garzetta*, raptors, and a whole range of other species inhabiting the understorey, thicket and trees.

There is a rich insect fauna here, including three species which are protected under the Habitats Directive (*Lucanus cervus*, *Euphydryas aurinia* and *Oxygastra curtisii*) and five protected under national law: the giant longhorn beetle *Cerambyx cerdo*, Southern Damselfly *Coenagrion mercuriale*, the hawkmoths *Hyles hippophaes* and *Proserpinus proserpina* and the large bush-cricket *Saga pedo*.

The Rhône

The Rhône has brought a mid-European continental flora towards the south, as well as a number of naturalised species some of which have become invasive: Ash-leafed Maple or Box-elder *Acer negundo*, False Indigo *Amorpha fruticosa*, Common Milkweed *Asclepias syriaca*, Tufted Love Grass *Eragrostis pectinacea* and Ragweed *Ambrosia artemisiifolia*.

In spite of severe degradation, riparian woodlands still exist along the lower reaches of the old Rhône – less disturbed than elsewhere – especially on islands. These woods are among the richest and most mature in the Vaucluse and include among other species ash and Pedunculate Oak with very diverse shrub and herb layers. Some riparian woodlands are dominated by Black Poplar, Hawthorn, willows or Dogwood, in a very varied mosaic of habitats supporting around sixty species of nesting birds, beavers, and many other species of animals. Further downstream, the riparian woodland becomes more typically Mediterranean with white poplars appearing.

The Sorgues

Typical of the Vaucluse, the Sorgues rise at the famous resurgence springs* of the Fountain of the Vaucluse, whose powerful discharge attains 10 m^3/s on average and varies from 6 to 120 m^3/s. There is always some flow, even during the summer, and floods are never devastating. The water is always cool – between 10 and 15°C – and flowing. There are some beautiful woodlands along the Sorgues, with communities of White Poplar, Alders, Elm, Ash, and Oak *Quercus robur*. These are associated with damp grasslands whose flora resembles that of the grasslands of Central European rivers, with Loose-flowered Orchid *Orchis laxiflora*, Bog Orchid *O. palustris*, Early Marsh Orchid *Dactylorhiza incarnata*, Clover *Trifolium patens*, Saw-wort *Serratula tinctoria*, Sneezewort *Achillea ptarmica*, Slender Marsh-bedstraw; *Galium debile* etc. Associated with this hygrophytic* vegetation, which is unusual in Provence, is a diverse community of birds, mammals, reptiles, batrachians and insects.

The Tech: the marks of a flood

A catastrophic flood in October 1940 destroyed practically all vegetation along the banks of the Tech. In the aftermath of the flood this vegetation re-established itself along the river, unevenly both in time and space.

Although there was some colonisation of the river banks between 1942 and 1953, the vegetation really only extended as far as the coarse sediments at higher elevations since in the years 1960 to 1974, there was a period of major river activity (eight floods of over 700 m^3/s at Céret). In a spatial sense, because the upper reaches underwent severe modification by the river, colonisation was promoted at only the highest elevations following significant input of sediment, which regularly destroyed vegetation at the lowest elevations and prevented since 1940, development beyond pioneer stages. In the lower reaches of the Tech, the Roussillon Plain, long since deforested, has been the scene of many changes with each new course taken by the river since the 1940 flood; each of these shifts creating new forest dynamics.

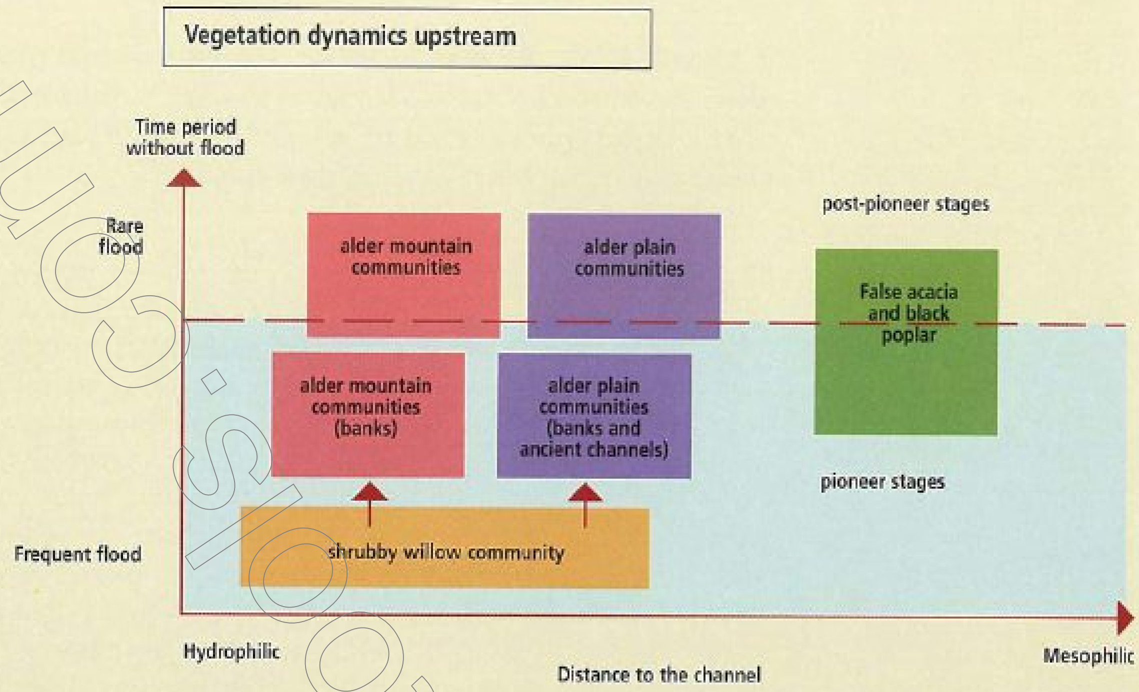
At present, three woodland types appear in turn as one travels downstream along the Tech: montane and low altitude alder communities and poplar communities (see figure p. 48). The degree of maturity of these stages is dependent on river dynamics. Higher up in the Pyrenean valley (the Céret basin and the upper reaches of the Roussillon Plain) vigorous river action has kept the vegetation at a pioneer stage, the post-pioneer stage showing only limited development. Lower down, the greater stability of the Roussillon Plain has allowed post-pioneer riparian woodland to develop. Still further downstream, near the river mouth, the mobility of the river bed has once again kept the riparian vegetation at the pioneer stage.

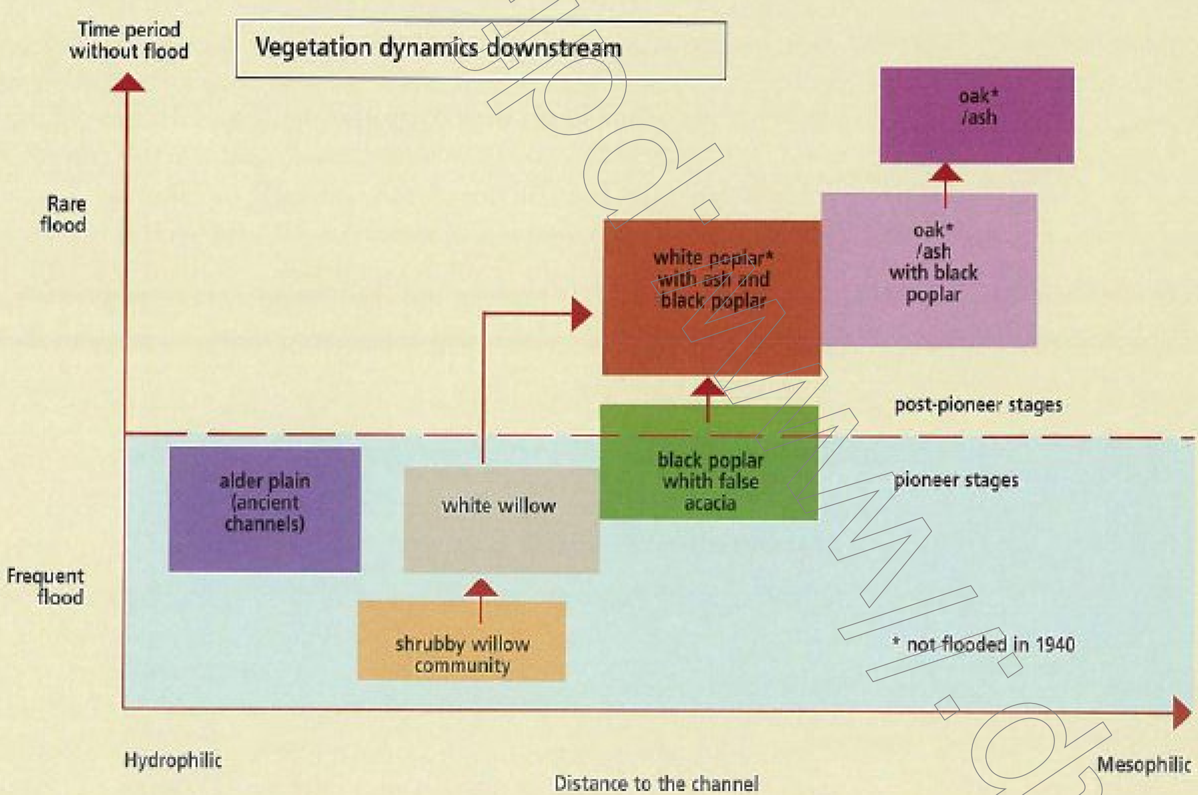
All in all, the riparian vegetation of the Pyrenean valley is clearly distinguished from that of the Céret and Roussillon Plains.

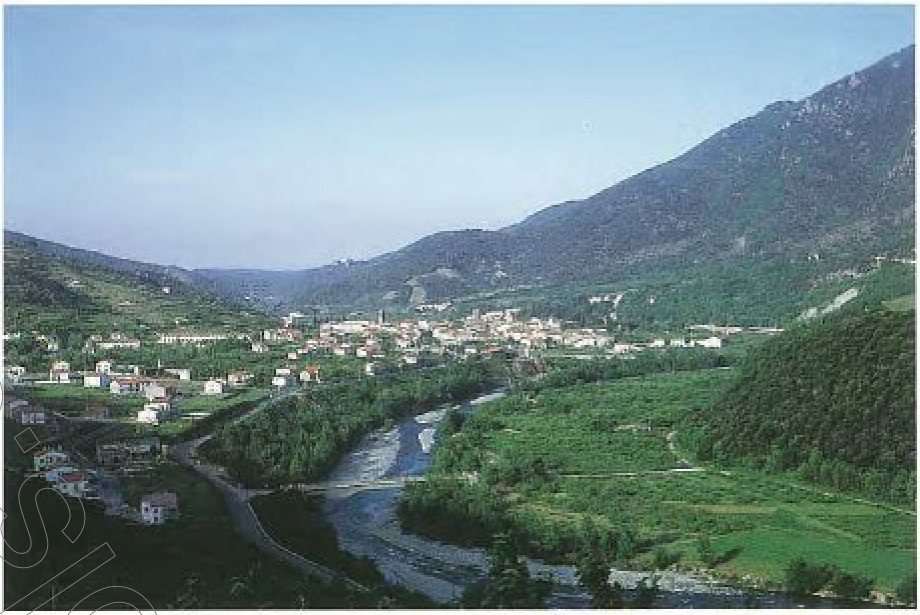
The Pyrenean valley

Willow scrub forms the first woody pioneer stage on riversides, with *Salix purpurea*, *S. elaeagnos*, *Buddleja davidii*, *Alnus glutinosa* and sometimes *Populus nigra*. The herb layer includes hygrophytic, nitrophilic and heliophytic* species, together with species derived from neighbouring supra-mediterranean forests. The willow scrub gives way to two types of alder community depending on the altitude.

Montane alder communities dominated by *Alnus glutinosa* are rich in Euro-Siberian riparian species such as *Stellaria nemorum*, *Stachys*


Vegetation dynamics upstream
Time period without flood
Rare flood
Frequent flood
post-pioneer stages
alder mountain communities
alder plain communities
False acacia and black poplar
alder mountain communities (banks)
alder plain communities (banks and ancient channels)
pioneer stages
shrubby willow community
Hydrophilic
Distance to the channel
Mesophilic


Vegetation dynamics downstream
Time period without flood
Rare flood
Frequent flood
oak* /ash
white poplar* with ash and black poplar
oak* /ash with black poplar
post-pioneer stages
black poplar whith false acacia
pioneer stages
alder plain (ancient channels)
white willow
shrubby willow community
* not flooded in 1940
Hydrophilic
Distance to the channel
Mesophilic



The Tech valley, France

Roché/Gasnault

sylvatica, Cardamine impatiens and *Angelica sylvestris*, together with species of hill and mountain woodlands as well as of tall herb fringe communities. Close to the river channel, alder is the only true tree species, with several species of willows *(Salix purpurea, S. elaeagnos, S. caprea)*. Further from the channel, development proceeds towards a post pioneer stage featuring the ash *Fraxinus excelsior*, Small-leaved Lime *Tilia cordata*, the elm *Ulmus glaba*, creepers *Clematis vitalba* and *Hedera helix*, and a shrub layer with *Sambucus nigra*.

Lower altitude alder communities dominated by *Alnus glutinosa* are closely related to the alder communities with *Fraxinus angustifolia* on the edge of the southern Cévennes. They are equally rich in Euro-Siberian riparian species including, amongst other species, *Carex pendula, Stachys sylvatica, Lamium flexuosum* and *Cardamine impatiens*. The species of mixed hill and mountain woodlands differ and are accompanied by species typical of White Poplar woodland. As with the montane alder communities, further away from the channel a post-pioneer stage may start to develop, in which Field Maple *Acer campestre* and Sweet Chestnut *Castanea sativa* may be found.

False Acacia *Robinia pseudo-acacia* and Black Poplar *Populus nigra* grow downstream of the valley on raised deposits. The presence of Ash and Elm here indicates development towards a post-pioneer stage.

The Céret and Roussillon plains

Sequence of riparian vegetation along the Tech: from upstream (mountain valley) to downstream (Roussillon Plain).

White Poplar communities extend across the whole of these plains, with the exception of a few old channels which are occupied by low altitude alder woods. Lower down there is a shrubby willow community; this is replaced by a pioneer tree community with *Salix alba*, then by a *Populus nigra* community half way between pioneer and post-pioneer stages, and finally by the *Populus alba* community. This sequence may be detailed as follows.

- The shrub willow community includes *Salix purpurea, S. elaeagnos, S. alba* and *Buddleja davidii*. Its establishment dates from the flood of 1979.

- The tree willow community corresponds to the *Salix alba* community where White Willow is dominant, sometimes with Black Poplar and Common Alder. The shrub layer here is poorly developed, with willows, Buddleja and knotweeds. As a very light-demanding community, survival is only thanks to periodic reinstatement after floods. Its current establishment dates from the floods of 1971 and 1977.

- The *Populus nigra* community, intermediate between pioneer and post-pioneer stages, occurs at low elevations. The False Acacia *Robinia pseudo-acacia* may be abundant here and the shrub layer may be fairly well-developed, with pioneer willows but also species associated with Downy Oak and Holm Oak woodland. Creepers are present, but not White Poplars. The herb layer includes some species also present in Eurosiberian riparian forests *(Lamium flexuosum, Alliaria petiolata, Carex pendula)*, species of the White Poplar community *(Arum italicum, Euphorbia amygdaloides, Cucubalus baccifer, Bryonia dioica, Humulus lupulus)*, the Holm Oak community (with *Helleborus foetidus*), and the Evergreen Oak community (with *Asparagus acutifolius*). The establishment of the Black Poplar community dates from the flood of 1940, but its woodland structure was not really attained until 1972-74.

- The *Populus alba* community is relatively rare and is restricted to sites which were not destroyed in 1940. The tree layer is notable for the dominance of White Poplar which coexists with Black Poplar, Ash and Oleander. The shrub layer is lacking in pioneer willows, which are replaced by White Poplar, Ash and Oleander, while species from the Downy and Evergreen oak communities are less well represented than in the Black Poplar community. Creepers are still well-represented, as are the herb layer species.

The two poplar communities of the riparian woodlands of the Tech (i.e. with and without White Poplars), appear as two variants of the typical Mediterranean White Poplar community[27]. However, the climax stage which may be seen for example in Bas Languedoc is far from being attained, and their structure is less complex; the poplars do not grow very tall and some species are absent: *Iris foetidissima, Viola odorata, Lithospermum officinale, Symphytum tuberosum*. In general,

27 - Tchou (1947-1948)

following the 1940 flood, the White Poplar re-established itself locally from the seed bank, but it has not been able to spread throughout the river corridor; on the other hand, the Black Poplar, a pioneer species, has spread and survived on low-level coarse deposits along the same corridor.

• The higher, drier levels of the Roussillon Plain, which also escaped the 1940 flooding, support an oak-ash community with Black Poplar *Populus nigra*, Narrow-leaved Ash *Fraxinus angustifolia*, False Acacia *Robinia pseudo-acacia*, Southern Nettle-tree *Celtis australis* and Holm Oak *Quercus pubescens*. These mixed woods also extend along the Tech. They may be considered as a degraded variant of the White Poplar community type. They include shrub species from the Eurosiberian mixed forest and Holm Oak woodland. Giant Reed *Arundo donax* may be abundant here. The herb layer is rather impoverished but nevertheless includes some species of the White Poplar and Holm Oak communities.

• Finally, some small trees of Downy Oak and Ash, the remnants of a climax riparian woodland, look out over the river corridor from the edges of the cultivated terraces.

Long-term effects

The example of the Tech illustrates the long-term effects of Mediterranean floods on riparian woods. The flood of October 1940 (2500 m^3/s at Céret) profoundly affected the riparian woodlands of the Tech, only sparing some relic fragments in the Roussillon Plain. The impact of more recent floods has been variable. Floods with a rate of less than 700 m^3/s at Céret have favoured the re-establishment of pioneer stages all along the river; those of over 700 m^3/s have destroyed the pioneer stages on the unstable deposits of the main channel but, conversely, have favoured development towards post-pioneer stages by consolidation of stable deposits higher up. The White Poplar *Populus alba* community appears here as one of these post-pioneer stages which has become permanent along a watercourse subjected to a succession of floods of catastrophic nature.

Michel Gunther/Bios

Multifunctional woodlands

Riparian woodlands are very popular in the context of river management. Their popularity stems largely from their capacity to purify runoffs, in other words to filter out materials derived particularly from agricultural land. Nitrogen and phosphorus are among the most important of these materials. This natural filtering role is often cited as reason enough to justify conserving, restoring and even recreating riparian woodlands.
The filtering function is undeniably of interest. However, sustainable management of riparian woodland cannot depend only on this one function; there is a need to consider the whole range of functions derived, the "multifunctionality" of riparian woodlands.

Riparian woodland
lining a river in an urban area

Riparian woodlands carry out functions which are many and varied, as well as being complementary.

• Regarding the aquatic environment, they stabilise river banks, protecting bank soils against surface erosion and strengthening their resistance to destabilisation.

They help to improve the clarity of water in rivers by reducing the amount of sediment from along the river banks. They also help to prevent the silting up of sensitive aquatic habitats, for example the spawning grounds of salmonid fish.

They trap nutrients which reach the rivers through diffuse inputs in surface or sub-terranean runoffs. This tends to counter-act the over-enrichment of rivers by phosphorus or nitrogen, through microbiological denitrification and absorption by plants. This effect complements the effect of shading which reduces light penetration, and limits increases in water temperature during the summer, thus reducing the growth of algae and macrophytes in watercourses.

They contribute to the maintenance of existing fish stocks through their effects on summer temperatures, on the diversity of aquatic habitats, and in supporting prey, both aquatic and terrestrial species.

• Regarding the terrestrial environment, riparian woodlands form corridors which facilitate the movements of certain species along hydrographic networks. These natural corridors may prove to be essential for the survival of fragmented populations functioning together as metapopulations.

They allow access to the banks of watercourses by livestock to be controlled since they limit the number of access points and, therefore, they reduce trampling, erosion, the direct input of excrement into the water, and even the number of animals which fall into the water after having ventured onto steep banks.

They complement grasslands and agriculture. Riparian woodlands produce forage, firewood and other, specialised, products. They also provide homes for various species of birds which can control pests in the adjoining agricultural land.

They form natural screens, protecting crops from the direct action of the wind and livestock from extremes of heat and cold.

• On a regional scale, riparian woodlands help to increase regional species diversity, both aquatic and terrestrial, including species of heritage value.

Finally, they constitute a major feature of Mediterranean riparian landscapes.

These different functions may be reduced into five themes which are developed below: flow dynamics, bank stability, water quality, the functioning of flowing water ecosystems, and biodiversity dynamics. To these five themes may be added that of riparian landscapes, the subject of the next chapter.

Confluence in a Mediterranean landscape

Jean Roché

Flow dynamics

The structure and functioning of riparian plant communities depends primarily on flood dynamics: riparian habitats are characterised by extreme instability. There is an alternation between terrestrial and aquatic environments here, forcing plants to adapt to contrasting living conditions. Riparian woodlands are subjected to the vagaries of both floods and low flow periods, and the woodlands themselves exert an influence on these factors.

Deep water

A deep root system allows riparian plants to maintain their evapotranspiration* rates during dry periods. In north-east Brazil, on some clayey soils, the Amazonian forest can absorb water from the ground from a depth of over 8 metres during the dry season[28]. Root systems are largely instrumental in the transfer of water from deeper to shallower layers. Moreover, this upward transfer is complemented by the downward redistribution of water from near the surface along the root channels. Herbaceous plants can also draw water from considerable volumes of soil, thanks to their highly branched root systems which, as in the case of *Festuca arundinacea*, can penetrate to a depth of 2 metres.

The water of riparian soils originates from precipitation, from the rivers and from groundwater. However, in arid or semi-arid climates, these sources vary widely in space and time. In these conditions, the ability to use water from different sources gives some species a distinct advantage over their competitors. Poplars and willows for example are replaced by tamarisks along some rivers of the southern USA: all these species use soil water from average depths of 3.5 metres, but the tamarisks also use the moisture from unsaturated overlying soils, and so they are capable of sustaining high transpiration rates when groundwater levels decline.

Intermittent water

The opportunism of riparian species can be surprising. Some pioneer plants of the Dead Sea coast use fresh water at times of flooding and not the extremely salty water of their rhizosphere*[29]. In summer, in the absence of flooding, these plants almost completely suspend evapotranspiration and water absorption through the roots, until the first winter floods. This faculty of absorbing only fresh or slightly brackish water whenever it is available influences the establishment of

28 - Nepstad et al. (1994)
29 - Yakir & Yechieli (1995)

pioneer plants along watercourses where flooding is intermittent. It allows them to take advantage of favourable wet periods while surviving through dry seasons.

Running water

The rate of flow is particularly significant for the growth of riparian trees in arid or semi-arid climates. In California, for example, an increase in flow rates by a factor of 4 or 5 in a watercourse used as a headrace channel, doubled the growth rates of riparian poplars *Populus trichocarpa*[30]. Similarly, an increase in available water triggered significant increases in population sizes of *Prosopis velutina*, another riparian species growing along watercourses in Arizona. Our understanding of the effect of flow rates on the growth of riparian trees in the Mediterranean needs to be improved as there are as yet, many unanswered questions; i.e. What is the effect of distance from the watercourse, or of the level of the groundwater, on the water regimes of the main tree species? How do these regimes vary in relation to seasonal and annual variations in flow rates? According to the species under consideration, past and present flow conditions will influence to a greater or lesser extent evapotranspiration, rates of germination and mortality, seed production, survival of seedlings, and both inter- and intraspecific competition.

Riparian vegetation is not simply passively affected by hydrological conditions. The vegetation itself in turn influences hydrology, by for example forming obstacles, and diverting or facilitating the flow of water, in accordance with the height, density, form and flexibility of the species present.

On a local scale, from the first stages of vegetational succession, pioneer plants affect the water regime of riparian soils during periods when water levels are low. They prevent newly deposited sediments from drying out, by providing shade and by water absorption through the roots, which may be considerably augmented by the presence of mycorrhiza. In periods of rain, during flows up to 5 cm deep, riparian herbaceous vegetation may trap over 50% of the sediment carried away from adjacent banks. This phenomenon is magnified when the mosaic of cover includes vegetation of different heights and degrees of pliability.

On a regional scale, development of riparian woodlands can affect the flow regime throughout hydrographic networks. In many Alpine rivers, the abandoning of traditional agriculture along the banks has stimulated sometimes spectacular development of riparian woodlands.

30 - Stromberg & Patten (1990)

On the River Ouvèze, the mean width of these woods increased from 50 to 92 metres downstream of Vaison la Romaine between 1947 and 1991, reducing the mean width of the flow channel from 83 to 48 metres[31]. This resulted in a considerable reduction in the capacity of the river to carry away water during major floods, as was shown by the catastrophic flood of 1992 when water flow was buffered by the woodland.

Another spectacular example is provided by the invasion of the banks of the Colorado River and its tributary, the Green River, by thickets of tamarisk *Tamarix* spp.[32]. Between 1910 and 1970 tamarisks spread up the rivers at a rate of 20 km per year, aided by abundant seed production (about 600,000 per adult tree per year), the lightness of their seeds (allowing for widespread dissemination by the wind), and a well developed capacity for vegetative reproduction*. Very dense thickets became established along the Green River, which had the effect of reducing the effective width of the watercourse from 13 to 55% and leading to the accumulation and consolidation of sediments up to 3.5 metres above low water level. These changes had two major consequences: 1) the river could no longer renew the banks during floods, preventing any recolonisation by native species, 2) the tamarisk thickets sucked up the groundwater until supplies were exhausted.

Evaporated water

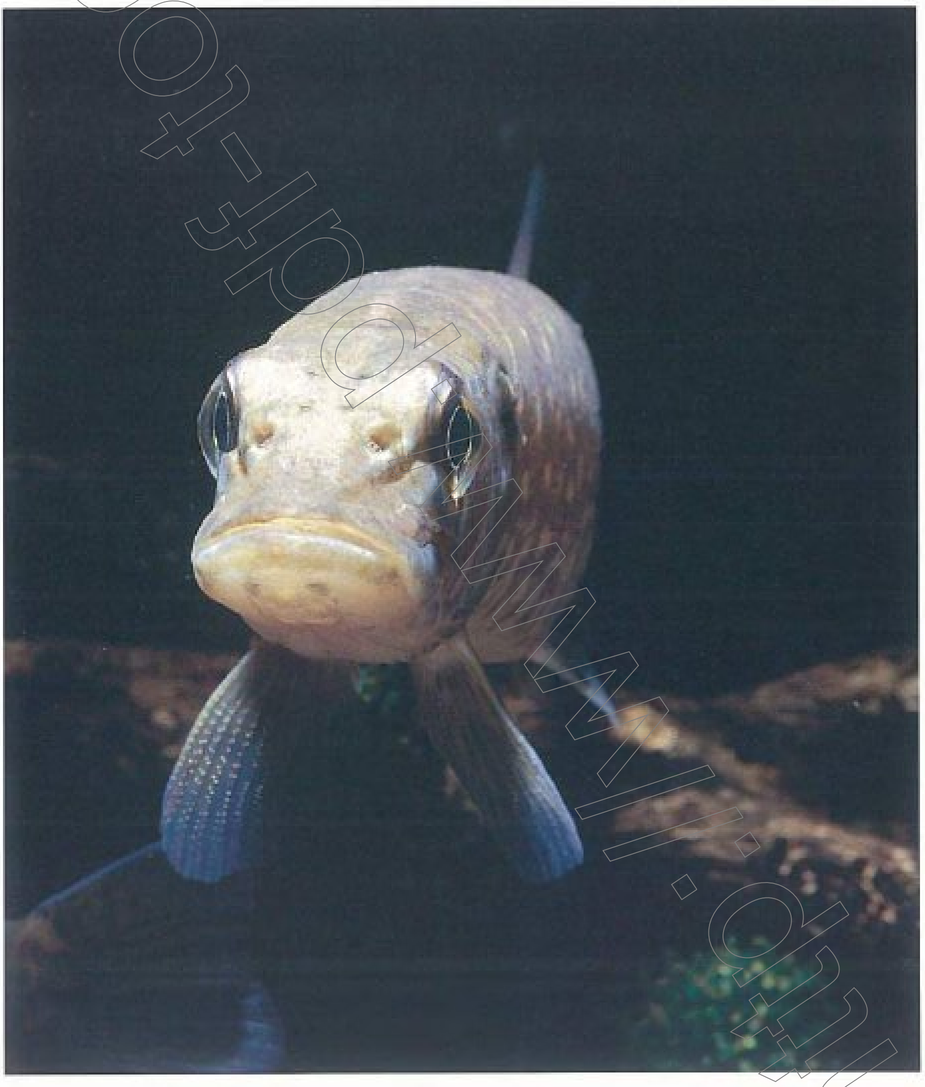
Riparian vegetation also affects the riparian water cycle by storing absorbed water and releasing it to the atmosphere by evapotranspiration, as is shown by measurements taken along the River Morava in the Czech Republic[33]. Between June and September, the water content of Small Balsam *Impatiens parviflora* may change with varying wet weights from 98 to 92% in the stems and from 94 to 90% in the leaves; for the Stinging Nettle *Urtica dioica* the corresponding figures are from 88 to 85% in the stems and from 86 to 80% in the leaves. During this same period, these two very common species along watercourses may increase in height from 16 to 38 cm *(Impatiens)* and from 40 to 80 cm *(Urtica)*. By comparison, the water content recorded from bushes and trees is generally lower, varying during the same June-September period from 76 to 55% in the stems and 75 to 65% in the leaves of hornbeams, from 54 to 58% in stems and leaves of oaks, and from 58 to 67% in stems and leaves of ash trees.

Absorption rates vary widely from one species to another, with the highest rates among poplars and willows. Measurements taken in the

31 - Piégay & Bravard (1997)
32 - Graf (1978)
33 - Penka et al. (1991)

growing season reveal mean daily rates of water consumption of 174 kg per day (max. 460 kg per day) for a 33 m tall oak and, at the same site, 73 kg per day (max. 203 kg per day) for a 34 m tall ash.

Evapotranspiration rates also vary according to the different vegetation layers: a study along the Morava shows that herbs contribute 3% of the potential evapotranspiration, bushes 9% and trees 88%. As for daily and seasonal variations, they depend on local environmental conditions, on the plant species, and on community structure. Overall, riparian woodlands act to humidify the surrounding air and they form the basis of an "oasis effect".



Claude Guihard/Bios

Pike, *Esox lucius*

Bank stability

Riverbanks may be affected by two types of erosion: undermining, whereby soil is removed practically particle by particle, and subsidence, which is more sudden and more spectacular. These two types are linked insofar as undermining predisposes banks to collapsing and may therefore in a sense be considered to be more destructive, even if it is often less noticeable.

In general, the presence of a layer of riparian vegetation reduces the risk of undermining and collapse bank failure. Firstly, the root systems of the plants reinforce cohesion of riparian soils at risk of collapsing, particularly where there are many fine roots. Secondly, the plants assist in the drainage of riparian soils, thereby reducing the risk of collapse due to waterlogging. Thirdly, plants growing at the base of the banks act as buttresses, protecting to some extent the soils above.

Variable effectiveness

The effectiveness of plant cover varies from one site to another along a watercourse. In the upper reaches of a river, riparian vegetation at the foot of the bank will improve its stability, often to a significant degree. Further downstream, along wide, deep rivers, deep-rooted trees on the top of the bank are likely to reduce erosion. Schemes adopted to protect banks from erosion tend to be modelled on natural conditions: herbaceous plants, reeds and pliable shrubs at the foot of banks, subjected to frequent flooding, shrubs and small trees with an understorey of herbs at mid-slope, and large trees with an understorey of other trees, bushes and herbs on the top of the banks. Various factors determine which species will thrive: water, light, frost etc.

Riparian plant cover is not always capable of stabilising a bank, for example on the outside bends of meanders where the steepness of the bank prevents the establishment of significant vegetation coverage. Also, the higher the bank, the less it can be protected by vegetation and, thus from the risk of collapsing. Aquatic or semi-aquatic vegetation reduces the speed of the current and, as a result, the risk of undermining*; however, as the quantity of aquatic vegetation increases it may direct the current against the banks and so increase the risk of undermining. This is a consequence of over-invasive reedbeds.

It is sometimes suggested that the excess load due to the weight of large trees on the banks may increase the risk of collapse. In fact this risk only occurs on banks which are almost vertical; in the majority of cases large riparian trees actually improve bank stability thanks to their deep root systems. The risk comes rather from trees which are too shallowly rooted, especially black poplars, which are easily thrown by strong winds. It also comes from shading, which prevents herbaceous plants from growing beneath the trees; their fine networks of roots can be very effective in maintaining the cohesive properties of some riparian soils. The banks of minor watercourses in Wisconsin for example, on sandy and clayey soils, proved to be more stable with a covering of herbs rather than with trees[34].The stability of the banks of watercourses depends in fact on a whole range of local factors: the type of sediments present, the plant species available, the severity and frequency of hydrological events and the size of the watercourse in question.

A wider context

Riparian woodlands play a double role with respect to soil erosion. As we have seen, they improve the integrity of stream banks, which they stabilise thanks to their root systems which serve to protect against undermining and subsidence. But they also facilitate the deposition of sediments in riparian zones and, as a result, partly compensate for soil erosion; they reduce the amounts of sediment which are carried into watercourses via surface runoff.

However, the use of riparian woodland as a remedy for soil erosion must be placed in a wider context, at the scale of an entire catchment area or of the whole hydrographic system from the river sources to the river mouth. The use of riparian woodland to reduce the destructive effects of soil erosion along Mediterranean rivers is inseparable from practices which aim to prevent erosion in agro-sylvo-pastoral systems. These practices must make every effort to re-establish the soils' herbaceous cover and to avoid overgrazing. Modern orchards, ploughed and treated with herbicides, are extremely vulnerable, whereas dehesas and traditional orchards show much greater resistance to erosion.

The annual loss of soil from olive groves in Andalusia, for example, is over 80 tonnes per hectare, with a maximum production of 200 t/ha/yr[35]. The wider picture suggests that the scale of soil loss in Mediterranean countries poses a real threat of silting up of reservoirs. In Spain, the storage capacity of 22 reservoirs on the rivers Ebro, Jucar and Segura decreases by 12 million m^3 every year. In France, the capacity of the Serre-Ponçon reservoir on the Durance decreases each year by 3 million m^3, halving the lifetime envisaged for the reservoir at the time of its construction.

34 - Trimble (1997)
35 - Pointereau et al. (2000)

Bank erosion

Jean Roche

It should be emphasised again that the stabilisation of riversides by riparian woodland is only one possible remedy for bank erosion. In fact this erosion need not be viewed only in a negative light. It is sometimes better to allow a river to stray from its course along some sections: this reinforces the diversity of riparian habitats as well as the structure of the riparian vegetation. It also eases the effects of flooding further downstream.

Any use of riparian woodland as a remedy for soil erosion must therefore be seen from the more general perspective of the management of catchment areas as a whole. It is dependent on the part of the bank affected, the section of the watercourse, and the geographical region, not forgetting the aspirations of the human populations involved.

Riparian woodlands: a remedy for soil erosion?

The stabilisation of banks by establishing a covering of vegetation requires very thorough preliminary assessment. To start with, the possible causes of erosion along the relevant stretch of river must be identified: these causes will determine the type of plant cover, its position, and the possible need for reinforcement using rip-rap. At the same time, the planning of the operation will need to involve a sufficiently large number of riparian landowners, given that works at any given site will affect downstream stretches of river. Planting must be as close to the foot of the banks as possible, i.e. where the cover will prove to be the most effective. It should be remembered also that riparian vegetation has little impact along big rivers, whose channels are more than thirty times as wide as they are deep.

As regards to species selected for planting, experience demonstrates that mimicking the variety of natural cover which occurs locally, allows vegetation to re-establish itself with a minimum of effort. However, in some sensitive situations it may be appropriate to use exotic plants in order to prepare the ground for indigenous species. In any case, the priorities for improving the drainage and stability of the soil are to establish dense undergrowth, species which root deeply and abundantly, and large trees at the top of the banks.

But it must also be remembered:

• that simply planting a layer of vegetation rarely halts the erosion of banks which are already heavily degraded,

• that this vegetation layer reduces the capacity of the channel to cope with heavy spates once established on islets or on rocky shoals in the river bed itself,

• that the trunks of dead trees and other large pieces of wood which fall into the water may cause log jams if they take up more than 10% of the cross-sectional area of a river,

• that bank erosion cannot be viewed only in terms of dangers; it also involves positive aspects to the extent that it keeps the major channels open, perpetuates the riparian mosaic system, and absorbs the impact of some floods, counter-balancing their effects downstream.

Water quality

Various types of inputs reach river courses from their catchment areas. Soil washed in from the adjoining land carries with it adsorbed phosphates, pesticides and heavy metals. Dissolved nitrogen compounds travel with them, together with leaf litter and micro-organisms. This contamination enters the watercourses in surges, during the sudden floods which are typical responses to the Mediterranean climate.

This pattern is accentuated by deforestation to create agricultural land, forestry activities, urban development and the extension of built-up areas. Modifications in the catchment area also cause the silting-up of aquatic habitats and spawning grounds, and lead to various kinds of pollution which are very difficult to control since they have diffuse points of origin.

Riparian buffer zones

Riparian vegetation mitigates the effects of this non-point source pollution by improving water quality. It slows down surface runoff, causing sediment deposition before the sediment reaches the watercourses; in favourable conditions, the natural vegetation along rivers can trap up to 98% of the sediment carried in from the catchment area[36]. In addition, this vegetation absorbs waterborne nutrients and therefore contributes towards their removal, for example by denitrification. Thanks to their deep roots, bushes, herbs and trees absorb significant amounts of underground water and, along with the water, nutrients and other dissolved material, carried in from agricultural land are also absorbed.

This buffering capacity of riparian zones – principally riparian woodlands – has stimulated much enthusiasm over recent years. It appears at first sight to provide a free and effective "natural service". However, this is only partly true, since the effectiveness of these riparian buffer zones depends on their situation, their precise composition, and so the uses to which they are put, and their dimensions. Many factors have to be taken into account, more often than not each situation is assessed on a case-by-case basis, according to the watercourses being considered, the regions through which they flow, and the socio-economic dimension.

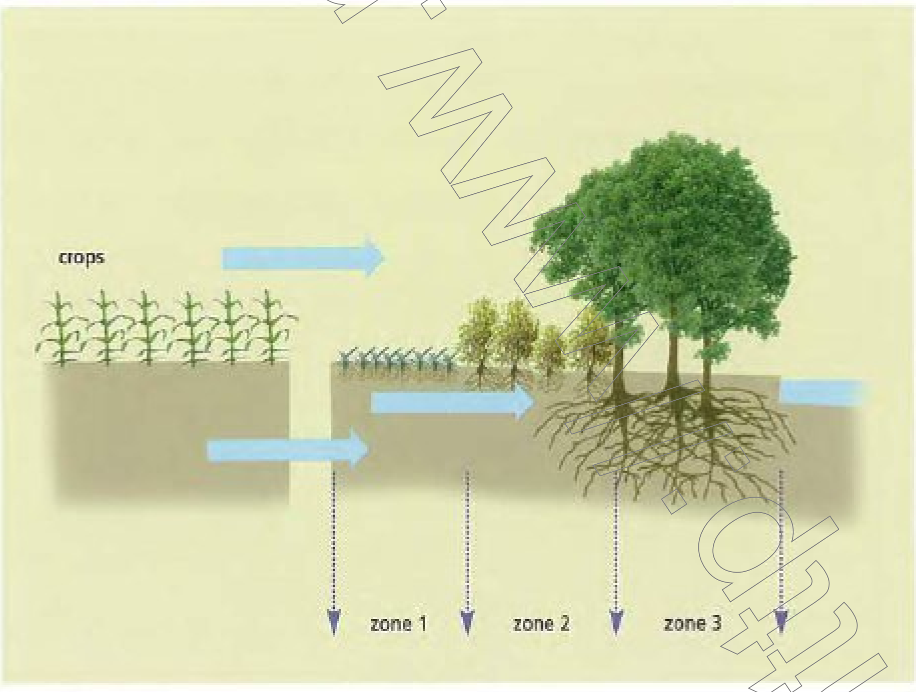
There is also an important precondition: no riparian buffer zone will work unless the surrounding land is being used in appropriate ways. In the absence of good land-use practices excessive amounts of

36 - Lowrance et al. (1995)

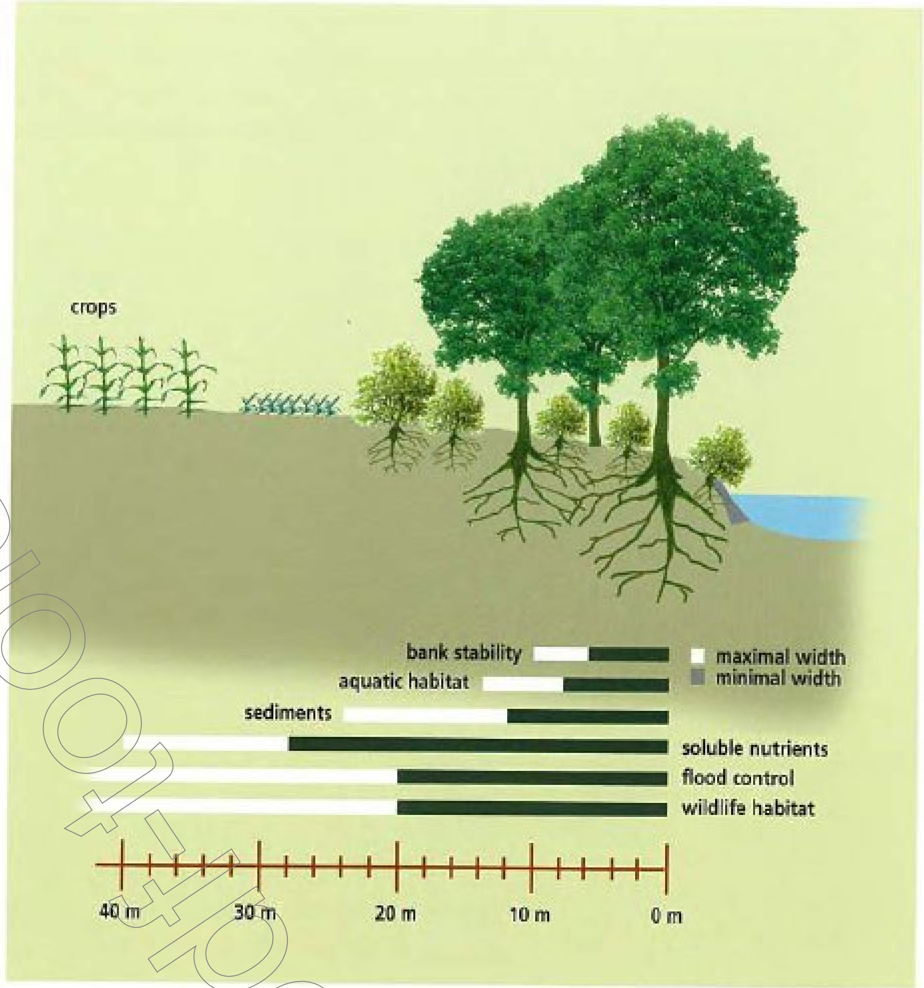
material running off the land will soon cancel out any buffering effect. It is vital to minimise the amount of fertiliser that is being shed from arable land, by applying fertiliser at times when there is little or no runoff, by blending it directly into the soil rather than spraying it over the soil, and finally by ploughing along the contours of the land.

The most effective riparian buffer zones conform with a multiple-species model which includes three separate parallel strips between the crop and the watercourse (see figure below). A herbaceous strip, next to the crop, spreads out the surface runoff, preventing flows being concentrated into rivulets which are liable to increase erosion; this strip may also filter out sediments, absorb nutrients and convert them into biomass. Next, a strip of mixed trees and bushes allows water to infiltrate into the soil, facilitating the absorption of nutrients and pollutants; it also allows nutrients to be stored over longer periods than the preceding strip, and it may be used for commercial forestry. The third strip, made up of natural woodland, lies nearest to the watercourse serving to stabilise the banks, provide organic material for the aquatic food web and maintain cool temperatures by shading.

The width of these riparian buffer zones is eminently variable. It depends on the volumes of water and sediments involved, as well as the characteristics of the surrounding land which may vary in terms of soil type, intensity of land use, presence of livestock, existence of marshy ground, etc. A width that is suitable for a given use in a given situation will prove to be ineffective elsewhere: there is no ideal width that can be applied in every situation. To put it simply, according to



The multiple-species model of a riparian buffer system comprises three separate parallel strips between the crop and the watercourse (after Lowrance *et al.* 1998, modified).



Possible widths of riparian buffer systems in relation to proposed uses (after Schulz *et al.* 2000, modified).

the minimum widths available, various uses can be envisaged, (see figure above), remembering that water quality protection does not preclude other uses of riparian buffer zones, whether for feeding livestock or for the harvesting of wood.

Nitrogen, phosphorus and pesticides

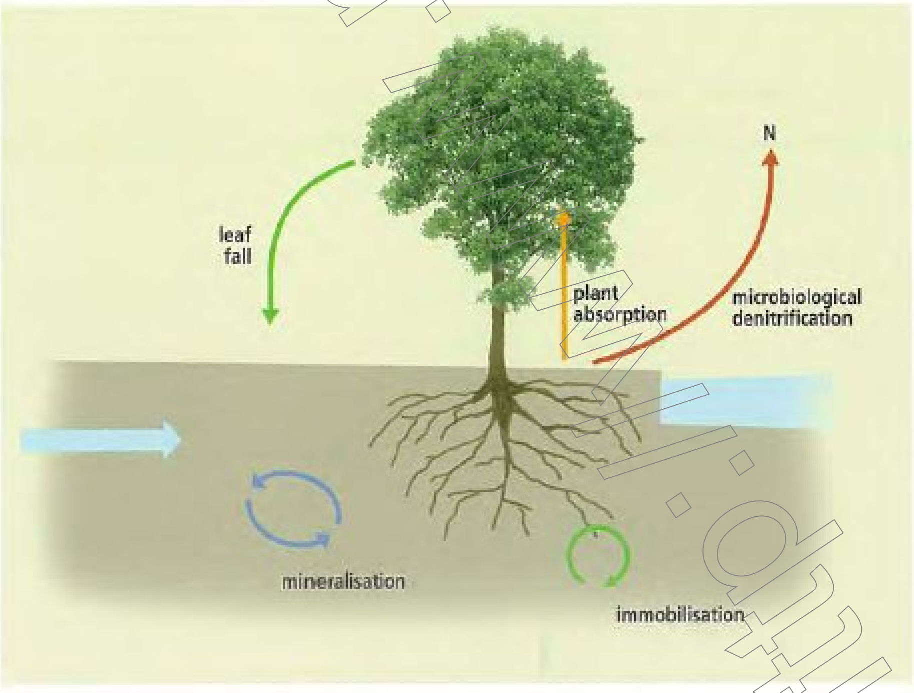
The filtration of runoff water by riparian woodlands calls for different approaches according to whether it involves the removal of nitrogen, phosphorus or pesticides.

• With regards to nitrogen, some bacteria of waterlogged soils use oxygen from nitrates to assimilate the carbon necessary for their growth and in so doing, release gaseous nitrogen into the atmosphere. This process – microbiological denitrification – plays an essential role in the removal of dissolved nitrates from runoff water. It removes the nitrogen permanently, unlike the process of absorption by plants, which essentially involves the temporary storage of nutrients, which return to the soil again during leaf-fall accumulating with the leaf litter (see figure p. 67).

Along a watercourse, the elimination of nitrates from water runoffs depends both on the hydrological regime and on the vegetation present. The hydrological regime is important because flooding saturates riparian soils, tending to create waterlogged conditions, while at the same time carrying in sediments and with sediments the organic carbon needed by denitrifying bacteria. The vegetation is important because it also provides organic carbon, by the decomposition of litter and by exudates from the roots.

Although well understood in principle, denitrification is not easy to achieve in the field. Firstly, the water must not lie stagnant in the riparian zones, otherwise other processes will intervene which prevent denitrification reaching completion; instead of nitrogen, oxides of nitrogen are released, which are known to exacerbate the greenhouse effect. Secondly, runoff can bypass the riparian woodlands, partly or completely soaking into the ground. Thirdly, local hydrological and geomorphological conditions can lead to microdistributions of carbon and nitrogen stocks which immobilise these elements, isolate them and impede mineralisation within riparian spaces. Moreover, the forest species present can modify the structure and functioning of microbe communities.

Conditions of unstable equilibrium are established, due to the combined effects of the flow regime of the water, soil type and vegetation cover: conditions which are themselves variable in space and in time. The control of these equilibria requires a very detailed knowledge of the area concerned. Decisions regarding the optimum

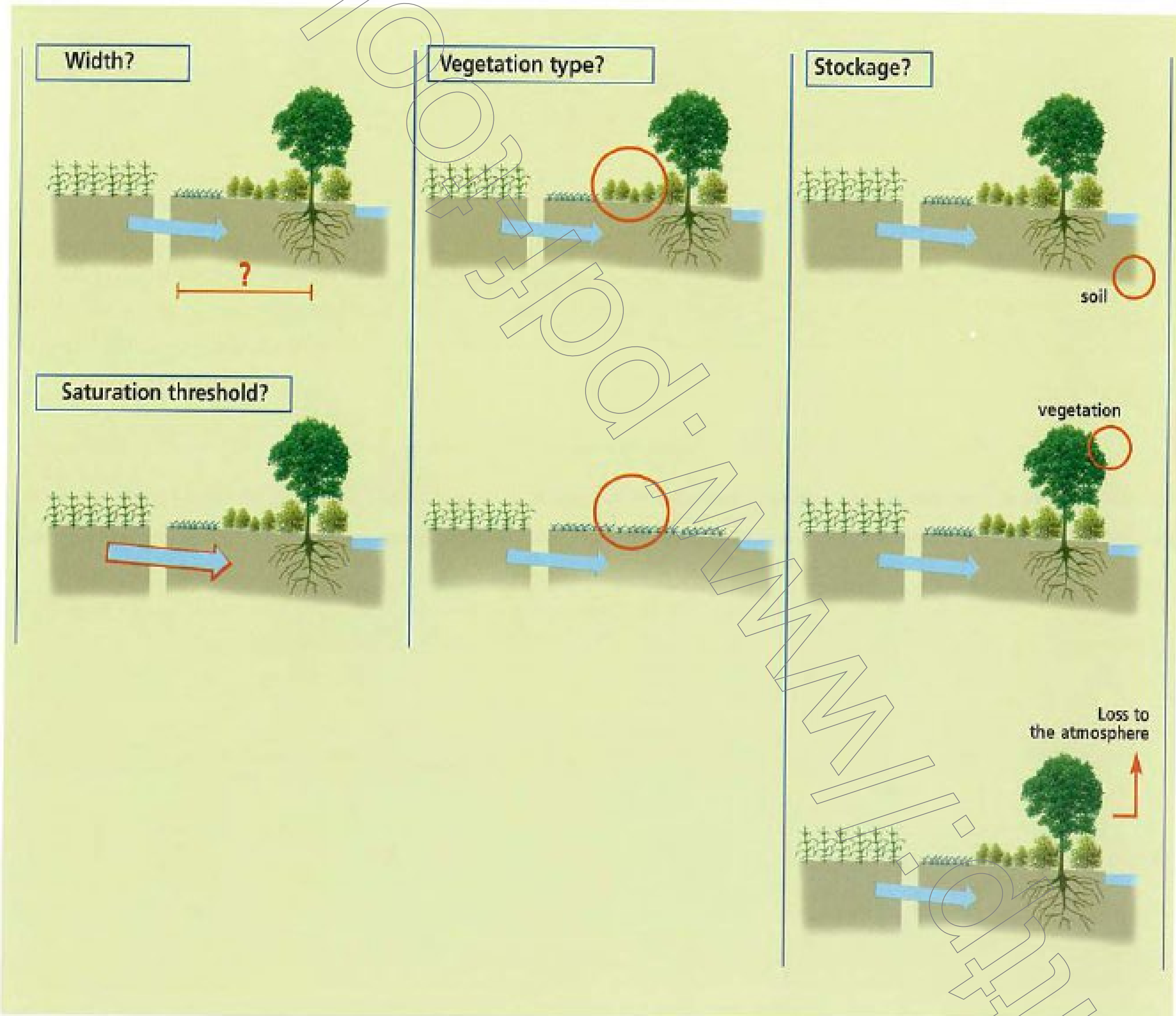


In microbiological denitrification nitrogen is given up to the atmosphere, whereas in the case of absorption by vegetation the nutrients are stored temporarily in plant tissues and subsequently return to the soil with leaf fall and the death of trees.

width of filtration buffer zones, saturation thresholds, and the plant species to be used for cover, are all dependent on this knowledge, and can only be considered in a local contex (see figure below).

• With regards to phosphorus, runoff can carry this element in two possible forms: in solution or in suspension. Various mechanisms promote the movement of phosphorus into water: erosion of soil particles which have phosphorus in association, desorption of dissolved phosphorus from these particles or from soils remaining in place in the catchment area. Phosphorus passes from one to another of these forms depending on the uptake and release of phosphate ions by the soil particles and on the concentration of dissolved phosphate. Above a certain concentration, which varies according to soil type, phosphate is adsorbed by soil particles; below this concentration it dissolves.

The effectiveness of riparian buffer systems depends on questions which can only be addressed on a local level. (after Lowrance *et al.* 1998, modified).



Riparian buffer zones retain phosphate by facilitating the deposition of sediments, by adsorption of dissolved phosphorus and through assimilation by riparian vegetation. Infiltration into the soil enhances these mechanisms by promoting the filtering out of suspended solids. Clearly therefore, the deposition of soil particles is the main mechanism for the removal of phosphorus in riparian zones. This mechanism is strongly dependent on a reduction in the speed of runoff across riparian soils. These soils are all the more effective if they are fine but sufficiently well drained, acidic, with a high oxide and clay content but low in organic matter and absorbed phosphate.

• Regarding pesticides, these also occur in solution and in suspension in runoff. Once applied to agricultural land, the likelihood of their dispersal depends on their mobility, on how quickly they are broken down, on the soil structure and on how much time has passed between their application and when they are washed away. Strips of herbaceous plants appear to act as effective filters as far as pesticides such as atrazine and lindane are concerned, even during periods of heavy runoff. The mechanisms by which they are trapped are still poorly understood.

Studies such as those carried out in the Chesapeake Bay catchment in the USA highlight the potential for riparian buffer zones to act as filtration sites, for nitrates dissolved in the water running off the land as well as for phosphorus adsorbed onto sediments (see table p. 71).

Buffer zones: from myth to reality

Riparian woodlands seem to be natural filters capable of taking up and even eliminating a large proportion of diffuse pollutants which reach a watercourse. However, this filtering capacity, attractive though it may seem, cannot justify uninterrupted planting all along hydrographic networks. Neither can it be a substitute for good catchment management. The use of riparian buffer zones as natural filters must be incorporated into management plans.

Above all the use of buffer zones must be adapted to local conditions; this is because in the first place, buffer zones do not filter out diffuse pollution everywhere with equal efficiency. In the upper parts of catchments, streams flow through areas where sediment and nutrients are being produced. These streams are the primary conduits for runoff from surrounding agricultural land. Further downstream, watercourses have the role rather of conveying material carried down from further up stream. Therefore, the most efficient filtration occurs in the zones alongside smaller watercourses upstream of the catchment areas.

The presence of a riparian woodland also does not automatically ensure the complete filtration of diffuse pollution. There may be complete filtration if there is a shallow groundwater layer lying close to the surface; it is much less thorough if the groundwater extends deeply below the rhizosphere, and especially if the rhizosphere is completely bypassed.

Moreover, filtration does not proceed with optimum efficiency from the outset. A period of 10 to 15 years may be necessary for a perennial plant community to develop in a riparian zone and to form a satisfactory soil. A strip comprising only herbaceous species may reach its optimum efficiency more quickly – in about five years.

However long this delay may be, maintenance is always essential in riparian buffer zones. During the early years of establishment, competition between herbaceous species must be controlled in order to prevent the spread of some undesirable species to the detriment of the other species in the community. Mowing or burning may prove to be necessary, as may the application of herbicide around young trees. In the longer term, the filtering capacity of a buffer zone will only persist if the biomass present is periodically removed, together with its store of nutrients, and if drainage channels are demolished as and when they appear.

Finally it must be emphasised, in support of the creation of riparian buffer zones, that they only take up a relatively small proportion of agricultural land. A buffer zone 10 metres wide and 500 metres long has an area of 0.5 hectares, and a zone 30 metres wide and

Jean Roché

Riparian buffer zone
in an agricultural land

buffer zone		reduction: 100 x (input - output) / input		
width (m)	plant cover	sediment (%)	nitrogen (%)	phosphorus (%)
4,6 (1)	herbs	61,0	4,0	28,5
9,2 (1)	herbs	74,6	22,7	24,2
19,0 (2)	trees	89,8	74,3	70,0
23,6 (1)	herbs + trees(3)	96,0	75,3	78,5
28,2 (1)	herbs + trees(3)	97,4	80,1	77,2

1. inputs: sediment 7.284 mg/l, nitrogen 14.11 mg/l, phosphorus 11.3 mg/l.
2. inputs: sediment 6.480 mg/l, nitrogen 27.59 mg/l, phosphorus 5.03 mg/l.
3. width comprises 4.6. metres of herbs plus 19 metres of trees.
4. width comprises 9.2 metres of herbs plus 19 metres of trees.

Effects of various riparian buffer zones on the reduction of inputs from surface runoff: evaluation based on studies carried out in the Chesapeake Bay catchment in the USA (after Lowrance *et al.* 1995, modified).

500 metres long takes up 1.5 hectares. Given the difficulties involved with using agricultural machinery close to watercourses, many of these areas are difficult to farm. Further, benefits other than protection may derive from a buffer zone, some "commercial" – such as the production of wood and forage – others "non-commercial" such as hunting, leisure areas, and the provision of natural habitats, both aquatic and terrestrial.

The functioning of running-water ecosystems

Riparian forests exert considerable influence on the structure and the functioning of running-water ecosystems[37]. This influence was the major inspiration for the river continuum concept*, one of the most well known and discussed theoretical bases of river ecology.

The concept is based on a simple observation: each river is in a continuous state of change from its source to its mouth. It takes into account physical properties, including width, depth, gradient, flow, as well as – and this is the basic hypothesis formulated by the authors of the concept – the biological processes on which the functioning of running-water ecosystems rely.

As figure p. 74 indicates, the headwaters benefit from nutrients contributed by riparian woodland, for example in the form of dead leaves, while the shade from the bank limits the penetration of sunlight, reducing the potential for primary production. These headwaters are classed as heterotrophic, signifying that most of their nutrient resources come from external habitats. The middle reaches, still fairly shallow but wider, are very clear, which makes the development of aquatic plant life possible: algae – or periphyton – covering hard river bottoms, and rooted aquatic plants – or macrophytes – sometimes grouped together in beds. This vegetation forms the majority of nutrient resources of these middle reaches, which are classed as autotrophic. As for the larger river reaches downstream, their typically turbid water strongly reduces their clarity deep below the surface, resulting in a return to heterotrophic conditions. Bankside woodlands can develop into alluvial forests growing between multiple river branches and on islands.

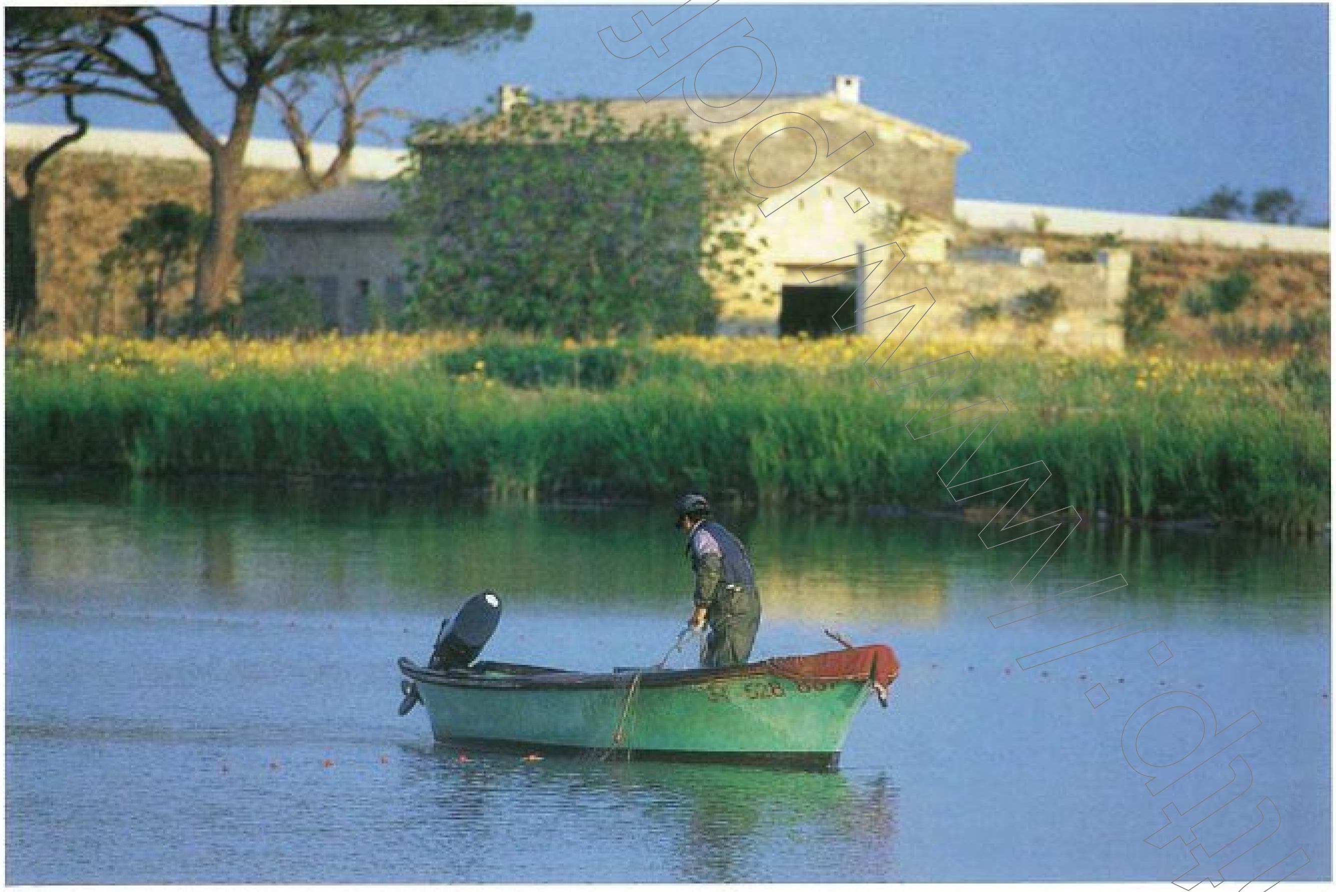
Riparian vegetation influences the structure and the functioning of running-water ecosystems through provision of shade and the contribution of organic material. The shading of streams and rivers reduces the maximum water temperature in summer, maintaining good oxygenation and enabling aquatic fauna to survive low-flow periods. Shading also reduces light penetration by filtering sunlight. This dual effect of riparian vegetation on temperature and on light reduces the risk of cultural* eutrophication to the extent that the planting of riparian trees is recommended to combat the unchecked growth of algae and macrophytes in small lowland rivers.

37 - Vannote et al. (1980)

The input of organic material into watercourses by riparian plants is also fundamental, whether in dissolved or particulate forms. A gradual decrease in particle sizes can be observed: large particles dominate upstream, and small ones downstream, just as dead leaves are broken down into increasingly fine pieces and dissolved in the water as they are carried along by the current. Animal communities adjust constantly to these changes in order to make the best use of the energy available along the course of the river. There is also a succession of functional groups of invertebrates on the river bed: shredders and filter-feeders in the headwaters, followed by predominant filter-feeders and scrapers in the mid-reaches, until filter-feeders are found to dominate. Similarly, there is a parallel succession of fish communities: following a classic European model this would proceed as Trout-Grayling-Barbel-Bream.

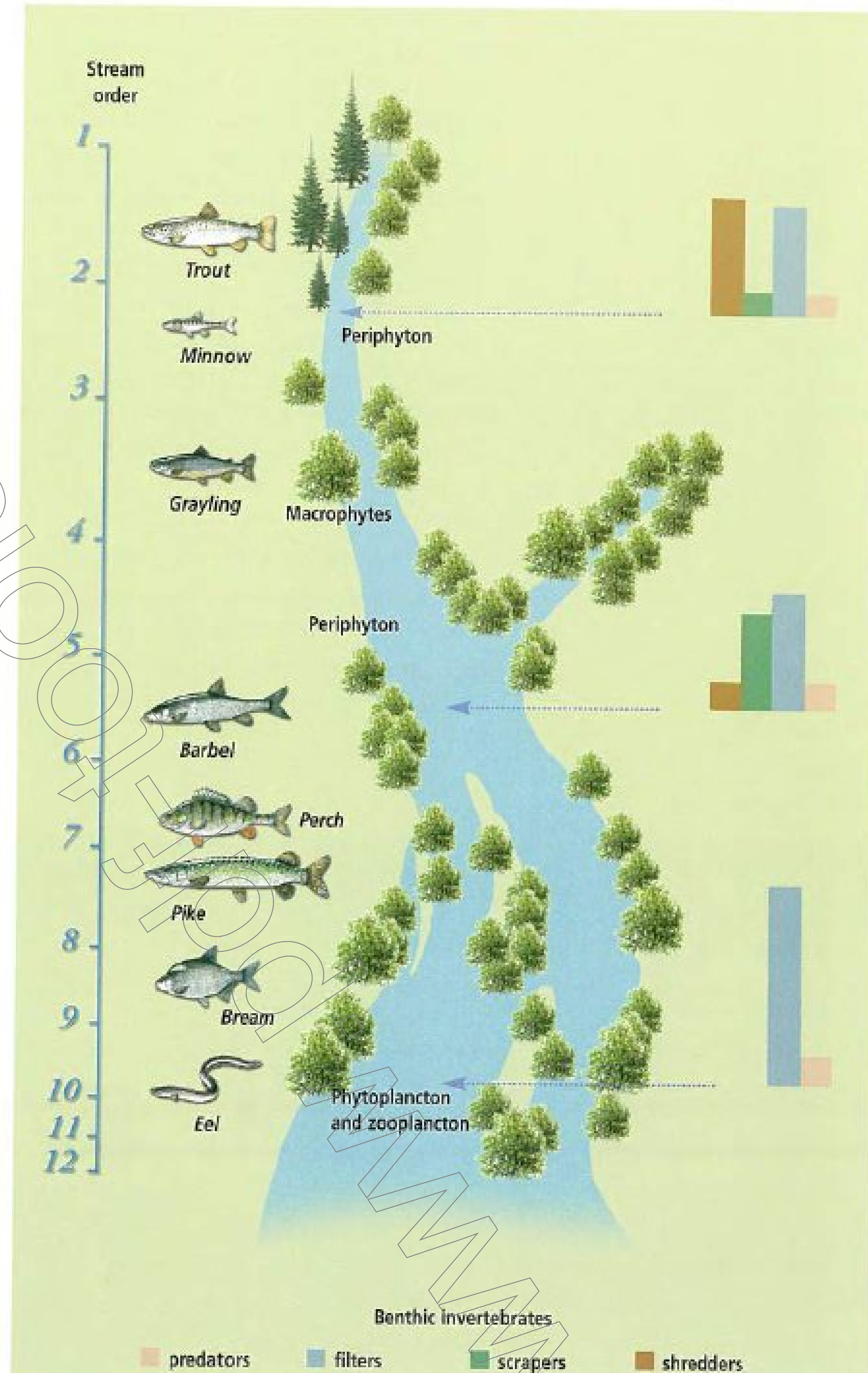
Dead leaves thus form an essential input of organic material into watercourses. As they decompose, they feed a whole community of invertebrates which, on the river bottoms, provide a source of food for fish. An experiment carried out in North Carolina is significant in this respect[38]. Its authors deprived a woodland stream of its leaf litter inputs in a zone 200 m long for three consecutive years. The result

Fisherman in a Mediterranean river



Bruno Pambour/Bios

38 - Wallace et al. (1997)



Riparian woodland and the river continuum concept (after Vannote *et al.* 1980, modified).

was unambiguous: of the 29 species of invertebrates contributing 95% of the zone's production, 17 species significantly declined in abundance and/or in biomass with the removal of the leaf-litter input. Note that this decrease not only affected detritivores, which are direct users of dead leaves; it also affected predators, thus modifying the whole food chain.

Calopteryx haemorrhoidalis

In addition to dead leaves, there are other inputs of organic material from riparian woodlands. These inputs include terrestrial invertebrates (grasshoppers, the imagos* of semi-aquatic insects, etc.) that have fallen into the water from the banks; these can be a major source of food for fish, as any angler knows, and are also made use of as bait.

Dead wood is another important source of organic material input. Tree trunks and branches regularly fall into watercourses. Some are stranded where they fall, while others are carried along by the current. This dead wood, whatever its fate, fulfils many functions in running-water ecosystems. It creates a wide variety of habitats, from deep pits with slow moving water to fast-moving, well aerated rapids. In so doing, the dead wood promotes the diversification of plant and animal life in streams and small rivers. Accumulations of dead leaves on submerged tree crowns become hotspots of biological activity. Dead wood is also a substrate on which algae can develop, attracting aquatic insects, molluscs and worms. A whole community of invertebrates also creates a link between the algae and detritus on which it feeds and predators, including fish. Fish also make use of accumulations of dead wood for shelter, protection from predators, and reproduction.

Biodiversity dynamics

All along watercourses, riparian areas are home to very diverse plant and animal communities. This diversity has a distinctive spatial organisation, made up of mosaics of habitats that are continuously changing, in time depending on the intensity and frequency of floods, and in space depending on variations in topography.

Floods destroy habitats, create new ones, and modify relationships between habitats. Topography affects the frequency and duration of the floods on the flood plain. At the local scale, the resulting heterogeneity offers a great variety of living conditions, to the extent that certain zones regularly perturbed by floods become hotspots of biodiversity. At the scale of the catchment, as riparian corridors go from the highest to the lowest altitudes, these hotspots extend all along hydrographic networks, adding to regional biodiversity.

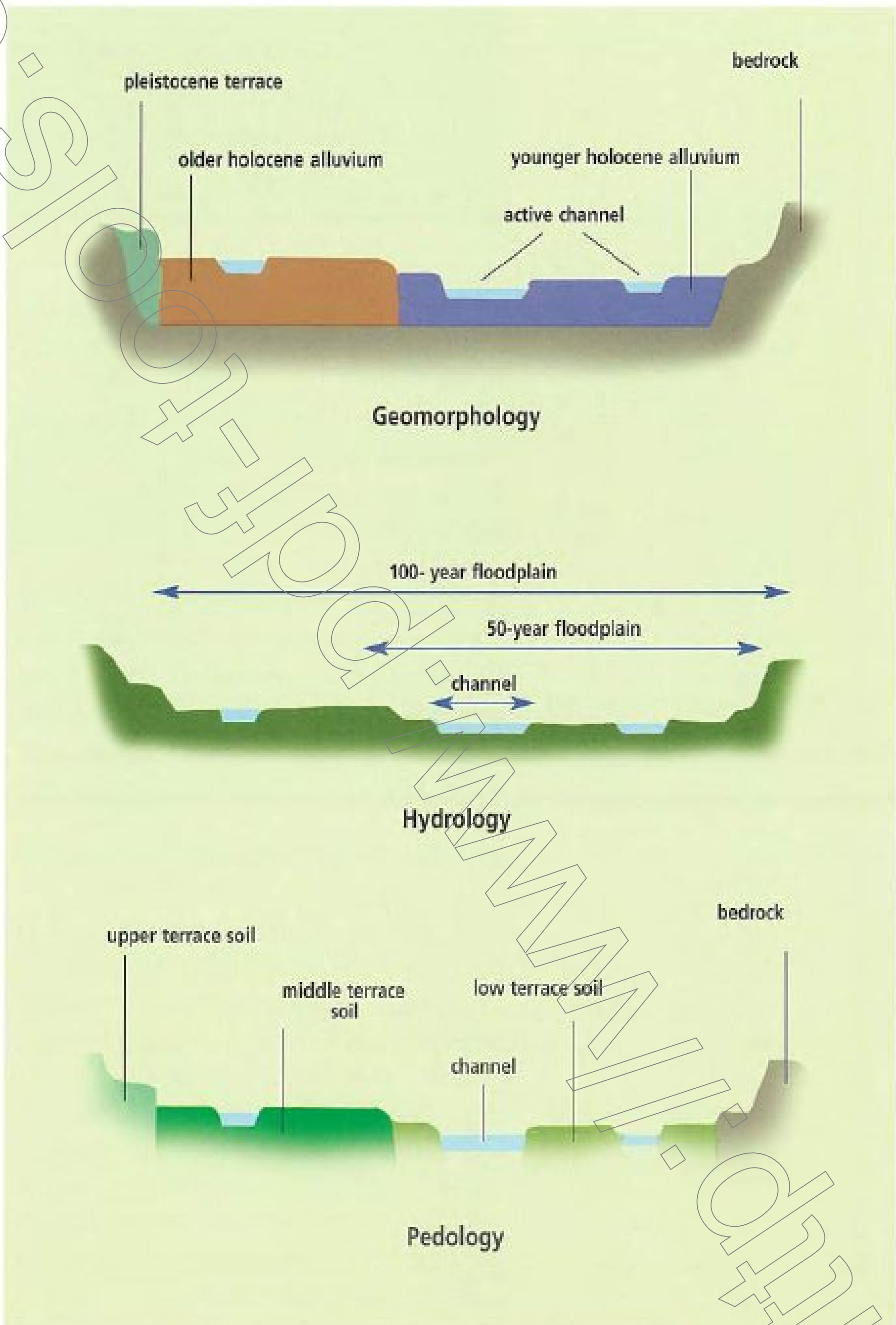
Each plant in the riparian forest grows on a given site if it can germinate and establish itself there, and if the ambient conditions allow it to survive, at least until it is able to reproduce. The distribution of species in riparian areas thus depends on both physical and biological factors. Physical factors include perturbations due to floods which are predominant in the lowest parts of the river banks, close to the running water. Biological factors include more subtle interactions – competition, symbiosis, browsing – which are predominant on the highest parts of the banks, relatively high above the river water levels.

Jean Roché

Nightroost of Cattle egret
Ardeola ibis

Physical factors

In a moist, temperate climate, the flood plain can be defined in hydrological terms (an area inundated once every year, every three years, or every ten years…) or in geomorphological terms (the area created by the river under current environmental conditions). These definitions are equivalent insofar as bankfull floods contribute to the creation of that flood plain; that is floods which are sufficiently sizeable to cover the flood plain. Terraces correspond to former flood plains left by a watercourse as it was creating its own valley.



Identification of a flood plain (Agua Fria river, Arizona) using geomorphological, hydrological and pedological data (after Bendix & Hupp 2000, modified).


Jean Roché

Wadi in Kabylia, Algeria

These distinctions are less clear in an arid or semi-arid climate. Here, alluvial areas change as violent floods disrupt sediments which are often friable. Under these conditions, flooding does not only extend over more or less horizontal flood plains, but also affects some secondary braided channels, which are higher than the main channel. Several definitions of a flood plain are thus possible, using geomorphological, hydrological and pedological data (see figure p. 77).

In these active alluvial zones, floods affect riparian vegetation in diverse ways. Vegetation is destroyed by the strength of the current, floating debris, prolonged saturation of the roots and soil erosion. The severity of these effects varies from one point to another, adding to the heterogeneity of riparian plant cover. But these floods also encourage the dispersal of propagules* and the colonisation of sites cleared of pre-existing plant cover, either as sites enriched with new inputs of silt or stripped of deposits to the underlying rock.

The various sectors of the alluvial area thus experience different types of hydrological perturbation. Close to the channel, bushy forms dominate, characterised by short stems, a resilience to disturbance and exposed conditions, and rapid sprouting from damaged stumps. Further away from the channel, on the flood plain, the species present find it more difficult to tolerate the destruction effects of floods, certainly to a lesser degree than species close to the channel. They are capable, however, of surviving to a greater extent fairly long periods of submersion and humidity. The species on the terraces tolerate neither repeated damage caused by floods nor prolonged periods of submersion and humidity.

From the point of view of plant community dynamics, on the banks and nearby, frequent disturbance maintains the riparian plant communities in pioneer stages through periodic rejuvenation; on the flood plain, the processes of plant succession can proceed and the communities reach mature stages. When the species present are compared, areas that are frequently flooded differ significantly from those that are flooded more rarely, whatever the watercourse. Often, poplars and willows predominate in the lower sections periodically affected by floods: these two genera rapidly colonise new areas and are resistant to any subsequent flooding – the poplars due to their height, the willows due to the flexibility of their trunks. Species of oak, on the other hand, colonise the highest sections of the flood plain. Between these two tree types, depending on the frequency of perturbations, maple, beech, hornbeam and plane trees may also establish themselves.

In an arid climate, two factors appear to predominate: the power of the watercourse, i.e. the energy developed per unit area, and the accessibility of water, i.e. the depth of the groundwater. These two factors have resulted in the riparian plants of a Californian watercourse being distributed along two ecological gradients[39]. As the power of the watercourse increases, rapid colonisers of denuded areas, such as the Seep Willow *Baccharis salicifolia* give way to species of large size such as the poplar *Populus fremontii*, and various species with flexible trunks: the alder *Alnus rhombifera* and various species of willow *Salix* spp. As the water table falls, in zones of weaker flow, *Baccharis salicifolia* gives way to *Salix* spp., *Artemisia tridentata*, *Eriogonum fasciculatum* and *Rosa californica*.

The power of a watercourse is closely dependent on its gradient. As the gradient is generally greater upstream than downstream, the position of any given section along the upstream-downstream continuum is determinant in the likely levels of flood impacts on riparian vegetation. An abundant bedload and steep gradients lead to the formation of braided channels with unstable valley bottoms over which the effects of floods can be locally devastating.

Floods thus influence the distribution of riparian vegetation according to the horizontal distances which separate the vegetation from the watercourses and which separate vegetation vertically from the groundwater. But this influence depends in the first place on the position of a given vegetation zone in the hydrographic network, the characteristics of this network and the events that occurred in the recent and distant past, as shown by the example of the River Tech. The identity of the present communities, and their biodiversity, depend on all of these factors.

39 - Bendix (1999)

Biological factors

Plants survive in a riparian environment by adapting to the constraints imposed by the hydrology and geomorphology of the river. This adaptation applies to all life processes, beginning with the production of large numbers of seeds by pioneer species to compensate for extremely reduced life expectancies. Adaptation to constraints also has its effects on the processes of colonisation, the dynamics of communities and the distribution of species throughout hydrographic networks.

Plants that are adapted to floods disperse their propagules – plant fragments, seeds or fruits – by floods, wind and birds. These propagules germinate and establish themselves rapidly on banks that have been recently modified and cleared of their former plant cover, often surviving renewed flooding. Also adapted to floods are riparian plant communities that succeed each other within changing mosaics in space and time, from pioneer communities of willow and poplar trees to mature communities of beech, oak and elm.

The colonisation of riparian soils by poplar trees illustrates how a riparian species is able to overcome the hydrological variables that affect riverbanks. Once they have established themselves in riparian soil recently stripped of vegetation during a flood, poplar seedlings only survive if sufficient water is available and they are protected from new floods. Consequently, on any one given riverbank, poplar seedlings only germinate and survive in locations low enough to benefit from close contact with the water table, but high enough to avoid being carried off by floods or covered by sediments. Debris dams and bushy vegetation afford some protection in a downstream direction, creating unique microsites benefiting recruitment. Pockets of fine sediment deposits with trapped moisture, also may provide fovorable microsites for poplar recruitment particularly at higher elevations. It is crucial that periods of seed dispersal coincide with the presence of damp, vegetation-free substrates, recently modified by a flood. For seedlings to become established at all, an early spring flood of sufficient magnitude to clear potential colonisation sites prior to seed dispersal is thus required. Where initial establishment is a success, seedlings will still only survive if the climatic conditions that follow favour their development, i.e. if the winters are cool, and the springs and autumns in several successive seasons are cool and damp.

Soil salinity can also be extremely important in the distribution of riparian communities in arid and semi-arid climates. The small basin of the River Andarax, in south-west Spain, is a good example in this respect, representative of numerous basins around the Mediterranean (see table p. 82). The Andarax drains around 2,200 km^2 of land which undergoes intense evapotranspiration in the summer. This evapotranspiration draws the salts accumulated in the soils towards the surface by capillary action. Table p. 82 presents 11 riparian sites in the basin and their plant cover. As the salinity levels measured in the water increase, riparian communities dominated by willows such as the Common Sallow *Salix atrocinerea* give way to communities dominated by the tamarisks (*Tamarix canariensis* and *T. africana*). Communities dominated by *Salix atrocinerea* (15 to 65% coverage) include species of more humid terrain such as *Rubus ulmifolius* and *Lonicera periclymenum* spp. *hispanica*, as well as *Alnus glutinosa*, which is dominant in sampling site 1. Communities of tamarisk occur at conductivities higher than 0.6 mS/m and 0.9 mS/m (respectively during maximum and minimum streamflow), and at sodium levels higher than 24 mg/l and 38 mg/l (respectively during maximum and minimum streamflow). Three distinct types succeed each other with increasing salinity: 1) *Tamarix canariensis* dominates (43 to 84% coverage), with the frequent presence of *Arundo donax*, a species of Asian origin introduced to stabilise the banks; 2) *Tamarix canariensis* still dominant (57 to 65% coverage), but accompanied by *Tamarix africana*; 3) *Tamarix africana* dominant (41 to 62% coverage) accompanied by *Tamarix canariensis*. Such species replacements along a gradient of salinity have significant effects on biodiversity distribution along Mediterranean watercourses.

Relationship between conductivity* levels, concentrations of sodium in the water, species richness and percent cover of species recorded at each of the sampling sites studied in the basin of the River Andarax in south-east Spain (after Salinas *et al.* 2000).

Sub-catchment *(a)*	Andarax upstream			Andarax downstream				Nacimiento		Tab. rambla	
Sampling sites *(b)*	1	2	3	4	5	6	7	8	9	10	11
Conductivity (mS/m) *(c)*	0,1 – 0,5			0,6 – 0,9				0,9 – 1,1		# 3,6	
(d)	0,2 – 0,7			0,9 – 2,0				1,0 – 1,2		# 5,2	
Sodium (mg/l) *(c)*	6 – 11			24 – 47				# 55		# 1200	
(d)	9 – 14			38 – 178				# 55		# 1900	
Species richness *(e)*	7	4	12	6	4	2	3	4	5	7	5
Alnus glutinosa *(f)*	///										
Salix atrocinerea	//	///	///	/							
Rubus ulmifolius	/	//	/	/							
Lonicera periclymenum		/									
Coriara myrtifolia			//								
Scirpus boloschoenus			/		/						
Bupleurum fruticosum			/								
Daphne gnidium			/								
Tamarix canariensis				///	///	////	////	///	///	/	//
Arundo donax				/	//	/	//		//	/	
Atriplex halimus							/			//	/
Tamarix africana								///	//	///	///
Nicotiana glauca									/	/	
Cynanchum acutum										/	
Eleagnus angustifolia								/			

(a) lower basins: upper Andarax on the southern slopes of the Sierra Nevada; lower Andarax; Nacimiento, principal tributary of the Andarax; Tabernas rambla, a dried-out gully susceptible to heavy, sudden flooding.
(b) sampling sites numbered in order of increasing salinity.
(c) during maximum discharge in March.
(d) during minimum discharge in September.
(e) number of species recorded at each of the sampling sites.
(f) percent cover of species recorded at each of the sampling sites: //// above 75%; /// 75% to 35%; // 35% to 10%; / 10% to 1%.

Riparian forests: examples of "ordinary* nature" and of the importance of plant engineering*

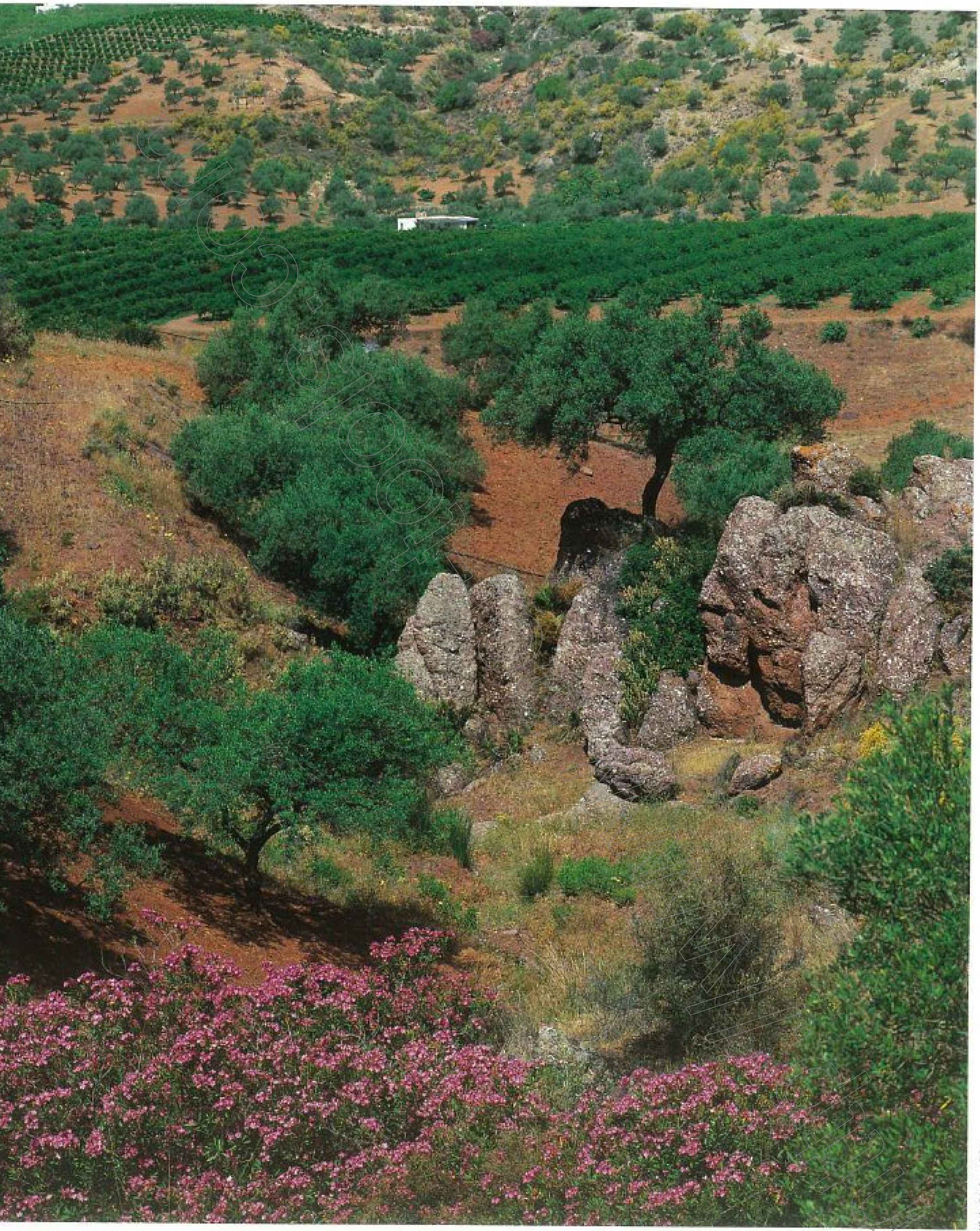
In contrast with the areas protected in parks and reserves, the wider environment is often neglected and suffers from lack of care and attention. In France, the Conservatoire Botanique National Méditerranéen de Porquerolles is committed, in collaboration with the Conseil Général du Vaucluse, to the enhancement of "ordinary nature". As products of "ordinary nature", riparian forests have become essential indicators of the state of the environment. For a long time neglected and destroyed, they were brought to the attention of the populations of the Vaucluse once again during the 1990s following a series of exceptional floods with devastating consequences. The images of log jams colliding with bridges and exacerbating the effects of the floodwaters will never be forgotten by those that saw them. The floods gave rise to widespread consideration of the role of plants, particularly riparian forests, in the flow regimes of watercourses.

Riparian forests have proved themselves able to reduce the effects of floodwaters, rendering them less of a threat. The value of integrated management of riparian systems taking plants into consideration has gradually become clear as has the importance of finding out more about these plants in order to use them to their best advantage. A LIFE Environment project was implemented on the site at Beauregard, on the banks of the Ouvèze, a small river which experienced a 100-year flood in 1992[40]. Experiments led to the selecting of a wide range of indigenous species of local origin, and in situ sampling, breeding, and planting of these species such that their capacity for adaptation on the selected sites could be evaluated (establishment, speed of growth, sensitivity to drought and parasitism, site coverage etc.). As a practical application of plant engineering, the results obtained were used to guide the restoration of large stretches of riparian woodland along the recently constructed TGV Méditerranée high-speed train line.

Any restoration of riparian forest by plant engineering can only take place after detailed consideration of objectives and means of implementation. This involves addressing the problem of flood management on threatened sites, without in any way neglecting other biological and landscape objectives. In addition, success in this field depends on: 1) the design of the restoration project, 2) the definition of planting techniques, including layout and choice of species, 3) the definition of the practical implementation of the project and the modalities of site and plant maintenance. In other words, the cohesion of plant engineering operations is all-important, and there is little room for improvisation. These operations should integrate technical specifications and the methods necessary for the maintenance of the plants and the restored sites. They should be based on a solid knowledge of the indigenous flora and its management. The experiments carried out in Mediterranean riparian woodlands testify to the importance of plant engineering combined with civil engineering operations in the conservation of "ordinary nature".

By Jean-Pierre Roux and Maurice Desagher,
Conservatoire botanique national méditerranéen de Porquerolles
and Conseil Général du Vaucluse.

40 - Piégay & Bravard (1997)



Klein/Hubert/Bios

Woodlands as landscape features

More than any other landscapes in the world, Mediterranean landscapes are social constructions, expressions of how human beings have interacted with their environment. This interaction goes back to the dawn of humanity, and has undergone constant and sometimes violent change, as a result of a rich and eventful history, of constant challenges to the ecological balance and of increasingly heavy exploitation of natural resources. Changes have not always occurred at the same time around the Mediterranean. Nowadays, for example, we see clearing of land and agricultural expansion in developing countries set against rural decline and abandonment in developed countries.

The changes observed relate to both the physical aspects of the landscapes and their social and cultural values, and concern for environmental protection often disappears in the face of the demands for economic development. Hence the tremendous pressure on ecosystems, and often irreversible repercussions for traditional rural landscapes – landscapes which are the result of a sustainable dynamic balance between the creation and use of the resources available and which testify to the co-evolution of human beings and their environment.

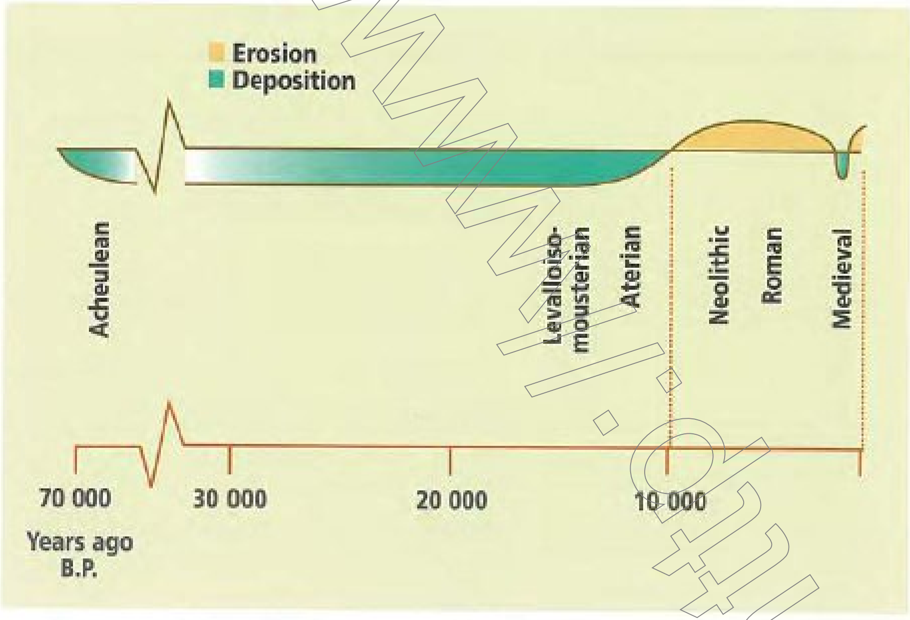
Landscape of Andalusia, Spain

Alternating phases of deposition and erosion

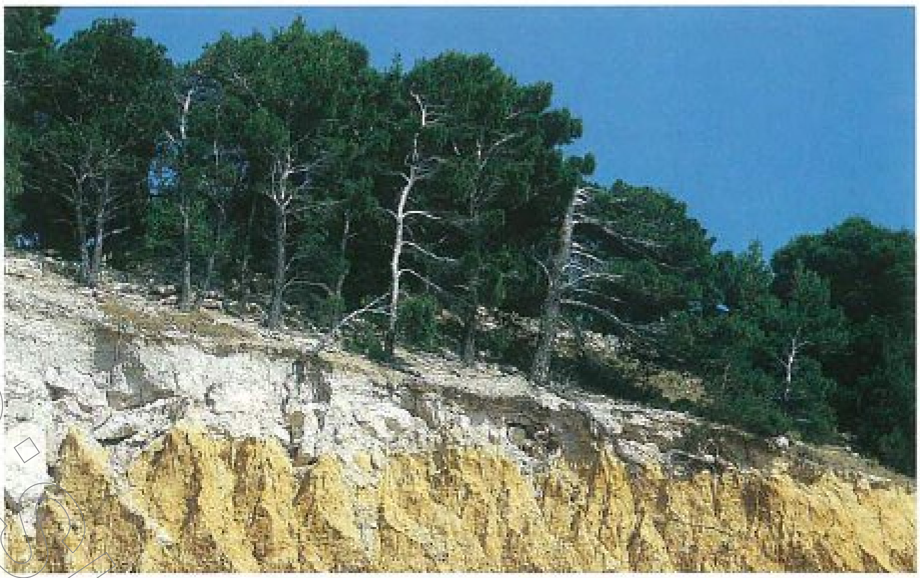
Over the millennia, there have been alternating phases of deposition and erosion in the valleys of the Mediterranean (see figure below). Thick layers of alluvium were deposited during the last Ice Age. These were deeply carved out in prehistoric times by rivers which, during their development, increased the drainage densities of their catchments.

This continued through the Roman era, only to be reversed in the Middle Ages, with new accumulations of sediments, up to ten metres thick. This phase was followed by the resumption of erosion which is still ongoing, characterised by new incisions and by a flattening of longitudinal profiles.

These successive phases of deposition and erosion seem to have marked all parts of the Mediterranean perimeter, north, south, east and west. Whatever the causes – probably both climatic and human – these events have established a common Mediterranean setting for present and future riparian woodland. The depositional phase has largely predominated since the retreat of the Würm glaciers (see figure below). But the erosion phase following sedimentation in the Middle Ages has greatly transformed the valleys, sometimes irreversibly.



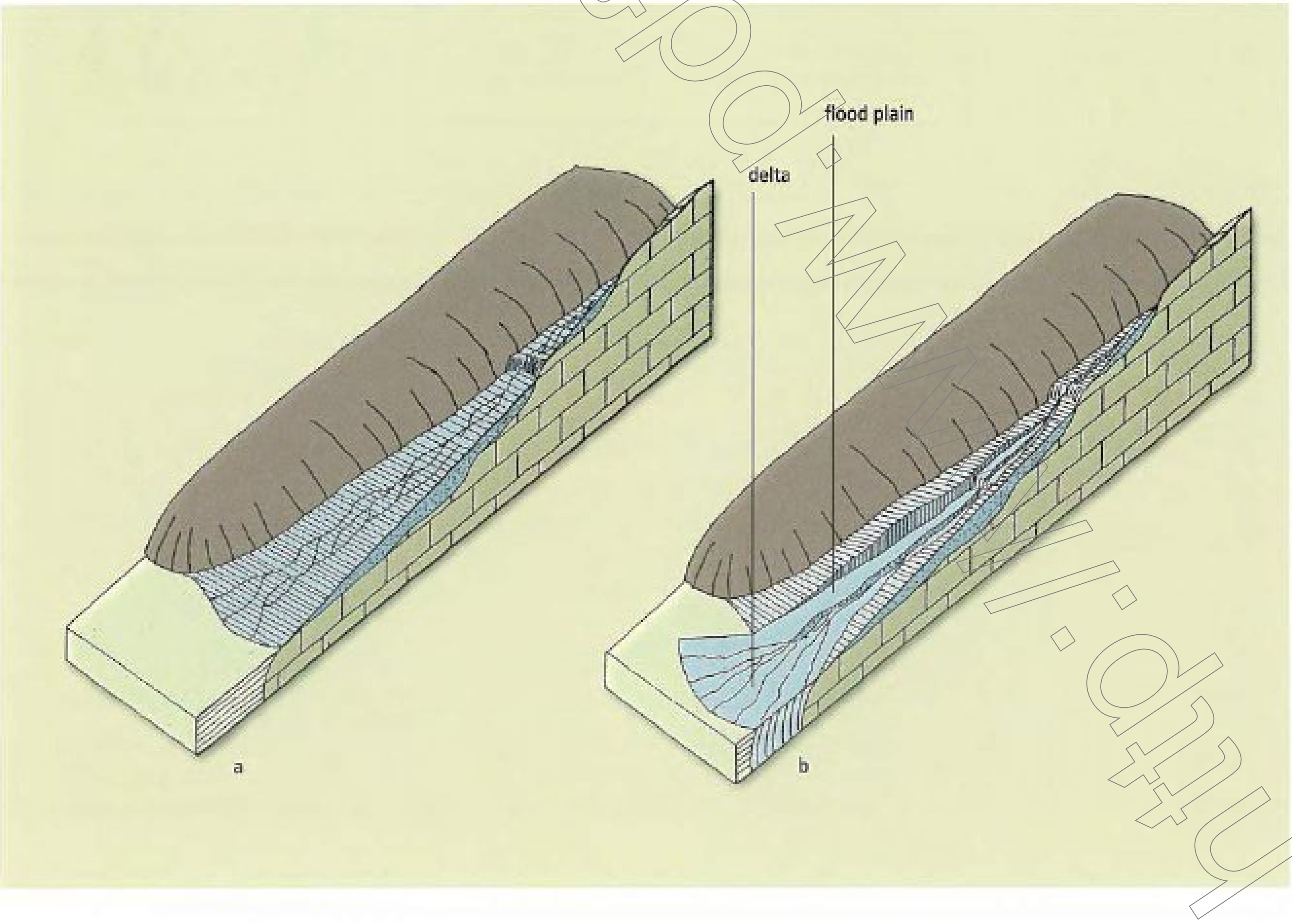
Chronology of erosion and deposition phases in the Mediterranean Basin. At some time during the historical times, many of the Mediterranean watercourses, which until then were carving out their beds, entered into a process of deposition or silting before the current phase of erosion (after Vita-Finzi 1969, modified).



Erosion: land and pines

This sequence of events has given the Mediterranean valleys their current shape and form. The channels were carved out of an alluvial floor of recent silt deposits. The true flood plain, or major bed on which riparian woodlands develop, lies below this floor (see figure below), which is only rarely reached, if there is exceptional flooding and this occurs close to the river mouth.

Morphology of a Mediterranean valley showing successively a) recent silting at the end of the period of aggradation, b) the resulting flood plain created from the river's action on these recent deposits, extending into the delta (after Vita-Finzi 1969).



Historical influences

According to some authors, the human impact on Mediterranean landscapes dates back some 50,000 years[41].

The transition from a nomadic to a sedentary way of life, which took place around 10,000 years ago, marked the beginning of a historical transformation. The cultivation of cereals revolutionised land-use practices, as did livestock breeding and the improvement of farming techniques. Within some 2,000 years, the swing plough, which simply dug into the soil, was replaced by a plough which turned the soil, lifting the roots of perennial plants and favouring the cultivation of annual crops. Over the generations, rural populations, self-sufficient with regard to wheat, olive oil, milk, cheese, meat, etc., built up a sustainable relationship with their environment. Around 3,000 to 4,000 years ago, some landscapes on Crete were already appearing as mosaics of cultivated fields, orchards and exploited semi-natural woodlands.

The relationship between humans and Mediterranean woodland underwent highs and lows as an analysis of historical data, pollen records and charcoal remains indicate[42]. Deforestation on a significant scale first occurred around 8,000 years ago and increased apace with the growth of human populations and the expansion of livestock herds and agriculture. It slowed down after the fall of the Roman Empire in the 5th century AD, picking up again in the Middle Ages with an increase in human activities, interrupted occasionally during periods of high mortality, for example in the 14th century during the Black Death. Massive deforestation occurred on the Iberian peninsula, particularly in coastal areas and along principal rivers, during the 15th and 16th centuries to support the naval power of Spain and Portugal. In France, the 19th and 20th centuries saw increased deforestation all around the Mediterranean; the advent of petroleum slowed down the rate of deforestation, at least in the northern Mediterranean.

Some deforestation that occurred over the course of history proved to be permanent: in Tunisia for example, the forest in the region of Sousse, deforested by the army of Julius Caesar to rebuild the Roman fleet, has never grown back. Neither has the woodland cut down from the plain between Tel Aviv and Haifa in Israel.

Water has always been a major cause for concern in the Mediterranean. The survival of people, cattle and agriculture has always depended on the successful collection and storage of water, a rare and precious resource. Hence the construction of dams, conduits and cisterns, as soon as human populations began to form settlements.

41 - Naveh & Dan (1973)
42 - Thirgood (1981), Blondel & Aronson (1999)

The "Jungle of the Jordan"

"... How will you do in the jungle of the Jordan?" (Jeremiah 12-5).
"Behold, how a lion coming up from the jungle of the Jordan..." (Jeremiah 50-44).
"... Hark the roar of the lions, for the jungle of the Jordan is laid waste" (Zechariah 11-3)1.

Whereas the high valley of the Jordan (which rises in the Sea of Galilee) is home to a typically Mediterranean riparian forest, with Plane *Platanus orientalis* and willows (including *Salix acomophylla*): the low valley has banks covered with *Populus euphratica* and *Tamarix jordanensis*. The *Populus euphratica* forest extends along the meanders of the river from the Sea of Galilee as far as the Dead Sea, as described in the Old Testament. This low valley extends over 105 km as the crow flies, and varies between 5 and 25 km in width. Its flood plain (Zor in Arabic, Geon HaYaeden in Hebrew) is partly wooded over a width of 0.6 to 2.0 km by *Populus euphratica*.

These trees measure up to 15 metres in height. They are known for their rapid growth and their aptitude for maintaining the soil in place, qualities which promote their development on the banks of the Jordan and on the flood plain. With tamarisks and other species, they form a wild, very dense forest, the "Jungle of the Jordan". This riparian forest used to be home to lions. Nowadays, leopards, wolves *Canis lupus*, jungle cats *Felis chaus*, and wild cats *Felis sylvestris* can still be found.

By Reuven Ortal,
Nature and National Parks Protection Authority, Jerusalem, Israel.

Much evidence of astounding expertise is now part of our heritage, an outstanding example being the aqueducts of the Pont du Gard in southern France. Many Mediterranean countries host evidence of water management which the Romans took to the limit. This management has without doubt had its effect on riparian woodlands.

To sum up, it must be stressed that centuries of land use and control over water have created landscapes unique in their variety. These landscapes have created the identity of the Mediterranean regions.

The search for a regional identity

Human beings and Mediterranean landscapes have thus co-evolved throughout human history. This common history does not conform well with north European or North American ideas about nature conservation. It obliges us to think about the conditions – cultural and aesthetic as well as ecological – that characterise the lands making up the Mediterranean region. Traditional landscapes often have strong regional identities, marked by the historical interactions between people, places and events.

How can we take account of these interactions? A method applied in Sardinia[43] offers one response adapted to the Mediterranean context. This method has been used for the Santa Lucia catchment; it is based on a landscape audit consisting of five stages:

- an exploratory study leading to the classification of various aspects of the landscape, their description, analysis from a historical and legislative point of view, and evaluation;
- an exploration of the environmental archives, enabling a preliminary map of landscape characteristics to be produced;
- a field study aiming to collect and study landscape data, past and present, and to attempt a preliminary subjective evaluation of these data;
- inputting this information in a digital format with the production of digital maps and the setting-up of a database for the production of a third set of maps;
- analysis and discussion of the digitised data.

The whole of the procedure attempts to extract the spirit of the place – the *genius loci* – by taking into account the interactions between humans and the natural environment. Two aspects of the exploratory study are particularly relevant in this respect: historical analysis and evaluation.

The historical analysis of the landscape aimed to reconstruct past relationships between people and their physical and natural environment. It made use of written archives, maps, paintings and old pictures, as well as aerial photographs and images from remote sensing; it also made use of field investigations and interviews with

43 - Makhzoumi & Pungetti (1999)

The Ibrahim, natural and cultural heritage of Lebanon

The Ibrahim, a coastal river situated 30 kilometres to the north of Beirut, was formerly known as the Adonis River. It has played an important role in the cultural history of Lebanon since pagan times when pilgrims went up the north shore of the river as far as its source in Afqa. The remains of several Roman temples can be seen in the valley as well as an aqueduct, of which only an arch remains, and an Ottoman stone bridge dating back to 1806.

Like the other coastal rivers in Lebanon, the Ibrahim follows an east-west course. It carves out a deep, narrow gorge over 28 kilometres long which widens out near the coast. *Ficus sycamorus, Nerium oleander* and *Salix* spp. cover its banks while its valley slopes are covered with a very dense maquis of some 60 families and over 200 species, including *Dittrichia viscosa, Rubus sanctus, Laurus nobilis, Piptatherum miliaceum, Conyza bonariensis, Oxalis pes-caprae* and *Parietaria judaica*.

A permanent watercourse, with an average annual flow of 15.52 m^3/s, the Ibrahim is

The Ibrahim lined with willow and interspersed with fig trees

subject to intense pressure in a region where water is a rare commodity. This pressure comes from industrial, agricultural and leisure sources. Industrial activities include three hydroelectric plants, a plan for the construction of two more factories and a paper factory. Agricultural activities include banana plantations, greenhouse crops and the traditional cultivation of fruit trees on walled terraces. The semi-natural landscape that remains is widely used for leisure activities.

This intense and varied usage has transformed the riparian landscape, prompting local initiatives and governmental actions to protect the Ibrahim and its precious natural and cultural heritage. However, this protection presupposes that effective sustainable and economically viable management strategies will develop. These include the consideration of past and present activities, the integration of natural and cultural values and the taking into account of the aesthetics as well as the use of land and water in a varied riparian landscape.

By Jala Makhzoumi and Maya Abboud, American University of Beirut, Lebanon.

Different land uses along the River Ibrahim: paper factory on the crest of the hill, the remains of the arch of a Roman aqueduct, and a banana plantation.

Ron Frumkin

Populus euphrates with ibex in En Avedat (Negev area, South Israel)

experts and with local people, including the elderly. It was thus possible to trace the history of the landscape of Santa Lucia from the very first agricultural developments until the present day, with all its changes of rhythm, its disruptions, and its reaction to influences from the outside world.

The evaluation of the landscape began with the classification of landscape features such as treelines, hedgerows, power lines, walls and buildings. It then considered various categories of perception: the visual, taking into account scale, enclosure, view beyond; the aesthetic, with an evaluation of the attractiveness of the place, taking into account variety, harmony, texture, colour; the psychological, with notions of security, stimulus, pleasure, sounds, odour.

The agricultural landscape of the Santa Lucia basin has clearly undergone significant modification over the years. The use and layout of the land have been transformed by property inheritance; sand and gravel extraction has made the landscape less attractive and modified the dynamics of the river; industrial and urban areas have grown in size. In addition, fires, overgrazing, and felling have changed the forest cover. The change from a rural to an urban way of life, like the change from private to public ownership of forest property, has also modified the relationship between the people and their environment. The role of people in this relationship is more and more that of spectators rather than active participants as the landscape is increasingly perceived from the outside and not from the inside. Hence the need for a landscape policy involving all social groups and based on increased efforts with regard to information and education.

The riparian landscapes of northern Cyprus

The mountains of Kyrenia and Troodos, respectively in the north and south of the island of Cyprus, determine the properties of the riparian landscapes. Two types of rivers flow down from these mountains. The first type follows a north-south course. They carve out deep gorges, covered in a dense and varied maquis, often with mature woodland patches. Here, humans have found sheltered spots, suitable for cultivation, creating contrasting landscapes. Olive trees, often cultivated along with lemon and other fruit trees, give these ravines a traditional rural character. When abandoned, the ravines are gradually recolonised by indigenous plants and the landscape reverts to a semi-natural state.

The river Lefke (Marathasa in Greek), in the west of the island, is an example of this first type of river. It rises in the Troodos massif and flows north for some 20 kilometres, as far as the sea. Its valley widens at the town of Lefke, providing space for olive and lemon groves, and where it is well supplied with water from the reservoir of Marathasa, situated 9 kilometres from the coast. Outside the town of Lefke, the valley, which narrows once again, becomes overgrowth with indigenous species (*Amaranthus* spp., *Arundo donax, Asparagus acutifolius, Calycotome villosa, Capsella bursa-pastoris, Crataegus azarolus, Dittrichia viscosa, Genista sphacelata, Ipmea* spp., *Lamium* spp., *Malva sylvestris, Nerium oleander, Phagnolon rupestre, Polygonum equisetiforme, Rubus sanctus, Urtica* spp., *Vicia sativa*), as well as species introduced onto the island (*Acacia* spp. and *Eucalyptus* spp.) and cultivated species (*Olea europea, Ceratonia siliqua, Opuntia ficus-indicus,* lemon trees and dates).

The central basin of the Mesarya, with no access to the sea, receives the second type of river, running from east to west. Generally fairly shallow, the levels of these rivers vary greatly according to the seasons: filled to the brim during the rainy season, many sections dry out in July and August, promoting the development of very varied plant cover. The two arms of the River Kanlidere (Pedieos in Greek), 12.5 kilometres long, are examples of this second type.The river bed has been incorporated into the urban sprawl of the capital, Nicosia, from which it receives waste water and domestic waste. Nevertheless, the Kanlidere harbours a rich and varied flora and fauna: more than 185 plant species, belonging to 62 families, have been recorded here[44]. The fauna is equally diverse, with fish, reptiles, birds, mammals and insects. Along the Kanlidere there is an alternation between a well structured landscape with eucalyptus (*Eucalyptus camaldulensis, E. gomphocephala* and *E. tereticornis*), together with acacias *Acacia cyanophylla* in the wider stretches, and, in the narrower sections, a landscape of dense reedbed communities with *Arundo donax*. The value of these landscapes lies in the contrast to surrounding constructions and the sustainable alternatives they provide to urban plantations.

By Jala Makhzoumi (American University of Beirut, Lebanon) and Serife Gunduz (European University of Lefke, Cyprus).

44 - Inventory of the flora and fauna of the river Pedieos, a program supported by the United Nations and the United States of Almerica (United Nations Office for Project Services).

The corridor effect

Riparian woods and the watercourses along which they grow, constitute natural "corridors" within river catchments. Numerous plant and animal species make the most of this "corridor effect" as a mean of spreading along hydrographic networks.

This is the case with tree seeds, which are transported by the current and deposited along in riparian areas further downstream. The life history of many trees of riparian woodlands thus begins with a journey down the river. This is the case with the ash, whose story is worth telling[45].

The ash is an anemochorous species, i.e. its seeds are dispersed by the wind. In autumn, the winged, seeded fruit – or samaras – of the ash drop from the tree, eddy and float on the surface of the water. Floods may transport the samaras a couple of kilometres downstream before depositing them on the riverbank. Each samara has a single seed: these remain dormant for around 18 months. After germination, the seedling – its leaves still simple – devotes most of its efforts to the development of roots capable of anchoring it solidly into the soil. Once this first stage is over, the young seedling is able to withstand any new floods, and its growth accelerates. Composite leaves then appear, as well as flowers. The flowers have both stamens (male organs) and pistils (female organs). But on any given tree, these organs do not reach maturity at the same time, and because of this time lapse, cross-fertilisation is necessary. Furthermore, the female organs tend to regress in older trees and it is often these that fertilise the young trees.

Each year, the young ash tree flowers in April, then produces samaras which, after the summer maturation, drop from the tree in autumn. Between the ages of 20 to 50 years, ash trees increase in height by 5 metres to 15 metres and produce increasing numbers of flowers and samaras. Most of the time, these samaras fall to the ground and germinate but frequently die prematurely due to lack of light. Others, carried by the wind and floods, land on sites ideal for germination, perhaps just a few metres away, in a clearing in the riparian forest, or several kilometres away, on a sunny riverbank.

Much later, in its 80th year, the old ash will succumb to a strong gust of wind and fall into the river; meanwhile, on the riverbanks its descendents will, in turn, produce a new generation of samaras.

This is how ash trees spread along riverbanks. In the past 65 years, the Flowering Ash, *Fraxinus ornus*, an ornamental species, has advanced

45 - Ronce (1999)

61 kilometres downstream from the spot where it was introduced on the Hérault, a coastal river near Montpellier[46]. Floods play an important role in these long-distance expansions, by transporting seeds, rearranging riparian soils and creating clearings which are conducive to the development of seedlings. They enable numerous riparian woodland species to expand along hydrographic networks.

This corridor effect gives riparian woodland a unique characteristic: a sensitivity to invasions by foreign species. In the Mediterranean region, this sensitivity even appears to single out riparian systems compared with other neighbouring ecosystems[47]. Among the species of foreign origin which invade Mediterranean riparian systems are trees such as False Acacia *Robinia pseudo-acacia* and Boxelder *Acer negundo*, as well as other shrubby or herbaceous species whose excessive spread needs to be brought under control, whether they have been introduced voluntarily or not: Ragweed *Ambrosia artemifolia*, False Indigo *Amorpha fruticosa*, Butterfly Bush *Buddleja davidii*, Indian Balsam *Impatiens glandulifera*, Large-flowered Primrose Willow *Ludwigia grandiflora*, Floating Primrose Willow *L. peploides*, Japanese Knotweed *Reynoutria japonica*, exotic goldenrods *Solidago graminifolia*, *S. altissima*, *S. gigantea*[48]. The first two of these species merit further discussion.

Ragweed *Ambrosia artemifolia* is an anemogamous composite. It is an invasive pioneer species with an allergenic effect that has spread down the Rhône valley but disappears like other mid-European species south of Avignon. It can appear on a massive scale, suddenly and sporadically, along the river corridors of some watercourses, for

A. J. Crivelli

Flowering False Indigo

46 - Thébaud & Debussche (1991)
47 - Blondel & Aronson (1999)
48 - Roux (1998)

example on sites disrupted by civil engineering works. Several other exotic species spread in similar ways in the Mediterranean region along riparian corridors as a result of local perturbations. The progression of these species can be slowed down, at least for a certain amount of time, through unfavourable climatic conditions, but among the more opportunistic species there may be an eventual invasion of existing communities, with the displacement of native species.

This would seem to be the case of the False Indigo *Amorpha fruticosa*, a leguminous plant in shrub form, one to six metres in height, with upright, branched stems. Its purply blue flowers, arranged in clusters, develop from April to June; they produce pods containing one or two seeds, the second seed often atrophied. The species spreads easily by means of its waterproof floating seeds; if cut, it can produce numerous vegetative shoots.

A native of North America, the False Indigo was first introduced into France in 1724. For a long time it passed unnoticed, then around a decade ago, populations suddenly began to expand[49]. False Indigo can proliferate and eliminate the other species growing in riparian woodland; this has occured over stretches of often more than 500 metres along the Rhône, the Po and several of their tributaries. The species had already been considered as invasive along several American rivers, notably the Snake, the Columbia, the Platte and the Connecticut. Particularly well adapted for proliferation along watercourses, it undergoes rapid germination, has seedlings which can develop in a water-saturated habitat, it can reproduce vegetatively, and its roots adapt themselves to variations in the water table.

49 - Dinger et al. (2000)

The mosaic effect

A richness in riparian species along riverbanks is usually an indication of considerable heterogeneity of habitat. This "mosaic effect" is characteristic of Mediterranean deltas; it is also characteristic of many river sectors.

At Kerkini, in northern Greece, the flood plain of the River Strymon was transformed into a reservoir by a dam, built in 1932 and raised in 1982[50]. After the dam was raised, the average level of the water in the reservoir increased by 2.2 metres, and the annual variation around this level was in the order of 1.3 metres. The consequence of this construction was a halving of the riparian forest, from 671 hectares in 1980 to 352 hectares in 1990. There is every indication that this forest, dominated by White Willow, will continue to shrink in size: there is tree mortality, a lack of regeneration because of the new hydrological regime, and grazing. Yet the Kerkini riparian forest as it stands currently contributes nevertheless greatly to the biological richness of the site. Populations of ducks such as the Common Teal *Anas crecca* and the Mallard *Anas platyrhynchos* have been greatly affected here. The Black-tailed Godwit *Limosa limosa* has disappeared altogether, a species whose main wintering site in Greece is Kerkini, where it would otherwise feed on annelid worms which it extracts from the mud on the riverbanks. In fact, the survival of an entire highly diverse ecosystem of invertebrates, birds, amphibians, and reptiles, depends on the maintenance of a mosaic of habitats with their many and varied interactions. Regarding the willow forest, planting and pollarding at higher elevations are needed to prevent the asphyxiation of shoots during high waters; and islands and slopes need to be raised to enable regeneration to take place on dry banks outside of the water. Such measures depend ultimately on awareness by the authorities of the protected area status of this site, which is on the Ramsar list – such an awareness is recognition of its value as a heterogeneous and interactive mosaic of aquatic, semi-aquatic and terrestrial habitats.

The maintenance of such mosaics is particularly important in the Mediterranean region. Riparian woodlands here are a remarkable element of the landscape for two major reasons. Firstly, they are areas of deciduous woodland, surrounded by vegetation with evergreen or marcescent foliage adapted to a dry environment. Secondly, their vegetation develops mainly in the summer, during a period of the year when other Mediterranean species have completed their biological cycle. To the corridor and mosaic effects can be added an oasis effect, which is another major reason for the high biological diversity in the Mediterranean region.

50 - Crivelli, Grillas & Lacaze (1995), Crivelli et al. (1995)

Jean Roché

Woodlands to restore and to maintain

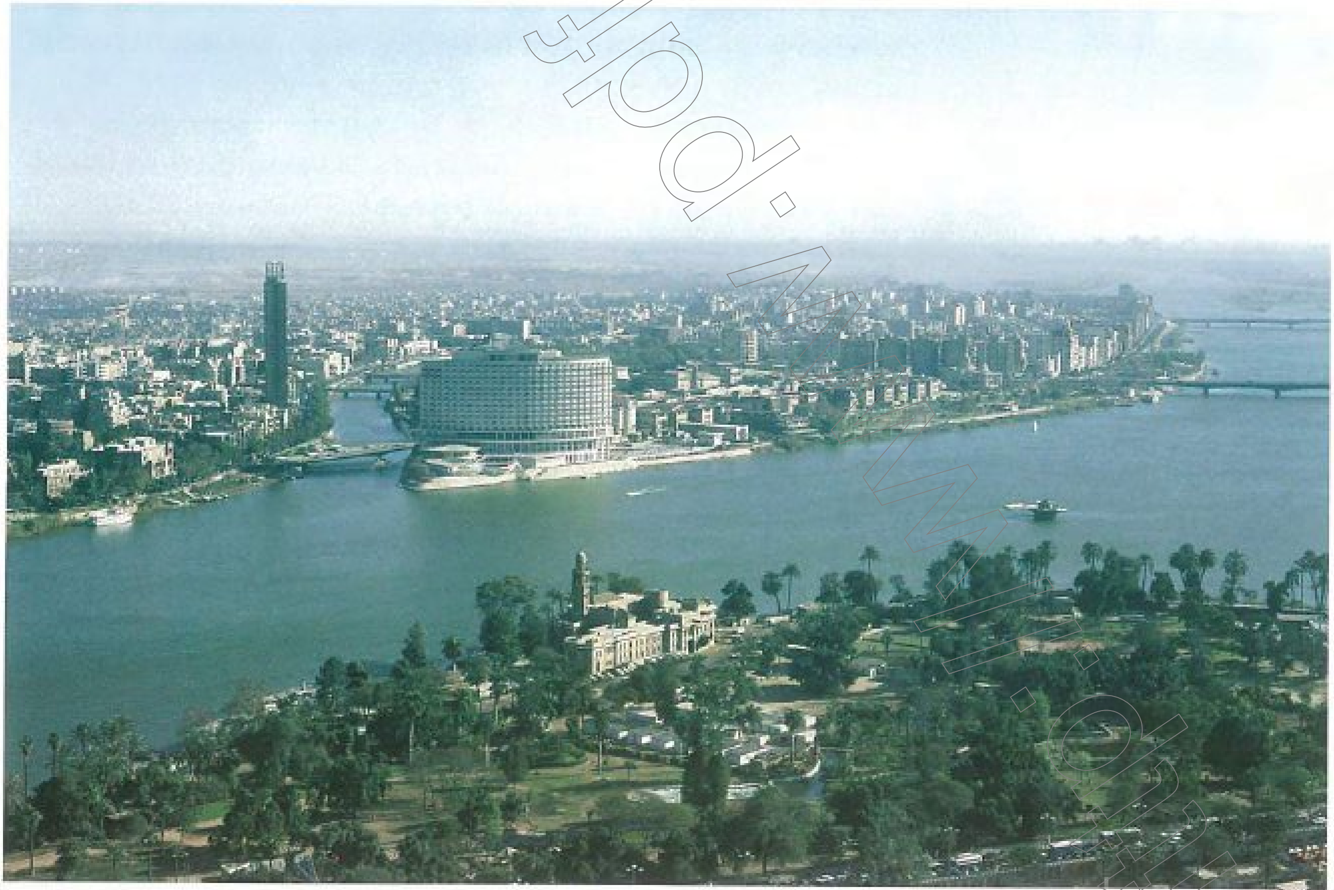
Almost everywhere, there is a need for the restoration of riparian woodland so that functions and uses that have partially or totally disappeared can be rediscovered. There is also an accompanying need for maintenance, which involves first reaching a satisfactory stable situation which can be sustained on a long-term basis. This does not, however, mean perpetuating the status quo. On the contrary, any maintenance action, like any restoration action, needs to be placed within a perspective of change. Ideally, it involves recreating the right conditions for this change.

Hydroelectric developments have frozen the fluvial dynamics of numerous Mediterranean rivers. The exploitation of water resources, aggravated by the extraction of aggregates, has lowered the river bed and flow rates whilst at the same time immobilising silt deposits. In these conditions, riparian woodlands move into the river bed itself, creating an obstacle to flow. Clearing, often carried out in a repeated and uniform manner, does not resolve the problem; it merely accentuates the disconnection between river channels and the alluvial zone, without reducing the risk of flooding. Sooner or later, rivers thought to be "tamed" often prove to be inadequately protected when a particularly powerful flood occurs.

Riparian woodland along the Ebro, in winter

That being the case, how can the goods and services provided by rivers and their surroundings be put to sustainable use? Such use presupposes a respect for the interconnections between morphological, hydrological and biological processes. Sustainable use of the goods and services provided by the rivers and their banks also requires an improvement in our capacity to predict changes in riparian systems, the promotion of a renewed perception of the role of wetland and riparian zones, and the creation of conditions for the participation of local communities in the management of riparian woodlands. Two frequently asked questions relating to Mediterranean rivers – those regarding vegetation clearing and the management of dead wood accumulations – are examples of riparian woodland management. Monitoring is becoming an increasingly essential part of woodland management, enabling the ecological integrity of river systems to be constantly evaluated using suitable indicators.

The Nile in Cairo, Egypt



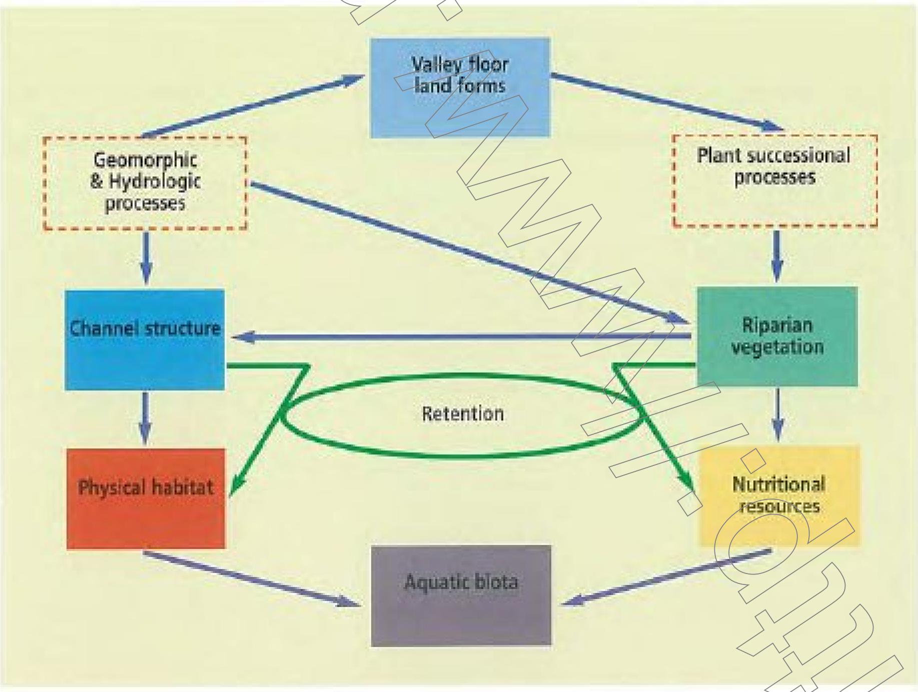
Roché/Gasnault

Interconnections

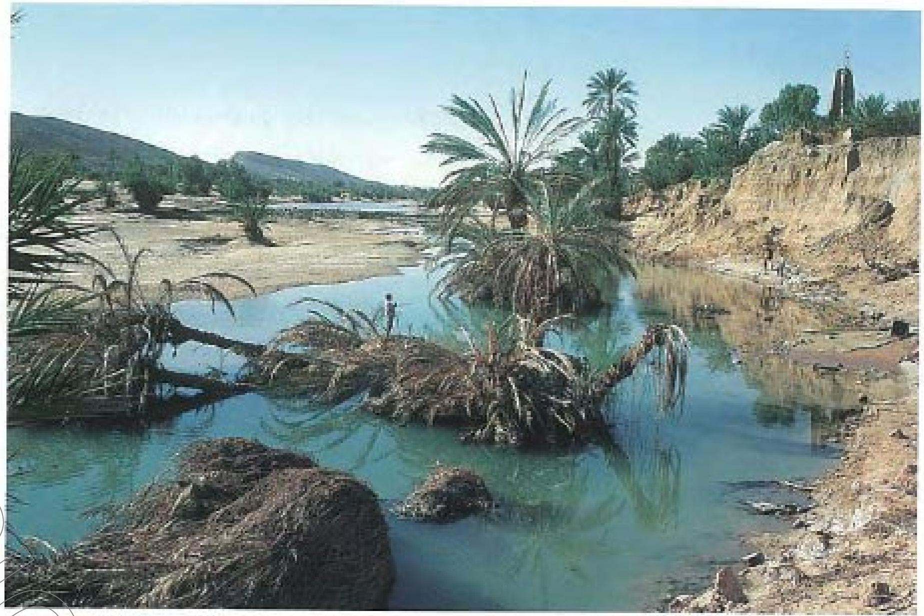
Riparian zones are interfaces between terrestrial and aquatic systems. These interfaces are not simply juxtapositions of distinct habitats; they are structurally and functionally distinct habitats, evolving according to their own characteristic processes, geomorphological and hydrological on the one hand and biological on the other.

On the flood plain, geomorphological and hydrological processes create mosaics in which the biological processes leading to plant successions develop (see figure below) These diverse processes interact to give structure to the active channel and the riparian vegetation along rivers. The distribution of habitats and nutrient resources and, ultimately, the development of aquatic communities, depend on this organisation. As figure below illustrates,the retention of organic material plays a central role in this cascade of causes and effects

Yet this retention depends essentially on the dynamics of riparian woodlands and on the dead wood which has accumulated in watercourses. Furthermore, the details of this dependency vary according to the sectors under consideration as one moves downstream from the source. The organic material torn from the



Relationships between geomorphological and hydrological processes, riparian plant successions and aquatic communities on a flood plain. The arrows indicate the predominant influences of components of the ecosystem and processes, (after Gregory *et al.* 1991).



Wadi Saoura at Kerzaz, Algeria

banks of the upper reaches spreads in successive waves along the branches of the hydrographic network and is deposited in the slower-flowing sections of the rivers. Upstream, inputs come from all of the surrounding catchments through landslides and avalanches; downstream, they come mainly from neighbouring riparian woodlands, through the toppling of old trees and collapsed riverbanks.

Predictive capacity

Restoration of riparian woodlands usually has two objectives: to restore a certain level of biodiversity and to develop techniques aimed at, for example, reducing the risks of erosion, limiting the input of nutrients, and sustaining aquatic life.

These objectives are not always compatible and, furthermore, optimum conditions for their development are not usually found along the same river section since they depend on parameters as diverse as hydrology, pedology, biology, economics and sociology. This diversity of causes makes the prediction of the effects and the consequences of restoration operations particularly difficult. We must recognise the fact that we often do not know how such riparian forests evolve and therefore are never sure of reaching the objectives set at the start, as the interactions between the processes are complex, variable, and difficult to transpose from one site to another

We therefore need to ask ourselves how we can improve our predictive capacity. This presupposes not only a theoretical knowledge of the functioning of riparian ecosystems, but also a concrete knowledge of the terrain, almost on a case-by-case basis. Hence the question: what principles to use for predicting the long-term consequences of the restoration of a riparian woodland?

Basic hydrological principle

As we have already pointed out, hydrological perturbations regulate the structure and functioning of riparian woodland. Yet the historical tendency has been to limit the extremes of hydrological regimes in order to stabilise the levels of the watercourses and to protect local inhabitants against floods as well as to satisfy their needs with regard to water supply, irrigation and energy. Hence the construction of increasingly sophisticated levees, channels, canals and dams. In most cases, these constructions have preceded the installation of flow measurement systems, which make the definition of baseline "natural hydrological regimes" difficult or even impossible.

However, restoring the biodiversity and the functions of a riparian wood cannot be achieved without returning to certain aspects of the natural regime which gave rise to this biodiversity and its functions. These aspects include the frequency and the volume of floods as well as their duration, periodicity and sequences, i.e. the way in which the high and low water events succeed each other temporally.

Yet, studies are often only informative about one or two of these aspects and only rarely deal with the long-term consequences of a hydrological event or series of events. It is thus necessary to use an experimental approach to predict the effects of the change in hydrological regimes and to guide restoration projects.

Other principles

Important as it is, the basic hydrological principle is not the only factor to be taken into account when predicting how a riparian zone will react to restoration works

1. The landscape context and position of riparian woodland along the river continuum determine its reactions to a restoration operation.

2. The speed of these reactions differs according to the characteristics under consideration, for example the productivity of riparian systems, their biodiversity, the carbon and nitrogen levels in soils.

3. The use of riparian systems as filters, i.e. their enrichment by nutrients leads to an impoverished biodiversity by promoting one dominant species to the detriment of others.

4. Certain perturbation regimes – variations in flow as well as browsing or vegetation clearing – can increase the biodiversity of riparian zones

5. Following restoration, certain species may prove to be capable of naturally colonising a riparian zone, whereas others do not reappear at their own accord, depending on the capacity of the propagules for dispersal or on the longevity of the seeds.

6. Whatever the scale considered, the trajectory followed by a recently restored riparian wood cannot be forecast solely on the basis of theoretical knowledge of possible plant successions. Historical aspects often turn out to be decisive

7. The genetic differences between populations of a given species can considerably affect the results of its reintroduction, particularly in the case of a rare or endangered species.

Necessity for experimental sites

The above principles can serve as a guide for the restoration operations of riparian systems. But managers can still be taken by surprise. We know for example that the hydrological regime is an essential condition of any restoration, but how can we know the exact consequences of a modification in the period, the frequency, the amplitude or the duration of floods? And how can we identify the deterioration threshold beyond which a particular riparian woodland cannot be restored?

The highly complex interactions between plant cover, hydrological processes and land forms make such questions very difficult to answer. Several interconnected reasons can lead to a given species dominating the riparian plant cover. Sometimes this will be the date of the last flood, sometimes the topography of the sites or the drainage conditions, with their consequences on humidity and nutrient levels in the soils. The plant cover itself influences the very flows that were responsible for plant establishment: by increasing the roughness of a site, which may sometimes considerably reduce the speed of the current; by encouraging the deposition of sediments, plant cover affects the nature and relative height of its own substrate and, as an indirect consequence, is itself modified.

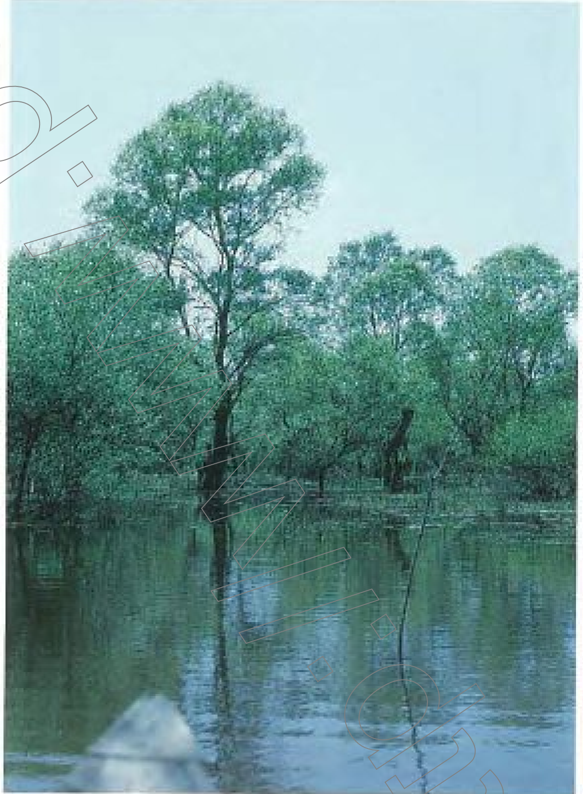
An experimental approach at various spatial and temporal scales has proven to be essential for taking into account these interactions and adjustments in all their complexity. But this experimental approach must integrate notions of ecology, biogeography, hydrology and geomorphology, as well as relevant aspects of the human sciences. It can only be seriously developed on experimental sites. Riparian conservation areas are a first step towards the creation of these experimental sites.

A conceptual model of channel evolution following channelisation

In little more than a century of navigation and flood control, many rivers have been modified, dredged and straightened. This channelisation has affected all the geomorphological processes at work in the modified reaches, as well as in those situated upstream of these sectors. It has caused increased erosion particularly of the river bed, collapsed banks, widening of beds and silting. Riparian trees have also been affected by these changes, which they in turn have also influenced. The model proposed by Hupp & Simons[51] describes the re-establishment of river structures and riparian woody vegetation cover following channelisation. It is based on the study of several tributaries of the Mississippi in western Tennessee.
This model distinguishes six stages, as shown figure p. 107. Riparian vegetation re-establishes itself in three successive groups of species during stages IV, V and VI. The first set contains pioneer species including *Salix nigra, Betula nigra, Acer negundo, A. saccharinum* and *Populus deltoides.* These trees establish themselves in the intermediary stages IV and V, as soon as the banks begin to stabilise and to build up. The second set contains species of relatively stable sites: *Carpinus caroliniana, Fraxinus pennsylvanica, Liquidambar styraciflua* and *Ulmus americana,* as well as *Taxodium distichum* and *Nyssa aquatica* when river bed degradation has not been too severe. These trees establish themselves during stages V and VI of the development of the riverbank, after the peaks of erosion and silting have been passed. The third set of species comes in following the re-establishment of the riverbanks and the re-forming of meanders. It contains mainly alluvial oaks *Quercus lyrata, Q. nigra, Q. falcata* var. *pagodaefolia* and *Q. phellos.*

The raising of the bed, the establishment of woody riparian vegetation and the building up of the banks are inter-connected processes which are largely responsible for the re-establishment of river channels after channelisation.

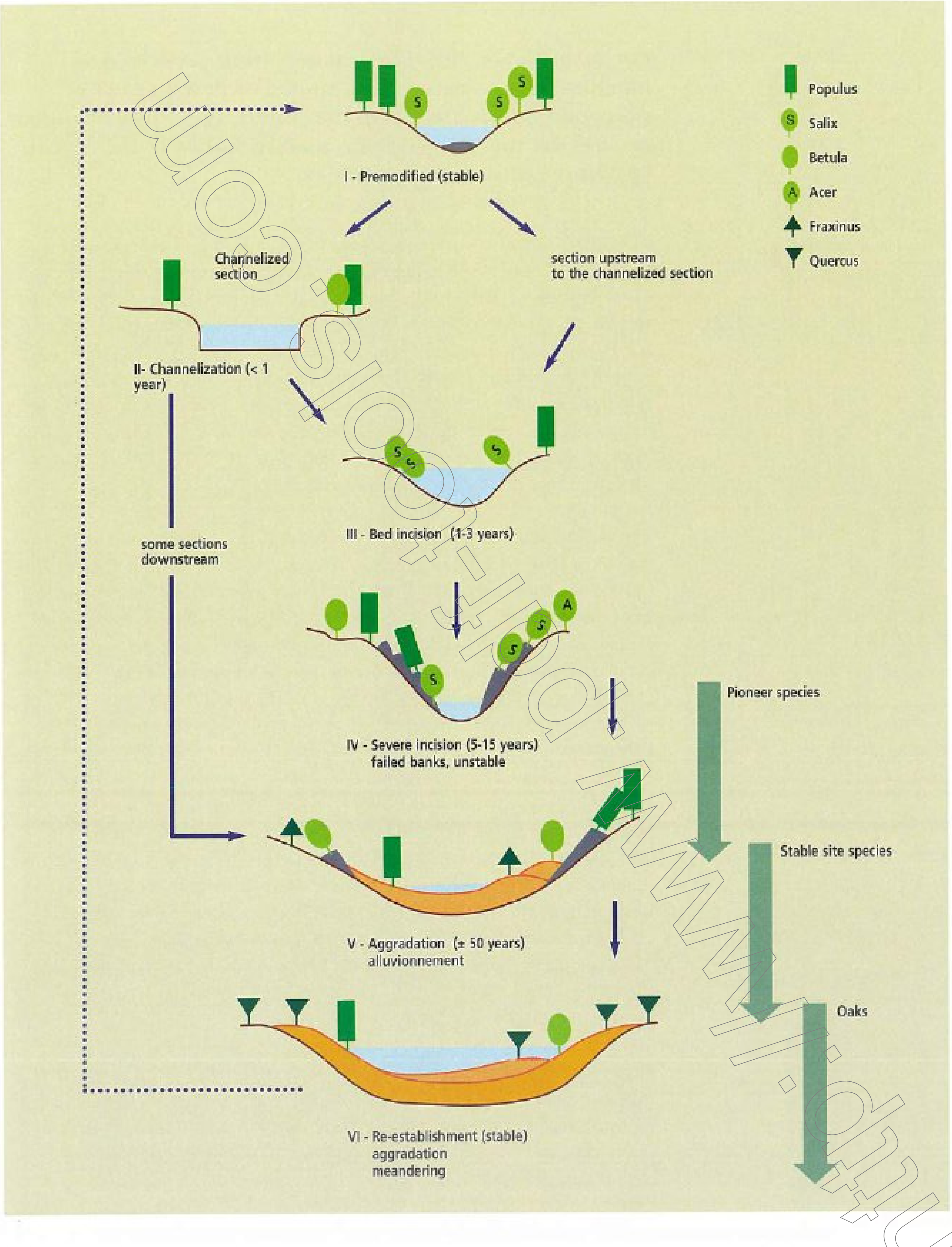
Riparian woodland at Lake Skadar, Montenegro



A. J. Crivelli

51 - *Hupp (1992)*

Six-stage model of channel evolution following channelisation (after Hupp 1992, modified)



A renewed perception

For many years, riparian wetlands were perceived as habitats to be transformed, drained or tidied up. This perception, inherited from the Middle Ages, only changed around the mid-20th century, mainly thanks to the action of nature conservation societies.

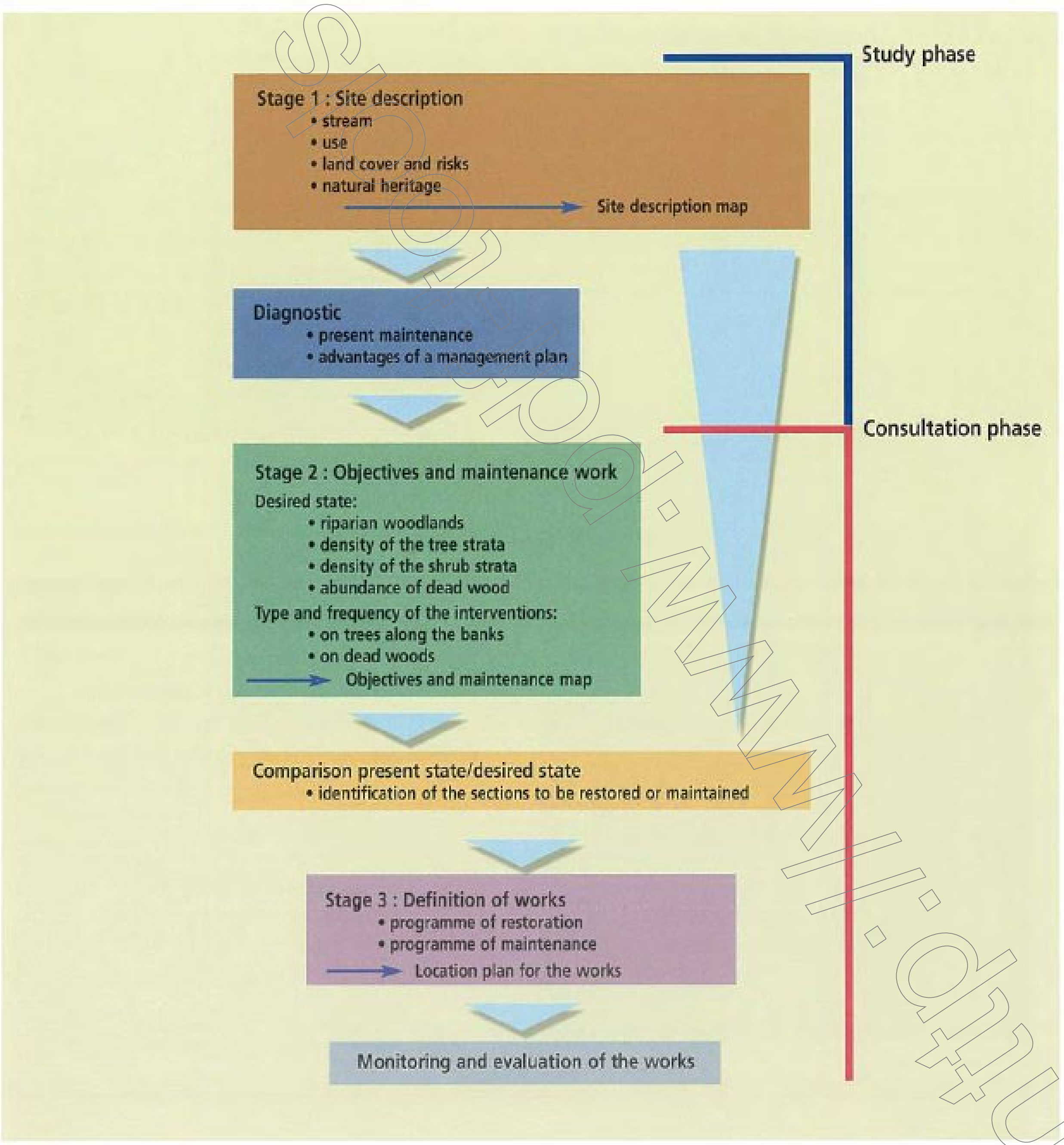
In the 1950s, these societies, under the auspices of the Global Alliance for Nature Conservation, then the IUCN (International Union for the Conservation of Nature), began an audit of the major wetlands of the world. They emphasised the biological role of wetlands in maintaining the balance of nature, and highlighted their importance as home to waterbird populations. An agreement was drawn up between countries to safeguard the most representative of these zones; this led to a convention relating to wetlands of international importance, known as the Ramsar Convention, signed in 1971. By 1999 a total of 114 countries had signed the convention.

The Ramsar Convention recognises the function of wetlands in regulating the hydraulic regime of watercourses as well as their role as habitat for a characteristic flora and fauna, particularly waterbirds. According to this convention, wetlands represent a resource of great economic, cultural and scientific value and should not be allowed to be degraded or disappear. Other international conventions complemented the Ramsar Convention, including the Berne Convention in 1979 and, more recently, the European Habitats Directive.

Wetland areas, including those lying along watercourses, are now recognised as living habitats which must be conserved or restored, and as a result we must, for example: 1) recognise the role of wetlands and their status as natural infrastructures, as well as their heritage and functional value; 2) take into account the social and economic cost of every project affecting natural wetland habitats; 3) create a pool of scientific and technical knowledge with regard to the management of wetlands; 4) exchange information, raise awareness, inform and train.

For some time now, scientists have been highlighting the distinctive features of the areas adjacent to flowing water bodies as distinct from still-water wetlands. All of these zones are obviously intimately connected with water. All are hotspots of biodiversity despite occupying proportionally only modest areas of land. But their differences are significant in several respects. These are manifested for example in the more terrestrial nature of riparian zones, and in their more linear and more interconnected spatial disposition. They are also and above all manifested in the influence of hydrological perturbation regimes on the spatial and temporal dynamics of riparian zones. These differences oblige us to recognise a distinctive character in the riparian zones of watercourses which distinguishes them from wetland zones in general and affects both their landscape qualities and the methods used for their management.

Drawing up a management plan for riparian woodland and dead wood: a study phase leads to a site description (stage 1), a consultation phase then leads to a statement of objectives and maintenance work required (stage 2) followed by a location plan for the works (stage 3) (after Boyer *et al.* 1998, modified).



Mediterranean riparian woodlands in the "Natura 2000" network

The Habitats Directive of 21 May 1992 designated a common framework for the "conservation of natural habitats and their fauna and flora[52]. This directive called for the putting in place of a network of special areas of conservation, the "Natura 2000" network, to maintain and restore natural habitats and wild spaces of interest to the community. It involves the implementation of sustainable development reconciling the conservation of natural habitats with economic and social demands. It also involves raising awareness of the necessity of protecting natural sites of special interest. Wetlands are among the habitats protected, along with riparian woodlands.

Penduline tit, *Remiz pendulinus*

Frédéric Fewe/Bios

Annex 1 of the directive of 21 May 1992 contains a list of "special areas of conservation", based on the CORINE Biotopes classification of all the habitats of the European Community. This list of special areas of conservation includes a number of Mediterranean riparian woodlands[53] :

• Gallery forests with *Salix alba* and *Populus alba* (44.141 and 44.6; 92A0[54]).
Salix alba, Salix fragilis, and related species dominate. The vegetation is multi-layered with *Populus* spp., *Ulmus* spp., *Salix* spp., *Alnus* spp., *Acer* spp., *Tamarix* spp., *Juglans regia,* and creepers. Poplars are the tallest trees in general, but they may be sparse or absent.

• Riparian formations on intermittent Mediterranean water courses with *Rhododendron ponticum, Salix* and others (44.52 and 44.54; 92B0).
These are thermo- and meso-Mediterranean alder galleries in deep valleys with *Rhododendron ponticum* spp. *baeticum, Frangula alnus* spp. *baetica, Arisarum proboscidum* and a rich fern community. Riparian gallery forest with *Betula parvibracteata,* a locally endemic species, also contains *Myrica gale, Frangula alnus, Salix atrocinerea, Galium broterianum* and *Scilla ramburei.*

• Forests of *Platanus orientalis* and *Liquidambar orientalis* (44.71 and 44.72; 92C0).
These forests, dominated by the Plane Tree and the Oriental Sweet Gum, belong to the *Platanus orientalis* community types.

52 - O.J. of the European Communities of 22 July 1992
53 - After the Interpretation Manual of the habitats of the European Union, October 1999
54 - Reference to the classification of the Palearctic habitats (version 1995) and separated by ";", to the annex 1 of the Official Journal (based on CORINE biotopes 1989).

Edwards/Still picturBios

Ancient woodland being strangled by an introduced species of climber *Sycios angulatus*, Po delta

Plane Tree forests form galleries along watercourses, temporary rivers and gorges in Greece and the southern Balkans. They constitute very rich communities, including *Salix alba, S. elaeagnos, S. purpurea, Alnus glutinosa, Cercis siliquastrum, Celtis australis, Populus alba, P. nigra, Juglans regia, Fraxinus ornus* etc., with mosses, lichens and often abundant ferns. These gallery forests are particularly well represented along the Ionian coast and in the Pindus, and more locally in Macedonia, Thrace, the Olympus massif, Pelion and the Peloponnese, as well as in Euboea and in Crete and in other Aegean islands. They tend to be restricted to gorges towards the south.

Plane woods are found on colluviums, detritus cones and other poorly stabilised substrates in Greece and can form galleries in gorges in Sicily. Sweet Gum forests form limited galleries in Asia Minor and Rhodes.

Thermo-Mediterranean riparian galleries (*Nerio-Tamaricetea*e) and south-west Iberian Peninsula riparian galleries (*Securinegion tinctoriae*) (44.81 to 44.84; 192D0). These are formations of galleries and low woody thickets along permanent and temporary watercourses of the thermo-Mediterranean zone and the south-western Iberian Peninsula, and are also found in wetter areas of the Saharo-Mediterranean zone. They contain *Nerium oleander, Vitex agnus-castus, Tamarix* spp., *Securinega tinctoria, Prunus lusitanica* and *Viburnum tinus*.

By Jean-Pierre Roux,
Conservatoire Botanique National Méditerranéen, Porquerolles

Support from riparian populations

How should a management plan for riparian woodland and dead wood be drawn up? Answers to this question may change from one river to the next, but they presuppose close collaboration.

The method shown in figure p. 109 suggests a preliminary phase of reflection on the reasoning behind the management plan, the motives of those involved and the functions of the riparian woodland under consideration. Once this preliminary phase is over, a plan is drawn up with the aim of producing a site description (stage 1), followed by a statement of objectives and maintenance work required (stage 2), then a location plan for the works (stage 3). The first stage involves a systematic overview of the sectors in need of maintenance, an analysis of the existing data and information searches among local authorities. The second and third stages presuppose close collaboration with local players and their technical and financial partners. The aim is to take the desired uses for the environments around water courses into consideration, so that a programme of restoration or maintenance can be defined.

The objectives with this kind of approach are often many and varied. For example: encouraging the movement of floods in order to protect a given sector or, on the other hand, slowing down the flow in order to preserve the downstream sectors; limiting or reducing shore

Jean-François Noblet/Bios

Tamarix plantation along a bank

erosion, the formation of log jams or dams caused by dead wood; conserving or transforming the appearance of a landscape; making the banks and river bed more accessible; limiting the inputs into a watercourse; encouraging fish life; preserving a rare habitat, the diversity of riparian environments and the species they harbour. Of course, these objectives are not all compatible within any given sector: encouraging fish life requires dead wood to be conserved; encouraging the movement of floods, on the other hand, requires the dead wood to be removed. Some objectives are more relevant to the headwaters of a hydrographic network, some are more relevant downstream. Some objectives apply to vulnerable habitats; some objectives require active intervention in one place while leaving natural processes to take their course elsewhere. Sectoring of objectives is thus essential.

Furthermore, restoration work should be distinguished from maintenance work. Restoration aims at obtaining a desired state, which differs from the existing situation; maintenance aims at maintaining the existing situation, which is already a desired state. This distinction is important: it enables the intervention of local authorities to be reoriented towards the key sectors of restoration. Owners of riparian properties are thus encouraged to fulfil their obligations with regard to land maintenance in sectors not covered by restoration work. These obligations – which are often prescribed by law – concern for example the maintenance of the widths and depths of watercourses, the maintenance of riverbanks by lopping and coppicing trees, and the removal of log jams and debris, floating or otherwise, to maintain the natural flow of the water, to preserve fauna and flora and to ensure the healthy functioning of aquatic ecosystems.

Information plays a vital role here. There are many questions to be asked, inevitably leading on to further questions; the answers are rarely straightforward and explanations always need to be adapted to the variety of situations to be dealt with, as we can see below with regard to vegetation clearing and the management of accumulated dead wood in rivers.

How is clearing to be carried out?

In many rivers, the control of river flow and the gradual stabilisation of river bed has resulted in the growth of vegetation that only regular mowing can bring under control.

Clearing of vegetaion is essential if the river is to cope with floods. But if clearing is carried out repeatedly and systematically, it can degrade the quality of vegetation present by suppressing shrub willow communities, destroying wooded islets, and promoting the expansion of certain species, such as Giant Reed, to the detriment of others. Clearing also contributes to the drying-out of riparian woodlands by enhancing them in relation to the bed, thus limiting their contribution to the diversity of riparian environments.

Lateral zoning across the river channel is thus recommended, comprising[55]:

- A permanently clear channel, ensuring a minimum flow width, if necessary along several arms;

- A strip where clearing may possibly take place and through which the channel can run, forming multiple branches or even moving from side to side by switching from one cleared route to another;

- Islands in the middle of this strip, which are maintained in a wooded condition, and which may perhaps be cleared by the shifting channels;

- A section where mobility is sufficient to ensure minimum ecological and sedimentary dynamics; this should include the strip for possible clearing plus some terraces, erosion of which could be encouraged;

- A zone of maximum mobility in which a shifting course could be accepted without necessarily undertaking any works to protect against erosion.

Such a zonation can provide a structure to clearance work, provided the clearing is adapted to the sectors under consideration and is accompanied by flow management which is propitious to the transport of coarse sediment throughout the watercourse and the mobilisation of silt deposited on the river banks.

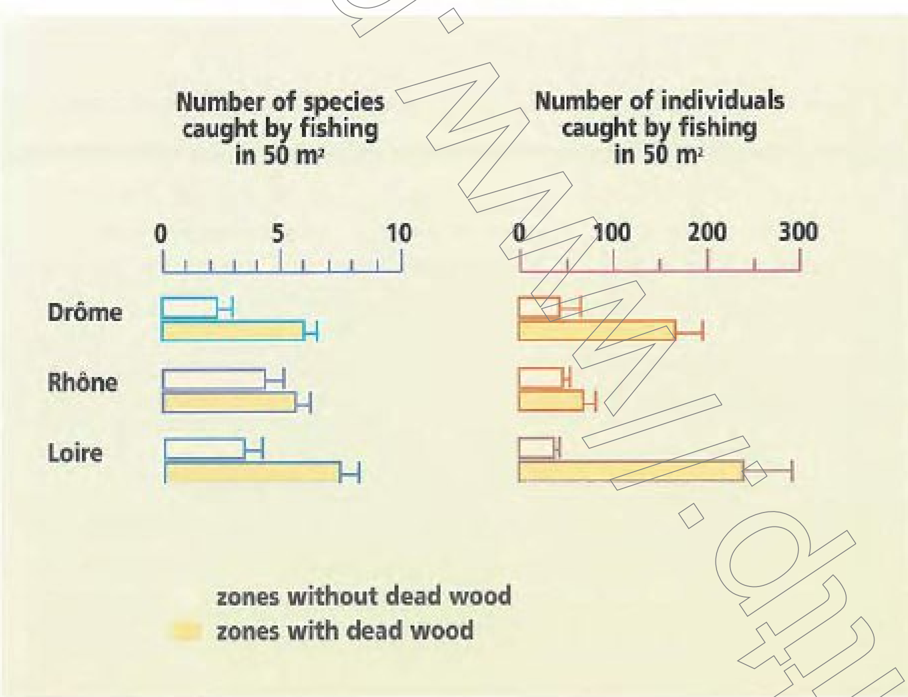
55 - Syndicat Mixte d'Aménagement de la Vallée de la Durance (1999)

What is to be done with dead wood?

For a long time, dead wood was systematically removed from watercourses because it can induce flooding and erosion. However, these risks should be neither under-estimated nor over-estimated.

The risk of flooding through the obstruction of the river bed and the raising of water levels upstream in fact only arises from large log jams*, in terms of both the quantity of dead wood and the size of the wood fragments, which means vulnerable sectors are limited to small water courses. However, watercourses are also threatened downstream of sectors where dead wood is produced. Dead wood travelling downstream for example accumulate along bridges, obstructing the passage of water and raising the water level, with possible damaging effects. As for the risk of erosion, this depends mainly upon the position of large trunks in relation to the river banks. Depending on their position, they can cause undermining of the banks, resulting in a widening of the watercourse.

Log jams, on the other hand, diversify running-water ecosystems. They provide abundant food for invertebrates and by encouraging the heterogeneity of aquatic substrates create a variety of shelters and



Influence of dead wood on the fish community in the Barbel zone in three large water courses (mean ± standard error). (after Thévenet 1998 in Piégay 2000, modified).

living conditions for fish. The relationship between the presence of dead wood and the richness of the fish communities has long since been proven (see figure p. 115).

The management of dead wood in rivers thus needs a flexible approach. Systematic removal is out of the question, as is total neglect; appropriate and well thought out maintenance practices are needed. The identification of objectives, sector by sector, will thus lead to recommendations to remove in one place and to maintain in another, in one case to reduce the risk of flooding or erosion, while in the other to promote aquatic biodiversity, to preserve fish resources or to store water in order to reduce the effects of floods further downstream. The installation of artificial structures for wood retention upstream of sensitive sectors will protect some structures, preventing, for example, tree trunks from collidingwith bridge supports. This precaution is essential given the regeneration of woodlands on the margins of some watercourses following the decline of agricultural and livestock activities.

All this presupposes improved knowledge of the dynamics of wood in hydrographic networks. Management of dead wood by sectors can lead to the retention or even reintroduction of log jams to maintain the diversity of aquatic fauna and flora, to improve fish resources or for better control of floods downstream. However, to implement such management one needs to know where the dead wood comes from, how it will decompose, and under what conditions log jams form. For the effective implementation of monitoring and intervention policies, such questions require exact answers.

This does not mean that the necessity of removing dead wood from rivers should be called to question each time risks of flooding and bank erosion appear; rather it involves diversifying our management practices. What we know about dead wood in rivers suggests that there should be a balance between measures for protection against flooding and erosion on the one hand and the functioning of aquatic ecosystems on the other. Certain countries are already going down this road. One example is Australia where attempts are being made to: 1) leave in place plant cover which occupies less than 10% of the surface area of the channel; 2) place the trunks of dead trees at angles of less than 40° with respect to the river bank; 3) remove dead wood from the middle of the channel to facilitate flow; 4) cut back overhanging branches if they risk creating log jams; 5) preferably remove isolated tree trunks which present a danger in isolation; 6) introduce dead wood into slowly flowing sections close to the river banks; 7) fix dead wood against the outside of meanders to improve their stability; 8) arrange dead wood from the smallest pieces to the largest in the direction of the current so that the whole structure is tapered in shape[56].

56 - AFFA (2001)

Indicators of ecological integrity

Any management of natural habitats, whether for conservation or restoration purposes, must be assessed. This assessment is the most important and the most difficult of all the tasks required of managers.

Which indicators should be used? Which methods should be adopted? How can both scientific rigour and site potential be fulfilled? These questions become even more difficult when they concern systems as dynamic in space and time as riparian woodlands, systems which are so dependent on hydrological perturbation regimes

The concept of ecological integrity has been in use for some twenty years now. Ecological integrity means the capacity of a habitat to support and maintain biological systems which are balanced, well developed and adaptable, as well as containing the whole range of species and processes which would be predicted for the region in question[57]. Measurement of ecological integrity of course requires a reference site and an appropriate scale in space and in time. It enables indicators reflecting very diverse and often disparate data to be identified.

Five indicators of ecological integrity in riparian systems have recently been put forward[58]. They take into consideration the characteristics of riparian running water systems.

Michel Gunther/Bios

Little egret
along the Strymon River, Greece

57 - Karr & Dudley (1981)
58 - Innis et al. (2000)

Microclimate

Mosaics of microclimates, with contrasting conditions of relative humidity, air and soil temperature, and solar radiation, may be used as indicators of the health of riparian woodlands.

Heterogeneit

These mosaics support species which differ from one another by their life cycles and the stages of plant succession in which they appear. This heterogeneity reflects the condition both of the hydrological regime and of the land use.

Biodiversity

The diversity of plant and animal species in communities is an overall reflexion of the biophysical modifications taking place in riparian woodland.

The proportion of terrestrial species

An increase in the relative abundance of terrestrial species indicates the extent to which hydrological fluctuations have been regulated. This is the case, for example, with conifers which establish themselves on dried-out riverbanks, replacing riparian woodland species.

Particles in suspension in the water

Analysis of their dynamics enables the state of development of riparian systems bordering watercourses to be assessed.

Such indicators are likely to improve methods for assessing the ecological integrity of riparian woodlands. Nonetheless, they will not be put to use without the widest possible discussion as possible between scientists, managers, decision makers and the general public.

Willows and the revegetation of riverbanks

Revegetating a riverbank consists of "revitalising" it with herbaceous or woody plants, usually in order to protect it against erosion. Willows are often popular with river managers because of their diversity, speed of growth, aptitude for propagation and regrowth, and the flexibility of their branches. They are used to protect the foot of the riverbank, by fascines or mattresses of branches fixed with stakes, bundles of sticks, or tangles of branches, brushwood and tree trunks. Willows are also planted as trees at the top of banks or as shrubs halfway up

There are two essential rules for successful revegetation of a riverbank: 1) use indigenous tree species adapted to local growing conditions, 2) use an array of species in order to increase the vegetation's chances of successful establishment. Knowledge of plant species is therefore essential from the outset. The table below summarises some of the characteristics used[59].

Willow trees such as *Salix fragilis* and *S. alba* can only be planted at the foot of the bank if they are kept in a shrub state through regular maintenance. Elsewhere, species such as *Salix daphnoides* and *S. elaeagnos* can form trees when conditions are favourable. It is also worth noting that *Salix fragilis* is too elastic to be used for fascines and that *S. triandra*, whose branches are too curved at the base, cannot be used for making stakes

Willow coppices can be used for the purification of waste water. If watered with the effluents of purification stations, willows will remove nitrate and phosphorus before the effluents rejoin surface and subterranean waters. The trees can then provide fuel for wood furnaces. This natural process has been tested or used in various countries – Sweden, USA, New Zealand, Australia, France.

Species	Normal size	bush	shrub	Tree
Salix aurita	1-3 m	x		
Salix nigricans	1.5-5 m	x		
Salix purpurea	1-6 m	x		
Salix cinerea	3-6 m	x	(x)	
Salix atrocinerea	3-6 m	x	(x)	
Salix triandra	2-7 m	(x)	x	
Salix viminalis	2-10 m		x	
Salix daphnoides	3-15 m		x	(x)
Salix elaeagnos	2-15 m	(x)	x	(x)
Salix fragilis	5-25 m			x
Salix alba	5-30 m			x

Characteristics of the willows that can be used for the revegetation of river banks

59 - *After Lachat (1994)*

Daniel Heuclin/Bios

Conclusion

Riparian woodlands differ from wetlands both from a structural and functional point of view.

From the structural point of view, they form linear systems throughout catchment areas, outlining the hydrographical networks along which they run. In addition, they develop on surfaces contoured by floods and marked by variations in topographical parameters, so that wet and dry conditions occur side by side in restricted and changeable spaces.

From the functional point of view, riparian woodlands are constantly subjected to the effects of hydrological vagaries, which are intense in response to the Mediterranean climate. Regularly modified by floods, and subjected to the processes of erosion and sedimentation, they are among the most dynamic ecosystems on the planet.

Oleander and palm trees in a wadi

Riparian woodlands are interfaces between aquatic and terrestrial habitats[60]. As a consequence, they are good indicators of the state of the water and the land, as well as, more generally, the landscape. Better still, they contribute to the management of these states, insofar as managing riparian woodlands contributes to water, land and landscape management.

The management of riparian woodlands is in the first place an integral part of water management. In the Mediterranean region, water resources are very unequally shared between the countries of the north and the south. The former, faced mainly with problems of water quality, have to reconcile the use of aquatic habitats with the protection and often restoration of these habitats; the latter, faced mainly with problems of quantity, must manage scarce water resources without in any way neglecting the preservation of habitats. The contrast between these countries is in danger of becoming even more marked in the future, as are two general tendencies, one towards using resources chiefly for irrigation needs, the other towards satisfying the growing needs of the coast to the detriment of those of the hinterland.

What is necessary therefore is the concept of "zero growth" for the exploitation of continental waters, regarding both withdrawals from and disposals into the aquatic environment[61]. This "zero growth", which in the long term is virtually inevitable, does not preclude increasing the quantities of water used, for example with the help of greater efficiency: development of recycling and use of brackish and sea waters. But everywhere it calls for economic and technological choices – negotiated, widely accepted, and varying according to region. These choices presuppose that the Mediterranean countries will be united in their aims and that they will agree to make great efforts to educate, raise awareness and inform. Success in water management depends in part on the attention given to riparian woodlands.

The management of riparian woodlands also plays a part in the management of land, particularly land erosion. This is an extremely complex process with poorly understood effects when methods used are too simplistic and do not take into consideration either the types of erosion in question, or the substrates involved[62]. Rivers have their part to play in the development of this process, mainly because of their instability and the natural and artificial changes in their hydrology. The most spectacular damage caused by rivers is that caused by the undermining of the base of steep, unstable riverbanks. Although this type of erosion only affects small surface areas, it can involve enormous volumes of sediments.

60 - Naiman & Décamps (1997)
61 - Margat (1992)
62 - Grove & Rackham (2001)

Conclusion

The vegetation of riverbanks can effectively reduce erosion when this is due to rains of low to average intensity. Its role becomes questionable, when the rains are as violent as those which regularly fall in the Mediterranean regions. The effectiveness of tree plantations, in preventing for instance the scouring and collapse of banks or in healing the damage caused by bulldozers, is arguable. Nonetheless, riverbanks are never more unstable as when they are devoid of vegetation. Riparian woodlands promote the establishment of mosses and ferns; they contribute humus which consolidates riparian soils; they prevent these soils from drying out and cracking, thus limiting their vulnerability when the rains return. In brief, they provide protection of the first order between episodes of catastrophic flooding. Such a role is far from negligible when one considers for example the rapid silting-up which threatens most of the reservoirs along Mediterranean watercourses.

Finally, riparian woodlands are essential features of Mediterranean landscapes. A river, its riparian wood, and the surrounding towns and villages form an indissociable whole. A riparian community has often very strong ties – economic, certainly, but also emotional, with riparian woodland[63]. We have seen that riparian woodlands can be excellent aids to land and water management. They enable us to benefit from natural services and to profit from the management of these services – but only provided their aspect as landscape features is taken into account, for riparian woodlands also reflect the perceptions and desires of those who are involved with them.

Integration of the landscape aspect of riparian woodlands is all the more necessary as their very existence depends on the care they receive. Only management which takes into account natural as well as social conditions can ensure the survival of Mediterranean riparian woodlands in the long term. For, like any other landscape, riparian woodlands are only sustainable if they are renewed and their natural and cultural identity respected.

63 - Le Floch (2000)

Annex :
Suitable species for use in the restoration of riparian woodlands in the Mediterranean region

The most suitable species for the restoration of a riparian woodland are those from nearby: their take-up rates are more satisfactory and their growth rates often high. The first task consists therefore in determining which species to include, and at what density, using knowledge of local plant communities, growth rates, the long term development, root systems etc. These choices must be taken in light of the soil type, local microclimate and position in relation to the level of the water table.

Once these choices have been made, and species selected in situ, it is advisable to contract in an expert with professional knowledge of the indigenous flora and its propagation. This should enable plants to be used which are correctly identified and located, and for which methods of collection, state of health, and quality of root system and aerial parts are known. It must be possible to monitor the works at every stage and, if necessary, to make adjustments. The quantities available should compensate for any vagaries of production or planting. Time is the greatest constraint here: three years can go by between collecting the plants and the time when the last plants are ready to be planted.

Another constraint is that the site chosen should be prepared at the end of the summer preceding planting. This preparation consists in removing undesirable coarse materials, preferably by mechanical scrub clearing, loosening the soil, and accurately staking out the sites of the different plant communities. Planting itself requires maximum protection for the species from the establishment of the nursery (temperature and humidity conditions during transport) until their putting in place (protection of the roots and aerial parts), in order to ensure the best conditions for success. Insofar as it is possible, planting is carried out after the end of October to enable the roots to start developing during the plants' dormant period.

The consolidation of banks by riparian woodlands is never an easy process in the Mediterranean region. A bank in need of restoration is in fact rarely in a condition to receive plants. It must first of all be profiled according to the initial degree of degradation, and sometimes built up with rocks to limit undermining. Once the base of river banks have been made safe in this way, the now well-known techniques of propagation, plaiting, fascines, etc. can be used. The sowing of high-density plants should ensure stabilisation of the surface and maintenance carried out every five to ten years will prove beneficial.

Once these plantings have been carried out, the success of the operations calls for further sustained effort: three to four years of regular watering and weeding are necessary before the plants can be considered to have successfully established themselves.

But to start with, knowledge of plant species is absolutely essential. The list below refers to possible species for use in the work of restoring riparian woodlands in the Mediterranean region.

By Jean-Pierre Roux,
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Acer campestre L.
(Field Maple)

Tree, 12-15 m in height with leaves with five unequal lobes.

Physiological properties: Heliophilic or photophilic, mesoxerophilic to mesophilic; slow growth rate; good stabiliser of riverbanks; creeping roots or taproots.

Soil types: Gravels, as well as clays or silts.

Planting advice:
At the top of the bank, well above normal flooding levels; use rooted individuals grown from herbaceous cuttings taken in spring (plant after at least two years in the nursery).

Acer monspessulanum L.
(Montpellier Maple)

Tree, 5-12 m in height with leaves with three rounded, equal lobes.

Physiological properties: Heliophilic or photophilic, xerophilic or mesoxerophilic; fairly rapid growth rate (high longevity); good stabiliser of riverbanks; creeping roots or taproots.

Soil types: Shallow, aerated soils.

Planting advice:
At the top of the bank, well above normal flooding levels; use rooted individuals grown from herbaceous cuttings taken in spring (plant after at least two years in the nursery).

Alnus glutinosa (L.) Gaertner
(Common Alder)

Tree, 20-25 m in height with heart-shaped leaves, glabrous on both sides.

Physiological properties: Heliophilic linked to the groundwater, very vigorous juvenile growth; excellent stabiliser of riverbanks; able to grow in waterlogged soils; taproots.

Soil types: Heavy, compact alluvial soils.

Planting advice:
Less than a metre at the most above the groundwater; use rooted individuals grown from seeds taken in autumn (plant after at least one year in the nursery).

Alnus incana (L.) Moench
(Grey Alder)

Tree, 10-15 m in height with pointed leaves, whitish beneath.

Physiological properties: Heliophilic linked to highly variable groundwater levels; can adapt to dry terrains, rapid growth rate; very good stabiliser of riverbanks; taproots.

Soil types: Immature, very permeable alluvial soils, subject to frequent erosion.

Planting advice:
Up to one to two metres above the groundwater; use rooted individuals grown from seeds taken in autumn (plant after around one year in the nursery).

Cornus sanguinea L.
Dogwood

Shrub, 2-5 m in height with blue-black spherical drupes.

Physiological properties: Heliophilic or photophilic, mesoxerophilic to mesophilic; rapid growth rate; good stabiliser of riverbanks; creeping roots.

Soil types: Heavy soils (clays or silts).

Planting advice:
On banks or at the top of banks; use rooted individuals grown from woody cuttings taken at

the end of autumn (plant after one year in the nursery); woody cuttings (1 cm in diameter, approximately 50 cm in length) taken at the end of winter and replanted immediately on the site.

Fraxinus angustifolia Vahl
(Narrow-leaved Ash)

Tree, 15-20 m in height with brown buds.

Physiological properties: Heliophilic, mesophilic to mesohygrophilic, fairly rapid growth rate, good stabiliser of riverbanks; taproots.

Soil types: Very loose soils, possibly temporarily waterlogged.

Planting advice:
From around one metre above the groundwater (can withstand flooding);
use rooted individuals grown from samaras taken at the end of summer or at the very beginning of autumn when they are still green to avoid problems of breaking dormancy (plant after one year in the nursery).

Hippophae rhamnoides L.
(Sea buckthorn)

Shrub, 1-5 m in height with silvery foliage and orange, globular berries.

Physiological properties: Heliophilic with very high water amplitude which withstands flooding very well; slow growth rate but high longevity; remarkably good stabiliser of unstable soils or those without vegetation; develops root system before aerial system.

Soil types: Prefers permeable alluvial soils, but can adapt to all soil types.

Planting advice:
Indifferent with respect to the groundwater; use rooted individuals grown from seeds taken in autumn (plant after three years in the nursery).

Laurus nobilis L.
(Sweet Bay)

Tree, 2-5 m in height with entire, aromatic leaves.

Physiological properties: Heliophilic with low water amplitude; slow growth rate.

Soil types: Light soils.

Planting advice:
At the top of the bank; use rooted individuals grown from seeds taken in autumn (plant after at least two years in the nursery).

Ligustrum vulgare L.
(Privet)

Shrub, 2-3 m in height with small, black, globular berries.

Physiological properties: Heliophilic or photophilic with low water amplitude; rapid growth rate; creeping roots.

Soil types: Clayey-silty soils.

Planting advice:
At groundwater level or slightly above; use rooted individuals grown from woody cuttings taken at the end of winter (plant after one year in the nursery).

Nerium oleander L.
(Oleander)

Shrub, 1-5 m in height with large aromatic flowers, generally pink in colour.

Physiological properties: Heliophilic with high water amplitude (withstands flooding well); fairly rapid growth rate; root system well developed and a very good stabiliser of riverbanks.

Soil types: Soils that are well drained or clayey to a greater or lesser degree.

Planting advice:
Fairly indifferent with respect to the groundwater; use rooted individuals grown from seeds gathered in winter or semi-woody cuttings taken in summer (plant after one or two years in the nursery).

***Platanus orientalis* L.**
(Plane)

Tree, 20-40 m in height with leaves with very marked lobes.

Physiological properties: Heliophilic with fairly low water amplitude; slow growth rate but very high longevity.

Soil types: Light, deep soils.

Planting advice:
At groundwater level or slightly above; use rooted individuals grown from woody cuttings taken in winter, or from seeds (plant after at least two years in the nursery).

***Quercus pubescens* Willd.**
(Downy Oak)

Tree, 10-25 m in height with sessile (stalkless) acorns.

Physiological properties: Heliophilic and thermophilic, mesophilic; very slow growth rate but high longevity, good stabiliser of riverbanks; taproots.

Soil types: Deep to moderately deep soils.

Planting advice:
At the top of the bank, as far removed as possible from the groundwater (cannot withstand frequent flooding); use rooted individuals grown from acorns taken in autumn (plant after at least two years in the nursery).

***Quercus robur* L.**
(Pedunculate Oak)

Tree, 25-35 m in height with acorns with a peduncle (stalk) of variable length.

Physiological properties: Heliophilic, with low water amplitude, very slow growth rate but high longevity, good stabiliser of riverbanks; taproots..

Soil types: Heavy clayey-silty soils.

Planting advice:
At the top of the bank, but not too far from the groundwater (withstands frequent flooding); use rooted individuals grown from acorns taken in autumn (plant after at least two to three years in the nursery).

***Quercus suber* L.**
(Cork Oak)

Tree, 10-25 m in height with very thick, fissured bark (cork).

Physiological properties: Heliophilic with low water amplitude; slow growth rate; good stabiliser of riverbanks.

Soil types: Light, deep soils.

Planting advice:
At the top of the bank, as far as possible from the groundwater (cannot withstand frequent flooding); use rooted individuals grown from acorns taken in autumn (plant after at least two to three years in the nursery).

***Salix alba* L.**
(White Willow)

Tree, reaching 12-30 m in height with silky, hairy leaves.

Physiological properties: Heliophilic with very high water amplitude; very rapid growth rate; taproots.

Soil types: Immature soils, subject to frequent erosion.

Planting advice:
Either at groundwater level or at the top of the bank and thus with little connection to the groundwater; use rooted individuals grown from woody cuttings taken in autumn or in winter (plant after one year in the nursery).

Salix elaeagnos Scop.
(Elaeagnus Willow)

Tree, 5-15 m in height with long, very narrow leaves with rolled edges.

Physiological properties: Heliophilic with very high water amplitude; fairly rapid growth rate; creeping roots.

Soil types: Coarse, permeable alluvial soils.

Planting advice:
Either at groundwater level or at the top of the bank, thus with little connection to the groundwater; use rooted individuals grown from woody cuttings taken in autumn or in winter (plant after one year in the nursery).

Salix purpurea L.
(Purple Willow)

Shrub, 1-5 m in height with subopposite, glabrous leaves.

Physiological properties: Heliophilic with low water amplitude; rapid growth rate; creeping roots.

Soil types: Immature soils, subject to frequent erosion.

Planting advice:
At groundwater level (or up to 1.5 m above the groundwater); use rooted individuals grown from woody cuttings taken in autumn (plant after one year in the nursery).

Salix triandra L.
(Almond Willow)

Shrub, 2-8 m in height with dented leaves.

Physiological properties: Heliophilic with very low water amplitude (permanently wet soils); rapid growth rate; creeping roots.

Soil types: Immature, alluvial soils, subject to frequent erosion.

Planting advice:
At groundwater level; use rooted individuals grown from woody cuttings taken in autumn or in winter (plant after one year in the nursery).

Salix viminalis L.
(Basket Willow)

Shrub, 2-10 m in height with narrow, very long leaves (up to 15 cm), silky beneath.

Physiological properties: Heliophilic with very low water amplitude; rapid growth rate; creeping roots.

Soil types: Immature soils, subject to frequent erosion (particularly sandy).

Planting advice:
At groundwater level; use rooted individuals grown from woody cuttings taken in autumn or in winter (plant after one year in the nursery).

Sorbus domestica L.
(Service Tree)

Tree, 5-20 m in height with composite leaves and small, yellow, pear-shaped fruits.

Physiological properties: Heliophilic or photophilic, xerophilic to mesophilic; slow growth rate; creeping roots.

Soil types: Deep soils (clays, decarbonation clay).

Planting advice:
At the top of the bank (cannot tolerate flooding, apart from exceptional flooding); use rooted individuals grown from seeds taken in autumn (plant after at least two to three years in the nursery).

Tamarix africana Poiret (African Tamarisk)

Shrub, from 2-5 m in height with fairly large flowers grouped in thick spikes.

Physiological properties: Heliophilic with very low water amplitude; tolerates brackish water; fairly powerful root system; fairly rapid growth rate, but relatively low longevity.

Soil types: Well drained, sandy soils.

Planting advice:
At groundwater level; use rooted individuals grown from hardwood cuttings taken in winter or at the beginning of the spring [outside the flowering season] (plant after around one year in the nursery).

Tamarix gallica L. (French Tamarisk)

Shrub, 2-5 m in height with small flowers grouped in loose, spindly spikes.

Physiological properties: Heliophilic with fairly low water amplitude; fairly powerful root system; fairly rapid growth rate.

Soil types: Well drained, sandy soils.

Planting advice:
At groundwater level or slightly above; use rooted individuals grown from hardwood cuttings taken in winter or at the beginning of spring [outside the flowering season] (plant after around one year in the nursery).

Vitex agnus-castus L. (Chaste Tree)

Shrub, 1-5 m in height with blueish flowers forming long, interrupted racemes.

Physiological properties: Heliophilic with low water amplitude; fairly rapid growth rate; stabilising root system.

Soil types: Well drained, sandy soils.

Planting advice:
Just above groundwater level; use rooted individuals grown from seeds or semi-woody cuttings taken in autumn (plant after around two years in the nursery).

N.B. : Some species may be legally protected. Their sampling and multiplication is submitted to authorisation.

Glossary

Achene: dry, indehiscent fruit, resulting from the maturation of a single carpel and containing a single seed.

Aquifer: one or several underground layers of rock or other geological strata sufficiently porous and permeable to allow for a significant current of underground water or the catchment of significant quantities of underground water[64]. An aquifer can be part of alluvial or karstic formations.

Biodiversity hotspot: the Mediterranean Basin has been designated one of the world's 25 biodiversity hotspots. These are places which host numerous endemic species but are also undergoing significant habitat loss. Hotspots are places which need to be the priority targets of biodiversity conservation efforts within a worldwide programme[65]. Each hotspot hosts at least 0.5% of the 300,000 endemic plant species known in the world, i.e. at least 1,500 species. With 13,000 plant species, the Mediterranean Basin comes in third place out of the 25 hotspots, after the tropical Andes (20,000 species) and western Indonesia – Sumatra, Java, Borneo, Malacca peninsula – (15,000 species). Its ranking is lower (13^{th}) when vertebrates – birds, mammals, reptiles and amphibians – are taken into consideration.

Capsule: dry, dehiscent* fruit, resulting from the maturation of two or more carpels.

Conductivity: parameter enabling evaluation of the water's total electrolyte load, i.e. substances likely to be ionised if an electric current is passed through them.

Cultural eutrophication: overfertilisation of continental aquatic systems due mainly to excess nutrients (notably nitrate and phosphate) which reach lakes and watercourses in a diffuse or point source pollution.

Cuticle: outside protective layer of the epidermis of certain plants. It is partly made of waxes whose functions include limiting evapotranspiration.

Dehiscent: describes fruits with a rigid husk which opens out spontaneously to release the seeds (unlike indehiscent fruits).

Dioecious: describes species of plants with distinct male and female plants, each with either male flowers with stamens or female flowers with pistils (e.g. willows).

Evapotranspiration: the vaporisation of water from soil and leaves through the action of the sun's rays. It is the result of both evaporation (directly from the soil and lakes) and especially the

64 - After directive 2000/60/CE of 23 October 2000

65 - de Marsily (1995)

transpiration of plants (from the water in the soil extracted by the roots). In a Mediterranean climate, it can vary from 7 to 10 mm per day on average, and fall to 0.1 mm per day in winter[66].

River continuum: according to the river continuum concept, the longitudinal profile of a river provides a continuous gradient of physical conditions in response to which the populations present adjust, notably with regard to the loading, transport, use and storage of organic material. Through these adjustments, the communities of producers and consumers in a given sector place themselves in continuous harmony with the dynamics of the physical conditions in the channel. Over the whole of the longitudinal profile, these communities will organise themselves in such a way as to ensure minimum loss of the energy conveyed by the river, the communities downstream profiting from the residues left by those upstream. The river continuum concept inspired much research during the 1980s[67], stimulating both enthusiasm and controversy. It has been gradually supplanted by new ideas concerning the ecology of running water.

Garrigue: open shrubland containing Cistus, Rosemary, Lavender, Thyme etc.

Heliophytic: having a strong affinity for sunny habitats.

Hygrophytic: having a strong affinity for damp habitats.

Imago: adult stage of the life cycle of insects.

Impluvium: measurement of the rainfall in a given area, often that of a catchment.

Log jam: accumulation, during a flood, of tree branches, limbs and trunks, possibly mixed with gravels and rock, blocking the course of a river more or less completely.

Low-flow period: lowest level of flow by a watercourse during an annual cycle.

Maquis: dense, closed shrubland, comprising mainly spiny plants and Kermes Oaks on siliceous soil.

Mesophytic: not tolerant to extreme values of an ecological factor, often excess or lack of water.

Monoecious: describes species of plants whose male flowers with stamens and female flowers with pistils occur on the same plant.

Ordinary nature: term used to describe "unlabelled" natural habitats, situated outside protected areas such as parks and reserves. Ordinary nature is what we see around us every day.

Pistil: female organ made up of a carpel (an ovary surmounted by a style and stigma). Generally, the female organ is made up of several carpels separated or united together. After fertilisation, an ovary becomes a fruit, and an ovule becomes a seed.

66 - Myers et al. (2000)
67 - Vannote et al (1980)

Pistillate flower: female flower containing one or more carpel(s) – each carpel including the ovary surmounted by the style and the stigma.

Plant engineering: term used to describe the knowledge and techniques used to protect river banks against erosion, and stabilise them using plants.

Propagules: term used to describe any part of a plant (seed, spore, cutting) able to give rise to a new plant. Propagules are thus the same as diaspores.

Resurgence springs: springs resulting from the return to the open air of a surface water course after being swallowed up by the cracks and fissures of a karstic network.

Rhizosphere: volume of soil occupied by the roots of plants or influenced by these roots. This influence tends to loosen the soil, acidify it, and exhaust it of nutrients and water or, alternatively, enrich it with various organic substances. These often emerge as excretions, or exudates, which are sometimes beneficial and sometimes not to other plants, including the microflora – bacteria and fungi – which is especially dense in the rhizosphere.

Staminate flower: male flower made up of stamens formed from the filament and the anther, which contains the pollen. The pollen is deposited on the stigma of the female flower, then germinates to reach the ovules situated in the ovary.

Thermophilic: having a strong affinity for warm habitats.

Undermining: degradation of a river bank through underlying erosion by currents.

Vegetative reproduction: natural or artificial production of new individuals without fertilisation occurring.

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Station Biologique de la Tour du Valat

Founded in 1954 by Luc Hoffmann, the Tour du Valat biological station is a private organization, managed by the Sansouire Foundation, whose work is recognized to be in the public interest. A team of approximately 80 people devotes itself to scientific activities, the management of the domain, and conservation actions.

An effective nature conservation policy must be based on scientific knowledge obtained from rigorous research. With this necessity in mind, the Tour du Valat has set up a research program on the functioning of wetlands, and more particularly that of reedbeds, temporary marshes, and rice paddies. It is also involved in long-term studies of colonial waterbirds in the Camargue and Mediterranean region. The conservation department makes great efforts to promote the transfer of knowledge obtained by researchers and managers by developing management plans for the Mediterranean wetlands, setting up training sessions, informing and supporting policies promoting the rational management of these resources, and publishing works of popularization.

Within this context, the Tour du Valat has given itself the mission ***"of putting an end to the loss and degradation of Mediterranean wetlands and restoring them"***.

Conseil Général de Vaucluse

The catastrophe at Vaison-la-Romaine, as well as subsequent catastrophes, forced attention onto rivers and their management. The Conseil Général de Vaucluse and its institutional partners have since put in place an active policy to help prevent the recurrence of such terrible events. Numerous studies carried out over the last decade have highlighted the necessity of restoring watercourses to their natural functioning.

Riparian woodland is an essential component of a watercourse's eco-system. Riparian woodland has been shown to significantly curb the damage of violent flooding. It is also a very dynamic natural habitat, and essential for a balanced Mediterranean landscape. To help conserve or restore these invaluable riverside woodlands, which are rich examples of "ordinary nature", the Conseil Général de Vaucluse has joined forces with the Conservatoire Botanique National Méditerranéen de Porquerolles for a series of experiments.

The main project undertaken is the Arboretum at Beauregard, on the banks of the Ouvèze, the river which flows through Vaison-la-Romaine. This Arboretum acts as a showcase for those who work in riparian management and will soon be open to the public. The European Union, as part of a "Life Environment" project, is the Arboretum project's principal partner.

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