THE IMPORTANCE OF FLOODING REGIMES IN THE CONSERVATION OF FLOODPLAIN FORESTS

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Introduction

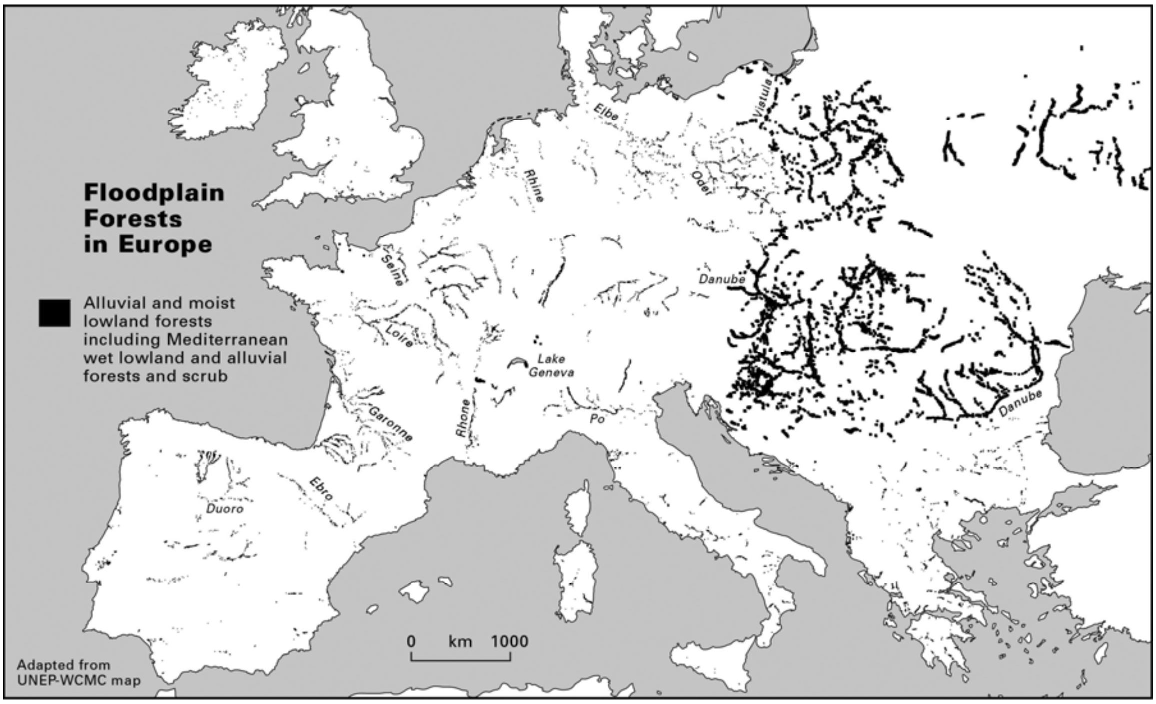
The riparian and floodplain zones of rivers are physically dynamic places, subject to the delivery and removal of water and sediments during flood events. Floodplain or alluvial forests are highly dynamic ecosystems that grow on these river floodplains. They depend on particular flood regimes for their continued existence as many of their tree species require flood disturbance and newly deposited sediments in order to regenerate. These forest ecosystems host a very high diversity of plant species, including trees and shrubs and provide habitats for a wide range of fauna. In addition they play other important roles, providing forested corridors through the landscape, sites for water storage and groundwater recharge during floods, opportunities for timber extraction and diffuse pollution control by recycling nutrients in farmland runoff. There is now considerable interest in the restoration of these forests in recognition of the numerous ecosystem services that they can perform. A key starting point for restoration of floodplain forests is a good understanding of the complex linkages between the physical and biological components of the forests. In order to achieve this, baseline scientific research has to be carried out so that accurate information can be provided for the design stages of the river restoration options. This paper will primarily discuss the relationships between the physical and biological components of floodplain forests and also some of the options for the conservation and restoration of these ecosystems.

The status of European floodplains

European floodplains have, with few exceptions, been occupied and used by humans for several thousand years. Most floodplains could be characterised as natural mosaics of forests, grassy clearings and small wetland areas prior to the Iron Age. Despite widespread use of floodplains for agriculture from the Iron Age onwards and consequent decrease in floodplain forest area, tracts of floodplain forest remained until the eighteenth century in many parts of Europe and particularly in the large river systems of Eastern Europe (Petts, 1989).

During the eighteenth and nineteenth centuries progress in civil engineering expertise resulted in widespread channelisation in order to improve navigation, to reclaim floodplain land for agriculture, to reduce flooding in urban areas, and in some northern regions to alter channel form for timber floating. Later, construction of dams and inter-basin water transfer schemes caused significant changes to the water delivery patterns in rivers downstream of these structures. As a result of all these engineering works, floodplains became physically isolated from their adjacent rivers with the result that channel movement and the formation of suitable regeneration sites for floodplain tree species became severely restricted and the previously typical vegetation mosaics became very restricted in extent. Pioneer tree species such as the Black poplar (*Populus nigra*) and many species of willow (*Salix* sp.) have been particularly badly affected by these trends. Thus, the loss of floodplain forests in the upper Rhône River in France are described by Roux *et al*. (1989) and by Hager and Schume (2001) along the Austrian stretches of the River Danube. In some countries like Belgium and The Netherlands, floodplain forests are close to extinction, and in England there are now no known sites where *Populus nigra* can regenerate sexually.

Today, very few floodplain forests remain in Europe; 90% of their original area has disappeared and remaining fragments are often in critical condition. They are considered to be one of Europe's most threatened natural ecosystems and are listed in Annexe I of the European Habitats Directive(92/43/EEC;1992) as a priority habitat type and are included in the Natura 2000 network of nature reserves. In western Europe they are more reduced in extent than in eastern and central Europe where some impressive patches remain (Figure 1).



(Figure 1; from FLOBAR2 document 'The Flooded Forest', 2003)

As well as reduced forest extent, the ecological quality of remaining forests is in question. Measures to 'restore' floodplain forests have been implemented in widely different ways. In many locations, natural self-regenerating forests have been considered unproductive and replaced with productive forestry plantations (often using hybrid poplars) within the floodplain forest zone. In many European countries state-owned riparian forests have been managed by forestry departments and some have been leased to private foresters and farmers who have removed floodplain forest to plant quick-growing exotic trees or crops (Girel *et al*, 2003). Recognition of this problem in some places has led to changed forestry practices to include native species such as locally-sourced *Populus nigra*. For example, this positive change has taken place in the Gemenc alluvial forests within the Duna-Dráva National Park on the Danube River in Hungary.

In addition to loss of habitat areas for this species, the extensive presence and proximity of hybrid poplar plantations has implications, which are not fully understood, for its genetic status. For example, in Spain, P. x *euramericana* and P.*nigra* var 'Italica' are common plantation species along rivers like the Duero although results from the EU-funded EUROPOP project showed little evidence of introgression at that time (Alba et al, 2002). These threats to Black poplar led to the establishment of a European network for the conservation of its genetic resource through the European Forest Genetic Resources Programme (EUFORGEN; www.euforgen.org). Under the auspices of this programme, the '*Populus nigra* network' was initiated to develop *'in situ'* conservation measures and to create *'ex situ'* collections of cuttings in several European countries (Rotach, 2001).

The regeneration of native floodplain forest species is also affected by the invasion of riparian corridors by exotic or non-native species. For example exotic woody species such as box elder (*Acer negundo*) and black locust (*Robinia pseudacacia*) often replace local species. These exotic species are most successful where channel dynamism is greatly reduced (Planty-Tabacchi *et al*., 1996) although riparian corridors are vulnerable to invasion by exotic species because they naturally experience frequent disturbance (Naiman *et al*., 2005).

European floodplain forest types

In the EU Interpretation Manual of European Habitats (1999) there are 5 categories of forest to be found along European rivers (Table 1).

Table 1. European riparian habitats based on Girel *et al*., 2003 and Richards& Hughes (in press)

EU Habitats (1999)	Description
91E0 Residual alluvial forests (**Boreal, Alpine & temperate Europe)**	Alluvial forests (*Alnus glutinosa, Alnus incana, Prunus padus, Fraxinus excelsior, Ulmus glabra*) of temperate and Boreal Europe (lowland, piedmont, montane and sub-montane rivers of the Alps, Pyrenees, Carpathians, Balkans and North Apennine); arborescent galleries of tall willows (*Salix alba, S. fragilis, Alnus, Fraxinus, Populus nigra, Populus alba*) on heavy soils periodically inundated, well-drained and aerated during low-flows.
91F0 Mixed hardwood riparian forests (**temperate Europe)**	Diverse riparian forests of the middle and lower courses of large rivers (eg, Rhone, Loire, Rhine, Danube, Elbe, Weser, Oder, Vistula), inundated by large floods; mature forests of hardwood trees (*Quercus robur, Fraxinus excelsior, F. angustifolia, Ulmus laevis, U. glabra, U. minor, Prunus avium, P. padus...*) growing on recent alluvial deposits; soils well drained or remaining wet between high-flow periods; the level of the water table determines the dominant species (from shallow to deep water tables: *Fraxinus, Ulmus* or *Quercus*).
92A0 White willow & white poplar galleries (**Mediterranean Europe)**	Riparian forests of the Mediterranean zone dominated by tall willows (*Salix alba, S. fragilis*) and poplars (*Populus alba, P. caspica, P. euphratica*) (Distribution: France, Greece, Italy, Portugal, Spain)
92B0 Riparian communities on intermittent rivers **(Mediterranean.Europe)**	Relict alder galleries (thermo- and meso-Mediterranean zones) with *Alnus glutinosa, A. cordate, Betula sp., Fraxinus angustifolia, Osmunda regalis* (Distribution: France, Italy, Spain, Portugal).
92C0 Plane & sweet-gum woods (**Mediterranean Europe)**	Riparian forests and woods dominated by *Platanus orientalis* and *Liquidambar orientalis*; presence of *Salix alba, Alnus glutinosa, Celtis australis, Populus alba, Fraxinus ornus, Cercis siliquastrum*. (Distribution: Greece, Sicily)

Healthy stands of these different forest types incorporate a mixture of forested and non-forested areas, the mosaic maintained by dynamic river processes.
Conservation and restoration of these floodplain ecosystems should concentrate on restoration of this habitat mosaic, preferably re-instating channel dynamism as part of the restoration process. Although conservation and restoration of remaining forested floodplains has been embraced as a priority in the EU Habitats Directive, many restoration projects that involve re-establishing some form of natural vegetation on a floodplain rarely include forested habitats within their objectives (Moss *et al.*, 2003). This can perhaps be explained by the fact that floodplain forests are often viewed as threats to both flood defence measures and engineering structures but it can also be seen as a cultural response to the fact that in many countries forests on floodplains disappeared from the landscape too many years ago for people to consider them as a natural component of the floodplain vegetation mosaic.

The functioning of floodplain forests

Floodplain forests are flood-dependent ecosystems. This has been established through a large number of studies involving both field observation and experimental work on the flow needs for the *regeneration* of riparian trees. These studies investigated the relationships between flood events, shape of the hydrograph and regeneration patterns through time, and showed that flood events are an important driving force in the development and progression of floodplain forest ecosystems. There are a number of reviews of this literature including Brinson (1990), Malanson (1993), Gurnell (1995), Naiman & Décamps (1997) and Hughes (1997). Many floodplain forest tree species require quite particular hydrological and sedimentological conditions for germination of their seeds and the eventual establishment of their seedlings. Nevertheless, general trends can be seen and these are summarised in Table 2 below.

Table 2. The four essential requirements for a self-regenerating floodplain forest (from Hughes and Muller, 2003; Hughes *et al.*, in press)

Flows needed by floodplain forests	• Regular flows which replenish and maintain floodplain water tables. These flows allow established trees to grow. • Periodic high flows which cause channel movement and sediment deposition. These provide potential regeneration sites and should be variable between years • Well-timed flows through the first growing season which allow delivery of seeds to the floodplain and establishment of seedlings. Unseasonal high flows can cause high mortality to seedlings in their first growing season.
Regeneration sites needed by floodplain forests	• Open sites as many pioneer tree species typical of floodplain forests cannot tolerate competition. • Sites that are moist through the first growing season to facilitate regeneration. • Sites near the water's edge because these tend to be moister and catch organic debris. However, sites right on the water's edge tend to suffer from flow disturbance and waterlogging. • A variety of sediment types to provide regeneration niches for a variety of species.
Water table conditions needed by floodplain forests	• Water tables accessible to the roots of seedlings through their first growing season. • Gradual recession of water tables following a flood. • Limited waterlogging.

Propagation materials needed by floodplain forests	• Seeds which are carried by the river and deposited during floods. The phenology of seed release and the timing of flood peaks are critical in any year for successful establishment of seedlings. • Vegetative material which arrives by flood or is deposited locally. • Seeds which are carried in the wind. Whereas seeds carried in the river always move from upstream areas to downstream areas, seeds carried in the wind tend to move in the direction of prevailing winds.

The precise requirements clearly vary between species and between biogeographical location but well-timed periodic floods most often lead to provision of these requirements. These overbank flood events can be described as '*regeneration flows'* (Hughes and Rood, 2003). Once floodplain forest trees are established, in order to grow they also require adequate river stage levels or '*maintenance flows*' throughout the year (eg. Andersen, 2005). *Regeneration flows* are often synonymous with flood flows and only occur periodically. In the natural situation regeneration flows may occur every few years or as infrequently as every 20 years. *Maintenance flows* are often closer to established minimum flows and much easier to provide within the operational practices of many European river management agencies. Temporal variability is a key characteristic of both types of flow and attempts should be made to reproduce these for effective flow management.

The pattern and spatial scale of regeneration across a floodplain and the volume of flows which promote regeneration also varies with channel pattern. In meandering rivers, parallel scroll bars commonly support lines of even-aged trees with the youngest trees nearest to the river. In braided and anastomosed river reaches, spatial patterns of tree ages are more random as islands are eroded and deposited across the floodplain.

In Europe, many studies have been carried out on the declining European Black Poplar (*Populus nigra*). This, like other members of the Salicaceae family, is a dioecious species and therefore individual trees are either male or female and it is thought that the different sexes might prefer different microhabitats and therefore hydrological conditions. Experiments to study the requirements of dioecious species demonstrate the complexities involved in understanding the links between the biotic and abiotic factors in floodplain forests (eg. Hughes *et al*., 2000).

Conservation and Restoration of floodplain forests

In order to conserve or restore riparian forests it is essential to link the natural science knowledge about the requirements of these forests to the range of possibilities in terms of whole-catchment river management, given that there are competing needs for resources within a catchment (Richards and Hughes, in press). At both catchment scale and local scale there is a considerable challenge for scientists to define ecosystem needs in a way that can guide policy formulation and management action (Poff et al, 2003). Most importantly, the water needs of humans and those of ecosystems must not be seen in competition (Richter et al, 2003) but as functionally linked and should include ecosystems as legitimate users of water (King and Louw, 1998; Naiman et al, 2002). (The following descriptions of restoration options are based on the FLOBAR2 (2003) document '*The Flooded Forest*'; Hughes et al, in press; and Richards and Hughes, in press)

Catchment-Scale management for floodplain forests

At the scale of the catchment, restoration initiatives are likely to involve management of physical processes in one or more places in the catchment upstream of the floodplain so that they eventually have an effect on the hydrological and sedimentological inputs to the floodplain zone. This type of disturbance management is 'indirect' but it is also most likely to be successful and sustainable in the long-term. It allows the river to flood, and the channel to move and create its own sites for the regeneration of trees. It is, however, difficult to achieve because it is not fully predictable and therefore not popular with river managers. It also requires consensus among a large number of stakeholders. There are several approaches in use:

1. *Managed releases downstream from impoundments*. This methodology involves planning flow releases from structures such as dams so that they provide maximum benefit to downstream aquatic and riparian ecosystems as well as to other users. The approach has achieved good results for floodplain forests eg. In the St Mary River in Alberta, Canada (Rood and Mahoney, 2000), in the Truckee River of Nevada, USA (Rood et al, 2003) and on the River Rhône where the site called Ile de la Platière has benefited from changed release patterns downstream of a barrage (Michelot, 1995). Detailed knowledge of the requirements of the germination and seedling establishment phases of the life-cycles of target tree species have to be known and ecologically relevant flows have to be characterised. It is easier to prescribe flows for a single ecosystem, like a floodplain forest, than satisfying multiple ecosystem needs. Planned floods can also re-naturalise the sediment dynamics of a river as shown in the River Spöl in Switzerland (Mürle *et al*., 2003). In practice the engineering design of the dam structure will influence the type of releases that can be contemplated and currently there is considerable effort by the Nature Conservancy in the United States to document the strategies and results of hundreds of such projects (see Richter & Thomas, 2007 and http://www.nature.org/initiatives/freshwater).

2. *Flow allocation methodologies*. River flows are altered as soon as water is used for human purposes. There is necessarily a limit to how much water can be taken out of a river and at what times of the year if an ecosystem like a floodplain forest is to remain self-sustainable. The question of how to allocate water to achieve sustainable water use for a range of ecosystems and human purposes is addressed by a series of holistic flow allocation methodologies, many of which have been developed in semi-arid areas in Australia, South Africa and North America (eg. King and Brown, 2007; Arthington and Pusey, 2003). They include the needs of floodplain ecosystems as well as in-channel ecosystems. They are reviewed in Postel & Richter (2003). The general approach of these methodologies is to determine the 'environmental flows' necessary to sustain aquatic and riparian ecosystems and then to integrate the identified flow needs with other flow requirements within the river basin. The applicability of these methodologies to the restoration of floodplain forests in Europe is discussed by Hughes and Rood (2003). Despite the EU Water Framework Directive and its River Basin Management Plans, management of total water volume and its seasonal distribution currently carried out by most national river management agencies in Europe tends to be limited to the management of water quantities in rivers to satisfy requirements for pollution dilution and the maintenance of specified minimum flows. In addition, within water management agencies institutional management of low flows is often separated from management of floods thus reducing the possibilities of holistic approaches and solutions.

3. *Sediment management.* In Europe, sediment loads of rivers have changed in quantity and type over the last 200 years in response to changes in mass movements in upper catchments, to sand and gravel extraction in floodplain zones, to the installation of upstream impoundments and to the armouring of river banks with artificial dykes. In the Drôme River in France measures are proposed to restore sediment loads to the river to improve the delivery of sediment to the Ramières du Val de Drôme Nature Reserve which is designated for its high quality floodplain forest in two active, braided river reaches.

Reach-Scale management for floodplain forests

At the scale of the reach, there are two main approaches to carrying out floodplain restoration. The first involves managing physical processes locally in the floodplain zone, for example by opening side channels in order to allow floods into selected parts of a floodplain. The second involves managing the landforms in the floodplain so that the physical disturbances act differently on each part of the floodplain. It is the most feasible form of river restoration in most parts of Europe and numerous river restoration projects use it though very few with restoration of floodplain forest as a specified aim. Restoration at this scale is easier to achieve than catchment-scale management because it is more predictable, it can be fitted in between heavily used river reaches and requires the consensus of few stakeholders.

Types of restoration at this scale can be categorized into a series of activities relevant for floodplain forests: (Hughes and Muller, 2003):

1. *Re-connection of side arms in rivers*. Most projects in this category aim to remove one or more sections of artificial embankments in order to allow flows to penetrate floodplain zones that have been cut-off. There are a number of examples of this approach that are well documented in the literature such as the Regelsbrunner Au project on the River Danube in Austria (Scheimer et al 1999) or the Bregnier-Cordon site on the River Rhône in France (Downs et al, 2002). Both these projects had as a major objective, the restoration of both the quality of floodplain forests and improved opportunites for forest regeneration by increasing lateral connectivities between the channel and the floodplain.

2. *Setting back or lowering flood defences or lowering the floodplain*. Good examples exist at the Millingerwaard Nature Reserve in The Netherlands where flood defences have been lowered and regeneration of *Populus nigra* is now occurring in response to a more active physical substrate. Creative configuration of the floodplain surface can mimic natural floodplain habitat heterogeneity to give conservation gains as well as flood storage gains.

3. *Management of river sediment loads.* Sedimentation is an essential process along the margins of river channels as newly created alluvial bars are prime regeneration sites for many species of floodplain vegetation. Groynes can be used to create artificial 'beaches' although their primary purpose is usually to maintain a channel for navigation. Re-activation of erosion in sites where embankments have been removed will alter the sediment loads downstream.

4. *Direct management of riparian vegetation.* Planting floodplain forests or waiting for natural regeneration to take place are both possibilities. In either case, management

of the vegetation that grows may be considered necessary though this is not in the spirit of self-sustainability. In many river basins, grazing by domestic animals in riparian zones prevents natural regeneration and fencing off the riparian zone becomes an important form of management. Management of the vegetation also has implications for the volume of woody debris that arrives in a river.

Conclusion

There is now considerable knowledge about the relationships between the biotic and abiotic factors in European floodplain forests though many complex problems remain to be explored. There are also many attempts at carrying out different types of river restoration though few have floodplain forests as a priority habitat. Recent studies of river restoration projects in the United States have clearly shown that for the effective use of scientific knowledge in river restoration practice there has to be a strong collaboration between scientists, managers and practitioners (Bernhardt et al., 2007) and a commitment to long term monitoring and evaluation of projects based on ecological performance measures (Rumps et al., 2007).

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The FLOBAR2 project published a well-illustrated document called '*The Flooded Forest*'. It can be downloaded free of charge from the following website: http://www.geog.cam.ac.uk/research/projects/flobar2/reports/final/flobar2.pdf

References listed in the text

Alba, N., Maestro, C., Agundez, D. and Notivol, E. (2002) Advances in the preservation of genetic resources in Populus nigra L. in Spain. In, Barbara van Dam and Sandor Bordacs (eds) *Genetic diversity in river populations of European Black Poplar*. Proceedings of an international symposium held in Szekszard, Hungary 16-20 May, 2001, pp125-136.

Andersen, D.C. (2005) Characterizing flow regimes for floodplain forest conservation: an assessment of factors affecting sapling growth and survivorship on three cold desert rivers *Can. J. For.Res*. 35:2886-2899

Arthington, A.H., and B.J. Pusey. (2003) Flow restoration and protection in Australian rivers. *River Research and Applications* 19:377-395.

Bernhardt, E. and 11 authors (2007) Restoring rivers one reach ata time: results from a survey of U.S. river restoration practitioners. *Restoration Ecology* 15(3):482-493.

Brinson, M.M. (1990) Riverine forests. Pages 87-141 *in* A. Lugo, M.M. Brinson and S. Brown (eds.), Forested wetlands, New York, Elsevier.

Downs, P. W., Skinner, K. S. and Kondolf, G. M. (2002) Rivers and Streams. In M. R. Perrow and A. J. Davy. *Handbook of Ecological Restoration, Volume 2 Restoration in Practice*. Cambridge University Press, Cambridge, UK, 267-296

The European Commission DG Environment (1999) Interpretation Manual of European Union Habitats EUR 15/2. Brussels.

Girel, J., Hughes, F.M.R., Moss, T., Muller, E., Nilsson, C. and Richards, K.S. (2003) A case for floodplain forests? In Hughes, F.M.R. (ed.) *The flooded forest: guidance for policy makers and river managers in*

Europe on the restoration of floodplain forests. FLOBAR2, Department of Geography, University of Cambridge, Cambridge, UK, p. 6-23.

Gurnell, A.M. (1995) Vegetation along river corridors: Hydrogeomorphological interactions, Pages 237-260 *in* A.M. Gurnell.and G.E. Petts (eds.), Changing River channels, Wiley, Chichester, 237-260.

Hager H. and Schume, H. (2001) The floodplain forests along the Austrian Danube. In E. Klimo and H. Hager (eds.), *The Floodplain Forests in Europe: current situation and perspectives.* Koninklijke Brill NV, Leiden and European Forest Institute Research Report No. 10, 83-100

Hughes, F.M.R. (1997) Floodplain Biogeomorphology. *Progress in Physical Geography* 21:501-529.

Hughes, F.M.R. and Muller, E. (2003) How can floodplain forests be restored? In Hughes, F.M.R. (ed) 2003. *The flooded forest: guidance for policy makers and river managers in Europe on the restoration of floodplain forests.* European Union-FLOBAR2, Department of Geography, University of Cambridge, Cambridge, UK p.49-70.

Hughes, F. M. R., and Rood, S. B. (2003) The allocation of river flows for the restoration of woody riparian and floodplain forest ecosystems: a review of approaches and their application in Europe. *Environmental Management* **32**:12-33.

Hughes, F.M.R., Moss, T. and Richards, K.S. (in press) Uncertainty in riparian and floodplain restoration. In Darby, S. and Sears, D. (Eds.) River Restoration:Managing the uncertainty in restoring physical habitat. Wiley, Chichester.

Hughes, F.M.R., Barsoum, N, Richards, K.S., Winfield, M. and Hayes, A. (2000) The response of male and female black poplar (*Populus nigra* L. subspecies *betulifolia* (Pursh) W. Wettst.) cuttings to different water table depths and sediment types:implications for flow management and river corridor biodiversity. *Hydrological Processes14:3075-3098*

King, J. and C. Brown. (2006) Environmental Flows:Striking the Balance between development and resource protection Ecology and Society 11(2):26 [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art26/

King, J. & Louwe, D. (1998) Instream flow requirements for regulated rivers in South Africa using the building block methodology. *Aquatic Ecosystem Health and Management,* **1**, 109-124

Malanson, G.P. 1993. *Riparian landscapes*. Cambridge University Press, Cambridge, 296pp.

Michelot, J.-L. (1995) *Gestion Patrimoniale des milieux naturels fluviaux: guide technique*. Reserves Naturelles de France, 67pp.

Moss. T., A. Klaphake, J. Monstadt, and Siener, M. (2003) What prospects for restoration? Pages 71-84 *in* F. M. R. Hughes, editor. 2003. *The flooded forest: guidance for policy makers and river managers in Europe on the restoration of floodplain forests.* FLOBAR2, Department of Geography, University of Cambridge, Cambridge, UK.

Mürle, U., Ortlepp, J. and Zahner, M. (2003) Effects of experimental flooding on riverine morphology, structure and riparian vegetation: The River Spöl, Swiss National Park. *Aquatic Science* 65:191-198

Naiman et al (2005) Origins, patterns and importance of heterogeneity in riparian systems. In Lovell, G., Jones, C.G., Turner, M.G. and Weathers, K. C. (Eds.) *Ecosystem function in heterogeneous landscapes*. Springer-Verlag, New York

Naiman, R. J., and H. Decamps, H. (1997) The ecology of interfaces:riparian zones. *Annual Review of Ecological Systematics* 28: 621-658.

Naiman, R.J., S.E.Bunn, C.Nilsson, G.E.Petts, G.Pinay, and Thompson, L.C. (2002) Legitimizing fluvial ecosystems as users of water: An overview. *Environmental Management* 30:455-467.

Peterken, G.F. and Hughes, F.M.R. (1995) Restoration of floodplain forests in Britain. Forestry 68(3):187-202.

Petts, G. E. (1989) Historical analysis of fluvial hydrosystems. In Petts, G.E. (ed.) Historical change of large alluvial rivers: Western Europe. Wiley and Sons, Chichester, p1-18.

Poff, N.L., Allan, J.D., Palmer, M.A., Hart, D.D., Richter, B.D., Arthington, A.H., Rogers, K.H., Meyer, J.L. and J.A. Stanford (2003) River flows and water wars: emerging science for environmental decision making. *Frontiers in Ecology and Environment* 1(6): 298-306.

Postel, S. and B. Richter. 2003. *Rivers for life: managing water for people and nature.* Island Press, Washington, D. C., USA.

Richter, B. and Thomas, G.A. (2007) Restoring environmental flows by modifying dam options . Ecology and Society 12(1):12 [online]: http://www.ecologyandsociety.org/vol12/iss1/art12/

Richter, B.D., Mathews, R., Harrison, D.L. and Wigington, R. (2003) Ecologically sustainable water management: managing river flows for ecological integrity. Ecological Applications 13(1): 206-224.

Richards, K.S. and Hughes, F.M.R. (in press) Floodplains in Europe: The case for restoration. In Moss, T. (ed.) *Restoring Floodplains in Europe:Policy contexts and Project Experiences*. International Water Association, London.

Rood, S.B., and Mahoney, J.M. (2000) Revised Instream flow regulation enables cottonwood recruitment along the St. Mary River, Alberta, Canada. *Rivers* 7:109-125.

Rood, S.B., C. Gourley, E.M. Ammon, L. G. Heki, J. R. Klotz, M. L. Morrison, D. Mosley, G. G. Scoppettone, S. Swanson, and P. L. Wagner (2003) Flows for floodplain forests: successful riparian restoration along the lower Truckee River, Nevada, U.S.A. *BioScience* (in press).

Roux, A.L., J.-P. Bravard, Amoros, C. and Pautou, G. (1989) Ecological Changes of the french Upper Rhone River since 1750. In Petts, G.E., Moller, H. and Roux, A.L. (eds.) *Historical Change of large alluvial rivers: Western Europe*. Wiley, Chichester, 323-352

Planty-Tabacchi, A-M., Tabacchi, E. Naiman, R.J., Deferrari, C. and Decamps, H. (1996) Invasibility of species-rich communities in riparian zones. Conservation Biology 10:598-607.

Rotach, P. (2001) General considerations and basic strategies. Pages 8-15 *in* F. Lefèvre, N. Barsoum, B. Heinze, D. Kajba, P. Rotach, S. M. G. de Vries, and J. Turok, editors. *In situ conservation of Populus nigra*. EUFORGEN Technical Bulletin, International Plant Genetic Resources Institute, Rome, Italy.

Roux, A.L., J.-P. Bravard, Amoros, C. and Pautou, G. (1989) Ecological Changes of the french Upper Rhone River since 1750. In Petts, G.E., Moller, H. and Roux, A.L. (Eds.) Historical Change of large alluvial rivers: Western Europe. Wiley, Chichester, p.323-352.

Rumps, J and 6 authors (2007) Stream restoration in the Pacific northwest: analysis of interviews with project managers. *Restoration Ecology* 15(3):506-515.

Scheimer, F., Baumgartner, C. and Tockner, K. (1999) Restoration of floodplain rivers: the Danube restoration project. Regulated Rivers, Research and Management 15: 231-244.

UNEP-WCMC (World Conservation Monitoring Centre) (2000) *European forests and protected areas: gap analysis.* Technical Report, UNEP-WCMC, Cambridge, UK. 27p.

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