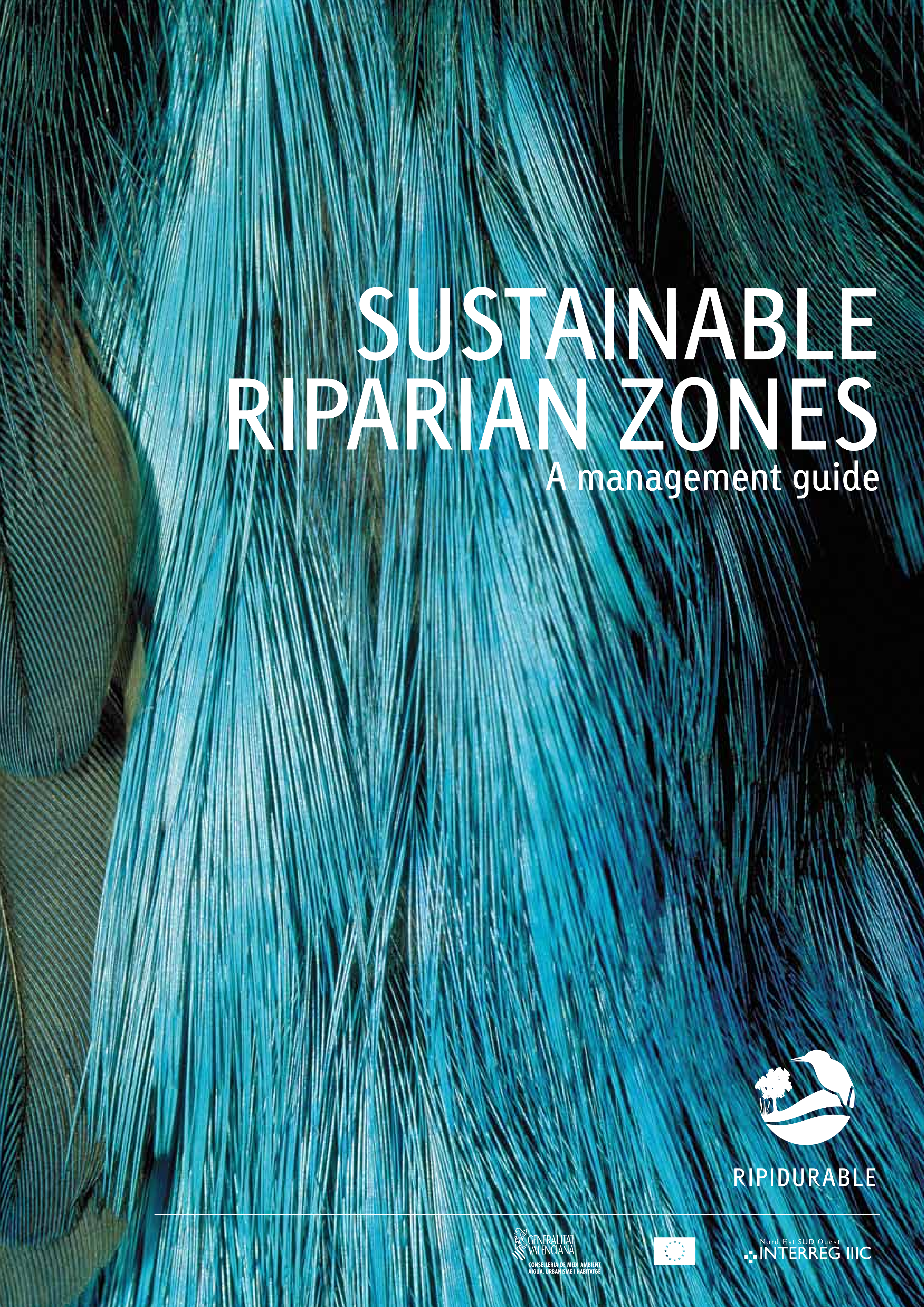

SUSTAINABLE RIPARIAN ZONES

A management guide

RIPIDURABLE

GENERALITAT VALENCIANA
CONSELLERIA DE MEDI AMBIENT
AIGUA, URBANISME I HABITATGE

Nord Est SUD Ouest
INTERREG IIIC

SUSTAINABLE RIPARIAN ZONES

A Management Guide

Edited By

Daniel Arizpe
Centre per a la Investigació i l'Experimentació Forestal (CIEF)
Conselleria de Medi Ambient, Aigua, Urbanisme i Habitatge, Generalitat Valenciana
Comarques del Pais Valencià 114-6, 46930 Quart de Poblet, Spain

Ana Mendes
Instituto Superior de Agronomia - Universidade Técnica de Lisboa,
Departamento de Engenharia Florestal
Tapada da Ajuda 1349-017 Lisboa, Portugal

João. E. Rabaça
LabOr - Laboratório de Ornitologia, Departamento de Biologia,
Instituto de Ciências Agrárias e Ambientais Mediterrânicas ICAM, Universidade de Évora,
7002-554 Évora, Portugal

ISBN: 978-84-482-4967-0
Legal Deposit no.: V-3315-2009

Design and Layout Development: Essência - ROFFdesign (http://essencia.roff.pt)
Printing: Gràfiques Vimar (http://www.vimar.es)
English edition: copy editing by Mary Georgina Hardinge with additional collaboration of Carlos Tortosa and Dylan Cox.

Front cover and separator page photographs:
António Luis de Campos: Front cover, introduction, part 2, part 3 and part 5;
Jean Roché: Part 1; **Daniel Arizpe**: Part 4; **Ana Mendes**: Appendices.

Foreword

It is a great satisfaction to see the publication of the Manual "SUSTAINABLE RIPARIAN ZONES – A MANAGEMENT GUIDE", a book that assembles an important set of technical and scientific contributions to the sustainable management of riparian zones.

This is certainly an issue of great opportunity and timeliness. Its importance results from the fact that riparian zones are of great value for the conservation of nature and biodiversity and also play a critical role in the modern management of water resources, which aims to protect these and their associated ecosystems. Both aspects represent priorities of major relevance in the scope of environmental policy.

The diversity of subjects found in the book and the in-depth treatment they are given, certify to the high scientific skill of the authors and contribute to the great quality and usefulness of this Manual. Currently, the rehabilitation of riparian systems constitutes an important step towards reaching ecological quality in water bodies, a challenge that we have to face, in the European context, owing to the application of the Water Framework Directive (WFD, Directive 2000/60/EC), transposed to the Portuguese legislation by the Water Law (Law no. 58/2005, 29 December 2005).

Analyzing the WFD and the Water Law demonstrates the great importance laid on the subject of the ecological quality of the water and aquatic and riparian ecosystems. One clear goal is "... to improve the protection of aquatic ecosystems, and terrestrial ecosystems and wetlands directly depending on them, in what its water needs are concerned".

Among the principles considered in the Water Law, we emphasize, among others, the principle of the environmental dimension of water, of the integrated management of water and related terrestrial ecosystems, the precautionary principle and the source prevention and correction principle.

Among the considered instruments, water resource protection and improvement measures integrated into management plans or adapted to specific purposes, call for actions such as the conservation and rehabilitation of river systems and riparian zones, the restoration and landscape enhancement of watercourses and adjacent zones, the conservation and rehabilitation measures of wetlands and any other actions that aim at fulfilling the environmental goals associated with the good condition and good potential of water bodies.

For all those purposes, plus the great underlying goal of achieving good ecological quality, the contents of this Manual are extremely relevant. It will certainly be useful in supporting innovative, demanding and sustainable management practices. It will constitute an important working tool for institutions operating at local and regional levels that are engaged in actions and tasks aiming to give tangible expression to the guidelines contained in the existing legal framework.

I would like to express my appreciation to the authors and editors of this book which is, undoubtedly, an important step towards a global, integrated environmental management of river systems, innovative and proposes to allow us to find the right answers to the important challenges that we face now and in the near future.

Prof. Dr. Francisco Nunes Correia

Minister for Environment, Spatial Planning and Regional Development of Portugal

Preface

The past hundred years have seen unprecedented population growth and the intensification and increasing efficiency of the technology that humans use in the course of their activities, in industry, commerce, building, and exploring for and extracting raw materials and biological resources. This growth has increased exponentially in the last thirty years, to the point where the web of human interactions and of intervention in ecosystems is now on a global scale. It is estimated that in the next 25 years the water requirements for the growing population will exceed the availability of this natural resource. In regions such as the Mediterranean, where access to water is uneven in space and time, the need to establish a pattern of human growth that is sustainable and conserves this resource and the aquatic ecosystems associated with it is evident.

The increasing use of water and land are having steadily more obvious effects on river ecosystems, including modification of the river's original longitudinal and transverse profiles, profound distortion of the natural runoff system, alterations in water quality, alterations in the type and quantity of the energy and food sources (organic matter and nutrients) that reach the ecosystem and alterations due to biological interactions with exotic species. The environmental aspect of river management, which initially centred on water quality and species protection, has now been succeeded by a holistic view of conservation based on maintaining fluvial processes and functions and on the integrity or 'health' of the river ecosystem. The operational objective is to return disturbed ecosystems to an ecological status approaching that which existed before the human disturbances took place. The Water Framework Directive enshrined this new view of water ecosystem quality in law and set dates for achieving good ecological status. Integrated management and restoration of aquatic ecosystems will be one of the major action areas in the future management of water resources.

The EU InterregIIIC-South project "RIPIDURABLE, Sustainable Management of Riparian Woods" ran from 2005 to 2008. It studied the ecology and dynamics of river corridors, including their hydrophysical and biological components, and how this knowledge can be harnessed to manage these ecosystems appropriately, particularly in specific function-restoration actions. Three important aspects marked the project:

a) a cross-disciplinary team that brought together skills and sensitivities from different scientific fields, including geography, ornithology, botany, ecology, forestry engineering and genetics, among others,

b) the highly topical and urgent nature of the subject matter, in view of the management and restoration requirements of the Water Framework Directive's environmental objectives, and

c) development and application of the knowledge acquired from the river corridors of various Mediterranean countries (Portugal, France, Spain and Greece) which have been intervening in and altering riparian gallery forests for millennia despite these being unique ecosystems in the landscape of many valleys, particularly in summer.

The enormous effort made by all the partners in the project in unreservedly cooperating and making their information and contacts available has contributed significantly to the quality of this guide. The warmth, closeness and enthusiasm with which all the authors shared their knowledge are reflected in the contents of this guide. May I just say that it has been a pleasure to be part of this team.

The editorial leadership of this project has involved a tremendous effort on the part of CIEF, the Higher Institute of Agronomy and the University of Evora to combine the learning and experience of different universities, research centres, conservation and regional development authorities and agencies. Despite the exertion, we considered that this was the correct way to go about conserving and improving our ecosystems.

While by no means exhausting the need for more and better information on Mediterranean riparian galleries and management and recovery methods, the information collected during the RIPIDURABLE project, and other projects in similar subject areas, nonetheless constitutes a systematic, structured body of knowledge, providing the basis for this Management Guide. The RIPIDURABLE members have not been alone in this, as contributions have also been made by other researchers involved in river restoration and upgrading projects, bringing different perspectives on the ecosystem and its management.

The result is an educational framework which we trust will be useful to everyone who deals in any way with river ecosystem management.

Maria Teresa Ferreira

Professor, PhD, Habil. Higher Institute of Agronomy,
Technical University of Lisbon

Contributors

Maria Helena Almeida
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt

Daniel Arizpe Ochoa (editor)
Centre per a la Investigació i l'Experimentació Forestal (CIEF), Conselleria de Medi Ambient, Aigua, Urbanisme i Habitatge, Generalitat Valenciana
Comarques del Pais Valencià 114-6, 46930 Quart de Poblet, Spain
http://www.cth.gva.es
mfr.banc@gva.es

Domingo Baeza Sanz
Grupo de Investigación en Hidrobiología / ECOHIDRAULICA S.L.
Rodriguez San Pedro, 11bis Oficina 407
28015 Madrid, Spain
http://www.ecohidraulica.com/equipotecnico.htm

Erwin Bergmeier
Abteilung Vegetationsanalyse und Phytodiversität, Albrecht-von-Haller-Institut für Pflanzenwissenschaften, Universität Göttingen
Untere Karspüle 2, 37073 Göttingen, Germany
http://www.geobotanik.org/bergmeier/index.html

Rhema H. Bjorkland
Duke University
135 Duke University Marine Lab Rd, Beaufort, North Carolina 28516, U.S.A.
http://www.duke.edu/

Ronald Bjorkland
Craven Community College
305 Cunningham Blvd., Havelock, North Carolina 28532, U.S.A.
http://www.cravencc.edu/

Pedro Brufao Curiel
Área jurídica de AEMS-Ríos con Vida / Facultad de Derecho, Universidad de Extremadura
Avda. de la Universidad, s/n, 10071 Cáceres, Spain
http://riosconvida.es

António Campeã da Mota
Direcção Geral de Agricultura e Desenvolvimento Rural
Av. Afonso Costa 3, 1949-002 Lisboa, Portugal

David Catita
Departamento de Ambiente e Ordenamento do Território / EDIA, Empresa de Desenvolvimento e Infraestruturas de Alqueva, S.A.
Rua Zeca Afonso, 2 - 7800 – 522 Beja, Portugal
http://www.edia.pt

Yorgos Chatzinikolaou
Hellenic Center for Marine Research / Institute of Inland Waters
46,7 km Atenas-Sounio, Mavro Lithari, Anavissos, Attiki, Greece
http://www.hcmr.gr

Rui Cortes
Departamento Florestal, Universidade de Trás-os-Montes e Alto Douro
UTAD, Apart. 10135001-801 Vila Real, Portugal
http://www.utad.pt

Henri Décamps
Centre National de la Recherche Scientifique and Université Paul Sabatier, EcoLab / Laboratoire d'écologie fonctionnelle
29 rue Jeanne Marvig, BP 24349, 31055 Toulouse cedex 4, France
http://www.ecolab.ups-tlse.fr

Panayotis Dimopoulus
Faculty of Environmental and Natural Resources Management, Lab. of Ecology and Biodiversity Conservation, University of Ioannina
Seferi 2, 30100 Agrinio, Greece
http://www.env.uoi.gr

Michael Döring
Wasserforschungs-Institut / Eidgenössische Technische Hochschule Zürich (EAWAG-ETH)
Eawag, Box 611, 8600 Duebendorf, Suiza
http://www.eawag.ch/index_EN

Maria Cristina Duarte
Jardim Botânico Tropical, Instituto de Investigação Científica Tropical, Lisboa, Portugal.
http://www2.iict.pt/jbt/

Alcibiades N. Economou
Hellenic Center for Marine Research / Institute of Inland Waters
46,7 km Atenas-Sounio, Mavro Lithari, Anavissos, Attiki, Greece
http://www.hcmr.gr

Dalila Espirito-Santo
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt

André Fabião
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt/def/

António Fabião
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt/def

Carla Faria
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt/def/

Rosário Fernandes
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt

José Anastasio Fernández Yuste
Unidad docente de Hidráulica e Hidrología de la Escuela Universitaria de Ingeniería Técnica Forestal, Universidad Politécnica de Madrid
Avda. de Ramiro de Maeztu s/n, 28040 Madrid, Spain
http://www.forestales.upm.es

Maria Teresa Ferreira
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt/def/

José Carlos Ferreirinha
Câmara Municipal de Alpiarça
R. José Relvas nº 374 - 2090 Alpiarça, Portugal
http://www.cm-alpiarca.airc.pt

Carlos Freitas
Direcção Geral de Agricultura e Desenvolvimento Rural
Av. Afonso Costa 3, 1949-002 Lisboa, Portugal

Bernard Frochot
Université de Bourgogne, Faculté des Sciences de la Vie et de l'Environnement, Laboratoire d'Écologie
B.P. 138, F-21004 Dijon, France
http://www.u-bourgogne.fr/

Diego García de Jalón-Lastra
Departamento de Ingeniería Forestal,
ETSI Montes Universidad Politécnica de Madrid
Ciudad Universitaria s/n, 28040 Madrid, Spain
http://www.montes.upm.es/

Sofia Giakoumi
Hellenic Center for Marine Research /
Institute of Inland Waters
46,7 km Atenas-Sounio, Mavro Lithari, Anavissos, Attiki, Greece
http://www.hcmr.gr

Carlos Godinho
LabOr / Laboratório de Ornitologia, Grupo
de Investigação em Ecossistemas e Paisagens
Mediterrânicas / ICAAM,
Universidade de Évora
7002-554 Évora, Portugal
http://www.uevora.pt

Maria da Graça Saraiva
Faculdade de Arquitectura da Universidade Técnica
de Lisboa / Centro de Sistemas Urbanos e Regionais
(CESUR)
http://www.fa.utl.pt/

Vassilis Hatzirvassanis
Granikou 57, Vironas GR-16233, Atenas, Greece

Rita Hipólito
Câmara Municipal de Alpiarça
R. José Relvas nº 374 - 2090 Alpiarça, Portugal
http://www.cm-alpiarca.airc.pt

Ana Ilhéu
Departamento de Ambiente e Ordenamento do
Território / EDIA, Empresa de Desenvolvimento e
Infraestruturas de Alqueva, S.A.
Rua Zeca Afonso, 2 - 7800 – 522 Beja, Portugal
http://www.edia.pt

Kasper Johansen
Centre for Remote Sensing and Spatial Information
Science, School of Geography, Planning and
Environmental Management. The University of
Queensland
Brisbane, QLD, 4072, Australia
http://www.gpem.uq.edu.au/crssis/

Johannes Konstanzer
Tiroler Umweltanwaltschaft
Brixnerstraße 2/3, 6020 Innsbruck, Austria
http://www.tiroler-umweltanwaltschaft.gv.at/

Gonçalo Leal
Direcção Geral de Agricultura e Desenvolvimento
Rural
Av. Afonso Costa 3, 1949-002 Lisboa, Portugal
http://www.dgadr.pt/

Irini Loi
ETANAM S.A.L.G.O. / Development Agency for South
Epirus - Amvrakikos S.A.L.G.O.
Lascaratou - Periochi Ydragogeiou, 48100 Preveza, Greece
http://www.etanam.gr

Juan Carlos López Almansa
Universidad Católica de Ávila
C/ Canteros s/n, 05005 Ávila, Spain
http://www.ucavila.es/

Miguel Marchamalo
Departamento de Ingeniería y Morfología del
Terreno, ETSI Caminos, Canales y Puertos,
Universidad Politécnica de Madrid /
Ecohidráulica S.L.
Prof. Aranguren s/n, Ciudad Universitaria 28040, Madrid, Spain
http://www.caminos.upm.es/imt/imt.htm

Carolina Martínez Santa-María
Unidad docente de Hidráulica e Hidrología de la
Escuela Universitaria de Ingeniería Técnica Forestal /
Universidad Politécnica de Madrid
Avda. de Ramiro de Maeztu s/n - 28040 Madrid, Spain
http://www.forestales.upm.es/

Michael M. McClain
Florida International University, Department of Environmental Studies
11200 SW 8th Street Miami, Florida 33199, U.S.A.
http://www.fiu.edu/

Ana Mendes (editor)
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt
aismendes@isa.utl.pt

António Mira
Departamento de Biologia, Grupo de Investigação em Ecossistemas e Paisagens Mediterrânicas / ICAAM, Universidade de Évora
7002-554 Évora, Portugal
http://www.uevora.pt

Ilidio Moreira
Instituto Superior de Agronomia / Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt

Kátia Morgado
Consultora autónoma

Christian Moritz
ARGE Limnologie
Hunoldstrasse 14; A-6020 Innsbruck, Austria

Robert J. Naiman
University of Washington, School of Aquatic and Fishery Sciences
Room 224B FSH; Box 355020, Seattle, WA 98195-5020, U.S.A.
http://www.fish.washington.edu/

Vanda Nunes
Câmara Municipal de Alpiarça
R. José Relvas nº 374 - 2090 Alpiarça, Portugal
http://www.cm-alpiarca.airc.pt

Francisco Nunes Godinho
Centro de Estudos Florestais / Conselho Nacional da Água
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.portugal.gov.pt

Filipa Pais
Divisão de Ambiente e Serviços Urbanos / Câmara Municipal de Montemor-o-Novo
Largo dos Paços do Concelho, 7050-127 Montemor-o-Novo, Portugal
http://www.cm-montemornovo.pt

Rui Peixoto
Instituto Superior de Agronomia / Universidade Técnica de Lisboa , Departamento de Engenharia Florestal
Tapada da Ajuda, P-1349-017 Lisboa, Portugal
http://www.isa.utl.pt

Teresa Pinto Correia
Departamento de Planeamento Biofísico e Paisagístico, Grupo de Investigação em Ecossistemas e Paisagens Mediterrânicas / ICAAM, Universidade de Évora
7002-554 Évora, Portugal
http://www.uevora.pt

João E. Rabaça (editor)
LabOr / Laboratório de Ornitologia, Departamento de Biologia, Grupo de Investigação em Ecossistemas e Paisagens Mediterrânicas / ICAAM, Universidade de Évora
7002-554 Évora, Portugal
http://www.uevora.pt
jrabaca@uevora.pt

Artur Ribeiro
Consultor autónomo
Rua Prof. Alfredo de Sousa, nº 6 5E - 1600-188 Lisboa, Portugal

Jean Roché
Consultor autónomo
53, rue de l'école, Le Sambuc, 13200 Arles, France

Joaquim Rosa do Céu
Câmara Municipal de Alpiarça
R. José Relvas nº 374 - 2090 Alpiarça, Portugal
http://www.cm-alpiarca.airc.pt

Paola Sangalli
Asociación Española de Ingeniería del Paisaje
Apartado 5064, 20080 San Sebastián, Spain
http://www.aeip.es

Adélia Sousa
Departamento de Engenharia Agrícola, Grupo de Investigação: Água, Solo e Clima / ICAAM, Universidade de Évora
7002-554 Évora, Portugal
http://www.uevora.pt

Paulo Sá Sousa
Departamento de Biologia, Grupo de Investigação em Ecossistemas e Paisagens Mediterrânicas, ICAAM, Universidade de Évora
7002-554 Évora, Portugal
http://www.uevora.pt

Klement Tockner
Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB)
im Forschungsverbund Berlin e.V., Müggelseedamm 310
12587 Berlin, Germany
http://www.igb-berlin.de/

Pilar Vizcaino Martínez
Grupo de Investigación en Hidrobiología / ECOHIDRAULICA S.L.
Rodriguez San Pedro, 11bis Oficina 407
28015 Madrid, Spain
http://www.ecohidraulica.com/equipotecnico.htm

Alexios Vlamis-Gardikas
Perrikou 40, Nea Philothei Athinon, GR-11524, Atenas, Greece

Stamatis Zogaris
Hellenic Center for Marine Research / Institute of Inland Waters
46,7 km Atenas-Sounio, Mavro Lithari, Anavissos, Attiki, Greece
http://www.hcmr.gr

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Introduction

Introduction

Talking about "ecological sustainability' and/or 'sustainable development' is conceptually complicated and controversial. The use in these two terms of a noun and an adjective derived from the verb 'to sustain' displays an evident ontological contradiction that has nonetheless become deeply rooted in every sector of society and language, especially political language, and has even reached the title of this book. Strictly speaking, 'to sustain' (from Latin *sustinere*, *sus-* 'from below' and *tenere* 'to hold') is a static notion, quite the opposite of 'development', which implies dynamism, movement, change, progress (Redclift, 2005; Noguera de Echeverri, 2006). Equally, if ecology is considered the science that studies the interrelations between living beings and their interactions with the environment, where the fundamental defining characteristic is the dynamics of physical, chemical and biological processes (Margalef, 1992), then attempting to 'sustain' these systems, which by definition are highly changeable, cannot fail to be somewhat paradoxical.

Why then devote a book to the sustainable management of riparian zones? These areas, being associated with river systems, are constantly influenced to a greater or lesser extent by a pattern of very sizeable alterations and hydrogeomorphological processes. Precisely for this reason, they harbour some of the most dynamic and heterogeneous sets of biological communities to exist in nature (Piegay *et al*., 2003; Ward and Tockner, 2001).

In order to understand 'sustainability', it must be remembered that the definition of this term is the result of a social and political convention that came into being with the Bruntland Report in the late 1980s and was ratified a few years later at the first Earth Summit conference, which gave rise to the Rio Declaration on Environment and Development (UNCED, 1992). This declared that sustainability requires balancing what are termed the 'three pillars' of development: economic growth, social justice and conserving the environment. People are central to these pillars, as set out in Principle 1 of the Declaration: "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature". According to this definition, it is human beings, from a totally anthropocentric angle, who define sustainability objectives, including conservation of the environment and of biodiversity. That is why concepts related to the term 'sustainability' are inescapably linked with a type of human activity and its impact on nature and why, as previously mentioned, defining 'environmental sustainability' in itself, *i.e.* from a biocentric angle, is questionable to say the least. The purpose of saying all this is to point out that here we are talking about 'sustainable riparian zones' with the conscious intention of intervening in their workings, whether allowing them to act freely, regulating them in some way or exploiting their natural resources. In other words, when we refer to the sustainability of riparian zones we are referring to riparian zone management.

Bearing in mind the wide diversity of interests that coexist in society as a whole and how lax the definition of sustainability is, it is very easy for radically opposed objectives to be accommodated within the same idea, so almost anything goes (Arribas Herguedas, 2007). This means that defining the criteria for a sustainable management programme for natural areas is essential, and suggesting the ideas that will help to define these criteria is precisely the main purpose of this book.

A sustainable or rational management model for the natural environment needs to be based on a deep understanding of how it works, making it possible to determine the impact that any human activity might have on the natural systems and attempt the greatest possible minimisation of such impacts. Riparian systems perform many very important environmental services for society, as will be seen in this book, and in order to guarantee the survival of future generations, preserving them over time must be one of the main objectives of any management measure. Equally, it is a known fact that the efficiency of natural systems in fulfilling their ecological functions and, consequently, in providing environmental services, increases in proportion to their conservation status and reaches a peak in unaltered or wild environments (SER, 2004; MEA 2005). Conserving the elements that help to maintain the natural dynamics of the riparian systems, in the case of good ecological status and restoring them when they are degraded, should be the optimal objective to pursue in every management plan. This is because in a system with good status the ecological succession processes fit the hydrogeomorphological and bioclimatic characteristics of the site and the biological communities that establish themselves in that site therefore possess greater resilience (Aronson *et al.*, 2007). As a result, it is presumed that the better conserved the natural area, the more stable it will be over time and the less it will need external action and resources to ensure that it functions well.

An understanding of how complex riparian systems function cannot be gained unilaterally but only through a multilateral approach that integrates many disciplines and points of view. Consequently, because this book aims to give the reader an overall view of what these natural systems are and how they function, a total of 64 authors have taken part, approaching the problems of riverside areas from their different specialist perspectives. Evidently, such a variety of approaches and points of view has made it quite complicated to give the book a coherent focus. As its editors, we hope that we have been up to the task.

This guide is intended as a practical tool that will be very useful for managers and those professionally engaged in river and riverside conservation and/or restoration, and also as a reference work for students and academics and as a source of ideas to arouse interest in these subjects among the public at large. If we have managed to convey to the reader the need to preserve and protect rivers and riversides, with their natural structure and functions, we shall be very satisfied.

Being a compilation, this volume can be approached either in order of chapters or by singling out individual chapters as the reader's own interests and needs dictate. This versatility is due to the effort invested in structuring the book in such a way that each chapter is an independent unit offering a complete idea if read individually, but also part of a coherent whole that builds up a cumulative body of knowledge if read from beginning to end. We have attempted to address most of the main subjects and aspects that affect the integrity of riparian ecosystems, always trying to take a broad view that will be applicable to the vast majority of cases. Nevertheless, a marked Mediterranean tendency is evident, owing to the origin of most of the authors and to the context in which it arose.

The first part defines basic concepts in the dynamics and morphology of riparian areas, the matrix in which all the other processes take place, and the rules that govern them. This part also defines basic riparian restoration principles, starting from a profound analysis of the very concept of 'restoration', and gives some examples of biophysical engineering models to estimate channel stability in relation to fluvial erosion processes. The second part briefly presents the biotic elements in riparian systems. The groups have been divided into vegetation, fish, amphibians and reptiles, birds and mammals. The different biological groups and species are addressed from the point of view of their habitats and dynamics, rather than through a species-level reductionist approach, as this is the information which is considered most relevant for management plans and restoration projects (Armsworth *et al.*, 2007). In this part, two sections describe the main riparian vegetation communities at both ends of the European Mediterranean region: the Greek and Iberian peninsulas. The third part is a miscellany on the theme of different tools for assessing and studying riparian areas. Rather than the more descriptive viewpoint adopted in the first two parts, particularly the second, this part confronts the reader with the complexity of approaching, understanding and, above all, quantifying nature and its processes before tackling the difficult task of describing and explaining them. Armed with a knowledge of the main elements of riverside areas and how they function, and with some ways to study them, the reader will be a little better prepared for moving into action. The fourth part describes the main elements in drawing up and carrying out an ecological restoration project with a multidisciplinary approach. It also deals with different techniques and machines used in channel and bank maintenance operations, as well as some soil bioengineering methods for stabilizing banks and methods and criteria for reintroducing and establishing riparian vegetation. Additionally, it gives some recommendations for woodland management and use in riparian zones. The fifth and last part presents three ecological rehabilitation projects undertaken in the course of the RIPIDURABLE project and two other projects from elsewhere. The theoretical arguments discussed in the preceding chapters can be evaluated in these five examples of action on riparian systems in very diverse contexts. One of the main points of interest lies in the different forms of land ownership and use and their influence on project execution and the subsequent management of the rehabilitated zones. Finally, readers are provided with a list of EU legislation and regulations with relevance to river and riverside management.

This book is the result of an interregional cooperation project called RIPIDURABLE (www.ripidurable.eu) which was co-funded by the European Community through the INTERREG IIIC South programme. The RIPIDURABLE project brought together ten partners from four Southern European countries for three and a half years with the objective of seeking solutions to problems related to riparian (riverside) zone management and restoration. The RIPIDURABLE partners chose the editorial team and conceived the structure and core contents of this guide through a participation process which was set in motion to gather the contributions and suggestions of the different members who took part in its design. The editors and a good number of the authors belong to the RIPIDURABLE partner organizations. The other authors are a large and diverse group of experts recruited in different ways to cover the remaining content requirements, who have become involved and taken a keen interest in this project. We know that all of them are very committed to their work and very busy with their day-to-day activities and we are deeply grateful to them for spending so much time and effort on this book. The least we can do is to give our thanks on record here. In fact all the authors, both in-house and external, have more than satisfied our expectations: many thanks to every one.

Creating a book takes more than just authors and editors, so we would also like to thank a number of other people who played a direct or indirect part. We particularly want to mention those responsible for the French edition, Paula Dias, and the Greek edition, Panayotis Dimopoulus, for their patience and understanding throughout the editing process. Georgina Hardinge made a vital contribution by correcting the English texts and provided pertinent comments. No less important are the contributions of Esther Tortosa, Ana Izquierdo, Rosa Gómez and Nuno Paulino, who helped in dealing with all the necessary legal and administrative processes. This book would not have been possible without the support of the institutions that funded it and the people who helped to make the complex processing of grants and payments function smoothly, so we would like to express our gratitude to the INTERREG IIIC South programme team in Valencia, particularlly to Amparo Montán Montesinos, to the members of the Portuguese National Coordination Unit, Fernando Nogueira and Raquel Baptista, and to the administration teams of the ten RIPIDURABLE partners. Our thanks also go to all those who kindly let us use their photographs and drawings, greatly improving the educational value and visual appearance of this guide, and to the designers, Vanessa and Patricia, for giving it shape and colour. Lastly, and above all, we are grateful to all the RIPIDURABLE project partners for placing their trust in us and supporting us at all times, and particularly to Stam, Arantxa, Carla, André, Carlos, Irini, Jean and Filipa.

At this point, all that remains for us to do is to hope that the book is to your liking and to wish you pleasant reading.

The Editors

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1

Morphology and Dynamics of Riparian Zones

MORPHOLOGY AND DYNAMICS OF RIPARIAN ZONES

Michael Döring
Klement Tockner

Defining and delineating riparian zones

Riparian zones are three dimensional transitional zones of direct interaction between terrestrial and aquatic ecosystems, extending from the edge of water bodies to the edge of upland systems (Naiman *et al.*, 2005; Malard *et al.*, 2006; Stanford *et al.*, 2005; Gregory, 1991; Figure 1.1.1). The size of the riparian zone ranges from very narrow strips in constrained headwaters, with the few geomorphic features they possess almost completely embedded into the riparian forest, to complex systems along large rivers characterized by physically diverse floodplains (Gregory, 1991; Naiman and Decámps, 1997). The width of the active zone increases from headwaters to large lowland rivers. However, the total area covered by riparian zones remains relatively constant across stream orders (table 1.1.1).

Riparian zones provide multiple ecosystem services, serving as mediators and integrators of the land-water interface, and are important sites for water storage, groundwater recharge, and nutrient and organic matter cycling (Dwire and Lowrence, 2006; Hughes, 1997). Therefore, riparian zones are key ecosystems within river catchment basins.

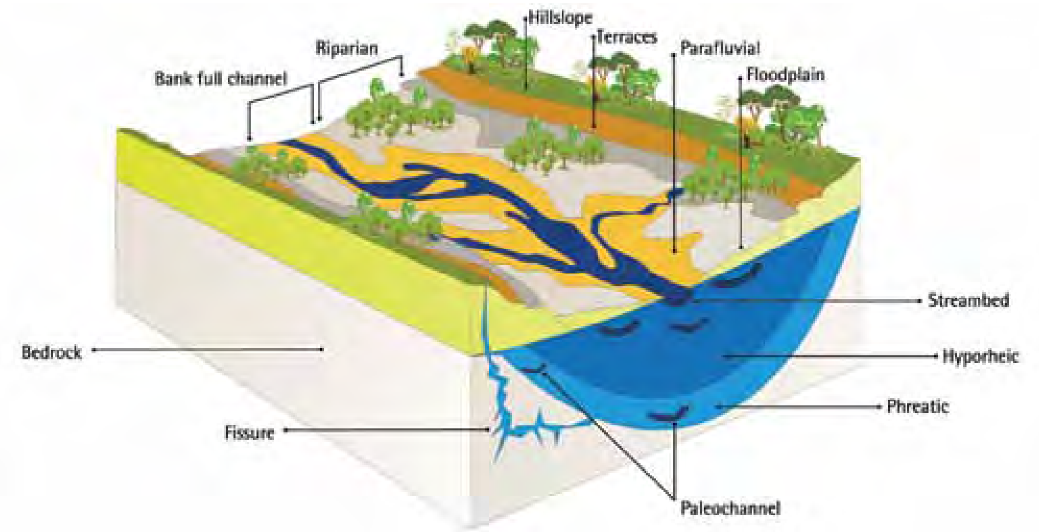

Figure 1.1.1. A three-dimensional view of a riparian ecosystem including surface and subsurface landscape elements (from Stanford *et al.*, 2005).

Table 1.1.1 Stream order, estimated number of streams, average and total length of rivers and streams, average riparian width and total riparian/floodplain surface area in the USA (after Leopold *et al.*, 1964; Brinson, 1993; Tockner and Stanford, 2002).

Stream order	Number	Average length (km)	Total length (km)	Estimated riparian width (m)	Floodplain surface area (km^2)
1	1,570,000	1.6	2,526,130	3	7,578
2	350,000	3.7	1,295,245	6	7,771
3	80,000	8.5	682,216	12	8,187
4	18,000	19.3	347,544	24	8,341
5	4,200	45.1	189,218	48	9,082
6	950	103.0	97,827	96	9,391
7	200	236.5	47,305	192	9,082
8	41	543.8	22,298	384	8,562
9	8	1,250.2	10,002	768	7,681
10	1	2,896.2	2,896	1536	4,449

Key driving factors in riparian zones

In riparian zones, the key driving forces for biogeochemical processes and biodiversity patterns include the routing of surface and subsurface water; production, decay and storage of organic matter; sediment transport; channel movement and habitat formation; disturbance and succession; and thermal heterogeneity. These drivers create a dynamic array of aquatic, amphibious, and terrestrial habitats which can be referred to as the shifting habitat mosaic (Poole, 2002; Ward *et al.,* 2002; Lorang *et al.*, 2005; Stanford *et al.,* 2005). "Shifting" refers specifically to the fact that the individual habitat types can change their location, size and configuration over time, although the overall abundance of various habitat types may remain constant (Arscott *et al.*, 2002).

Riparian zones are open systems, dynamically linked longitudinally, laterally and vertically by hydrological and geomorphic processes and vegetation succession (Gregory, 1991). These factors act as primary ecosystem drivers that create, structure, maintain, and destroy the heterogeneous and complex array of different riparian habitats. Habitats range from bare sediment surfaces (*e.g.* sand and gravel bars) with extreme thermal variations and high water stress, and therefore low productivity, to environments rich in resources that sustain high productivity, such as vegetated islands and riparian forests (Doering *et al.*, in review, Tockner *et al.*, 2006a; Naiman *et al.,* 2005; Figure 1.1.2). Repeated rejuvenation creates and maintains the diversity and complexity of habitat patches of different ages and successional stages. Habitat age diversity can be used as an integrative indicator to assess the integrity of riparian systems. Flow regulation, channelization, and the truncation of the sediment regime reduce age diversity, mainly through the loss of young habitat types (early successional stages, often with endangered pioneer species).

Hydrology is the master variable shaping riparian zones. Hydrological and geomorphological structuring of riparian zones depends on the timing, duration, frequency and magnitude of flow and flow pulses (Naiman *et al.,* 2005; Malanson, 1993; Gregory, 1991). Flooding, including channel movement, creates and structures vegetation distribution, topography and geomorphic landforms (Hughes, 1997; Gregory, 1991). Infrequent large floods of short duration (*e.g.* 100-yr flood event) tend to be destructive, causing vegetation mortality and erosion over large areas, whereas smaller flow and flood pulses (*e.g.* annual flood event) might be constructive by deposition, local erosion, and transport of materials and propagules (Hughes, 1997).

The erosion and deposition of sediments and nutrients affects the succession trend of soil and vegetation patterns across riparian zones, and vegetation in turn affects hydraulic and geomorphologic patterns through its ability to bind sediments and nutrients and to hold up water passing through the riparian zone (Gurnell and Petts, 2006; Hughes, 1997). These complex abiotic-biotic feedbacks lead to extreme variations in soil properties, in terms of moisture, grain size and nutrient content (Gregory, 1991; Doering

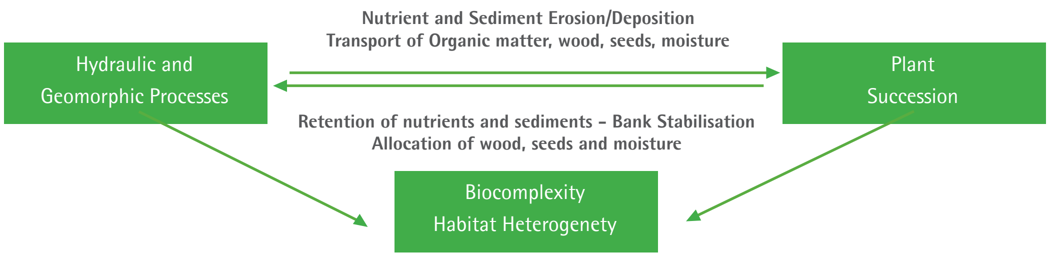

Figure 1.1.2 Dynamic relationship among hydrologic, geomorphic and ecological processes, thereby creating biocomplexity. Biocomplexity can be defined as the degree to which ecological systems comprise biological, social and physical components in a spatially explicit structure, including the historical contingency through time. The three dimensions of biocomplexity are heterogeneity, connectivity, and history.

et al., in review; see table 1.1.2). Consequently, riparian plant communities exhibit a high degree of structural and compositional diversity. Beside fluvial disturbances, riparian plant communities are also affected by disturbance regimes in adjacent upland areas, such as wind, fire, and outbreaks caused by phytopathogens and insects.

Large wood derived from riparian vegetation and distributed by flood pulses is an important component of riparian areas. It provides habitats and refuges for flora and fauna and retains organic matter and nutrients (Gurnell, 1997; Hughes, 1997; Gurnell *et al.*, 2005). Vegetated island development largely depends on large wood accumulations supporting vegetation growth by trapping fine sediments, retaining moisture and nutrients from decomposing plant material (Gurnell *et al.,* 2005). Vegetated islands are "high energy landforms" (Osterkamp, 1998) along rivers that correspond to instream riparian patches. Islands are key landscape elements along rivers because of their high ecotone length, their rich fauna and flora, and their importance as a source of nutrients and organic matter for adjacent, less productive, areas. At the same time, they are among the first landscape elements that disappear as a consequence of flow regulation and river channelization. Islands can be considered as sensitive indicators of the integrity of riparian corridors.

Riparian corridors and landscape connectivity

The individual habitat types of riparian zones differ widely in their degree of productivity, soil organic matter, sediment respiration, and capacity to mineralize organic matter. Very productive vegetation patches such as islands are often linked to habitats of lower productivity such as bare gravel (Brunke and Gonser, 1997; Tabacchi *et al.,* 1998; Tockner *et al.,* 2005; Gurnell *et al.*, 2001; Table 1.1.2).

Riparian zones play an important role in removing and retaining inorganic particles, organic matter, and nutrients. Riparian vegetation increases the roughness of the soil surface and can cause reduced velocity and consequently sedimentation of particulates. Fine plant roots and microbial communities in the soil and litter, as well as above-ground plant organs, are able to assimilate dissolved nutrients from surface and subsurface waters. Therefore they have an important buffer function for pollutants delivered from upstream or from adjacent terrestrial landscapes. Studies in the costal plains of Georgia (USA) showed that the riparian forest retained more than 65% of the nitrogen and 30% of the phosphorous reaching it in the soil solution from surrounding agricultural land (Lowrance *et al.,* 1984).

Riparian zones offer an abundant and diverse array of food resources for both aquatic and terrestrial communities. For example Fisher and Likens (1973) showed, for the Bear Brook in New Hampshire, that more than 98% of the organic matter of streams and rivers was supplied by the surrounding riparian forest. Similar values were reported by Langhans (2006) for the Tagliamento river in NE Italy. In addition to particulate organic matter (POM), riparian zones can contribute substantial amounts of dissolved organic matter (DOM) and nutrients to river ecosystems. Soil water DOM and nutrients originate directly via leaching from unsaturated regions of riparian zones during floods or indirectly from subsurface flow (Naiman and Déchamps, 1997; Gregory 1991). The exchange of organic matter and nutrients among the different riparian landscape elements and the river largely depends on season and hydraulic conditions, but can be particularly substantial during flooding events (Langhans, 2006).

Table 1.1.2 Differences in soil/sediment organic matter (OM), autotrophic biomass, Net Primary Productivity (NPP), sediment respiration, and leaf-litter decomposition in aquatic and riparian landscape elements in the Tagliamento corridor (estimated values from different sources).

	Soil/sediment OM (g OM m^{-2})	Autotrophic Biomass (g OM m^{-2})	NPP (g OM m^{-2} yr^{-1})	Sediment respiration (g OM m^{-2} yr^{-1})[4)]	Leaf decomposition (k-value)[5)]
Terrestrial					
Bare Gravel	500	200	200	50	0.0020
Pioneer Island	2000	600	800	300	0.0019
Established Island	6000	5000	2000	1500	0.0023
Riparian Forest (Softwood)	10000	7000	2000	1500	0.0019
Riparian Forest (Hardwood)	12000	7000	2000	1500	0.0019
Aquatic					
Lotic Channel	500 - 5000	10 -60[1)]	0[2)]	500 - 1500	0.0231
Parafluvial Pond	6000	50	0[2)]	1500	0.0052
Orthofluvial Pond	10000	1	-1500[3)]	-1500	0.0055

1) main channel presumably 10–20 g OM m^{-2}, surface-disconnected alluvial channel presumably up to 50 g OM m^{-2}
2) lotic channels P/R = 1
3) heterotrophic system (shading by dense riparian forest canopy) P/R ca. 0
4) estimates based on preliminary data (M. Doering, unpubl.)
5) preliminary data, coarse mesh-bags method using *Populus nigra* leaves (S. Langhans, unpubl.)

Riparian zones: Regional centers of biocomplexity

Riparian zones make a considerable contribution to the heterogeneity and dynamics of their adjacent habitats. They reduce solar heating of stream water by shading, especially in low order streams, and provide cooling through evapotranspiration of soil moisture and shallow groundwater. The different landscape elements of the riparian zones enhance surface-subsurface water exchange and subsequent thermal heterogeneity in streams. Riparian vegetation controls channel and bank stability. Channel separations are often mediated by islands and large woody debris, thereby creating numerous different habitats such as pools, riffles and runs (Gregory, 1991; Naiman *et al.*, 2005). Because of their location at the deepest point of the valley floor, riparian zones play a critical role in controlling and integrating the flux of energy and matter within the entire watershed.

Finally, riparian zones are biodiversity hotspots of global importance (Richardson and Danehy, 2007; Naiman *et al.*, 2005). Riparian zones provide also important refuges for aquatic and terrestrial assemblages from which recolonization may take place after a disturbance event. Depending on the location along a river corridor, dominant geomorphic processes (*i.e.* disturbance regimes) change, and this again influences the availability of refuges and the specific adaptation of biota to cope with these disturbance regimes (Tockner *et al.*, 2006b; Table 1.1.3).

Table 1.1.3 - Fluvial style, disturbance regime, refugia, and adaptation of aquatic macroinvertebrates along a riparian corridor (from Tockner *et al.*, 2006b).

Location, Fluvial style	Disturbance Regime	Refugia	Adaptation
▪ Headwater Straight	▪ Avalanches Debris flow Drying	▪ Tributaries Hyporheic zone Substrate heterogeneity	▪ Drift Morphological adaptation Life cycle
▪ Piedmont section Braided	▪ Avulsion Cut and Fill Processes	▪ Shore habitats Dead zones Large wood Hyporheic zone	▪ Mobility Flexible life history Risk spreading
▪ Lowland section Meandering	▪ Inundation Lateral Channel Migration	▪ Floodplain Large wood Backwater/pond	▪ Physiologic/ethologic adaptation Diapause

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BASIC RIVER-RESTORATION PRINCIPLES

José Anastasio Fernández Yuste
Carolina Martínez Santa-Maria

There are no recipes or ready-made solutions that accurately detail the steps to be taken in a river restoration project. This is because every river is a different reality, a new problem, and there are no universal solutions. In each case, the strategy must be based on analysis and thoughtful consideration. Technical proposals should make use of the available knowledge of the processes involved and of the relevant materials and procedures.

This chapter considers the conceptual aspects of river restoration that should guide the identification of problems, and of their causes and effects, in order to set priorities and objectives, plan strategies and design actions to preserve the true nature of rivers. It presents some of the principles governing technical proposals for river restoration.

What is a river?

In the non-specialised world, a 'river' is simply a channel. In the best of cases it includes aquatic and riparian biota. This limited concept of a river – a course of water flowing between banks – is not only incorrect (because it is incomplete), it is also perverse.

It is incomplete because a river is a much broader and more complex reality than just a watercourse and a riverside. The river basin is much more than a mere linear drainage network structure. On a wider territorial scale, it supports a complex system of interactions in space and time that give rise to many closely associated, highly dynamic processes. A river must therefore be considered a system in which it is not always easy to separate cause from effect, where biotic and abiotic components interact continuously and dynamically. This system must be defined within a wide territorial framework, which requires consideration of its entire space and its total dynamics. To this should be added the river's condition as a structuring element of the landscape, an extremely important aspect in regions such as the Mediterranean, where water is scarce and irregular both in time and in space and is thus a key factor in the composition, organisation and structure of the entire territory. A river is far more than the mere composition, structure and functions of the fluvial system, it is the very pillar, which connects and structures the surrounding ecosystems.

An inadequate understanding of rivers can also be perverse because a limited approach can easily lead to serious mistakes:

a) The priorities defined are not always in tune with actual needs.

b) Work begins without due consideration for the river's response or its potential for natural self-restoration.

c) The techniques and materials used to solve or ameliorate one problem cause new problems or worsen other existing problems.

The source of local problems is hardly ever to be found in the length of river that is being restored. It is quite possible that the solutions applied to some of the local problems that have been identified may cause new problems upstream or downstream and alter the dynamics of other processes, thereby leading to yet greater dysfunctions than those they were meant to correct in the first place.

These failures might be used by some to point out that the approach is mistaken and that rivers must be completely domesticated and controlled, illegitimate aspirations that certain sectors of society advocate as the only way to deal with river maintenance issues.

It is therefore critical, above all, to understand and acknowledge what a river really is. The task of providing an academic definition that stands alone as an accurate, complete and sufficiently descriptive depiction of the true essence of a river is not at all easy, given the wide-ranging, complex and extremely intricate nature of the subject. The following should be regarded as a kind of preliminary approximation:

A river is a natural course of water and sediments in which a very close, dynamic and permanent interaction of aquatic and terrestrial biotic and abiotic components and their processes and functions takes place within a very wide framework of space and time.

Based on such a definition, despite its undoubted complexity, a few more didactic points may be made. Table 1.2.1 covers some of these points.

Table 1.2.1. - What is a River.

A river is:	A river is not:
Water with adequate quantity, quality and flow regimes	An evacuation channel for water and sediments
The space that is needed for its geomorphological dynamics to develop	A sump
A mosaic of biotopes following different gradients: transverse – channel, banks floodplain; longitudinal – upper, middle and lower course; and vertical – channel, hyporheic zone and aquifer	A unused space
Both aquatic and terrestrial biota, with very different degrees of dependence on the river	A source of water resources
Processes and relations, occurring within highly variable space and time scales, between the components of the river itself and between the river and its surrounding ecosystems	A body of water flowing through a town
Part of man's cultural and sentimental heritage	A park equipped with more or less attractive sheets of water
	A stick of plasticine to be moulded at will
	A place to go fishing and swimming
	A mere hydraulic system

A river is water, space, and time. A river is life – its own private life – and a vessel for the life of others. A river is permanent change and diversity. A river is a road and a bridge. A river is an opportunity to feel emotion and fill one's soul.

How does a river work?

From time immemorial, man has profited from rivers without pausing to understand the basic environmental principles that allow the fluvial system to preserve its vitality. The relatively recent development of fluvial ecology has generated several models that help us to understand how rivers function. The most representative examples are shown in table 1.2.2.

There is currently wide agreement within the scientific community that the natural flow regime is the main organising agent of fluvial ecosystems. The flow regime provides a structure for both aquatic and riparian components and processes. It models their environmental conditions and allows for a variety of habitats and for dynamic interaction between these habitats (Bunn and Arthington, 2002; Arthington, 2002; Nilsson and Svedmark, 2002; Richter and Richter, 2000; Naiman *et al.*, 2002; Poff *et al.*, 1997; Strange *et al.*, 1999).

The flow regime determines channel shape, size and complexity, the distribution of riffles and pools, the structure of aquatic habitats, the quantity and characteristics of food resources and the nature of the interactions between channels, banks, floodplains and phreatic zones.

Table 1.2.2 - Conceptual models of the river (from Nilsson and Svedmark, 2002).

Model	Brief Description
▪ The river continuum concept (Vannote *et al.*, 1980)	▪ A gradient of energy and matter is available along the length of the river. This determines a continuous distribution of biocenoses all along its pro file, in a permanent process of adjusting in space and time to the different levels of (energy and matter) availability.
▪ Four-dimensional organisation (Ward, 1989)	▪ The structure of lotic ecosystems is based on four dimensions: longitudinal (channel-channel); lateral (channel-floodplain); vertical (channel-phreatic zone); and temporary. In turn, each of these dimensions can be analysed as a gradient in itself.
▪ Natural Flow Regime (Poff *et al.*, 1997)	▪ The natural flow regime is critical for ecosystem integrity and sustains biodiversity. Every river is a response to the characteristics of the five main natural flow regime components: magnitude, frequency, duration, timing, and rate of change.

The motor of fluvial system functionality is not a single discharge, but a flow regime that changes throughout the year and varies from year to year. Within the flow regime, floods are critical to the structure and stability of the river channel, keeping its morphology in dynamic balance in both the plan view and cross-section. In addition, floods guarantee transverse connectivity with the floodplain, allowing bidirectional flow not only of water but also of organisms, sediments, propagules and nutrients. Furthermore, they stimulate the creation and rejuvenation of lateral canals and pools and the formation of sandbars, and facilitate access to breeding areas. The magnitude, variability and duration of floods has an influence on the particle size of the materials that are transported and deposited along the water course, on river-bed removal and on maintaining surface/subsurface/ground water exchanges between the channel and the aquifer.

The degree, variability and duration of droughts, or minimum discharge, are also critical to aquatic and riparian ecosystems. These volumes restrict habitat availability when conditions are more unfavourable and their natural patterns of duration and seasonality act as barriers against the intrusion of foreign species that are not suitable for these environmental characteristics.

The rate of change of the flows, or flashiness, is also of great biological importance. It is a proven fact that many species emerge from states of repose when sharp increases in water levels take place; flow regimes thus trigger many biological processes such as pre-reproductive upstream migrations or scattering phenomena. In unaltered regimes, organisms are able to respond to the rates of rise and recession during floods, since they have enough time to react, protect themselves or flee when changes are about to occur. The above characteristics of magnitude, variability and duration must also be in harmony with the life cycles of species. Floods, droughts and spates must occur at the right times, in tune with water temperatures and the number of daylight hours. This allows hydrological variables (water depths and speeds) and environmental variables (water temperature and oxygen contents, substrate characteristics, etc.) to evolve in step with biota life-cycles and guarantee the survival of thriving communities.

The complexity of interactions between the flow regime and the rest of the fluvial system components is such that it must be studied at different space and time scales. This is why successful conservation of the biodiversity and functionality of riparian ecosystems depends on the ability to protect or restore the main aspects of the natural flow regime: magnitude, frequency, duration, timing, and rate of change.

What do we mean by restoration?

Concepts

At every meeting or convention of specialists, sooner or later a debate arises about the concept of 'restoration' and the advisability of keeping or replacing the term. Accurate terminology is always desirable and we need to establish definitions so that we know exactly what we are referring to when we use this or that word. Accordingly, this section aims to define the concept of restoration and other concepts that are used in connection with rivers and river management, such as rehabilitation and mitigation. Too much time and energy should not be wasted on hair-splitting terminological debates, however; our efforts will be more profitably expended on solving the problem at hand by devising potential solutions and applicable techniques than on discussing the use of 'restoration', 'rehabilitation' or 'mitigation'. Briefly, then, the definitions of the three most widely used concepts are:

RESTORE: to recover the natural composition, structure, processes and functions of a river, thereby allowing it to once again achieve full integrity and preserve its self-regulated dynamic balance.

REHABILITATE: to recover the composition, structure, processes and functions that are as close as possible to the river's natural condition.

MITIGATE: to achieve a status that is significantly different from the river's natural state, but reaches a compromise with the inevitable limitations to which the river is subjected.

It is not infrequent to place a higher value on restoration than on the other two alternatives, but this approach is quite mistaken. If inevitable limitations exist, and this has been proved objectively and unequivocally, there is no longer any possibility of restoring the river to its original, rightful condition. In such circumstances, mitigation might offer results that are far from ideal but is as worthy of consideration as restoration, in the sense described above. In both cases, the best possible situation is sought. The parallels with medicine are clear, and highly illustrative, as suggested in figure 1.2.1.

The term 'restoration' is all too often used as an infamous Trojan horse. Seemingly wonderful projects are frequently announced, described as the "restoration of the river at such and such a place", and then turn out to be unacceptable outrages. In the best of cases, these projects go no further than planting a few trees and shrubs, creating a 'fluvial park' that condemns the river to an unnatural state of immobility, or only considering certain species which may be iconic but hardly justify the subordination of whole ecosystems to their needs. We should make sure that the term 'restoration' really means what it is supposed to mean and that the project in question is actually in line with that true meaning.

The term 'restore', as used here below, should be taken in its generic sense, meaning all actions aimed at guaranteeing the best possible conditions in order to restore or come close to restoring the river's natural state.

Reference scenario and objective scenario

A crucial step in this process, as set forth in the Water Framework Directive (WFD), is to establish reference conditions: a pattern that objectively defines the basic characteristics of the river in its natural state. These characteristics should be detailed explicitly in order to clearly define the reference scenario: the river as it should be.

In all climatic regions, and especially in the Mediterranean area, this step is extremely important, since the 'natural river' or 'the river as it should be' often does not match the idyllic image of an ideal river that people have created for themselves: the 'poetic' or 'picturesque' notion of an ever-brimming course of water whose banks are permanently stable

Figure 1.2.1 Differences between restoration, rehabilitation and mitigation. (Based on Rutherfurd, *et al.*, 2000).

and nicely flanked by tree-shaded promenades and whose moderate rises never overflow.

It is not surprising that public demands often conform to precisely that imaginary idea of a river. These thoughtless demands must be countered by teaching society that the appropriate and truly desirable river is one that exists in harmony with the surrounding environment and the climate and that a true river must not be corrupted with alien landscapes but needs to seek its own canon of fullness and beauty. People should be taught and shown that any attempt to turn a river into something which it is not can only deprive it of its dignity; they should be made to understand that any result thus obtained will in the end prove short-lived and useless and may even have dramatically disastrous consequences.

In general, it is not easy to establish the reference conditions of a river. The task becomes particularly difficult when referring to its middle and lower courses, as centuries of human activity have dispossessed the river of almost all of its original features. The characterisation of reference conditions should include information about at least the following:

Natural Flow Regime, which is what determines the true nature of a river more than anything else, in terms of both its biotic and abiotic components. The Natural Flow Regime can be determined using methods such as those proposed by Richter *et al.* (1998), Richter and Richter (2000) or Martínez Santa–María and Fernández Yuste (2006a).

Channel migration zone, the area the river claims for the purpose of adjusting its energy flows and its solid and liquid discharges. It is also the space occupied by river biota and serves as a corridor connecting the different landscapes which make up the terrestrial ecosystems that the river flows through. Historical maps, or pictures of the oldest available aerial photography, depicting the status of the area before human action introduced widespread alterations, can be employed in defining and characterising fluvial spaces. Empirical equations such as those recently developed by Lee and Julien (2006) can also be used. These equations make it possible to calculate a suitable size, based on bankfull discharge, for the main geometrical ratios of the plan-view and cross-section channel.

Aquatic and riparian biota, the ultimate expression of fluvial system processes and functions. In this case it is more difficult, or even impossible, to find up-to-date information on reference conditions. From the 1950s to the 1980s, river-management criteria in Europe were based exclusively on exploiting water resources. These criteria, which may be comprehensible from a historical point of view, led to policies concerning the licensing, planning and organisation of fluvial spaces that produced very run-down middle and lower reaches, as has come to light since the recent publication of the impact and pressure reports required by the WFD. However, reference-biota characterisation can make use of results obtained in comparable rivers, or apply the natural composition and structure that scientific knowledge allows us to assume on the basis of the ecotype and the position of the reach under study.

While certainly important, a reference scenario is not enough, since the pristine river it seeks is all too often a utopia. It must be known and valued, but it cannot become the goal unless there is a real chance of its being achieved. The 'possible' river, i. e. the 'target scenario', must be defined by analysing the actual and potential availability of adequate quantities, qualities and regimes of water and space and, of course, by considering the social, political, economic and cultural aspects.

This 'target scenario' is the best possible river and must be defined with rigour, objectivity, and a generous amount of hopeful expectation. It should be:

CONGRUENT with the current concept of rivers as complex dynamic systems and structuring elements of the landscape;

AMBITIOUS yet REALISTIC, having goals that are in line with the diagnosis and limitations of the situation and shying away from utopian, unrealisable expectations that will only lead to technical, political and social discouragement;

PRECISE, defining the necessary programmes and actions in detail and incorporating indicators for appropriate monitoring of the degree of compliance with the established goals;

IN HARMONY with fluvial dynamics, thereby promoting natural processes in such a way that the river itself does most of the work;

AUTONOMOUS: restoration work should only point the way, then let the river's own physical and biological potential follow its course;

SEQUENTIAL:

1) Recovery of hydrological regime and water quality

2) Recovery of channel migration zone and fluvial morphology

3) Recovery of riparian vegetation

4) Recovery of aquatic biota;

TIME-ADJUSTED to the dynamics of the processes involved;

BASED ON A GLOBALLY ACCEPTED CONSENSUS that satisfies the expectations of the different social groups on the basis of environmental, social and economic sustainability;

RESTORATION PROGRAMMES OR PROJECTS that do not address reference-scenario characterisation and do not submit a target scenario on the basis of an assessment of the current situation, the factors that influence it and the possible opportunities cannot be considered feasible. The target scenario must enjoy public support and allow technically and socially viable intervention alternatives to be proposed. The most appropriate of these should then be selected after considering the fluvial ecosystem as a whole.

Besides the river 'as it should be' (the reference scenario) and the 'best possible' river (the target scenario), there is the river we actually have, the river 'that is'. Getting to know the river and describing all its different aspects in sufficient detail, or at least those that are most important to its functional integrity, is the key to making the right diagnosis, proposing the best solutions to mitigate the effects of the dysfunctions that have been detected and attempting to eliminate their root causes. The whole process should give the river what it needs to activate its own self-recovery mechanisms.

The task of characterising the river 'that is' must include an assessment of current flow regimes, fluvial spaces and aquatic and riparian biota, but it must also identify and evaluate the different pressures and social demands that are being brought to bear on the system and identify whatever legal, economic and political opportunities can be used to strengthen the restoration process.

In short, river recovery programmes cannot be viewed as a mere collection of isolated actions, they must be the result of a deeply thought out process that considers the fluvial system as a whole, including its present condition, its potential, and the relevant social context in which any restoration activities are to take place.

First things first

When it comes to setting restoration priorities, two basic aspects must be taken into consideration:

a) Which river or reach should be addressed first?
b) Which tasks should come first?

Prioritisation criteria: where do we start?

In order to define action priorities, it is reasonable to apply economic, social and environmental efficiency criteria: the river or reach where the lowest expense – in all three senses – will produce the closest approximation to reference status should be considered first.

The application of this principle means that protective action must be prioritised. Such action may be based on the following pattern:

1) Identifying and characterizing the best-preserved rivers or reaches

2) Approving legal measures to avoid deterioration of selected areas, defining fluvial-space uses which are strictly compatible with river dynamics and functions

3) Encouraging changes of use in and around fluvial spaces, including compensation for any loss of income that may derive from such measures

4) Defining and applying an environmental flow regime that guarantees availability of water in such quantities, qualities and regimes as are adequate to ensure maintenance of the geomorphological and biological attributes that are compatible with good ecological status of the water course

5) Introducing measures that eliminate or at least limit the impacts on these rare stretches of almost unspoilt water course and/or, as far as possible, remove or reduce the pressures brought to bear on them

6) Bringing about programmes that will increase social awareness and public involvement in safe-guarding this natural and cultural heritage

Secondly, attention should turn to river courses where there is scope for restoration or rehabilitation, that is to say, fluvial spaces in which it is possible, gradually and sequentially, to restore their composition, structure, functionality and dynamics to conditions that approximate reference status.

Lastly, consideration should be given to spaces where only a mitigation programme is possible. This is mostly applicable to urban reaches, where damage is often irreversible. Unfortunately, these areas are usually the first to be considered for heavy investment on the basis of nothing more than political opportunism. The fluvial space is thus 'recovered' with the sole aim of scoring points for the local council. Often it is the river that is made to fit the measure of the town, rather than the town and its citizens adjusting to the river by giving up spaces and adopting uses that allow co-existence with it.

The above, harsh as it may sound, should not lead us to the radical conclusion that rehabilitating reaches in urban spaces should be disregarded because of its lack of environmental efficacy, or is only to be considered if it is possible to achieve a sufficiently 'natural' target scenario, where public use and enjoyment must then be limited and restricted. Neither one nor the other is the case. Projects in urban environments frequently offer exceptional opportunities:

a) They make the public aware of the state of the river and of the need to limit the use of its water and surrounding space. This means making sacrifices that will benefit the restored river, which in turn will offer the town and its people new opportunities for enjoyment.

b) They encourage a new way of looking at the river, a new culture that will make it easier to obtain investments and sacrifices for other rivers outside the built-up area. In other words, even when investment in urban reaches is not environmentally efficient it can be very profitable indeed in terms of changing people's attitudes to fluvial spaces. This intangible asset is critical for raising awareness of the need for rivers to be respected and helped to recover, in all their different aspects.

The comments in the final point above aim to underline the relative nature of the priorities described in this section. It is advisable to have a standard, some kind of reference point, but it should never become inflexible. In order to set priorities and make the decisions that will allow our rivers to recover, analysis, reflection, discussion and rigour are essential, as is making the most of all available opportunities.

Criteria for prioritisation of interventions: what to do first?

River ecosystems have great power of recovery in the face of conditions created by extreme situations. This resilience is particularly marked in the Mediterranean region. Floods and droughts, with their undeniable disturbance they cause among aquatic and riparian biota, are also essential elements for preserving ecosystem composition and structure.

Rivers have in fact developed mechanisms that allow them to make use of exceptional events as indispensable renovation factors for maintaining their basic processes and as barriers to limit access by alien species. Those mechanisms and this resilience must be acknowledged and taken into account in fluvial restoration by letting the river deploy its natural recovery capacities and do most of the work.

Fluvial restoration should be a labour of tutoring and guidance, of creating the minimum necessary conditions, rather than a radical intervention that seems to solve the problem once and for all. That is the basic premise. The sequence of events should be as described in table 1.2.3.

There are three aspects which to a greater or lesser degree determine a river's ability to recover:

WATER (right quality and regime) + SPACE + TIME

Based on these three aspects, the river itself can trigger the processes that allow it to achieve its status as a system in permanent and more or less changing fluctuation around a condition of dynamic balance. Once the river has water and space at its disposal, the next step is to examine the possibility of speeding up the recovery process by:

Table 1.2.3 Stages of the fluvial restoration process.

Stages	Functions and components to be recovered
Stage I	Recovery of hydrological regime and water quality
Stage II	Recovery of channel migration zone and fluvial morphology
Stage III	Recovery of riparian vegetation functions
Stage IV	Recovery of the aquatic habitat

1) dismantling artificial elements that may be constricting the channel, unless there are potential risks involved that make such an action inadvisable;

2) restructuring the basic patterns of the river's past morphology;

3) reinstating the vegetation to develop a favourable biotope that includes fauna and serves its natural purpose as a corridor, a filter element, a source and a barrier.

Some necessarily general considerations about the basic actions involved in most river recovery programmes are presented in the next section.

Recovery of functions, components and processes

Recovery of hydrological regime and water quality

It is a well-known fact that utilisation of the water resources of a river basin must inevitably alter the river's flow regime in terms of magnitude, variability, seasonality and frequency, all of which are critically significant for the ecosystems. Regime recovery entails defining the hydrological characteristics that must be met by the flow regime in order to maintain the basic elements of the natural composition, structure and functionality of the fluvial ecosystems, as well as associated terrestrial ecosystems characteristics. That is why the resulting new regime is called an 'environmental', 'ecological' or 'maintenance' regime.

Magdaleno (2005) offers a splendid review of concepts and methods for calculating ecological flow regimes. More recently, Martínez Santa-María and Fernández Yuste (2006b) proposed a new environmental-flow estimate method called the Environmental Flow Regime (EFR), which gives not just one, but a whole series of potential environmental regimes or scenarios and evaluates them on the basis of their degree of approximation to the natural regime. In pre-existing dams, this gives resource managers a tool for incorporating environmental aspects within the decision-making protocol in an objective and quantified manner. In newly-constructed dams, the EFR also makes it possible to define management scenarios whose environmental cost can be quantitatively and qualitatively defined, with a view to resource-allocation optimisation measures. After explaining the crucial role of the natural regime in the composition and functioning of fluvial ecosystems, it is only logical to conclude that environmental-regime design should use the natural regime as a reference point and try to reproduce the natural hydrological patterns that are most significant from an environmental perspective.

To this end, the following **basic design principles** of an environmental regime are defined using EFR methodology:

1. Maintenance of the interannual variability structure
'Wet', 'standard' and 'dry' years are included in analogous proportions to those identified in the natural regime. This guarantees the maintenance of all the processes associated with hydrological diversity within the environmental regime.

2. Maintenance of the intra-annual variability structure
Ensuring that flow fluctuation throughout the year is comparable to that of the natural regime for each type of year; this will guarantee the maintenance of natural seasonal patterns within the environmental regime.

3. Maintenance of driest-month flows
Stricter preservation of the driest-month flows of the natural regime for each type of year, since these are the most restrictive conditions for biota in the Southern European and North African climatic region.

4. Maintenance of flood patterns
Inclusion of floods that are related to biological processes (small-magnitude and high-frequency floods), particularly those associated with fish-spawning phenology, to ensure that they are

sufficient to remove the finer deposits accumulated on the river-bed and that their seasonal patterns are appropriate.

5. Maintenance of geomorphological floods and connectivity floods
Inclusion of geomorphological and floodplain-connectivity flood values that are comparable in magnitude and duration to those of the natural regime. Interannual variability should be considered and natural seasonality respected. The variability of rise and recession curves must not influence the dynamics of natural aquatic communities as a result of individuals being displaced during rises or suddenly disconnected from the main body of water during recession periods.

6. Maintenance of absolute minimum values
Establishing minimum flow events – in terms of magnitude, duration and seasonality – for resilience thresholds based on natural-regime values, in order to ensure that the biota can recover from disturbances caused by low discharges.

Achieving flow-regime recovery without ensuring a minimum level of water quality does not make sense. Together with regime-restoration activities, it is also necessary to introduce measures that guarantee the recovery of water quality in accordance with general hydrological planning objectives.

Recovery of fluvial space of freedom and morphology

The river has an intense and dynamic morphological life that requires free space above and beyond the current channel and riversides, because its dynamic nature must be considered within a wide time-frame in which immobility is almost entirely nonexistent.

Channel migration zone

The channel migration zone (CMZ) can be defined as the part of the floodplain that the river needs, under natural conditions, in order to move laterally and achieve a good discharge/sediment load balance. This balance is the result of the interplay between the potential energy defined and made available to the channel by the floodplain, and the energy invested in transporting the water and its sediment load and in the interaction between the vegetation, channel bed and banks. It is easy to define the CMZ accurately when human activity has not altered the fluvial space, because the river marks its own clear limits. When human action has transformed the environment, however, the task may become practically impossible. A general reference protocol for CMZ definition should include the following:

a) Photointerpretation and historical cartography

b) In meandering courses, the applicable ratio is CMZ ≈ 10 w, where CMZ is the width of the migration zone and w the channel width in bankfull conditions

c) The recent use of laser technology for aerial photography allows a high degree of accuracy in the reconstruction, making it possible to

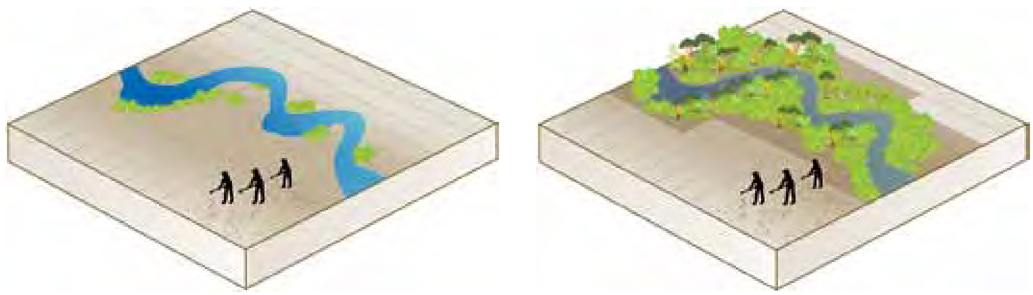

Figure 1.2.2 Recovery of fluvial space of freedom and functionality through compensation payments for land-use changes. (Based on Johnson, 1999).

Box 1.2.1 Fluvial morphology and habitat

- **Microhabitat**: The hyporheic zone – the interstitial saturated area of the bed and banks that contains part of the river's water or is affected by infiltration – is an essential element of the river, both because of its capacity as a biotope for the system's trophic base (periphyton; benthic organisms) and because it defines the properties of the physico-chemi cal exchanges with the phreatic zone and of the resistance to flow. At the "micro" scale, section morphology also determines the hydraulic characteristics – depth, velocity, turbulence, shear stress – which in turn define the aquatic biotope. These characteristics are thus decisive for competition, feeding, interaction, reproduction and shelter. They also determine local sedimentation dynamics and influence the processes that scatter propagules, micro-organisms and organic matter.
- **Mesohabitat**: At this scale, morphology establishes the presence, sequence and persistence of riffles and pools, the mesohabitat forms that determine aquatic-biotope diversity. It also determines riparian and neighbouring floodplain characteristics, thereby influencing the corridor's functions as habitat, barrier, conduit, filter, source and sink, which are critical to fluvial ecosystem integrity.
- **Macrohabitat**: At this level, morphology determines the location, characteristics and dynamics of the longitudinal sequence of planforms and is therefore the key element in the longitudinal evolution of the fluvial ecosystem's biotic and abiotic components.

identify old meanders and abandoned branches and supplement the information obtained from conventional aerial photographs (Magdaleno, 2006)

Defining the CMZ is the first step, but it cannot be left at lines on a map. Administrative, legal and technical strategies must be put in place so that the available information can be used for the benefit of the river. Within the CMZ, more detailed areas should be defined: successive strips running parallel to the river channel, representing spaces with specific environmental functions (Malavoi, J. *et al.*, 1998). Through considering the peculiarities and characteristics of those strips, limitations can be established on soil uses, which must be compatible with environmental functionality. Another complementary strategy for achieving the desired CMZ is to promote land-use changes on private land. In rural environments or areas surrounding towns, the aim is to reinstate spaces that the river needs which are currently used for farming, stock-breeding and/or forestry (figure 1.2.2).

Aid for the creation of riparian spaces should envisage the following:

1) Morphological adjustments that safeguard the riparian area, its continuity and its connectivity with the river-channel and the surrounding terrestrial ecosystems

2) Recuperation of the vegetation with appropriate species, ensuring that their origins and genetic diversity are controlled and respected

3) Sufficient continuity to ensure the efficacy of the projects over time

4) Payment of compensation for loss of income resulting from new land uses

A critical analysis of Common Agricultural Policy experiences of similar action to replace farmland with woodlands can provide criteria and strategies to guide these interventions.

Fluvial morphology

A river is a three-dimensional system in which matter, energy and biota are transferred along its longitudinal, transverse and vertical axes. Flows in the direction of the stream, lateral interaction with banks and floodplains and exchanges with alluvial aquifers are all important. Fluvial hydrosystem integrity depends on the maintenance of those three dimensions, on hydrological, geomorphological and biological components and processes, and on the dynamic interaction between them (Petts and Amorós, 1996).

In this context, morphology is undoubtedly a crucial element of the river. It is the system's response to matter and energy inputs. That response is the result of interaction between existing matter – the flowing liquid and the solid volumes, the energy available for its transfer – defined by the gradient of the floodplain, and the energy that is necessarily lost in the transfer process. Strictly speaking, morphology and its dynamics are an abiotic element of the river, but because they influence the quantitative and qualitative characteristics of the aquatic and riparian biotopes (box 1.2.1), they have a significant effect on the biota.

When considering any intervention involving fluvial morphology, the first thing to remember is that no shape or form can be forcibly imposed on a river. This leads to one immediate conclusion: in order to incorporate fluvial morphology into river action plans, it is essential to possess the necessary tools to define the basic morphological characteristics of the river section in question and the relation between these and the variables that have shaped them. In other words, it is vital to know the morphological patterns that determine the dynamic balance of the reach in order to assess its current morphological status and undertake actions that achieve a structure which is in harmony with the desired morphological dynamics.

Before continuing, some important points require a few brief comments. Fluvial morphology is the result of interaction between very complex processes that take place at a variety of different stages in space and time, with high rates of feedback. It is not always easy to segregate cause from effect, or dependent from independent variables. Furthermore, the results that are available for characterisation of these processes are still far from being organised into a definitive doctrinal corpus. It is therefore necessary to point out that the calculations in the literature should be considered more as an order of magnitude than as a true and definite value. A first approach to fluvial morphology reveals four degrees of freedom represented by four planes: the longitudinal gradient, the plan-view form or planform, the cross-section and the riverbed or channel-bed forms. These four degrees of freedom are not independent from one another, but they have different dynamics in space and time. Some considerations of planform and cross-section, the two most significant degrees of freedom, are presented here below.

Planform

Early work in this field (Leopold and Wolman, 1957) sought to establish simple relations between basic planforms (straight, meandering, braided, anastomosed) and the variables by which they are controlled to a greater or lesser extent, such as gradient and bankfull discharge (*Qb*) (table 1.2.2). Subsequent work (Parker, 1976; Berg, 1995) incorporated certain more complex variables (Froude number, specific power, etc.) that allow for

Box 1.2.2 Bankfull discharge

- **MORPHOLOGICAL criterion:** this is the discharge that 'fills' the channel, meaning the channel below the floodplain. Morphological determination can be performed with the indicators proposed by Dune and Leopold (1978): point of change from bank slope to floodplain level; point of change from steep to significantly flatter slopes; change in type of vegetation; changes in texture of deposited sediments. Some exceptions apply to these general rules. In arid or semi-arid environments, for example, there are rivers that have macro-channels, adapted to extreme events, with a much smaller active channel which moves freely within the macro-channel; the active channel is the one that should be considered for *Qb* characterisation (Van Niekerk *et al.*, 1995).

- **SEDIMENT TRANSPORT criterion**: this is defined as the increment of discharge that transports the largest fraction of the sediment load over a period of years (Andrews, 1980). Its value may be calculated simply by selecting the flow that maximises the result of multiplying the frequency by the solid volume. In addition to being more objective and sounder than the above criterion and integrating the physical process that is responsible for channel geometry, this proce dure represents a conceptual advantage by bringing together two key aspects, magnitude and frequency, within the *Qb* concept.

- The practical difficulty of applying the morphological criterion and the complexity associated with determining the frequency curve for sediment discharge have led to the development of different protocols for faster calculation. One procedure worth considering is to work out the discharges corresponding to 1- to 5-year return periods, circulate them over a hydraulic model of the river section (using HEC-RAS, for instance) and identify the one that comes closest to 'filling' the channel.

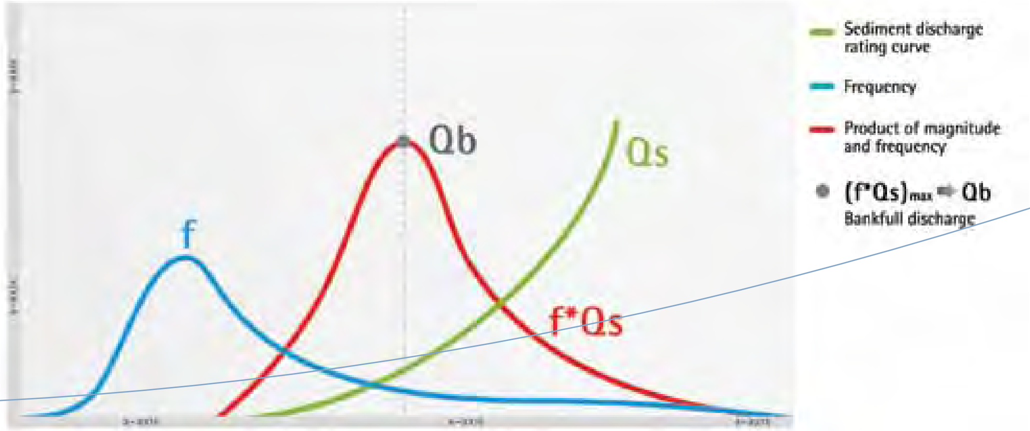

Figure 1.2.3 Bankfull discharge and sediment transport.

more accurate calculations. If no other references are available, using the relationships and figures described by these and other authors can supply specific information about the planform of the river that is to be restored.

It is important to bear in mind that the morphology of the reach must be determined on the basis of flow rates after the restoration of flow regimes. Thus, if intense regulation is present the morphological pattern corresponding to that situation should not be used as a geomorphological target scenario. It will be necessary to determine the correct morphology, based on the bankfull discharge when the environmental flow regime is applied.

Cross-section

Cross-section characterisation only requires two variables: width (*w*) and mean depth (*d*). Regime theory establishes potential relationships between *Qb* (independent variable) and the variables

w=aQbb ; d=cQbf .

The specialised literature abounds in studies that have allowed these parameters to be estimated (Andrews, 1980; Hey and Thorne, 1986; Castro and Jackson, 2001; Lee and Julián, 2006). Because these relationships are empirical functions it is very important to make sure, before using them, that the characteristics of the experimental range used to

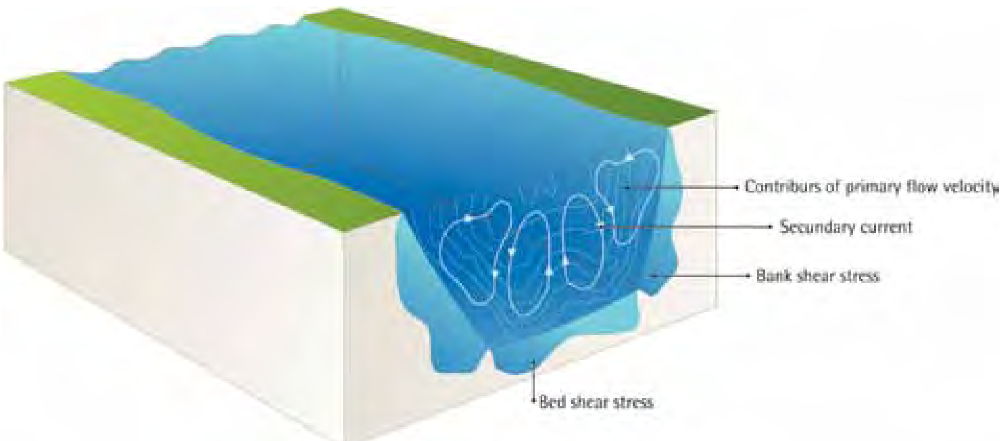

Figure 1.2.4 Shear stress distribution in a standard cross section.

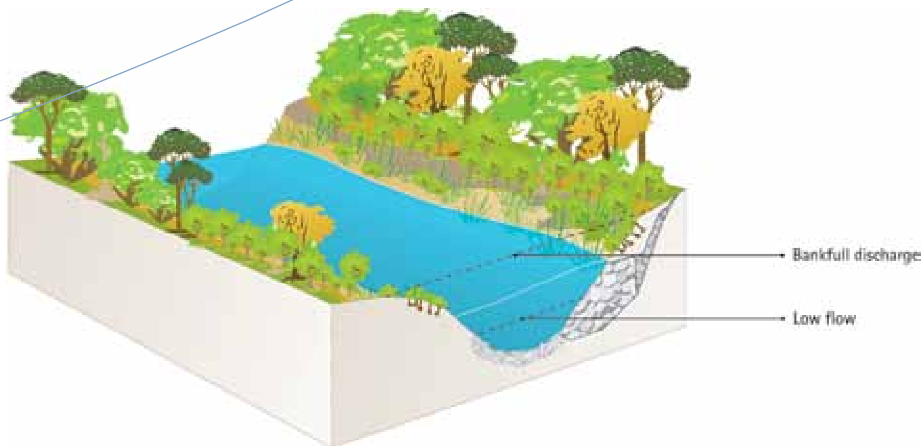

Figure 1.2.5 Streambank treatment in a curved reach according to shear stress distribution.

estimate them are in line with those of the applicable project. In addition, it is always advisable to use more than one relationship in order to obtain a wide spectrum of results.

Riverbed forms

Where sand-bed rivers are concerned, sediment ripples, dunes and antidunes are very much related to the type of regime; ripples and dunes are associated with subcritical (tranquil) flow (Froude number <1), while antidunes are associated with supercritical (rapid) flow (Froude number >1) and can change within short spaces of time. They play an important role because they induce significant energy losses, but their importance is not as great from the point of view of restoration morphology, as they are highly variable over time.

In gravel-bed rivers, the sequence of riffles and pools is to be found in both straight and meandering reaches. Gravel beds are much more stable over time than sand-bed forms and they provide the river with a high degree of hydrological and granulometric variability, with a prominent role in aquatic-biota diversity. The genesis and dynamics of these riverbed forms lie beyond the scope of the present overview; readers who are interested can consult the section on riffles and pools in David Knighton's magnificent book (1998).

Jumps and pools are typical of mountain courses with gradients in excess of 3-5%. Morphologically, they can be characterised by the distance between consecutive jumps (*L*) and by fall height (*H*). The distance between jumps is two to three times the width of the channel (Chin, 1989). Abrahams and Atkinson (1995) propose $H/L \approx 1.5\,S$, in which *S* stands for the channel gradient. The role of this pool and jump sequence in mountain channels is crucial, since it ensures intense energy dissipation, an essential component in controlling the high amount of potential energy that steep gradients give to the flow.

Restoration cannot impose, it must simply offer guidance: the river is both the sculptor and the sculpture, the creator and the creature

Stabilisation of bank slopes

Once the objective-scenario morphology has been determined, whatever measures are necessary to allow the river to reach and maintain that objective status must be put in place. The starting point, of course, is to guarantee the channel migration zone, since, as has already been pointed out, morphology is essentially dynamic: the river moves, although it always does so within a reference pattern and on the basis of more or less well-defined dimensional features. Based on those possibilities, it is advisable to carry out actions that speed up the river's repossession of its shape and space.

One of the problems that these interventions must address is bank slope stability. It is not a question of fixing them totally and permanently, but rather of helping them to remain stable for long enough to allow the vegetation and other natural processes to adjust to the intended new river conditions. One important exception applies, however: when bank instability jeopardizes the safety of people, property or infrastructure, permanent stabilisation must be considered in the absence of alternative solutions. To secure bank slope stability, the following must be done:

1) Determine the magnitude of shear stresses and their distribution over the cross-section

2) Adjust the materials, execution and maintenance operations to the magnitude and distribution of these stresses

3) Ensure the maximum environmental functionality of the solutions applied

It is not infrequent for the third of these criteria to be applied while disregarding the other two. This not only leads to failure in achieving the desired stability, but can also cause a design error to be interpreted as a sign of inadequacy of the materials and components that should be securing environmental functionality. This mistaken conclusion can discredit the material rather than the project designer and discourage the use of new approaches and techniques.

As regards shear stresses (tangential force per unit of surface), it is crucial to bear in mind that they are at a maximum at the base of the bank slope and decrease in a significantly linear manner until they reach zero on arriving at the free surface (figure 1.2.4).

In order to ensure slope stability, it is therefore not advisable to use a single solution. The materials that offer the greatest resistance to the action of the flow when they are properly laid, such as rip-rap, tree trunks and stumps, organic fibre rolls, etc., should be placed from the base up to the usual flood level (a return period of not more than one year). Up to the level of the ordinary floods that define the channel (a return period of 2 to 5 years), bioengineering elements may be used (organic blankets, live fascines, brush mattresses, etc.). Above that level, only vegetation is necessary unless special circumstances apply (figure 1.2.5).

The use of bioengineering elements requires a very careful protocol to be drawn up, in terms of materials, execution and maintenance. As already mentioned, the chosen species must be selected with the following points in mind:

1) Compatibility with the geobotanical characteristics of the river reach

2) Root and branch structures must be well suited to bank slopes; roots should grow rapidly and provide good plant and soil anchoring and branch structures should exhibit appropriate behaviour during floods

3) The plants and reproductive material should proceed from the same region of provenance and guarantee adequate genetic diversity

4) As regards planting, the time of year and, the weather conditions and soil moisture should be considered carefully. These aspects are not always given the importance they deserve, especially when those involved are used to working with inert materials which are unaffected by these factors

5) Maintenance should be expressly considered in the project design. Adequate time-periods and resources must be provided for to ensure the preservation of the living material that has been installed.

Lastly, it should be pointed out that bioengineering must not be used indiscriminately in river restoration projects. Like any other material or technique, its use should be based on an in-depth analysis of the relevant problem, on the consideration of current conditions and on reasonable expectations as to its efficacy, *i.e.* its ability to solve or ameliorate the problem or dysfunction detected and to achieve the desired effect with the fewest means in the shortest possible time. In other words, every attempt should be made to avoid the frequent mistake of thinking that simply because these techniques use living or dead plant material, they guarantee the success of any project in which they are used.

Recovery of riparian woodland function

From a strictly botanical point of view, stream corridors consist of a series of phreatophyte species – water-dependent plants – that need to be near the ground water level in order to ensure that their roots have adequate access to moisture and thus allow the plants to complete their biological cycle. This is critical for riparian function, since higher levels of water availability facilitate evapotranspiration even when water is scarce, creating a more humid and temperate atmosphere than that of the surrounding environment. Sterling (1996) describes a difference of up to 7.5 º C between the temperatures inside and outside a riverside grove.

Conditions in which riparian woodland offers adequate plant cover, interception of sunlight and rainfall and effective protection from the wind favour optimal water use, leading to lower temperatures near the ground, which have a positive influence on

Figure 1.2.6 Conduit function of riparian corridor in an ephemeral stream network (ramblas) (Source: Instituto Cartográfico Valenciano).

many soil processes. From a structural perspective, the environmental conditions of riparian spaces are therefore quite different from those of their surroundings. All these microclimatic changes are perceived by many organisms that inhabit riverside habitats, where they feed, seek shelter in extreme weather conditions, reproduce and interrelate. A river is not just a channel filled with water and sediment, its strictest and most limited definition. Thanks to its riparian corridor, it is also a parallel conduit of animal and plant species, organic matter, thermal conditions and energy (figures 1.2.6 and 1.2.7). Riparian vegetation is thus a fundamental component of fluvial systems, but its survival can only be guaranteed if the river's flow regime, migration zone and morphology have previously been reinstated.

Figure 1.2.7 Filter function of riparian corridor. (Source: Instituto Cartográfico Valenciano).

Riparian restoration must strive not only for aesthetic rehabilitation, but also, most especially, for recovery of environmental functionality. The key points of reference are the natural communities of the well-preserved reaches, which will offer the reproductive material for recuperation purposes and criteria for the recovery of biotic and structural heterogeneity.
Respect for the patterns of nature is crucial for guaranteeing success in riparian woodland restoration. It must be remembered that phreatophyte species need to be closer to the water but that this sometimes entails their destruction, since they are subject to catastrophic rises and floods, alternating with extremely dry periods, and sharp variations in water level. It should therefore be borne in mind that riparian woodlands in their most natural state are not strictly mature, stable and permanent in time. On the contrary, they are open ecosystems made up of a mosaic of highly heterogeneous microhabitats undergoing successive stages of development (Sterling, 1996).

The main goal of restoration programmes should therefore be the recovery of natural hydrological regimes, as the determining factor in the process of dynamic change taking place within riparian woodlands.

If the river has an adequate flow regime, high quality water and physical space in which to move, its biological potential is immense. In such conditions, within relatively short periods of time, the river can recover its riparian band in a natural way. Human intervention should thus be seen as short-term aid; the first rises and floods, with their load of water, sediments, seeds and propagules, are the definitive source of the energy and materials that model and restructure the riparian corridor.

Recovery of the aquatic habitat

Recovery of the habitat for aquatic biota is the last step in the proposed process of fluvial restoration. This is so for an obvious reason: the main factors controlling the available habitat quality and quantity are the hydrological regime, the channel's physical characteristics, the water quality and the riparian ecosystems.

It does not therefore make sense to address habitat recovery, and much less consider the introduction of species, if the above-mentioned four factors have not reached an acceptable level of functionality. Conversely, in a reach in which flow regime, water quality, morphology and riparian conditions have been restored it is highly probable, unless human pressure is extreme, that the aquatic biota will gradually colonise and settle the fluvial space.

In addition to the considerations noted above, specific actions can be carried out with a view to speeding up and/or complementing the habitat's natural availability, fostering the development of communities that are healthy in terms of their structure, composition and diversity.

The main objective of this type of action is basically to encourage hydraulic diversity. To this end, different structures are set up in the channel and on the banks to break down the homogeneity of certain hydraulic parameters, depth or velocity, for instance, and induce variations in other dependent hydraulic variables such as shear stresses, turbulence, secondary flows, etc. This hydraulic diversity, in combination with granulometric and morphologic variability and other environmental gradients, will gradually create different microhabitats with very different levels of biotic potential. Projects should be designed to cover the widest spectrum of habitable conditions. Examples of these types of action are (FISRWG, 1998):

Boulder cluster: Groups of boulders placed in the base flow channel to provide cover, create scour holes, or areas of reduced velocity.

Weirs or Sills: Log, boulder, or quarrystone structures placed across the channel and anchored to the streambank and/or bed to create pool habitat, control bed erosion, or collect and retain gravel.

Fish passages: Any one of a number of instream changes which enhance the opportunity for target fish species to freely move to upstream areas for spawning, habitat utilization, and other life functions.

Log/Brush/rock Shelters: Logs, brush, and rock structures installed in the lower portion of streambanks to enhance fish habitat, encourage food web dynamics, prevent streambank erosion, and provide shading.

Tree cover: Felled trees placed along the streambank to provide overhead cover, aquatic organism substrate and habitat, stream current deflection, scouring, deposition, and drift catchment.

Wing deflectors: Structures that protrude from either streambank but do not extend entirely across a channel. They deflect flows away from the bank, and scour pools by constricting the channel and accelerating flow.

Self-recovery, time and monitoring

Different fluvial restoration actions must be carried out in the right order and must be in tune with the river itself, which should be allowed to make full use of its potential for self-recovery. This requires good planning – first things first – as well as time. If global morphological restoration is the aim – unchannelling work, for instance – on-site definition of the planform and the basic geometry of the section are a prior requirement. Banks should then be stabilised where necessary.

Beyond that, no more action on the morphology is advisable, since the river itself will take care of it. Specifically, it would not be advisable to forcibly set up a sequence of rapids and pools, create beaches in curve interiors, or generally and indiscriminately secure all river-bank slopes. To the non-specialist, this may seem like leaving things unfinished, but that is only partly true, since man's work as a facilitator has finished at that point and the river can now lead its self-recovery process towards morphological stability. The river needs time to develop its own recovery process and return to its natural state. It is not always feasible to design projects that allow for that time because society often demands tangible, short-term solutions. Nevertheless it is desirable, indeed indispensable, for restoration projects and programmes to set accurate time-frames and define the objectives to be achieved in each of the main stages.

Setting accurate time-frames leads to an immediate conclusion: the project will not be finished until each and every proposed stage of the process has been completed. This leads to another crucial but often forgotten aspect of river restoration projects: monitoring. In general, direct actions have a rather short time-limit and are soon concluded; but contrary to general belief, these actions do not signal the end of the project. Once they are completed, monitoring is needed to make sure that the stated aims of each stage of the project have been achieved and that the river has responded to the actions taken. If the river is not recovering in harmony with the goals, changes and new actions can be proposed in order to achieve the final goal.

Public involvement

The WFD defines public involvement as a significant component of hydrological planning, which should promote active social participation in the development and implementation of river-basin hydrological plans. Some river-basin authorities are in fact beginning to incorporate 'public-involvement departments' into their organisational structures.

This public-involvement process must be applied to river-restoration programmes and projects because that is what the law requires, but it should also be based on a conviction that public participation is the tool that will help to garner society's support for these projects. It must not be forgotten that river restoration projects generally take place over extended periods of time and their final results do not become completely and effectively apparent until long after the work has been done. For these projects to be successful, the public must often give up the use and enjoyment of spaces and activities for the benefit of the ecological integrity of the fluvial system, so it is crucial to have popular support in order to achieve the desired results.

Restoration plans should thus include adequate funding and time-scales to ensure proactive public participation.

Viewing the whole picture

Finally, an integrated flowchart is presented, a general protocol that may be applied to all river restoration projects. Such a protocol must underline the most important steps and stages involved in the restoration of fluvial reaches and stress the need to consider them as a whole, within the context of a strategy that requires making use of each and every one of these different elements (table 1.2.4).

The best metaphor to illustrate this strategy is that of a doctor treating a patient. Just as it would be unacceptable to reach a medical diagnosis, and much less give treatment, without considering the patient's clinical history and conducting a physical examination, the design, calculation and execution of a fluvial restoration project cannot be approached without defining the reference scenario, identifying alterations and their potential causes and effects and realistically defining the target scenario. No medical treatment can be administered without due monitoring and no river restoration process can be deemed to have concluded if adequate monitoring measures have not been put in place.

Restoration or rehabilitation programmes must be based on a deeply thought-out process that considers the fluvial ecosystem as a whole and bears in mind all the environmental, social, economic, cultural and emotional issues.

Table 1.2.4 Stages of the fluvial restoration process .

Restoration flowchart

CLINICAL HISTORY	▪ Recovery of hydrological regime and water quality ▪ Review of available documentation (cartography, aerial photographs, previous studies...) ▪ Hydrological, sedimentological, morphological and biological characterisation of the system ▪ Identification of human actions that have affected the fluvial system ▪ Uses and demands ▪ Definition of reference conditions (reference scenario)
EXAMINATION	▪ Identification of alterations and their effects on the reach, and also upstream and downstream from it ▪ Identification of factors that influence or restrict the restoration process, as well as alternatives and opportunities
DIAGNOSIS	▪ Cause/effect relationship and its dynamics in space and time ▪ Degree of reversibility of damage ▪ Priorities and action sequence ▪ Accurate and realistic definition of objective scenario
TREATMENT	▪ Design of technically, economically and socially feasible alternatives for action ▪ Selection of the most appropriate action on the basis of the fluvial system as a whole ▪ Implementation of an educational and social communication programme ▪ Design, calculation and execution
MONITORING	▪ Maintenance ▪ Adaptive management ▪ Assessment of results

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THE IMPORTANCE OF GEOMORPHOLOGY IN SETTING THE RULES FOR RIPARIAN REHABILITATION

Rui Cortes

Fluvial geomorphology and the riparian corridor

When dealing with the restoration of riparian layers, a very important aspect is knowledge of the channel dynamics and assessment of the river bank condition. In fact, if critical bank failure is found or the instream conditions are far from equilibrium, with extensive lateral instabilities and widening processes, it will not be possible to establish riparian vegetation. Besides, these assessments need to be made to provide the basis for deciding the bio-engineering techniques that are needed to achieve a certain bank (or river bed) stabilization, as a first stage, followed by installation of the appropriate vegetation. Information about hydraulic geometry is necessary, based on the concept that a river system tends to develop towards an equilibrium between the channel and the flow of water and sediments.

Riparian vegetation plays a major role in channel evolution and stability since it directly influences the sediment erosion, transport and deposition processes. It should be stressed that is not possible to establish guidelines for the rehabilitation of a river corridor without information on the hydrogeomorphological characteristics of the stream.

The intention of this chapter is to provide everyone involved in river management with simple equations and an explanation of relationships so that they can understand the character of streams and predict the geomorphological dynamism of the river channel. The formulae presented here do not require any specific knowledge of hydraulics and must be viewed as just illustrations, bearing in mind that this chapter goes on to describe the most relevant physical processes that occur in a stream. However, they do use comprehensible variables that provide useful information about the relations between geomorphological processes linked to erosion and common hydraulic parameters.

The ability of a stream to interact between erosion, transport and sedimentation can be expressed easily by the stream power ω per unit bed area (W/m^2):

$$\omega = \rho g Q S / w$$

where ρ is the density of water, g the gravity acceleration, Q the mean annual discharge, S the channel slope and w the channel width.

A very extensive study carried out for UK rivers observed quasi constant ω values ($2 > \omega < 1{,}815$ W/m^2), showing the capability of the different types of channels to adjust dynamically to stream power, and supported a finding that erosional instability occurs when $\omega > 35$ W/m^2 (Sear *et al*., 2003). However, the conditions for channel instability also depend to a great extent on the diameter of the bed particles, since river beds composed of smaller particles become unstable at lower stream power values. Thus, in beds where the dominant material was silt, gravel, gravel/cobble and cobble, movement took place at 37.8, 73.3, 78.8 and 142.0 W/m^2 respectively. However, the extreme difficulty in finding simple relationships between stream power and channel stability is apparent (Sear *et al*., 2003). One explanation for this is associated with vegetation, which has significant impacts on all these processes, increasing the complexity of the predictions. Nevertheless, the relationships can be easily understood from one of the equations that link velocity and flow resistance, like the Manning equation (developed for conditions of uniform flow), which is very useful because it allows flow velocities (V) to be computed through differences in hydraulic roughness (n, Manning's roughness coefficient, a term that is directly related to resistance to flow):

$$V = 1/n \, R^{2/3} S^{1/2}$$

where R is the hydraulic radius and S the water surface slope.

It is obvious from this simple formula that an increase in roughness, *i.e.* the coefficient n, decreases the velocity. This is exactly what happens near river banks with mature riparian vegetation, which creates a resistance to flow and diverts the current to the middle of the channel. In spite of the difficulty in computing n with precision in natural channels (it involves a great number of tables, with correction factors) it is clear that the speed of the current decreases with increasing roughness. A common procedure to estimate n uses:

$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m$

where: n_b - base value for a smooth, straight channel (as in the tables), n_1 - correction for surface irregularities, n_2 - correction for variations in cross section size and shape, n_3 - correction for obstructions, n_4 - correction for vegetation, m - correction for the magnitude of channel meander

Among all these correction factors, it is generally the woody riparian vegetation (associated with n_4) that contributes most to the reduction in velocity, influencing near-bank flow hydraulics and bank erodibility. This is crucial in situations of bank instability. Moreover, this vegetation, with the effects of its roots on soil strength, bank morphology and bank hydrology, also has synergistic consequences for improving the stability of the river channel. The photos in figures 1.3.1 and 1.3.2 reflect the consequences of the phenomena illustrated by the above formulae in a Mediterranean gravel-bed channel with high energy in autumn, when flows peak to extreme values.

Figure 1.3.1 A stream in south Portugal (Odelouca) characterized by high hydrodynamism caused by infrequent floods leading to intense geomorphic processes. Where the riparian layer is not highly disturbed it acts as an effective resistance to flow, increasing n and diverting the flow to the centre of the channel, which avoids the collapse of the banks. However, colonization by exotic reeds, a first indication of fragility, can be seen in some spots.

The stems and trunks of riparian vegetation modify the distributions of near-bank velocity and boundary shear stress. This contribution is more significant in channels with width/depth ratios of less than 12 (see the compilation by Lawer *et al.*, 1997). In the near-bank zone, flexible vegetation reduces the velocities and shear stresses experienced by soil surfaces, primarily by shifting the velocity profile upwards, which turns the highest velocities away

Figure 1.3.2 The same stream in a more disturbed segment. The orchards have affected the riparian layer, decreasing the hydraulic roughness of such highly energetic systems. These channels have high sediment transport loads and their cross-sections are characteristically triangular at the bends, with a point bar on the inside of the bend opposite a steep, very eroded outside bank. In these situations the streams are far from dynamic equilibrium and the riparian vegetation is absent or exhibits little diversity or structure (with a dominance of exotic species).

from the soil boundary, and secondarily by damping turbulence. These authors consider that trees create very different hydraulic mechanisms compared to herbaceous vegetation and that the spacing pattern of woody vegetation increases the complexity of fluvial dynamics: tree trunks act as large-scale roughness elements, reducing velocities through drag. Nonetheless, although trees moderate extreme velocities near the banks, local pockets of instability may be promoted by the trunks, producing areas of accelerated flow and the heavy turbulence associated with wake zones, leading to erosion in some gaps in non continuous riparian layers.

It is not only live stems that are important for explaining fluvial hydrodynamics: large woody debris (LWD) also contributes significantly to the geomorphic processes. Accumulations of LWD may armour the channel bed and banks in some places, leading to sediment deposition, while in other reaches they may scour the channel, increasing erosion, through flow concentration and deflection (Piégay and Gurnell, 1997; Kondolf and Piégay, 2005). These compilations suggest the following main contributions of LWD to channel morphology:

a) Sediment storage, by influencing the distribution of stream power

b) Modification of the hydraulic characteristics and the dimensions and stability of the river bed, increasing the lateral connectivity of the main channel with the side channels and the riparian zone

c) structural complexity of channels, with considerable effects on the diversity of ecological habitats

d) dynamics of transport and deposition of the different fractions of particulate organic matter.

The relationships between the channel and the flows of water and sediments are empirical and the main problem is that they require a large amount of data referring to relatively long periods. Most of the formulae are derived from the following power functions (where the parameter D_{50} can be excluded for simplification).

$$w = k_1\, Q^{k2}\, D_{50}$$
$$d = k_4\, Q^{k5}\, D_{50}^{\ k6}$$
$$S = k_3\, Q^{k8}\, D_{50}^{\ k9}$$
$$Z = Z_0 = a + b\, e^{(-kt)}$$

where:
- w and d are reach average width and depth
- S is the reach average slope
- D_{50} is the median bed particle size in mm
- Q is the bankfull discharge in m^3s^{-1}
- Z is the channel bed elevation (at time t)
- Z_0 the elevation of the channel bed at t_0
- a, b and k_i are coefficients determined by regression, where a assumes positive values in the case of aggradation or negative ones in degradation conditions
- t is the period of observations since $t_0 = 0$.

When dealing with the stability of the river channel and the surrounding riparian zone, it is often more important to predict the extreme situations, for instance to express bankfull width (w_b) as a function of either mean discharge (Q), or bankfull discharge (Q_b):

$$w_b = k_7^{\ k10} \qquad \text{or} \qquad w_b = k_{11}\, Q_b^{\ k10}$$

These formulae also have the advantage that their coefficients and exponents are more stable than in the previous ones: for instance, k_{10} is generally a value around 0.50 and for gravel bed rivers, k_7 varies between 2.85 and 3.74 (Hey and Thorne, 1986; Stewardson, 2005).

Of course, the exponents and coefficients must be obtained for a specific stream or watershed and can only be extrapolated to other conditions if the substrate material or longitudinal geometry (meandering) is similar to the cases studied, because they exhibit high variation between regions. In order to facilitate access to reliable field data, the USDA (2000) published a compilation of writings by different authors, that includes coefficients and site descriptions for a wide range of geographical situations.

For Stewardson (2005), reach hydraulic geometry can be efficiently described by only three hydraulic variables: surface width, water depth and mean velocity. But as mentioned above, use of the formulae requires previous long-term studies unless similar conditions are found in the bibliography. Restoration of the riparian layer often demands a quantitative assessment of bank stability. In the case of cohesive banks, the occurrence of a failure, generally along a discrete surface deep within the bank, takes place when fluvial erosion at the toe of the bank leads to very steep bank angles and the weight of the bank material exceeds the cohesive forces.

The critical bank height (Hc) for planar failure is given by:

$$Hc = \frac{4c}{\gamma} \times \frac{\sin I\alpha \cos \phi}{1-\cos(I-\phi)}$$

In situations where extensive failures need to be considered, it is probably more appropriate to use the formula:

$$Hc' = (2c/\gamma)\tan(45 + \phi)$$

Where c is bank material cohesion (kPa), ϕ friction angle, I bank angle and γ the bulk unit weight of the bank material (kN m^{-3}).

These formulae may appear a bit frightening but, once again, they aim to illustrate the relations between the components. For instance, if the erosion creates a vertical profile in the river bank (increasing *I*) it decreases *Hc*, so the bank will probably collapse. Again, when planning to rehabilitate river banks, it is necessary to know that if a high bank angle is required, the bank height must be decreased unless more cohesive materials (*c* value) are used, with a high friction angle (*ø*). These terms stand for the possibility of relative movement of the internal particles, which depends essentially on their shape; less spherical particles are, of course, more stable. Still, if *Hc* needs to be determined, standard reference manuals provide the values for these two variables according to the local materials and no calculations or laboratory testing are required for practical purposes.

Using the last of the above equations, it is also possible to construct curves for different friction angles and consider saturated soils (the most dramatic premise) in order to calculate the critical vertical height from the bulk unit weight (figure 1.3.3). However, it must be remembered that these calculations refer to soils and do not consider colonisation by riparian vegetation. For instance, with mature riparian trees the Hc values can be increased significantly.

A simple overview of the knowledge of the stream is not complete without information on bedload transport. A wide range of equations has also been developed for this purpose, but none is universally applicable since they all rely mainly on empirical and experimental work, especially in flumes with uniform bed materials (Thorne *et al.*, 2003). Bearing these limitations in mind, the empirical relationship presented by Bathurst *et al.* (1987), which attempts to relate the critical water discharge per unit width (Q_c) with the median particle size D_{50}, is as follows:

$$Q_c = 0.15 g^{0.5} D_{50}^{\;1.5}\, S^{-1.12}$$

According to this formula, the stability of the river bed (high values of critical discharge) increases with the size of the particles but decreases with slope; this equation must be considered more appropriate for uniform bed materials, however. Similarly, stream power can also be related to bed particle size, defining its critical value ($\omega' = \omega/w$, where w is the channel bed width) as the power required to initiatiate bed sediment motion:

$$\omega' = 290(D_{50})^{1.5}\ \log\left(\frac{12d}{D_{50}}\right), \text{ where } d \text{ is depth}$$

Once again, this is a formula that provides useful information about the stability of the stream (within its naturally dynamic character): as the water depth increases it accepts higher stream energy, whereas shallow waters induce more turbulence and the displacement of bed particles.

Figure 1.3.4 shows the longitudinal trends of these hydraulic and morphological parameters, namely the generally opposite relationship between stream power and stored sediments and that ω peaks where *S* and *Q* are maximized.

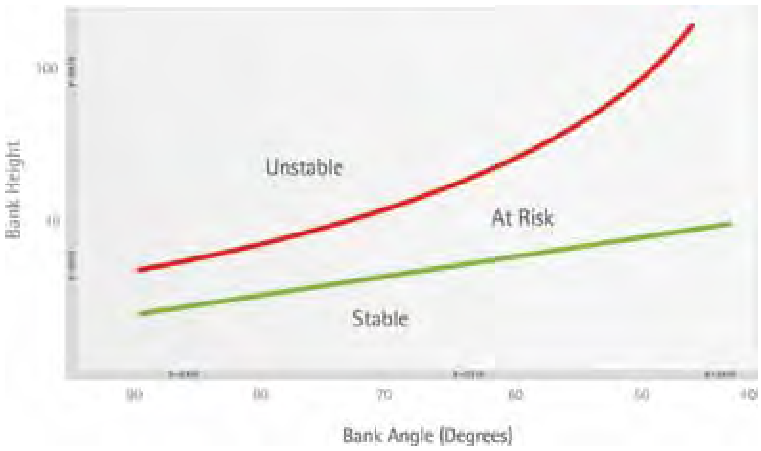

Figure 1.3.3 Bank stability chart to relate bank stability to height and angle (only indicated for saturated conditions). Bank height is in log scale. (Adapted from Kondolf and Piégay, 2005).

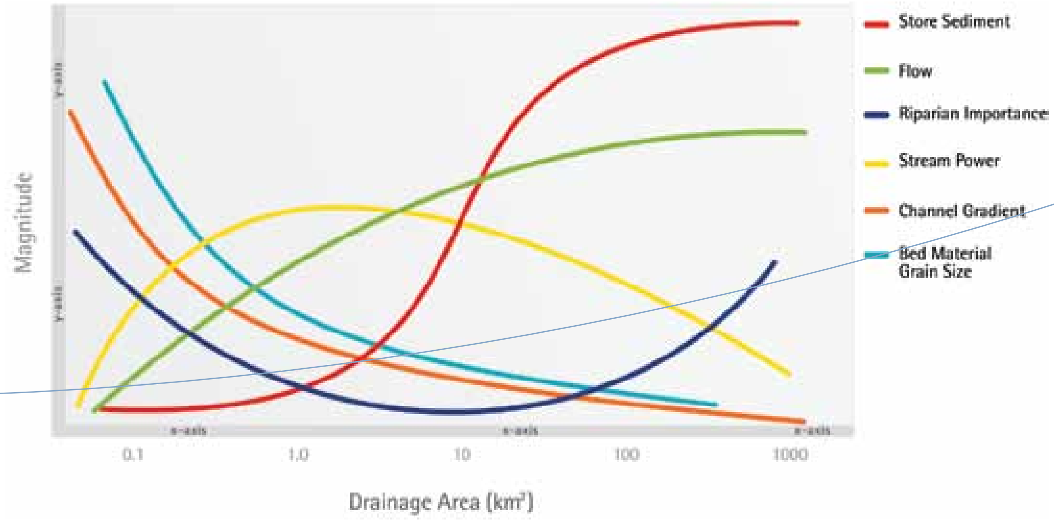

Figure 1.3.4 Longitudinal variation of hydrogeomorphological features (logarithmic scale) associated with the transport and deposition of sediments and the role of riparian vegetation (modified from Church, 2002). The importance of the riparian strip is controversial, since the downstream part of large catchments is generally fully regulated in European rivers. However, the intention is to express the role of this vegetation both in upland areas, where it is associated with the input of particulate organic matter, and close to the mouth, owing to its significance for wetland areas.

Riparian buffers: guidelines for determining their width and structure depending on the conservation objectives

Reviews by Wenger (1999) and Webb and Erskine (1999) of the scientific literature on this subject agree in some important respects:

- **Extent:** Buffers should be placed on all perennial, intermittent and ephemeral streams to the maximum feasible extent. This means that the riparian strip should follow the entire length of the stream, although taking into consideration that this is not possible in low order systems or when cliffs are an important feature.

- **Vegetation:** Riparian vegetation should be exclusively of native species in order to provide the most appropriate habitat and also to preserve genetic integrity and biodiversity. At a certain distance from the stream, harvesting may be accepted.

- **Width:** This parameter must rely on the main functions that the buffer is intended to perform: whereas control of fluvial erosion or habitats for aquatic species may be based on a narrow strip, aspects like sediment removal or nutrient retention require greater width.

- **Protection:** the rehabilitated corridor should be fenced off from stock.

These rules are not such a simple matter, especially the composition and density of vegetation and the width of the intervention, since they must be specified in much more detail for each situation. Concerning the width calculation, it should be mentioned that such a large number of works have been published, each with their respective formulae, that anyone who has to start dealing with this matter will firstly feel overwhelmed by the amount of information and will then try to seek help from outside the literature. There is even a reasonable number of computer programs designed to make this task easier, like the sophisticated REMM (Lowrance *et* *al*., 1998), which allows managers to determine water quality impacts with different simulated widths, after defining vegetation, soil and topographic conditions. Unfortunately, these models are either too data intensive or not calibrated and their variables are complex or difficult to obtain. However, the very simple procedures described below are adequate for specific objectives and may be accepted for most European conditions.

For a buffer strip to trap sediments and associated pollutants, Nieswand *et al.* (1990) proposed a direct relation between the width of the riparian strip (W) in metres and the percentage slope (S), with a coefficient k of 15 describing the standard buffer width for a slope of 1%:

$$W = k\,(S^{1/2})$$

This is, of course, a simple relation; criticism of it is based on the width of the buffer, which is clearly too wide for low order streams. In fact, a 15 % slope is the limit for this relation. Information compiled from a great number of authors for such streams gives the following formula, which is easier to adapt to most conditions:

$$W = 10 + c\,(S),$$

where S is again expressed in % and c is a coefficient ranging from 0.15 to 0.30 according to the topographic and geologic conditions (c decreases in headstreams).

This formula is more appropriate for rivers with higher gradients in low order streams, whereas the previous one is more appropriate for lower segments in sedimentary areas.

An excess of sediment can have numerous deleterious effects on stream biota. It reduces the habitat for fish and invertebrates when it is deposited in the stream bed and affects primary productivity by decreasing light transmittance, as well as acting directly by causing mortality in fish or in filter-feeding macroinvertebrates. For the riparian vegetation, a high accumulation of silt and fine sand may also reduce seed germination, causing eroded banks to remain unstable. Riparian buffers can contribute decisively to controlling stream sedimentation by:

- Trapping terrestrial sediments in the surface runoff
- Decreasing the velocity of sediment-bearing storm flows and river bed scour
- Trapping the suspended particles so that they settle in the bank instead of the river channel
- Stabilizing streambanks, so preventing erosion
- Trapping large inputs of woody debris, which then trap transported sediments.

Desbonnet *et al.* (1994) reviewed works on the subject with reference to the east coast of the USA and reported that increasing the buffer width by a factor of 3.5 provides a 10% decrease in sediment removal. They also concluded that high efficiencies were obtained with 60 m wide strips. This is far too large to be accepted in European headstreams. Wenger (1999) compiled contributions of different authors from different continents specifically for upland areas and stressed that in slopes ranging from 10 -15 % with dense riparian vegetation, it was possible to reach efficiencies above 80 % with widths of only 5 - 10 m.

Concerning vegetation guidelines, a great number of textbooks mention the proposal by Welsch (1991) of a three-zone riparian buffer system for agricultural areas: the first zone does not exceed 5 m and is placed near by the river, being composed of undisturbed forest with the role of erosion control; the second zone, up to about 25 m, is a more complex area where moderate harvesting may occur; it is designed for nutrient removal; while the third zone, with a maximum width of 7m, is a grassed strip with controlled mowing and grazing; its function is related to distributing the run-off along the slope in order to decrease the velocity of the water that flows into zone 2, which is essential for efficiency in decreasing the nutrient concentration.

Of course this is a good representation of a theoretical system with the principal aim of reducing non-point pollution, but it lacks practical adaptation because of topographical constraints and the difficulty of carrying out such specific management in each zone. Naiman *et al.* (2005) adopt the same criterion of the

3 zones but diverge with regard to their respective sizes and functions: zone 1 should exceed 10 m and must combine bank stabilization and shading with wildlife habitat creation and nutrient removal; here selective timber harvesting may occur; zone 2 is designed to slow flood waters when the banks are inundated and to increase landscape diversity, but consists of only one or two rows of native shrubs (minimum width 3-4 m); finally, zone 3 has a similar function and size to that described by Welsch (1991) (the priority is to reduce overland flow) and is composed essentially of grasses and forbs. However, studies on Mediterranean areas are lacking and even if there were no disagreement on the advisability of establishing different vegetation layers, in relatively arid areas it is more appropriate to organize the strips in accordance with the water availability and soil conditions of the site, using well-adapted local species (*e.g. Juncus* spp., *Tamarix africana, Vitex agnus-castus, Nerium oleander,* etc.)

Assessing the ecological integrity of riparian habitats

Naiman *et al.* (2005) consider that identifying reference sites is critical and is a fundamental aspect of assessment. Classifying riparian assemblages and riverine habitats also requires an integrated analysis of physical, chemical and biological factors. These authors compiled a summary of a large number of assessment techniques (twelve, almost all developed in the USA) but concluded that their application is sometimes questionable and that managers prefer 'realistic' rapid assessment methods.

In Europe most of the methods used are not specifically for analyzing the quality of the riparian layer. However, there are an increasing number of assessment protocols that include riparian characteristics due to their essential role in the functioning of fluvial systems. In Germany, for instance, the Working Group of the Federal States on water issues (LAWA, 1993) laid the foundations for the development of protocols that consider morphological and structural features of the river bed and the riparian zone when assessing the quality of surface water bodies. These protocols are being applied by managers in German speaking countries and continue to be improved (Muhar *et al.*, 2000; Kamp *et al.*, 2004). In the UK, where river quality assessment methods have been successively improved, the River Corridor Survey or RCS (NRA, 1992) and the River Habitat Survey or RHS (Raven *et al.*, 1997) are important tools. This last method, which uses a recognized reach-scale assessment technique, now covers all the geomorphological variation of Great Britain and Ireland. It has also been constantly modified to incorporate urban or heavily engineered rivers, adopting the name of Urban River Survey or URS (Davenport *et al.*, 2004), or for assessments in Mediterranean rivers (Buffagni and Kemp, 2002). In France, the SEQ-MP is probably the main technique for assessing river conservation status and has also been widely applied across the country. SERCOM (Boon *et al.*, 1997), QBR (Munné *et al.*, 2003) and RQI (González del Tánago *et al.*, 2006) deal mainly with riparian features. These last two indices were developed for the Iberian Peninsula. Whereas the QBR index does not use the reference condition and deals strictly with the condition of the riparian layer, the RQI links the state of this vegetation with the hydro-morphological characteristics of the river segment in question.

Historical data should not be forgotten, however. Piégay and Saulnier (2000) used a series of aerial photos covering a period of over 50 years to establish a map of the River Ain basin in France that documented spatial and temporal rates of channel mobility in order to predict the evolution of channel shifts, *i.e.* streamway zone width, and their future consequences for the riparian forest. While mapping riparian vegetation across entire watersheds to assess its integrity requires hard labour, progress on satellite imagery is making it possible to map the degree of conservation of riparian buffers even for narrow strips. This is possible thanks to the use of satellite imagery with moderate (20 – 30 m) and very high (1 – 5 m) spatial resolution, which give additional information and make these images comparable to aerial photographs. The advent of Lidar technology, a very helpful tool based on three-dimensional laser imaging of the vegetation cover (Goetz, 2006; for more information see chapter 5.3 of this book), has made it possible to map the height distribution of the vegetation in the buffer zones and to demarcate the precise limits between riparian forest patches and adjacent types of land cover. Information on remote sensing of riparian buffers has proved to be a good predictor of the ecological condition of streams, since it can be related sufficiently to stream health metrics like IBI (index of biotic integrity) scores (Van Sickle *et al.*, 2004).

Guidelines for streambank stabilization

In many situations, because of accelerated erosion, the banks need to be stabilized (by permanent or temporary techniques) prior to taking any necessary measures for the recovery of the riparian vegetation. This is absolutely indispensable when high rates of bank failure occur and plant establishment is virtually impossible. The authorities in charge of river management should always bear in mind that it is not possible to apply direct seeding or planting when the river banks remain unstable. Soil bioengineering bank stabilization systems are the most suitable for such situations. The objective is to facilitate a return to the natural functions and to create habitats that may provide support to aquatic communities and to those that use the riverine areas. However, these techniques (see table 1.3.1 below for the main groups of procedures and part IV in this book) should not be considered a panacea and must be performed by experienced personnel under the guidance of experts in a number of fields such as hydrology, soils, biology and forestry. Most of these techniques are illustrated by a few cases of restoration projects described further on in this chapter.

Table 1.3.1 should be complemented by observing figures 1.3.5 to 1.3.8.

Simons and Boeters (1998) define a few simple rules for work in the field to reinforce river banks:

a) Indicate clearly the area to be improved and places for depots

b) Define the necessary access restrictions

c) Determine in advance the most suitable period for the work (generally from the end of spring for soil movement and autumn for seeding and planting

d) Avoid nutrient input in the streams

e) Work as much as possible from the channel outwards

f) Avoid equipment that compacts soil in the riparian strip or damages vegetation it is important to preserve.

Table 1.3.1 Main procedures used to reinforce eroded river banks that should be used before or in combination with revegetation. These techniques are not independent and it is often advisable to combine different methods.

Techniques	Characteristics	Applications and Technical requirements	Effectiveness
Bank shaping and planting	Correcting the bank slope so that it does not exceed the critical height, preceded by toe reinforcement and followed by placing topsoil and planting	In streams with moderate stream power with low erosion levels, in conjunction with other practices	Enhance colonization of native species
Branch packing	Alternate layers of live branches and compacted backfill.	For eroded patches of streambank away from normal submersion	Rapidly establishes a vegetated bank providing quick soil reinforcement, also allowing colonisation by local species.

Techniques	Characteristics	Applications and Technical requirements	Effectiveness
Brush mattress	Continuous layer of live or dead branches, attached to the ground with live stakes.	Use above base flow levels when banks are threatened by high flows	Creates immediate protection, quickly restoring riparian conditions
Geotextiles;. coconut fiber roll	Natural fibers placed over the banks and attached by dormant cuttings; coconut rolls are staked near the toe of the bank	Appropriate after bank shaping where moderate stabilization is required in the absence of high shear stress	Besides decreasing erosion along the entire bank, provide conditions that increase soil humidity, which increases the viability of rooted plants
Dormant post planting	Tree planting along streambanks to increase hydraulic roughness	More useful in semi-arid areas or in banks with reduced sloughing	Quickly establishes riparian vegetation and reduces stream velocities near the banks
Vegetated gabion	Wire-mesh baskets filled with cobbles and boulders, covered with soil, where live branches are introduced to root	More appropriate for steep slopes and in high stream power conditions, requires a stable foundation; can be used only at the base of the bank	Gives high channel toe protection for steep banks where other techniques may fail
Riprap or stone toe revetment with joint planting	Cover of rock material (from stones to boulders) with live stakes introduced into the openings	To be used in areas subjected to high erosion, often after previous geotextile revetment, and where correction of bank angle is difficult	Long term durability in moderate slopes and moderate to high stream power, like the outside of bends
Live cribwall	Interlocked boxes of logs alternating with filling layers of soil and live branch cuttings	Interlocked boxes of logs alternating with filling layers of soil and live branch cuttings	Provides a natural appearance in comparison with gabions or rip rap, and rehabilitates banks that had a high soil loss
Live fascine	Rows of branch cuttings evenly spaced along the entire slope, or only in the interface between the water and the bank (for low flow conditions), and partially covered by soil	Can be generally applied in low slopes; often requires bank shaping and toe protection	Allows colonisation by natural vegetation, but does not resist high water velocities and must be combined with other bioengineering systems
Tree revetment	Row of attached trees over the toe of the streambank, anchored to the base	For use in medium order streams where wood material is available	Very effective in increasing hydraulic roughness, creating conditions to reduce the current and trap sediment
Vegetated geogrid	Live branch cuttings arranged in alternate layers perpendicular to the bank, with compacted soil placed over geotextile	Especially recommended for high slopes excavated by the stream, but may require a stable foundation or even toe protection when strong currents are frequent	Quickly establishes a thick layer of riparian vegetation, but may affect natural colonisation.

Techniques	Characteristics	Applications and Technical requirements	Effectiveness
▪ Wing deflector	▪ Structure made of boulders, or of barriers of live cuttings, that penetrates into the channel	▪ Can be used in low or medium order streams, especially in agricultural areas where the stream was channelled; when arranged alternately on both banks, produces a meandering thalweg.	▪ Deflects flow away from the bank and has the ability to constrict the channel by accumulating sediments near the bank and removing them from the middle of the channel, besides increasing the physical heterogeneity and, consequently, the diversity of the habitats

Applications

Three cases where some of the techniques mentioned in table 1.3.1 have been applied are presented briefly below (Cortes *et al.*, 2004; Boavida *et al.*, 2008). The rehabilitation objectives and physical characteristics are quite distinct in each case but they share one important aspect: these structures should not be applied extensively but adapted to each spot, taking account of the natural variability along the selected river segment, the different degree of stability of the banks and the need to develop the riparian vegetation.

It is also necessary to define the right scale and to gather relevant ecological information from the catchment by conducting an appropriate inventory of the biological elements and the associated physical environment. Not only will this prior field work make it possible to define the present situation, *i.e.* the reference state, so that the relative efficiency of the interventions can be assessed in the future thorough a monitoring program, it is also essential in order to analyse the linkages between the selected area and the surrounding ecosystems. Therefore, such observations should encompass a larger area, not confined to the strict limits of the site where the bioengineering techniques are going to be employed. Besides, such a survey is very useful for setting the goals of the project more precisely.

In the cases presented here, the assessment showed the deviation between the affected areas and those around them and allowed the objectives of the rehabilitation to be defined: while in the River Odelouca extensive rehabilitation was more advisable, the Estorãos and Tâmega rivers needed active intervention in a relatively more limited segment.

In the first case, R. Odelouca, located in the south of Portugal, the same river presented two contrasting situations: upstream and downstream from a new water supply reservoir. This is a river with typically Mediterranean influences, running through sedimentary layers, with a dynamic river channel strongly influenced by flash floods. Additionally, it is surrounded by intensive soil use, dominated by orchards which extend into the poor riparian strip where native vegetation has been replaced by exotic species, mainly giant reed (*Arundo donax*). A laborious appraisal of the problem in all the catchment concluded that measures to stop the enlargement of the channel in the most critical reaches upstream of the reservoir were required (see figure 1.3.5 for an observation of the multiple techniques designed for this segment in order to stabilise the banks and river bed, as described in table 1.3.1). Downstream of the dam (figure 1.3.6), on the other hand, even if it was necessary to control erosion, the priority was to address the entirely new hydrological conditions arising from the considerable modification of natural flow regimes caused by the regulation of the river (which even made it necessary to define a minimal instream flow). Here the design included modifying the river bed by laying out a meandering new channel in a segment where the river had been progressively excavating the river banks. The purpose was to allow a reasonable water depth in order to create the conditions for the threatened fish populations to complete their life cycle (two species are endemic to this region). This new channel is stabilized by rock rolls or gabion rolls, flexible "sausages" of local rock material in nylon or wire netting to which plant rolls are fixed or in which soil and seeds are introduced. Deflectors and rock islands are introduced along the channel to incorporate shelters for the aquatic community. The rest of the river bed (former channel) will be improved (filled with soil and bio-degradable geotextile) to receive several rows of native hygrophylous species (reeds and shrubs), while a geotextile revetment on the original banks will provide suitable conditions for willows and alders.

Mattresses of the cut and dried material of the exotic Giant Reed will be extensively applied in the upstream and downstream sections of the river, covering the banks and followed by post planting, to avoid the extremely rapid invasion of this species.

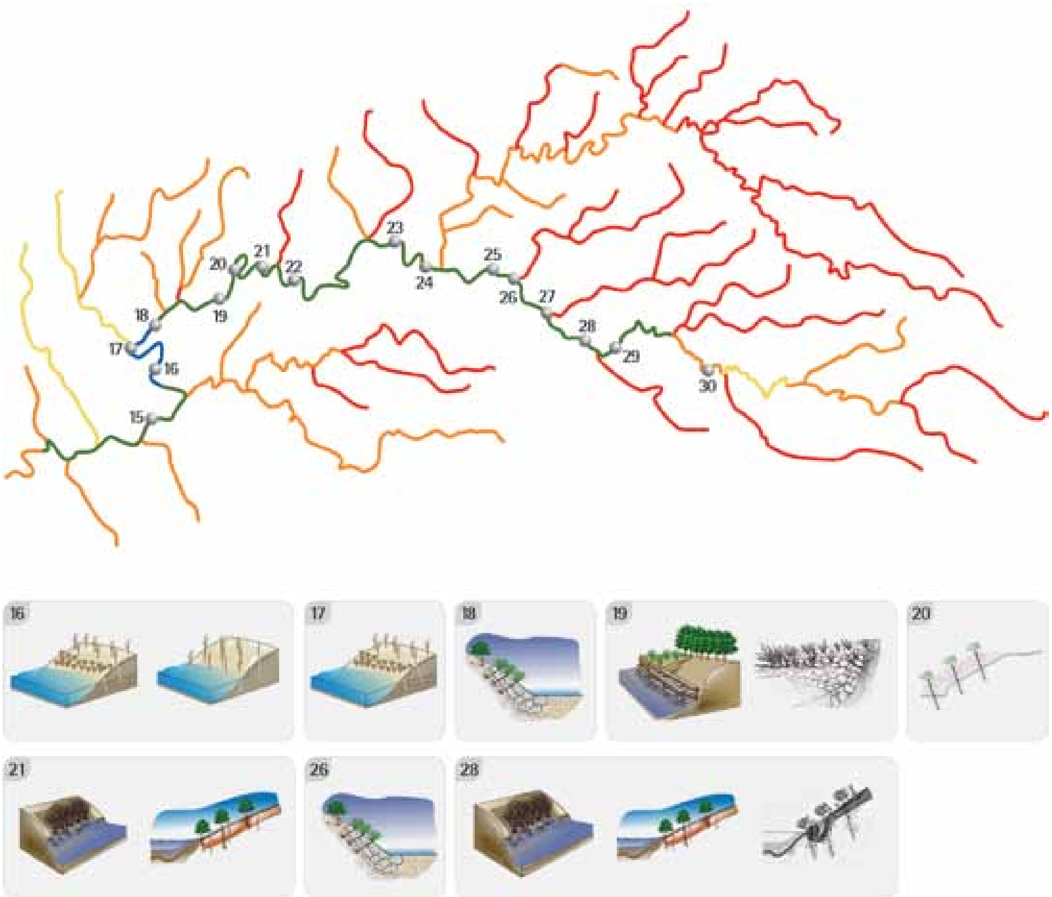

Figure 1.3.5 Illustration of the different techniques used to enhance the river channel in the upstream area by protecting the banks and improving the riparian layer. They include bank shaping and planting (16 and 17), brush mattress (21a and 28a), dormant post planting (trees and shrubs) with geotextile (21b and 28b), vegetated gabion (20), vegetated rip rap (18, 19b and 26) and cribwall (19a). Numbers correspond to monitoring sites along the river.

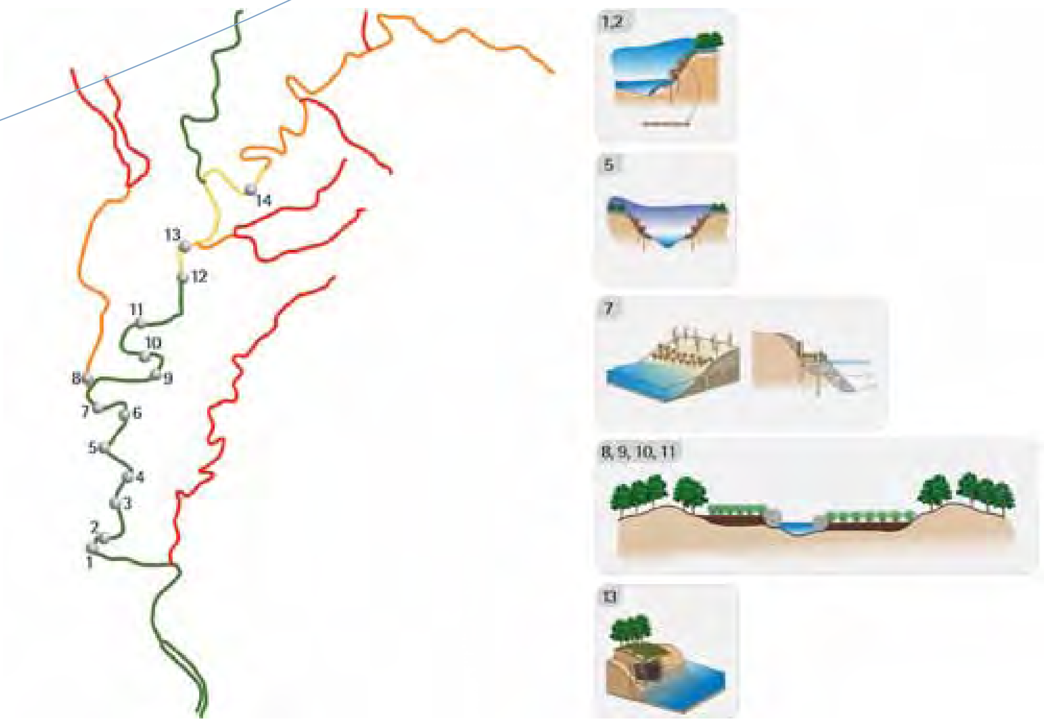

Figure 1.3.6 Design of the techniques to improve the downstream section of R. Odelouca, which will be affected by flow regulation. There is a combination of soil-bioengineering techniques to stabilize banks with a procedure to create a sinuous low flow channel in the over-wide part to contain the reduced flow coming from the reservoir (in sites 8-11). This procedure uses rock rolls to edge the excavated channel; different riparian layers are defined, from herbaceous plants and shrubs next to the wet channel (which requires the deposition of soil) to riparian trees near the original banks. In the narrower downstream section, the gradient of the bank slopes is corrected by creating terraces supported by post walls.

The intervention in the river Estorãos (figure 1.3.7) was designed to consolidate the collapsing banks, the result of previous bottom dredging which caused the critical height of the banks to be exceeded. This was the first step towards the subsequent establishment of vegetation and towards avoiding the deposition of fines in the river bed, which was also affecting the spawning of migratory fish (Lamprey) and Brown Trout. In order to decrease the visual impact and increase the physical heterogeneity, different techniques were combined according to the instability detected along the river segment, namely gabions, different types of rip rap (variable height: from stone toe protection to a complete rip rap revetment), stone wing deflectors and organic fibre rolls, besides simple bank shaping followed by planting. Visual mitigation of the artificial structures was achieved by using live stakes of native vegetation or joint planting in the rock rip raps and gabions.

In the artificial ponds of the river Tâmega (figure 1.3.8), the result of previous sand and gravel extraction, the main objective was to favour recreational activities.. Also, the inventory showed a dominance of exotic fish species because of radical habitat disruption. The use of artificial structures was strictly limited to the spots were it was necessary to stabilize the banks or to protect them from the pressure of visitors. In the other areas extensive habitat improvement was preferred, removing the remains of previous human activities, cutting weeds and creating the conditions for a natural bank appearance with a more diverse riparian layer. Figure 1.3.8 illustrates the procedures used along the main area chosen for rehabilitation (left bank). This was where the short term rehabilitation priorities focused, as it offers better accessibility to visitors and had suffered a greater impact from the accumulation of soil heaps and the alteration of the soil cover. As the right bank was not seriously affected by the extraction activities and still preserved its natural vegetation, it remained unchanged.

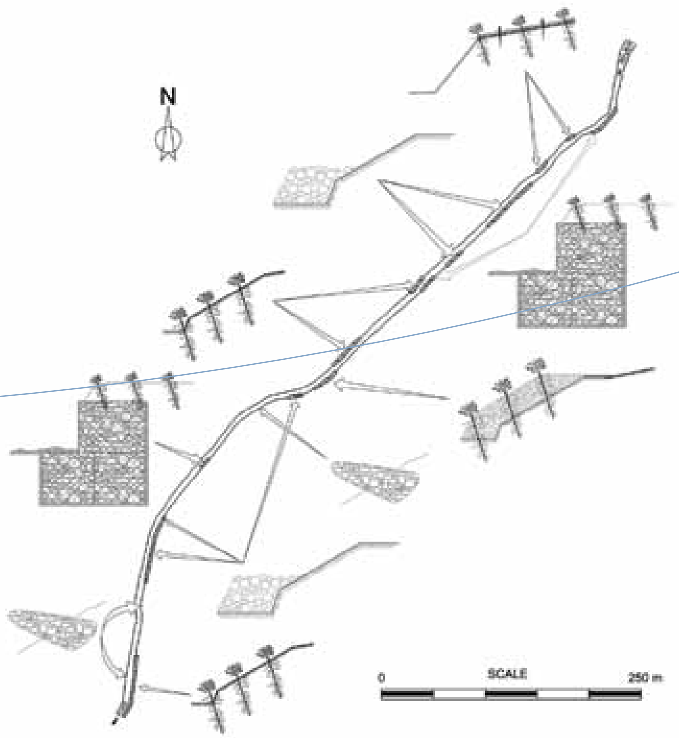

Figure 1.3.7 Distribution of selected stream bank stabilisation techniques along the target segment of River Estorães (about 1 km). The use of vegetated gabions, different forms of rip rap with joint planting, wing deflectors and bank shaping with vegetated geogrids (soft gabions) may be observed.

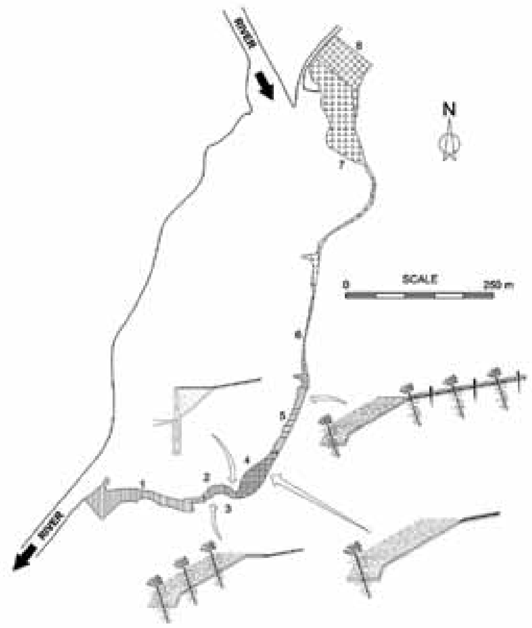

Figure 1.3.8 Examples of the mixed techniques used for rehabilitation along one of the banks of the widened channel of the River Tâmega. From downstream to upstream: 1. rip rap and establishment of sods and grasses; 2. rip rap and joint planting; 3. post wall: 4. toe rip rap and bank shaping covered with grass; 5. toe rip rap and branch mattress (with live stakes); 6 and 7. weed cutting and removal of soil heaps; 8. recreational area.

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Biodiversity Descriptors. Rivers as Ecological Corridors

VEGETATION AND FLORA OF RIPARIAN ZONES

Panayotis Dimopoulos
Stamatis Zogaris

Introduction

A remarkable number of recent scientific studies have proven the outstanding importance of riparian vegetation for maintaining a rich and distinctive biodiversity (Tockner and Ward, 1999; Poiani *et al.*, 2000; Décamps and Décamps, 2002). Riparian vegetation features have often been called "linear oases" since they harbour scarce resources and conditions found nowhere else in the surrounding landscape (González-Bernáldez *et al.*, 1989). Especially in open non-wooded or agricultural landscapes, the native riparian woodland maintains "an importance out of proportion to its extent" (SNW, 2000). Furthermore, riparian zones have been termed "critical transition zones" which serve as conduits for substantial fluxes of materials and energy between both terrestrial and aquatic ecosystems (Ewel *et al.*, 2001). These dynamic transitional zones and their distinctive vegetation provide important "ecosystem services" ranging from nutrient filtering to flood-protection (Naiman *et al.*, 2005). Understanding region-specific vegetation dynamics in riparian zones is critical for making generalisations transferable to management, conservation and restoration (Middleton, 1999; Nilsson and Svedmark, 2002).

The scientifically-based management of riparian vegetation is not a simple procedure. Riparian zones are considered "among the biosphere's most complex ecological systems" (Naiman *et al.*, 2000). One of the problems encountered when striving to conserve and manage riparian zones is that they are often very heterogeneous, unstable systems, difficult to classify into predictable systemic entities (Bunn *et al.*, 1999; Goodwin, 1999). Due to their patchy and frequently "disturbed" vegetation formations, conservation practitioners must cope with complicated management problems. Misunderstanding and neglect have very often led to mismanagement.

Natural riparian vegetation communities are considered one of the most anthropogenically disturbed and threatened natural habitat types in Europe. Over 90% of the large river floodplains have already been modified by river engineering or have been cultivated and are therefore considered "functionally extinct" (Tockner and Stanford, 2002). Some types of riparian vegetation have been altered so much that they are difficult to imagine in their natural state (Wenger *et al.*, 1990; Angelstam, 1996; Chytry, 1998). In many parts of Europe and on other continents also, important small relics of riparian forests often exist away from official protected areas and are very vulnerable to anthropogenic pressures (Hughes, 2003; Natta *et al.*, 2002). There is an urgent need to preserve existing intact riparian woodlands and to speed up a pan-European effort to restore native riparian vegetation along rivers on this continent (Tabacchi *et al.*, 1998).

This chapter provides a review of fundamental concepts concerning riparian vegetation and flora, with a focus on riparian woodlands. Emphasis is placed on riparian woodlands since they epitomise natural riparian woody vegetation over most of Europe and are considered one of the most vulnerable riparian zone features.

Attributes and definitions

One of the most perplexing issues in river ecology involves the precise definition and delineation of riparian zones and their associated vegetation (Verry *et al.*, 2004). Although important progress has been made during the last two decades, there are no universally accepted delineation criteria for riparian vegetation (Baker, 2005; Naiman *et al.*, 2005). Since riparian zones are usually considered part of an ecotone, an "ecological boundary" between the terrestrial and aquatic realms, it is especially difficult to create classification criteria to identify riparian types and their boundaries. In a strict sense, the riparian zone with its adjacent stream is sometimes not considered a distinct self-regulating ecosystem with recognisable boundaries (Lampert and Sommer, 1997). Riparian zones are often conceived of as a mixed transition zone where different environments meet; however, these zones have distinctive and recognisable properties and may be conceived of as "open systems" harbouring unique and recognisable river-side features (Gregory *et al*., 1991). Despite these conceptual discrepancies, certain descriptive region-specific definitions and delineations of riparian zone types are effective for inventory and management when investigations are well-designed (Harris, 1988; Naiman, 1998; Aguiar and Ferreira, 2005).

Evolving definitions

Riparian zone definitions are still evolving and even the word "riparian" has only rather recently been used to define particular vegetation communities. Reference to river-side woodlands (often variously termed riparian, alluvial, gallery or riverine woodlands) in various European languages has been frequent throughout the latter half of the last century, but the particular definitions vary (Yon and Tendron, 1981; Décamps and Décamps, 2002). Riparian zones and their vegetation classifications are today increasingly multidisciplinary and hierarchically structured; hence, slightly differing region-specific and purpose-specific definitions will probably persist.

A comprehensive operational definition for practical delineation of riparian zones and their vegetation must derive from our understanding of the region-specific lotic environment and the specific purpose or needs of the riparian vegetation delineation scheme. It is important to remember that when working with riparian vegetation from a management perspective, the practical concept of riparian zone should strive to follow a conceptual continuum successively encompassing three important factors: definition, delineation and resource estimation (Verry *et al*., 2004).

Two definitions for a management approach are given below: a broad vegetation-based definition of riparian zone and a practical definition to guide the delineation of riparian woodlands.

Riparian zone vegetation

Naiman and Décamps (1997) give the following much-cited definition of lotic riparian zones which also includes a reference to specific vegetation qualities: "the riparian zone encompasses the stream channel between the low and high water marks towards the uplands, where vegetation may be influenced by elevated water tables or flooding and by the ability of soils to hold water". This generic definition presumably does not include the stream's aquatic portion although it does include the stream's edge – the area that is usually defined as the active channel (see figure 2.1.1). This definition has gained wide acceptance since it defines riverside areas where surface and subsurface hydrology connect water bodies with their adjacent uplands and influence the extent of hygrophytic vegetation (NRC, 2002; Décamps and Décamps, 2002; Baker, 2005).

Riparian woodland

It has become important to focus on a specific definition for the distinctive and usually recognisable woody vegetation adjacent to a stream or river (Verry *et al.*, 2004). Riparian woodland has often been used to help delimit the riparian zone; for example, Hunter (1990) refers to the riparian zone as "the band of forest that has a significant influence and conversely is significantly influenced by the stream". Therefore, we suggest that a riparian forest or woodland should be dominated by hygrophytic woody vegetation and should interact with surface and subsurface waters through a strong functional and structural relationship with its adjacent lotic waterbody.

In order to create an operational delineation of riparian woodland, it is important to use criteria that are easily and practically assessed on the ground. Riparian woodlands usually create streamside bands of woody vegetation (dominated by trees and high shrub), usually beginning at the immediate edge of the stream's active channel (Stromberg, 1997). The first perennial woody vegetation that forms a lineal band of vegetation near the water's edge can be denoted by an imaginary line which we will call the "woody greenline" (a concept modified from Winward, 2000). The riparian woodland extends landwards towards the upland terrestrial realm where topography and soil dryness exclude the dominance of hygrophytic vegetation; the lineal boundary where the true terrestrial vegetation begins defines an imaginary "woody brownline" (figure 2.1.1). "Woody brownlines" are much easier to delineate in semi-arid or agricultural landscapes, although even in forest landscapes vegetation changes are strongly influenced by soil wetness and microtopography. Of course, these two linear conceptual boundaries may often be fuzzy; but for practical definition and inventory purposes they could be useful guides, as Winward's (2000) much-cited approach has shown (Verry *et al.*, 2004).

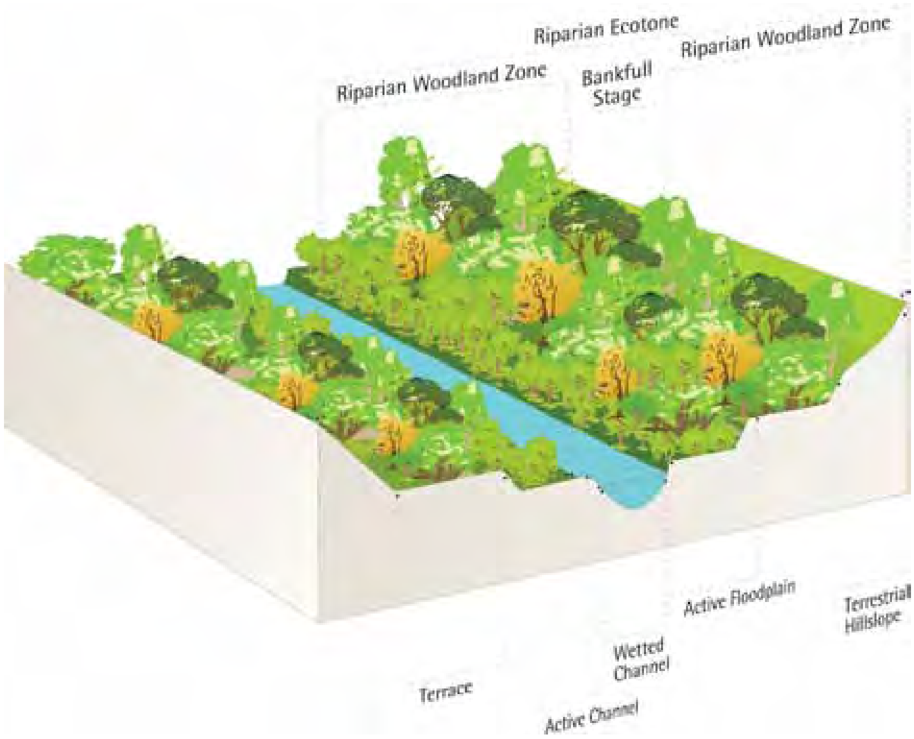

Figure 2.1.1 Sketch of the 'riparian ecotone' and the streamside 'riparian woodland zone', which is a component of this ecotone and is defined by the dominance of hygrophilous woody vegetation and by its topographic proximity to the river's active channel.

The vegetation

Riparian vegetation and floral characteristics

As mentioned above, riparian plants —especially woody species— are often used for identifying and characterizing riparian zones, so the floristic assemblages are important in researching, planning and managing these areas.

Riparian vegetation usually includes very physiognomically and floristically heterogeneous vegetation assemblages. These vegetation formations have, in part, the capacity to change rapidly both over time and with regard to the space they occupy. As a result, riparian zones are composed of characteristic assemblages that are sensitive to particular environmental conditions or disturbances. Riparian vegetation is usually dominated by characteristic hygrophilous species since riparian soil is saturated within rooting depth for at least part of the growing season. Most plants and plant communities of riparian zones on floodplains are adapted to mechanical stress from water flow as well as substantial fluctuation in water levels with frequent changes due to inundation; for example, flooding in the winter, spring and early summer, and dry periods in the summer and autumn. They are able to survive such flood events without permanent damage or can regenerate rapidly if damaged (Bohn *et al*., 2004). Most importantly, this vegetation differs considerably in structure and function from adjacent terrestrial vegetation; compared to the surrounding landscape, riparian woodlands often hold the most floristically distinctive and structurally diverse vegetation (Nilsson *et al*., 2002; Baker, 2005).

Woody plants determine the structure of riparian woodlands and dominate as over-story life-forms. Of these, deciduous broadleaved trees (*Salix* spp., *Populus* spp., *Ulmus* spp., *Fraxinus* spp., *Alnus* spp., *Prunus* spp. and *Quercus* spp.) are the most frequent; more rarely, conifers (in the north of Europe and in the mountains) or evergreen hardwoods are found, usually as companions or sometimes forming stands in mild-winter Mediterranean areas.

Under-story plant assemblages are also often diverse. Hemicryptophytes and geophytes are regularly present. The latter play an important role, particularly in the (early) spring aspect of deciduous floodplain forests on nutrient-rich soils. For floodplains in more humid and warm areas, lianas that sometimes grow up to the tree tops are also characteristic (Bohn *et al*., 2004).

Characteristic plants of riparian woodlands include specialist species that exploit the humid conditions and high water table associated with the river's fringes. As mentioned above, these species possess particular adaptations to life in riparian zones. Riverside conditions create constraints that act as an ecological filter to select those species that are most suited to establishing themselves and persisting. For example, only a few tree species can survive very long periods of inundation; these include, particularly, poplar *Populus*, willow *Salix* and alder *Alnus* (Middleton, 1999). In this way, prolonged flooding alone may determine forest type in a particular vegetation band along the river. The species-rich Oak-Elm-Ash (*Quercus-Ulmus-Fraxinus*) woodland can only develop on higher, less-frequently flooded ground than Willow-Poplar (*Salix-Populus*) formations (Ellenberg, 1988).

Evidently, water availability and water action drastically affect the plant species composition within riparian areas, but not all woody plants are dependent on surface water availability. For example, some riparian species such as Planes (*Platanus* spp) are phreatophytic; they are hygrophilous species which rely on groundwater availability, not just on the surface water in the adjacent river channel (Dawson and Ehleringer, 1991).

These species are very capable of coping with great surface water flow variability (Stromberg, 2001); because of this, species such as Oriental Plane (*Platanus orientalis*) are widespread along a major part of the longitudinal gradient in many rivers of the southern Balkans (see figure 2.1.2).

On the basis of their ecological strategies in riparian zones, riparian plant species can be classified into four major types (Naiman and Décamps, 1997):

a) Invaders – produce large numbers of wind and water-disseminated propagules that colonize alluvial habitats;

b) Endurers – resprout after breakage or burial of either the stem or roots by floods or after being browsed by animals;

c) Resisters – withstand flooding for long periods during the growing season;

d) Avoiders – lack adaptations to specific disturbanc types (*i.e.* individuals germinating in an unfavourable habitat do not survive).

Many specialist hygrophilous species can endure in the semi-aquatic conditions found in wetlands, which are commonly present within riparian zones.

On the basis of the probability that a species will survive in wetland sites, plant species wetland indicator values have been developed (Mitsch and Gosselink, 1993). For example, a simple North American system (US FWS, 1996) places riparian plant species into five categories along a wetland-upland gradient with the following categories: Obligate Wetland, Facultative Wetland, Facultative, Facultative Upland, Upland (for an application see Baker 2005).

Species-rich transitional zones

Depending on the geographic region, riparian vegetation formations are often several times richer than those found in surrounding terrestrial or aquatic habitats and usually harbour specialised species restricted to these riverine semi-terrestrial areas (Sabo *et al.*, 2005; Naiman *et al.*, 2005; Nilsson and Svedmark, 2002). This species richness is explained mainly by the following:

1) Flooding, surface and ground water flow regimes; these mainly create the remarkable spatial and temporal heterogeneity of riparia.

2) Lateral variation adjacent to the river: variations in micro-topography and geomorphology, soils and groundwater levels; this is usually the result of lateral river channel movements forming both a mosaic and a micro-zoning of vegetation patterns with different disturbance histories and different successional progressions and regressions.

3) Longitudinal variation: environmental gradients varying along an upstream-downstream progression; they vary in effect depending on elevation, relief, stream and riparian zone size and dynamics.

4) Climate and microclimate, which also vary with altitude and relief and are affected by topography (*e.g.* ranging from gorges to floodplains).

5) Upland valley features which cause frequent geomorphologic disturbances in riparian zones, such as landslides, mud flows and avalanches, which in turn create heterogeneity and re-set successional stages (Naiman, 1998).

6) Plants use riparian areas as migration corridors. As rivers often flow through different biomes, they transport species along their corridors; alpine species are frequently found in river corridors at much lower elevations. As a result, riverine riparia are gathering places for a region's floristic diversity (Nilsson and Svedmark, 2002).

Species-richness varies in rivers, usually following a longitudinal pattern, from the headwaters to the estuary. Ward and colleagues (2001) provide a longitudinal generalisation identifying three broad types of fluvial units and their relative species-richness patterns. This generalisation includes:

a) constrained river unit which shows an increase in biodiversity downstream;

b) a braided river unit with relatively low species richness; and,

c) a meandering river unit with high diversity. In most temperate rivers, species richness is usually higher in the middle reaches in natural river formations, although certain habitats may be poorer (*i.e.* braided reaches) or richer (*i.e.* lowland riparian wetlands) (Décamps and Tabacchi, 1994; Nilsson and Svedmark 2002).

Conceptual generalizations concerning riparian woodland classifications

Increased attention to riparian vegetation management has generated a need for more specific inventory and classification systems (Pettit *et al.*, 2001; Ferreira *et al.*, 2001; Goodwin, 1999; Leonard *et al.*, 1992). Classification is crucial in order for research to move on to empirical relations and then to a theoretical understanding of fundamental riparian-vegetation patterns and processes (Ward *et al.*, 2001; Tabacchi *et al.*, 1998). Classification is also vital in order to be able to describe type-specific reference conditions, a process which is especially important for ecological assessment and for building restoration goals (Aronson *et al.*, 1995; Ferreira *et al.*, 2002).

Initially, most plant-based classifications of riparian woodlands were simple and descriptive and were usually based on phytosociological units (Van de Winckel, 1964; Gradstein and Smittenberg, 1977). Much attention was given to the "uniqueness' of remnant stands and many natural history descriptions helped delineate the distinctiveness of varied riparian vegetation (Carbiener, 1970). Later riparian vegetation patterns were described in relation to strong longitudinal and lateral gradients, associated primarily with water availability (Chessel, 1979; Dister, 1988). More advanced classification methods recognized that both hydrologic and geomorphologic processes shape vegetation patterns (Montgomery, 1999) and attempts have been made to incorporate these into classification schemes (Hupp and Osterkamp, 1985; van Coller *et al.,* 1997; Aguiar *et al.,* 2005).

Several classification systems based on riparian vegetation patterns use plant community type as the fundamental classification unit (Ellenberg, 1988, Naiman, 1998). Plant community type is defined either by the present floristic composition (actual vegetation) or the potential natural vegetation (Swanson *et al.,* 1988; Chytry, 1998). Stratification of community types is based primarily on the over-storey or on a combination of over-storey and under-storey vegetation, although the over-storey or canopy vegetation is a better integrator of long-term patterns at the landscape scale (Forman, 1995; Harris, 1999). One effective classification scheme for natural riparian areas combined natural plant community types and geomorphologic features in order to delineate distinctive stream-vegetation valley types (Harris, 1988).

Related to this is a plant-based classification method of mapping "vegetational complexes", a region-specific classification that considers "spatially-associated plant communities within a relatively homogenous part of the landscape" (Schwabe, 1989; Corbacho *et al.*, 2003). As with other biotic classification systems, the most valuable schemes focus on relationships to biotic-relevant physical environmental factors.

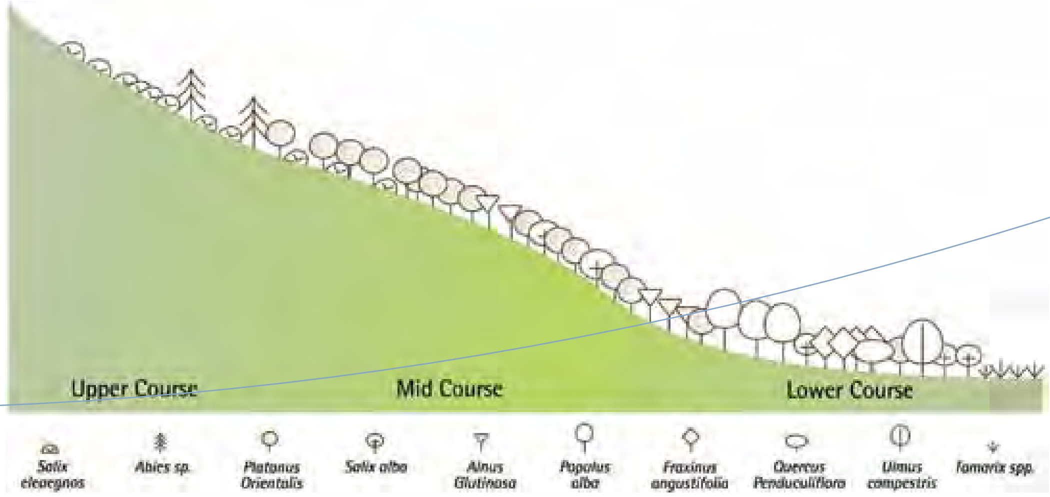

Figure 2.1.2 Generalization of natural longitudinal change in the major streamside hygrophilous tree species along the rivers Acheloos and Alfios, Western Greece. The lower mid-courses and lowlands harbour the largest number of hygrophilous woody species, since riverine flood-plain habitats are much larger here and large karstic springs produce large perennial flows and rich wetlands. Note the dominance and wide distributional breadth of a phreatophyte, the Oriental Plane (*Platanus orientalis*).

Generalizations about water flow types in riparian areas

Simple examples of attempts to categorise stream types and their riparian zones have often concentrated on the river's surface water flow typology (Uys and O'Keeffe, 1997; Ward *et al.*, 2001; Hansen, 2001). Riparian vegetation is often important in highlighting the distinctiveness of three hydrographically very different stream types, perennial, intermittent and ephemeral (figure 2.1.3), which have long been mapped and inventoried in relation to stream ecosystem types (Leopold, 1994; Gordon *et al.*, 2004). Perennial streams have visibly flowing surface water throughout the year. Intermittent streams are more variable and are typically without water in the drier months. Water appears on the streambed only during the wetter season or for prolonged periods after precipitation events. This occurs because underground water is sufficiently close to the soil surface to rise above the surface after being recharged by precipitation. Therefore, intermittent streams have an important connection with ground water; in contrast, ephemeral streams usually do not. This creates distinct hydrological and vegetation characteristics that usually help in distinguishing intermittent streams from ephemeral streams. In most cases, only perennial and intermittent streams can support riparian vegetation that behaves as functioning riparian vegetation communities. Although water does flow down ephemeral streams (*e.g.* storm water), the water table is usually not sufficiently close to the soil surface to allow hygrophilous vegetation to access the greater quantity of water it needs to grow. Vegetation growing along ephemeral streams may be more densely structured, or grow more vigorously, but generally there are no dramatic differences in composition compared to the surrounding upland vegetation. There are exceptions to this, as has become evident from many relative studies (Radabaugh *et al.*, 2004) which lead to the conclusion that the distinction between ephemeral and intermittent streams should be primarily based on the hydrological regime and secondarily on the vegetation. In a seasonally-arid climate where dryland rivers dominate, the duration of surface water flow usually sets the level of environmental harshness (Giller and Malmqvist, 1998), so this distinction is important and usually plays an extremely important role in the riparian zone's natural vegetation composition.

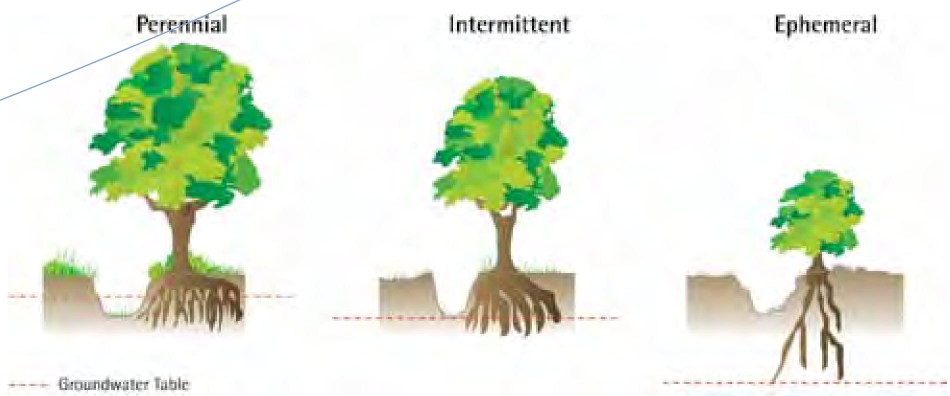

Figure 2.1.3 Generalised scheme of perennial, intermittent and ephemeral streams and associated woody flora. Modified from Baker (2005).

Perpetual Succession

Many researchers have attempted to group riparian plant assemblages and relate them to environmental factors (Haslam, 1987; Szaro, 1990; Aguiar *et al.,* 2000). Often, many of these attempts are confounded by frequent spatio-temporal changes in these communities, related to a multitude of successional patterns (Barker *et al.*, 2002). The frequent natural changes in riparian zones create conditions that have been called "perpetual succession" (Campbell and Green, 1968). There are still varying views of the role and significance of successional patterns in riparian systems and researchers are still probing the importance of ecosystem-level processes versus population-level processes (Mitsch and Gosselink, 1993; Middleton, 1999). As mentioned above, this dynamism is largely responsible for the remarkable environmental heterogeneity of riparian zones. Typically, the vegetation of riparian areas usually includes a range of successional stages. When human activities influence and confound natural disturbances, the patterns encountered in riparian vegetation communities may be multiplied or, in vivid contrast, a depauperated, simplified, species-poor vegetation may result (Décamps *et al.*, 1988). The characteristics of riparian vegetation also vary with the areal extent of the river systems: small riverine areas beside intermittent streams are usually less diverse than along larger rivers. Typically, riparian zones frequently also contain wetland habitats, which may be termed floodplain or riparian wetlands, creating a variety of aquatic and semi-aquatic environments such as ponds, reed-beds and swamp forests within the riparian zone (Mitsch and Gosselink, 1993).

Is riparian vegetation wetland vegetation?

In the recent past riparian zones were considered types of wetland habitat (Mitsch and Gosselink, 1993, Swanson *et al*., 1988; Cowardin *et al*., 1979; Johnson, 1978). In recent years, in most inventories and reviews, riparian zones are considered to be distinct from wetlands, although differences from wetlands are not easily defined (Innis *et al*., 2000; Décamps and Décamps, 2002; NRC, 2002; Baker 2005). It has long been known that it is often very difficult to construct precise boundaries between a wetland and a riparian zone, since there is so much overlap, and real-world ecotones are often super-complex broad boundaries (Minshall *et al.* 1983; Verry *et al*., 2004). Certain classifications that target wetlands in particular will obviously continue to include riparian zone habitats (Middleton, 1999). But even though wetlands and riparian zones both have a strong association with the hydrologic regime and both occupy a fuzzy borderline between the aquatic and terrestrial realms, there are several differences between them.

Riparian zones usually support semi-terrestrial vegetation assemblages and differ from most wetlands in their characteristic spatial attributes, disturbance regimes, hydrologic setting, and community organization (Innis *et al.,* 2000). Wetland habitats (*e.g.* marshes and swamps) are dominated by semi-aquatic and aquatic vegetation. Most typical wetlands are usually inundated for longer periods of time. Riparian vegetation differs spatially, being characteristically linear and often well-connected in a linear form, showing distinctive patterns in response to longitudinal gradients (*i.e.* upstream-downstream differences). Wetland vegetation formations are usually more isolated in space, rarely linear, most often circular or oblong in shape, and usually show more patchiness than riparian zones (Innis *et al.,* 2000). Irrespective of how similar or different they may be, however, for many years now wetlands and riparian areas have been treated very differently both in terms of management and in conservation policy (NRC, 2002). In numerous cases, many typical wetland types have been the object of more management interest than riparian areas since they are more "aquatic" or more "freshwater" systems or are directly associated with strict conservation policy and/or protected lotic areas (Silk and Ciruna, 2005). Since wetlands and riparian zones are closely related entities, it is important to use our understanding of both these transitional systems for their best possible conservation, since both function as similar "keystone habitats" in the landscape (DeMaynadier and Hunter, 1997).

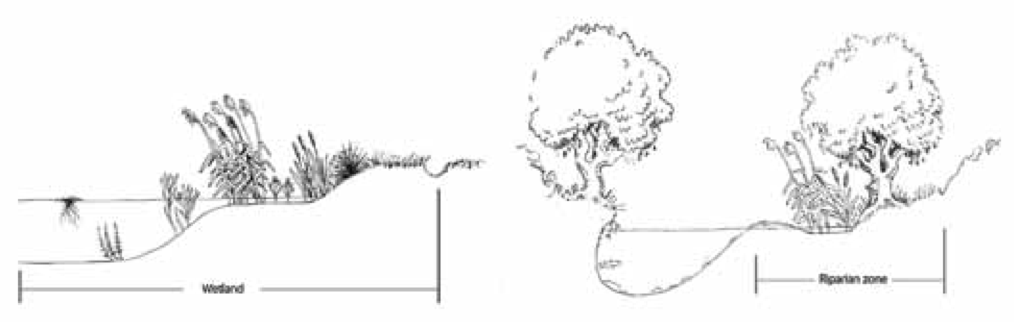

Figure 2.1.4 Simplified conceptual view of wetland versus a typical riparian zone, showing the close relationship between these two related transitional zones; semi-aquatic wetland habitats usually exist within the wider riparian zone (from Zogaris *et al.*, 2007).

Environmental factors affecting riparian vegetation

The vegetation that develops in riparian zones has complex relationships with multiple abiotic parameters at varying scales: region, river basin, river segment and site (Bunn *et al.,* 1999). As mentioned above, generalizing about the distribution and extent of riparian areas over a region or a landscape unit is not straightforward, due to the inherent heterogeneity of forms that riparian vegetation may take. Understanding fundamental biotic-environmental relationships and building conceptual models or using surrogate environmental parameters (such as surface water regime flow patterns) can aid in making useful generalisations for management. It can be surmised that at least four overriding environmental factors or "system drivers" affect the major vegetational characteristics of riparian zone vegetation (Nilsson and Svedmark, 2002); these are climate, hydrology, geomorphology, and biogeography (figure 2.1.5). All four work interdependently and therefore often influence each other with system feedback. These drivers and their specific mechanisms help produce three characteristic general attributes seen in riparian zones:

a) Perpetual succession – the complex vegetational regeneration and degeneration processes seen in river valleys (Middleton, 1999; Sakio, 1997).

b) Fluvial pathway effects – the three dimensional pathways: longitudinal, lateral and vertical (Ward *et al.*, 2001; Scott *et al.*, 1996)

c) Species-rich ecotone effect created by the biophysical heterogeneity of the land-water interface (Naiman, *et al.* 2005, Robinson *et al.* 2002)

The system drivers are reviewed below, with a brief explanation of the environmental mechanisms involved in shaping the form that riparian communities take.

Figure 2.1.5 Simplified conceptual model showing three basic characteristics of riparian zones which are governed by their biogeographic, hydrologic, geomorphologic and climatic drivers, and how they relate to particular mechanisms which affect them at various scales. Modified from Nilsson and Svedmark (2002).

Climate

Climate sets local hydrological cycles and is the ultimate broad-scale determinant of vegetation structure. As a source of water and energy, climate may influence many processes affecting riparian vegetation at river basin scale (Giller and Malmqvist, 1998). A key component of the climate-driven hydrological cycle is stream flow, which directly affects the specific behaviour of river flow types. Climatic effects such as rain-shadow areas on the leeward side of mountains locally create seasonally-semi-arid conditions in many southern European river basins and in some extreme cases the arid conditions create distinctive temporary river systems (*i.e.* the *ramblas* in Spain) (Salinas *et al.*, 2000). These temporary rivers are not to be confused with alpine torrents, although torrential behaviour may be common in ephemeral and intermittent streams. In other cases, climatic conditions may create remarkably stable river systems that are simple and more predictable than the flashy harsh hydrologic behaviour seen in semi-arid or Mediterranean type environments (Décamps and Décamps, 2002). Rivers with perennial flows can be expected to have a better-developed and broader zone of riparian vegetation, in contrast to intermittently flowing rivers.

Hydrology

The flow regime is considered the grand structuring force in river systems and greatly affects riparian vegetation (Poff *et al.,* 1997). Running water shapes the form of the river environment; due to its spatial and temporal variability, it ultimately affects the size, shape, structure and extent of riparian vegetation. The flow characteristics which affect the riparian zone are the following: magnitude, frequency, rate of change, duration, timing and permanence (Nilsson, and Svedmark 2002).

Hydrological disturbance regimes, such as flooding, are especially important to riparian vegetation. This has recently been used as an important criterion in defining the riparian zone boundaries through the operational use of the "flood-prone area" (Verry *et al.*, 2004). Floods of different magnitudes and frequencies affect different riverine and riparian components. A spatio-temporal hierarchy has been useful in interpreting the relative stability of riparian formations as influenced by flooding (Hughes, 1997). High-magnitude floods influence large geomorphologic features, such as new channels and riparian wetlands; minor floods affect individual plant species (figure 2.1.6.). Therefore the hydrology, especially the surface flow regime, is known to shape the successional evolution and ecological processes affecting riparian plant communities (Nilsson and Svedmark, 2002).

Water availability is critical to hygrophilous plants, that is, plants which are adapted to relatively high or continuous high soil moisture content. It usually shows remarkable temporal and spatial variability. Temporally, water availability may range form complete drowning during high-water conditions to desiccation during conditions of total water absence. Water availability is associated with water flow, both height of flooding and permanence of flow, and with the locally-prevailing geological and soil conditions. Although the surface water's action is prominent during floods, riparian zones are connected to the river basin's water resources largely through linkages to groundwater.

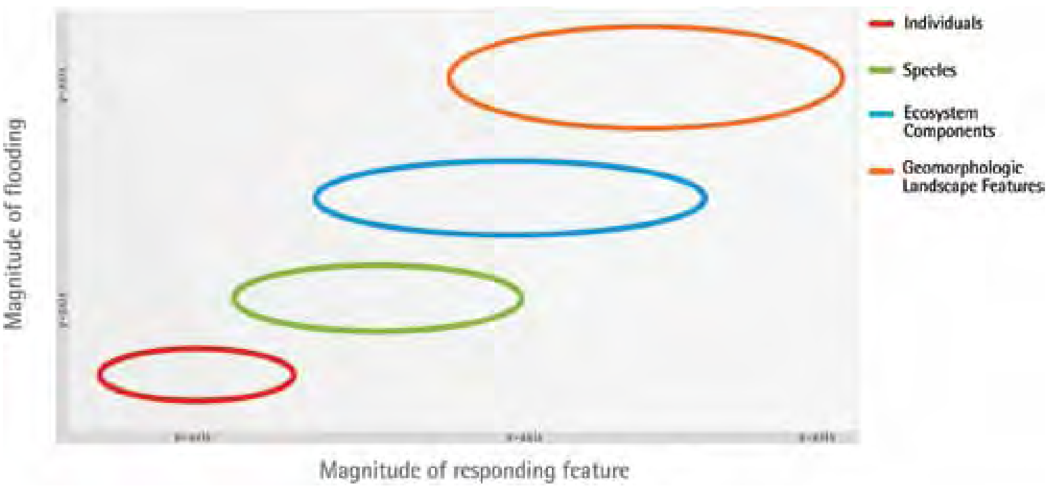

Figure 2.1.6 Simplified conceptual model showing three basic characteristics of riparian zones which are governed by their biogeographic, hydrologic, geomorphologic and climatic drivers, and how they relate to particular mechanisms which affect them at various scales. Modified from Nilsson and Svedmark (2002).

Geomorphology

Fluvial-geomorphic form and process are among the most important factors controlling the distribution patterns of woody vegetation in riparia. In fact, there is a close, interdependent relationship between fluvial landforms, their geomorphic processes and riparian vegetation (Gordon *et al*., 2004; Hupp and Osterkamp, 1996; Hickin, 1984). Vegetation also greatly affects the river's geomporphology. Woody vegetation may strongly affect the rates of erosion and deposition, and in large part may be closely tied up with the overall stability of fluvial forms and structures (Naiman, *et al.* 2005). One very important aspect of the riparian vegetation's contribution to channel stability and change is its provisioning of coarse woody debris (Gurnell and Gregory, 1995); these woody materials help create river features since they greatly assist sediment accumulation. Riparian vegetation succession stages are usually a good indicator of specific landforms and, thus, of the general hydrogeomorphic conditions.

Biogeography

Finally, biogeography is also an important "historical" driver in forming the riparian vegetation composition and structure. The influence of historic changes in geography and biological barriers to dispersal caused by geological events (*e.g.* glaciations) determines the available species pool for a given riparian area. The differential effects of climatic change on the biota have usually greatly impacted the natural species pools of riparian zones (Nilsson and Svedmark, 2002). Furthermore, the riparian woodland attributes (such as patchiness and resilience to disturbances) are highly dependent on the life-history characteristics of the particular species present (Aguiar and Ferreira, 2005). The contribution of biogeographical theory (such as island biogeography) has not been adequately tested on riparian systems, but since degraded riparian ecosystems are artificially fragmented they may act as "islands" and may vary depending on their size and their relative isolation from other forest areas in the vicinity (Holl and Crone, 2004). Since it has long been proven that the community dynamics of the vegetation operate across multiple scales, it is important to consider the regional-scale biogeographic effects on riparian vegetation (Richardson *et al*., 2007).

Human alterations affecting riparian vegetation

Riparian vegetation is also an important indicator of the conservation status of river corridors. The riparian vegetation, as a biotic community, serves as an integrator of ecological conditions and anthropogenic pressures expressed over different temporal and spatial scales, and therefore can assist in environmental assessment (Ferreira *et al.*, 2002; Munné *et al.*, 2003). This is why every effort should be made to gain a practical understanding of the basic responses of the vegetation to specific and combined anthropogenic disturbance.

Hydrologic and geomorphologic alterations

Many human alterations of riverine environments, especially of natural hydrology and river geomorphology, may affect riparian vegetation. With a proliferation of high dams, diversions and waterway engineering on rivers, the effects of a loss in river "connectivity" becomes a serious problem for riparian zones. Dams not only inundate large areas of natural riparian vegetation, they also disrupt the longitudinal pathway used by plants, reducing or severely altering natural dispersal (Nilsson and Svedmark, 2002; Pringle, 1998). Manipulation of hydrological regimes through irrigation works and embankments has also disconnected rivers from their adjacent riparian floodplains (Thomas, 1996). The result is an artificial fragmentation of plant communities where there had been an extensive linear continuum with interactive lateral and longitudinal dimensions. In the absence of a regular alternation of flooding over and falling dry, the alluvial plant communities may die back (Rood and Mahooney, 1990) or develop into other, non-riparian forest communities; for example, pedunculate oak-ash and oak-elm floodplain forests degenerate into pedunculate oak-hornbeam forests (Hügin, 1980 [1984]).

The fragmentation and isolation of riparian zones from their river channels (as in embanked floodplains) or from longitudinal continuity (as in the case of damming) is a complex problem and it is often difficult to predict the effects of this degradation on riparian vegetation communities. When riparian communities are disconnected from their rivers they no longer receive and release plant propagules to the same degree and in the same amounts as in natural conditions (Nilsson and Svedmark, 2002). Riparian zones become more isolated from the surrounding landscape and overall diversity usually decreases (Nilsson and Berggren, 2000; Aguiar and Ferreira, 2005). Both cumulative and synergistic effects caused by progressive desiccation and fragmentation may reduce species and structural diversity. Forest fragmentation may be associated with structural simplification, which may have grave consequences for local and landscape biodiversity. Fragmentation of certain forest habitats and reduction of structural properties within the forest (*e.g.* decreased deadwood, old trees and snags, loss of certain tree species) are important problems that also affect riparian ecological integrity.

Forestry, agriculture and grazing

The combination of forestry and agriculture has extensively altered riparian areas throughout most lowland areas in the Northern Hemisphere (NAS 2002; Anglestam, 1996). Agriculture and in many cases forestry are also responsible for chemical pollution, excessive erosion and siltation of riparian zones. Modern forestry has also degraded floodplain forests through severe alterations in the tree species composition (especially in lowland tree plantations). Livestock grazing, especially in localised parts of the Mediterranean, has a disproportionate effect on riparian areas because livestock tend to concentrate in riparian vegetation, which provides rich shade, water, and forage (Kauffman and Krueger, 1984). Conversely, a total absence or release from ungulate grazing pressure may create habitat conservation problems; since rapid woody plant regeneration causes a loss of many open habitats (water grasslands etc) and may cause an overall loss of species richness in riparian areas (Benstead *et al.*, 1999).

Industrial, urban and recreational impacts

Mining, river regulation for transportation, and urban development have widespread impacts on riparian zones. As vegetation is replaced by impervious surfaces (roads, buildings, factories, parking space), infiltration, water recharges and natural hydrology are all modified. Finally, recreation is a problem locally, since careless and poorly conceived construction and disturbance may seriously degrade the aesthetic and biodiversity values of locally important riparian vegetation areas.

Alien species

Riparian zones have frequently been disturbed by a kind of "biological pollution" created by the establishment of non-native or alien plant species. River ecosystems are highly prone to invasion by alien plants, primarily due to their dynamic hydrology and physiography; rivers act as conduits for the dispersal of plant propagules; and when rivers are disturbed by anthropogenic pressures, they are prone to hosting invasive species (Naiman, 1998; Nilsson and Berggren, 2000; Aguiar *et al.*, 2001). The following definitions concerning alien species and their effects are based on Richardson and colleagues (2007). "Alien plants" include all non-native plants that are located at a site due to an "introduction", which means that a plant has been transported by humans across a major biogeographical barrier. "Naturalisation" takes place when an alien species becomes widely established, when abiotic and biotic barriers to survival are surpassed and various barriers to reproduction are also overtaken. "Invasion" assumes that the plants produce reproductive offspring in areas distant from the sites of introduction. Invasive aliens which change the character, condition, form or nature of natural habitats over substantial areas may be termed "transformers" (Richardson *et al.*, 2000). Usually, only a very small percentage of alien species are transformers – in southern Europe, Giant Reed (*Arundo donax*) and Locust Bean (*Robinia pseudoacacia*) are characteristic transformer species. Finally, another important problem associated with the introduction of alien species is the introduction of pathogens (such as fungi) which can cause extensive damage to native species (*e.g.* Tsopelas, 2004).

Conclusion and conservation implications

Riparian ecotones, and especially their woodlands, are among the landscape features with the longest history of human disturbance among European habitats (Wenger *et al.*, 1990). The lowland floodplains were already inhabited and affected by human societies in the Neolithic period; alluvial woodlands have been grazed, cleared, burned and converted into either grassland or extensive arable land for many centuries. Such fragmentation and whole-scale alterations to riparian zones have led to extensive changes that have affected river corridors as a whole (Brown *et al.*, 1997; Nilsson and Berggren, 2000). Despite this history of widespread anthropogenic change, these formations are remarkably resilient (Angelstam, 1996, Naiman *et al.*, 2005). A mix of natural and human disturbances often creates heterogeneity in relic riparian woodlands. In cultural landscapes it is often difficult to define or decide on the best management and/or restoration pathway for riparian conservation (Grove and Rackham, 2001). The heterogenic riparian features, their complex associations and the diverse applications of management can create controversy and complicate the formulation of robust generalisations about riparian conditions for promoting conservation management (Keith and Gorrod, 2006; Décamps and Décamps, 2002).

Overall, the natural floodplains and riparian woodlands of Europe are numbered as amongst the most threatened of all European natural ecosystems (Angelstam, 1996; Prieditis, 1999; Tockner and Stanford, 2002). Attention has therefore been paid, for several decades now, to the preservation of exceptional sites and to restoration attempts (Géhu, 1980 [1984]; Henrichfreise, 1996, 2001; Hügin and Henrichfreise, 1992; SNW, 2000). The delineation of protective "buffer strips" as a policy-relevant application has been widely applied, although it is difficult to "prescribe" general rules for natural vegetation buffer widths, since natural riparian formations are so heterogeneous (Broadmeadow and Nisbet, 2004; Rodewald and Bakermans, 2006). The potential for re-naturalisation and regeneration of disturbed riparian zones through protection and restoration of a near-natural water regime still exists in many cases (*e.g.* by dismantling embankments and barrages). If riparian forests are left to develop freely, they can usually reach a natural appearance in 60-80 years, *i.e.* much quicker than the 200 years or more it takes for forest on drier soils to develop a similar character (Szczepanski, 1990; Angelstam, 1996). But because of the need to restore both hydrology and geomorphology if restoration is to be complete, innovative and pragmatic approaches are often necessary in ecological restoration projects.

Unfortunately, much good-meaning riparian vegetation restoration work is being promoted "with little knowledge of their natural structure and functioning" (Ward *et al.*, 2001), meaning that mistakes in restoration can create restoration or management failures (Wissmar and Berschta, 1998). Many restoration projects fail or are really a poor contribution to conservation, especially in a cost-benefit sense, and this is often because of the insufficient understanding of natural conditions (*i.e.* reference conditions) and their natural functioning. It is very important for conservation practitioners and management authorities to have a thorough understanding of the region-specific natural history as well as the fundamental ecology of riparian vegetation formations and to be able to interpret natural and anthropogenic influences and processes at various spatial scales (*i.e.* site, river segment, river basin and region) (Robinson, *et al.* 2002; Richardson *et al.*, 2007). A better understanding of the complex workings of region-specific riparian vegetation is necessary for more effective, dynamic and integrative conservation management.

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RIPARIAN WOODY VEGETATION IN GREECE

Panayotis Dimopoulos
Erwin Bergmeier

Riparian vegetation in Greece is extremely diverse. While generally Mediterranean in character, it is given a boreal touch in the Rodopi mountains by *Alnus incana* or conveys subtropical impressions as in the South Aegean with *Phoenix theophrasti*. Apart from woody plants, riparian vegetation comprises tall, dense reeds of clonal graminoids as well as ephemeral plants on gravel and mud deposits in summer. Forests consist of one or a few dominant tree species, with shrubs, lianas, and a variety of herbs depending on geographical latitude, altitude, valley topography, flooding regime, sediment type and soil nutrient content. In the north, tree species of the genera *Alnus, Fraxinus, Populus* and *Salix* prevail, while further south, *Platanus orientalis* and shrub species such as *Nerium oleander* and *Vitex agnus-castus* are common.

Mountain streams without hydrological impact are generally little or not at all disturbed, although reservoir dam projects have already severed several valleys. Many permanent streams in the south have become seasonal as a result of decreasing rainfall and increasing water consumption for irrigation and tourism. Due to hydrological interference and changes in land use, especially in the mainland lowlands, the hardwood-dominated riparian forests of *Quercus, Fraxinus and Ulmus* are in evident peril of extinction. Riparian woody vegetation in Greece is referable to the following phytosociological syntaxa:

1) *Alnion incanae* (syn. *Alno-Padion*) comprises *Alnus* forests along riversides, chiefly in the mountains of the northern half of the mainland, as well as residual hardwood forests with *Quercus, Ulmus* and *Fraxinus* in the flood plains of big rivers.

2) *Populetalia albae*, occurring throughout Greece, comprises *Platanus orientalis* gallery forests as well as frequently flooded woods of poplars (*Populus nigra, P. alba*) and willows (*Salix alba*).

3) *Salicetea purpureae*, widespread on the mainland, comprises willow scrub, including various shrubby and arborescent willows such as *Salix alba, S. amplexicaulis, S. elaeagnos, S. purpurea, S. triandra* and *S. xanthicola.*

4) *Nerio-Tamaricetea* is scrub composed of *Tamarix parviflora*, other tamarisks, *Nerium oleander, Vitex agnus-castus* and *Phoenix theophrasti*. It is at its most diverse in the southern part of the mainland and in the bigger islands.

Riparian forests of *Alnus glutinosa*

Riparian forests and arborescent galleries of *Alnus glutinosa*, *Alnus incana* or *Salix alba* occur throughout nemoral Europe. In Greece, as in much of the Mediterranean area, they are restricted chiefly to the mountains of the northern and central mainland. As defined here, such forests are equivalent to the 'Alluvial forests with *Alnus glutinosa* and/or *Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)*' habitat type (91E0) of the EU Habitats Directive.

Alnus glutinosa reaches its south-easternmost limits in Europe in the Aegean, while *A. incana* only just reaches Greece, where it occurs in the Rodopi Mountains in mixed forest stands. *Alnus glutinosa* riparian forests are periodically inundated by rain- and melt-waters but are otherwise well-drained and aerated. The soil is stony or sandy. The herb layer includes many tall forbs such as *Angelica sylvestris, Cardamine amara, Carex pendula, Carex remota, Carex sylvatica, Equisetum telmateia, Filipendula ulmaria, Lycopus europaeus, Lycopus exaltatus, Lysimachia punctata, Osmunda regalis, Peucedanum aegopodioides, Ranunculus ficaria, Rumex sanguineus* and *Urtica dioica.*

The structure and functions of these riparian ecosystems depend on the water regime. The stands are generally highly dynamic due to natural disturbance. Existing stands are either not managed or sometimes used for woodcutting or grazing.

Human activities that endanger or constitute a potential threat to this habitat type are related to flood control, irrigation and drainage.

Water reservoirs are the most obvious impacts but diversion of spring waters and rivulets also affects the hydrological regime in the catchment area of the *Alnus* forests. Such human interventions are increasing continuously (*e.g.* recreation infrastructures on Mount Itamos-Sithonia). Many stands have been replaced by *Populus* plantations or drained for arable land.

Figure 2.1.1.1 *Alnus glutinosa* grows on the banks of the river Aoos, Epirus (Photo: P. Dimopoulos).

Riparian mixed forests with *Quercus pedunculiflora, Ulmus minor* and *Fraxinus angustifolia*

Forests of hardwood trees (*Fraxinus, Ulmus, Quercus*) are widespread in nemoral and southern Europe. They are restricted to the big river systems but have vanished widely due to hydrological regulation. The remnants of such forests in Greece are on the brink of extinction. They form part of the 'Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia* along the great rivers' habitat type (91F0). The Balkanic subtype which occurs in Greece corresponds to the *Leucojo-Fraxinetum angustifoliae*.

The most significant trees of these riparian forests in Greece are the hardwoods *Quercus pedunculiflora, Fraxinus angustifolia* (with 2 subspecies), Ulmus minor (with 2 subspecies) and *Ulmus procera*. The undergrowth is well developed, with *Aegopodium podagraria, Leucojum aestivum, Ranunculus ficaria, Silene cucubalus, Solanum dulcamara* and *Urtica dioica*. Well preserved forests (which in Greece are invariably small) are rich in lianas: *Humulus lupulus, Periploca graeca, Vitis vinifera, Tamus communis.*

Prior to regulation and drawdown, the floodplains of the larger rivers were regularly inundated. The habitat is enormously dynamic, depending on the flooding regime and provided that this is not restricted by human interference. There is considerable input and accumulation of fertile sediment which renders the habitat highly productive and favours the production of large annual quantities of phytomass, especially in the herb layer.

These forests have been subject to intense human impacts that influence the habitat conditions and water regime, such as groundwater drawdown. The stands themselves have been cut, mainly in order to extend agricultural land. Livestock grazing is also common. The existing forests are remnants of formerly much more extensive and widespread wetland forests.

The few remaining stands are very small and suffer from impacts from adjacent agricultural areas. The severest threats still originate from changes in the water regime, especially non-flooding by inundation water and the drawdown of the water level due to river regulation. The hardwood riparian forests are very fragile ecosystems and must be considered the most threatened forest habitats in Greece.

Figure 2.1.1.2 Riparian mixed forest with *Fraxinus angustifolia* and *Quercus pedunculiflora* in the Argios Varnavas wood (Photo: Arantxa Prada. See chapter 5.3).

Salix and *Populus* woods

Salix and *Populus* multi-layered riverine forests are widespread in Europe and beyond, in Asia and the Near East. However, extensive stands are rare, especially in the Mediterranean. Arborescent willows (in Greece exclusively *Salix alba*) and tall poplars (in Greece *Populus alba* and *Populus nigra*) are usually dominant along gravelly and sandy river shores. Shrubby willows (*Salix amplexicaulis, S. elaeagnos, S. purpurea, S. triandra* and *S. xanthicola,* the latter restricted to the north-east) occur in patches in riverbeds and gravel banks. Such forests and scrub correspond to the "*Salix alba* and *Populus alba* galleries" habitat type (92A0) as defined in Annex I of the EU Habitats Directive.

Willow thickets are generally not managed. In the past, as well as nowadays, they have been degraded and removed, mainly at river deltas and lakesides, where land reclamation for agricultural crops and poplar plantations as well as for sand and gravel mining has reduced their distribution area irreversibly. They are also used for grazing and hunting. The management of these forests must focus on protection.

This habitat type is among the most threatened, particularly where arborescent stands occur in deltas, along estuaries/river mouths and at lakesides. It is sensitive to changes in water balance and to water pollution and is affected by irrigation and drainage. Hydrological management, road building and constructions along streams and lakes have degraded or destroyed many stands, often irreversibly. Together with clearing for agricultural purposes (after drainage) and for plantations of fast-growing poplar cultivars, habitat transformation has reduced most of its area. Other severe threats are extensive gravel and sand extractions. Degradation through changes in water level or flooding regime or by water pollution favours colonization of the habitat by alien species. For preservation, it is essential to maintain or reinstate the natural flooding regime of the stream or lakeshore. Large-scale sand and gravel extractions should be banned, as well as plantations of exotics

Figure 2.1.1.3 *Salix purpurea* scrub and *Salix alba* galleries ongravel banks of the river Voidomatis, Epirus (Photo: E. Bergmeier).

such as *Populus* cultivars and *Eucalyptus*. Clearing and cutting of riverine forest should be prohibited. Greece is among the few European countries with a non-artificial flooding regime in at least some major rivers (Aoos, Evros, Pinios). The entire length of these rivers should become nature reserves.

Platanus orientalis woods

Platanus orientalis woods are eastern Mediterranean in distribution. *Platanus orientalis* forms gallery forests along Greek, Sicilian and southern Balkan water courses, temporary rivers and ravines. These stands are distributed throughout the Greek mainland and archipelagos, colonising poorly stabilised alluvial deposits of large rivers, gravel or boulder deposits of permanent or temporary streams, spring basins, and particularly, the bottom of steep, shady gorges, where they constitute species-rich communities. In Annex I of the EU Habitats Directive, plane woods are listed as habitat type 92C0: "*Platanus orientalis* woods". *Liquidambar orientalis* gallery forest also belongs here.

Apart from south-western Anatolia, *Liquidambar orientalis* only occurs in the Petaloudhes Valley on Rhodos, with poorly developed undergrowth and a ground layer dominated by *Adiantum capillus-veneris* in damp areas. This forest harbours a unique population of the Jersey Tiger Moth, *Panaxia quadripunctaria. Platanus* is often associated with *Nerium oleander* in the south and with *Salix* species in the north. *Vitis vinifera*, *Tamus communis* and *Smilax aspera* are common lianas. Among the more characteristic herbs are C*arex pendula, Equisetum telmateia, E. arvense, E. ramosissimum, Hypericum hircinum* and *Melissa officinalis*.

Because of the functional benefits of *Platanus* woods in preventing erosion, stabilizing banks, retaining water and solid materials, conserving soil quality and preserving local climatic conditions, their ecological value cannot be overestimated. As regards biodiversity, their value is related to the provision of residence (they comprise unique biotopes for many animals and also for hygrophilous plant species), their position as a corridor at the landscape scale and their contribution to the mosaic character of the landscape. Besides, their aesthetic and recreational value is prized.

Platanus orientalis woodlands are not managed today except for grazing, but have frequently been pollarded to feed the animals. Even now, waste dumping and wood-cutting remain significant impacts. Due to their great ecological value, their management should have an exclusively protective character. The conservation status of *Platanus orientalis* forests is favourable in most of the sites. Plane forests depend on at least temporary water flow and are thus sensitive to hydrological changes (water diversion, riverbed constructions, reservoirs) and to water pollution.

Figure 2.1.1.4 Riparian forest with formerly pollarded *Platanus orientalis* and *Equisetum telmateia* trees on the stream banks. Near Skotina, Greek Macedonia (Photo: E. Bergmeier).

Thermo-Mediterranean woods and scrub with *Nerium oleander*

Thermo-Mediterranean riparian woods are abundant in the south and east of the Iberian Peninsula, less frequent in eastern Provence, Liguria and Corsica, and also occur in southern Italy, Sardinia and Sicily, southern and western Greece, the Aegean and Ionian archipelagos and Crete. Outside Europe, the habitat type occurs in more eastern parts of the Mediterranean and in North Africa and Mesopotamia. In Greece, such woods are mostly dominated by *Nerium oleander* or *Vitex agnus-castus*, more rarely by *Tamarix* species and, only in southern and eastern Crete, by the arborescent palm *Phoenix theophrasti*. Thermo-Mediterranean woods and scrub correspond to the "Thermo-Mediterranean riparian galleries and woods" habitat type (92D0), but the palm stands are included in the "Palm groves of *Phoenix*" habitat type (9370) which occurs only in the Canaries (with *Phoenix canariensis*) and Crete. *Phoenix theophrasti* occurs only in Crete and in south-western Anatolia. Among the more common graminoids in these two habitat types in Greece are *Juncus heldreichianus, Saccharum ravennae, Arundo donax*, and *Scirpoides holoschoenus*. *Rubus sanctus* is a common shrub along the margins.

Vegetation types with *Nerium oleander* span a wide ecological spectrum. Soils may be brackish or influenced by fresh-water. Periods of soil water saturation may be seasonal or permanent, soils loamy, sandy or often stony. They develop at drier sites than *Salix, Populus* and *Platanus* woods. The habitat plays an important role in the physiognomy of the southern landscapes, where woodlands are scarce, and constitutes an important aesthetic component. In the Aegean Islands, they add especially to landscape diversity, indicate water occurrence and offer a refuge in the otherwise dry, open and often barren landscape that surrounds the moist sites.

Nerium wetlands support many migrating bird species and form a habitat for other wetland species of the eastern Mediterranean fauna. Management of vegetation units of this habitat is not practiced, but measures should aim at conservation and/or improvement of the sites as required. Generally, the conservation status of the habitat is favourable within its distribution range. However, as the plant communities depend on water they are sensitive to changes in hydrological conditions and many stands have vanished due to groundwater manipulation or have been polluted by garbage dumping. Nitrophilous species often invade disturbed stands with a decreasing groundwater level. In some sites, the vegetation is burnt with the aim of increasing the agricultural surface area, but *Tamarix* and *Nerium* regenerate after fire.

Figure 2.1.1.5 *Phoenix theophrasti*, an endemic palm of southern Aegean coastal river mouths in south-west Anatolia and Crete, here at the mouth of the Megalou Potamos near Preveli (Photo: E. Bergmeier).

Domingo Baeza Sanz
Diego García de Jalón-Lastra
Juan Carlos López Almansa
Miguel Marchamalo
Pilar Vizcaino Martínez

RIPARIAN WOODLANDS IN THE IBERIAN PENINSULA

All the riverside woods in the Peninsula belong to the *Querco-Fagetea* and *Nerio-Tamaricetea* phytosociological classes. *Populetalia albae* is the order with the greatest number of Iberian vegetation associations. Others are *Salicetalia purpureae* and *Tamaricetalia.* The riparian forests of Western Europe occupy more or less waterlogged soil, depending on the fluctuations in water volume in the watercourses, and are typically gleyed.

Riparian woodlands of the *Populetalia albae* order grow in both the Mediterranean and the Eurosiberian region. In the Mediterranean region, Narrow-leaved Ashes (*Fraxinus angustifolia*) and other arboreal species such as elms, poplars, nettle-trees, etc. are frequent. In the Eurosiberian region, the dominant species are the Common Ash (*Fraxinus excelsior*) and other Eurosiberian species. Certain herbaceous plants are common to both regions, including hops (*Humulus lupulus*), White Bryony (*Bryonia dióica*), Soapwort (*Saponaria officinalis*), Berry Catchfly (*Cucubalus baccifer*), Dulcamara Bittersweet (*Solanum dulcamara*).

A very practical type of classification is one that groups riparian plant formations by woodland type (Sánchez Mata and de la Fuente, 1985), distinguishing:

a) Poplar woods
b) Elm woods
c) Ash woods
d) Alder woods
e) Willow woods
f) Tamarisk woods.

Poplar woods

The Spanish make a distinction between choperas and alamedas, depending on whether the dominant species is the *chopo* or black poplar, *Populus nigra,* or the *álamo* or white poplar, *Populus alba.* This section covers both. In the Mediterranean region, poplar woods are found in valley floors, on deep, gleyed alluvial soils close to rivers and streams but not necessarily in direct contact with the water. They are even able to survive periods of drought during the summer months. They colonize the strips close to the river that are not totally exposed to flooding but are influenced by the level of phreatic water. The soils in which they grow are usually silt/sand types with a high calcium carbonate content.

Figure 2.1.2.1 Riparian gallery of Black Poplars in a Mediterranean landscape (Photo: J. Vicente Andrés).

In a site occupied by black poplars, these are often found to be anthropogenic, giving rise to profound changes in the original community whether it is white or black poplars that they replace, since human plantings normally employ non-native species and varieties. In general, white poplar woods are found in dryer regions at lower altitudes, such as along the main stems of the big rivers of the central plateau, although more hygrophilous and xerophilous variations exist within this woodland type.

At their highest level of development, these woods can present three strata. The first is made up of poplars up to 30 m tall, the second is composed of less high trees, such as Fraxinus angustifolia and *Ulmus minor* and the third is formed of shrubs (*Cornus sanguinea* and *Ligustrum vulgare*, for example). There is also a herbaceous stratum with a predominance of hemicryptophytes and geophytes (*Arum italicum, Ranunculus ficaria, Symphytum tuberosum*, etc.).

Poplar forests with a greater Mediterranean influence (*Vinco-Populetum albae*) and continental-type ones (*Rubio-Populetum albae*) in more interior locations of the Peninsula exhibit slight differences in behaviour and floristic composition.

Along the banks of the mesomediterrnanan bioclimatic belt rivers in areas closer to the Mediterranean sea, we find what Folch (1986) calls the *alameda litoral*. In this kind of riparian wood the species composition is enriched by the woody species *Fraxinus angustifolia*, *Ulmus minor*, *Crataegus monogyna*, *Coriaria myrtifolia* or *Rubus ulmifolius* and an *herbaceuos strata* formed by *Vinca diformis*, *Arum italicum* and *Rubus caesius* among others.

Poplar woods with a more xeric appearance but a similar structure to these are found in the more continental areas of the interior of the Iberian Peninsula, in the mesomediterranean belt of the Castile-Maestrazgo-La Mancha and Aragon bio-geographic provinces. They contain a smaller number of Atlantic species, whereas willows (*Salix neotricha*), licorice (*Glycyrrhiza glabra*) and common or dyer's madder (*Rubia tinctorum*) are common. Towards the seasonally totally dry upper reaches of rivers such as the Ebro these poplar woods (association of *Rubia tinctorum* and *Populus alba*) are generally in contact with elm woods. Occasionally, when the dryness of the soil is greater, they are in direct contact with the climatophile series of holm oaks.

Figure 2.1.2.2 White Poplar stand. (Photo: Olga Mayoral and Miguel Ángel Gómez).

Elm woods

Elm woods and ash woods are the most extensive riparian woodlands associated with floodplains or river terraces where the water table remains close to the surface of the ground only during the rainy or freshet seasons and falls sharply in the summer months, causing a partial drying-out of the horizontal surfaces. The attenuated water deficit favours the strategy of deciduous trees and the presence in the undergrowth of species that are typical of climax deciduous forests.

Because of their distribution on the highest parts of embankments, terraces and banks, these woodland types enter into contact with mixed oak woods. This vegetation structure is found on deep soils which, while moist, are less so than in the poplar woods. Generally, the dominant species are ashes (*Fraxinus angustifolia*) and elms (*Ulmus minor s.l.*). These woods are usually stratified into a tree canopy of up to 20-30 m in height, a microphanerophytic and lianoid stratum and a final stratum of hemicryptophytes and geophytes.

Three types of elm woods may be distinguished: those of the continental peninsular regions of the meso- and supramediterranean bioclimatic belts, those of valley floors and torrent courses in the meso- and supramediterranean belts, already clearly in transition to the mountain belt, and those of the more xeric areas in the south of the Valencia region. The first of the three types is generally made up of black poplars, elms and ashes; when on occasion the soil is sandy, alders commonly appear. Geophytes such as as arums (*Arum italicum*) are also frequent. They generally occupy cool, fertile soils with good permeability and a clay texture and are deeply disturbed by human activity because they can be turned into irrigated land for growing fruit and vegetables.

Elm forests in the Eurosiberian region are enriched by characteristic species of this region such as *Carex sylvatica* ssp. *paui, Acer campestre,* etc. The more Mediterranean elm groves are relatively resistant to long periods of drought. They are very poor woodlands and are commonly covered in ivy (*Hedera helix*).

These elm woods are in contact with poplar groves on flat land in the mesomediterranean belt or with the climatophile series of holm oaks towards dryer areas. It is now difficult to find formations of this type, although they can be encountered in two different ecological situations (Lara *et al.,* 1996): one is along the courses of streams and rivers with smaller volumes of water and more severe summer droughts, where poplars cannot be planted because of the lack of water; the other is in floodplains and river terraces, where pockets of vegetation badly degraded by farming uses may be seen.

Figure 2.1.2.3 *Ulmus minor* specimens near Madrid (Photo: Jacinta Lluch).

Ash woods

Ash forests are very common in both the Mediterranean and the Atlantic region of the Iberian Peninsula. Their formation is highly complex and will be simplified here below for use as a guide to reforestation.

Ash forests are found on valley floors, in flat open areas between mountains and in wide valleys in the supramediterranean belt, on cool soils with a fluctuating waterlogging profile. Their physiognomy is dominated by narrow-leaved ashes (*Fraxinus angustifolia*) and Pyrenean oaks (*Quercus pyrenaica*), although some authors speak of another association of ash trees with *Arum italicum* and *Ranunculus ficaria*. In their floristic composition, as well as these ashes and oaks, mountain ashes (*Sorbus aucuparia*), alder buckthorns (*Frangula alnus*), maples (*Acer monspessulanum*), etc. are normally frequent, as well as some shrubby species typical of thorny edges: roses (*Rosa* spp.), brambles (*Rubus* spp.) and honeysuckles (*Lonícera híspáníca*), etc.

These woodlands are usually converted into wood pastures, preserving the trees to shade the livestock during the summer months. Nonetheless, examples can be found of associations forming galleries. These are hygrophilous ash forests on the banks of small rivers with practically constant phreatic moisture, usually with willow shrubs in the undergrowth, and can populate both rocky and sandy substrates. Towards zones with greater hydromorphy, the ash forests are generally in contact with alder forests or their substitution stages, and towards more xeric zones, with the climatophile series of cork oaks or holm oaks, unlike supramediterranean ash forests, which connect on their dry side with the Pyrenean oak or holm oak climatophile series.

Figure 2.1.2.4 Riparian belt of Narrow-leaved Ashes in the Alentejo, Portugal (Photo: Daniel Arizpe).

Alder woods

Unlike poplar, elm and ash woods, alder woods grow on alluvial soils that are permanently water-saturated throughout the year. As well as the common alder (*Alnus glutinosa*), other typical species of these riparian woodlands include taxa such as *Clematis campaniflora, Galium broterianum, Osmunda regalis, Salix atrocinerea, Scrophularia scorodonia*, etc.

The common alder is widely distributed throughout Europe, in both the Mediterranean and the Eurosiberian region. It prefers acid soils, loose and sandy, but can also grow on clay soils. This tree can fix atmospheric nitrogen and convert it into ammonia compounds thanks to its symbiosis with *Frankia alni*, which lives in its roots, entering them through the root hairs in the same way as other angiosperms. Through root excretion, nodule necrosis, leaf mulch decomposition and rainwater running off the trunk, branches and leaves, the nitrogenated compounds return to the soil and the water and enrich them.

The frequent interest in repopulating with this tree springs from two causes: one is its contribution to nitrogen fertilization and the other is that it contributes to soil genesis and favours water productivity yet does not accelerate water eutrophication, as the alder tree canopy prevents long-cycle aquatic plant growth in the water. This is because the dark green leaves of the alder absorb the visible spectrum selectively and reflect part of the sunlight that falls on them, leading to conditions of semidarkness beneath the crowns of the trees. A further reason for the particular importance of this fact is that alder leaves stay on the tree until the end of autumn.

Obviously, the combination of these factors will have particular effects on the structure of this type of wood. In optimum conditions, alder forests are made up of a canopy of *Alnus glutinosa, Fraxinus angustifolia, Celtis australis* and *Corylus avellana*, among other trees. The microphanerophyte stratum is usually more sparse, although some nemoral ferns develop a considerable biomass.

Since alders tolerate a wide range of soil acidities they are found in very varied situations, notably oligotrophic alder forests on siliceous substrates with carbonate-poor waters and mesotrophic alder forests with limy substrates bathed in mineral-rich waters. Oligotrohic alder forests typically take the form of a narrow strip of woodland alongside a watercourse with an absolute predominance of alders. In mesotrophic alder forests, although alders are still dominant, various willows with different soil preferences make their appearance. These grow downstream from the oligotrophic forests, taking advantage of chemical changes in the substrate and in the water.

Figure 2.1.2.5 Mixed forest of *Alnus glutinosa* and *Fraxinus angustifolia* in southern Portugal (Photo: Daniel Arizpe).

The western alder forests are found from low-altitude zones (practically on the sea-shore) of the thermomediterranean bioclimatic belt up to heights of 900-950 m in the mesomediterranean belt of the western sectors of the Carpetan-Iberian-Leonese biogeographical areas (districts in the provinces of Orense and Salamanca) as well as being very well-represented in the Portuguese-Extremaduran biogeographical area, in the basins of the rivers Tiétar, Almonte, Ruecas, Guadiana, Tormes, Agueda, Alagón, Mondego etc.

In colder zones the alder forests can be in contact with hazels (*Corylus avellana*), while towards the warmer zones of the Guadalquivir and Guadiana river basins, in the thermomediterranean bioclimatic belt, there is an evident presence of oleanders (*Nerium oleander*) and some thermophile species such as *Dorycnium rectum, Smilax aspera, Frangula alnus* subsp. *baetica, Luzula forsteri*, etc. bridging the natural transition to the alder forests of the Cadiz-Huelva-Algarve habitat. The streams and rivers in the thermo-mediterranean belt of the Cadiz-Huelva-Algarve biogeographical area have good examples of alder woods of great ecological and landscape value, with numerous endemic taxa such as *Rhododendron ponticum ssp. baeticum* and tropical disjunct ferns such as *Davalia canariensis, Culcita macrocarpa*, etc.

Alder forests are also found in higher areas along the headwaters of the rivers and streams in the highest reaches of the Tormes, Alberche, Jarama and Henares river systems, where thermophile species such as *Clematis campaniflora, Scrophularia scorodonia, Osmunda regalis*, etc. are typically lacking but Atlantic species such as birches (*Betula celtiberica*), hollies (*Ilex aquifolium*) and aspens (*Populus tremula*) are frequent.

Eurosiberian alder forests are slightly different, as they contain Atlantic taxa. The riparian alder woodlands of the Cantabria-Basque Country and Galicia-Asturias regions (in a broad sense) are interesting. As the macroclimate of these areas shows little seasonal contrast and the winters are mild, they frequently provide refuge for certain ferns with high heat requirements (*Woodwardia radicans, Stegnogramma pozoi*, etc.), so their ecological value is considerable and they deserve maximum protection.

The floristic and aerial biomass composition is very varied in the Eurosiberian region and a number of alder forest associations have been described in the lands from the Pyrenean mountain ranges to the Galicia-Asturias areas.

From the dynamic point of view, almost all the alder woods are in good contact with willow groves or with the climatophile series of holm oaks or Pyrenean oaks. In the middle reaches of rivers and in wide valleys they are in contact with supramediterranean ash forests.

Figure 2.1.2.6 River covered by a dense stand of Common Alder (Photo J. Vicente Andrés).

Willow woods

Simplifying, a distinction can be made between willow groves with tree-sized specimens and those where shrubs predominate. Tree-sized willow woods have a physiognomic preponderance of common sallows (*Salix atrocinerea*) although numerous species typical of the *Populetalia albae* order are frequent, in contrast to formations of willow shrubs of the *Salicetalia purpureae* order. The differences are increased by the presence in the latter of brambles (*Rubus curylifolius, R. ulmifolius, R. caesius*) and certain ferns.

Willow tree woods contain a mosaic of trees: sallows are more or less predominant but they also contain beeches, birches, aspens, Pyrenean oaks, ashes or

Figure 2.1.2.7 Stands of *Salix alba* in the lowlands of the Júcar River area in Valencia, Spain (Photo: Daniel Arizpe).

mountain ashes. Willow shrub formations divide into two types: siliceous or calcic.

The presence of other willow species depends on various factors, including the degradation to which some willow thickets are subjected. For instance, those on siliceous ground are accompanied by *S. salviifolia.* If degraded they may contain other willows such as *S. fragilis, S. triandra or S. purpurea var. Lambertiana*, when more eutrophic, *S. purpurea* and *S. x matritensis*. Supramediterranean common sallow forests have their optimum habitat by flat, slow-moving streams and on water-saturated soils. The soils where they grow are moist, with an organic horizon. They are frequent in the Carpetan-Iberian-Leonese biogeographical area (association of *Rubus corylifolius* and *Salix atrocinerea*).

Other more localized communities worthy of note are the common sallow woods of the Ibero-Atlantic thermomediterranean belt, where marsh ferns (*Thelypteris palustris*) are common, which are known as an association of *Vitis sylvestris* and *Salix atrocinerea*, and Portuguese-Extremaduran willow forests, rich in ash trees (association of *Fraxinus angustifolia* and *Salix atrocinerea*, etc.).

In willow shrub formations, a very broad range of combinations is found. *Salix salviifolia* communities, which can be predominantly *S. salviifolia* or mixed with *S. purpurea* or *S. eleagnos*, are noted for their wide distribution. When there is no one dominant species they are usually described as mixed willow thickets. Hybrids of these trees or, depending on the location, other species such as *S. triandra*, sometimes contribute to the formation of the community.

Figure 2.1.2.8 Mountain stream with *Salix purpurea* and *Salix eleagnos* (Photo: Daniel Arizpe).

Riparian vegetation in the hottest zones: Tamarisk, oleander and *tamujo* thickets

In the warmest areas of the Iberian Mediterranean region, rainfall is typically irregular and, apart from the main rivers, watercourses remain dry for most of the year. Optimum hydrolologic conditions only return after the short periods of rain. The usual pattern is very heavy rainfall for short periods of time that turns dry watercourses into torrents of rushing water. Torrent courses (*ramblas*) are particularly abundant in the SE corner of the Peninsula and flooding following rain is frequent, occasionally with serious consequences.

Because of the extreme conditions, tree formations do not exist on these particular riverbanks, which have developed a highly specialised type of vegetation: tamarisk, oleander and *tamujo* thickets.

Figure 2.1.2.9 Well-adapted Oleanders (*Nerium oleander*) withstanding successfully a strong spate in an Iberian *rambla* (Photo: Daniel Arizpe).

Tamarisk thickets are shrub or tree formations of little physiognomic density made up of various species of tamarisks (*Tamarix africana, T. boveana, T. gallica, T. canariensis*); on rare occasions they form small closed thickets. Their optimum habitat is areas with hot, arid or semi-arid climates, reaching into thermo- and mesomediterranean belt areas with a dry climate in riverside situations that are unfavourable for deciduous riparian woods. They can colonize sandy, clay or chalky torrent courses and even some enclaves in continental or littoral saltpans, owing to the strong resistance to salinity of some species (*Tamarix boveana, T. canariensis*).

Figure 2.1.2.10 *Tamarix canariensis*, an adapted colonizer of ephemeral streams (Photo: Daniel Arizpe).

These communities can replace willow or other formations in two ecological situations: in very thermoxeric conditions, with oligotrophic substrates, following degradation of the riparian woodlands, or when there are water table salinity or water pollution problems.

Oleander and tamujo thickets are other analogous shrub vegetation types. Oleander formations (physiognomically dominated by *Nerium oleander*) can form dense populations of permanent vegetation colonising torrent courses, generally stony. Their optimum habitat is in the Murcian-Almerian biogeographical area, although they also exist in certain thermophile enclaves of the Portuguese-Extremaduran biogeographical area. A tamujar is a spiny shrub formation in which *tamujos* (*Flueggea tinctoria*) are the prevalent species. They colonize stony siliceous riverbeds in the Portuguese-Extremaduran biogeographical area.

All these formations are very important for controlling the typical erosion processes of these zones. As well as helping to stabilise the soil, they also populate riverbanks where the presence of other species is limited by the quality of the water.

Riparian birch woods

Riparian birch woods are very interesting as they are almost a relict in the Mediterranean region, typically found in certain mountain enclaves and sometimes forming mixed forests.

Figure 2.1.2.11 *Betula alba* stand in *Serra da Estrela*, Portugal (Photo: Antonio Pena).

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THE INFLUENCE OF RIPARIAN VEGETATION ON FRESHWATER FISH

Francisco Nunes Godinho

Fish and riparian vegetation

Rivers and streams are influenced by multiple factors, often interacting at different spatial and temporal scales. Catchment land use and riparian vegetation interact to affect water quality and aquatic habitats and therefore influence aquatic communities, including fish (Meador and Goldstein, 2003).

Riparian vegetation is important for fish as it affects aspects like light and water temperature and quality, as well as habitat and food availability (Zalewski *et al.*, 2001). Consequently, the removal of riparian vegetation can be an important cause of fish habitat degradation.

Physical changes to the instream habitat, such as increases in sunlight and water temperature due to reductions in the canopy cover, can alter the thermal environment of the river. This could be particularly limiting for coldwater fish species, such as the salmonids (Murphy *et al.*, 1986, Weatherly and Ormerod, 1990, Torgensen *et al.*, 1999), whose worldwide populations have been contracting and are expected to contract further due to global climate change (Chu *et al.*, 2005). Nevertheless, increased sunlight exposure and higher water temperatures could stimulate the growth of aquatic macrophytes, changing the instream habitat structure and the amount and type of food available for salmonids (Bunn *et al.*, 1998), whose individual growth could increase locally (Lobon-Cervia and Rincon, 1998).

In warm water streams, increases in water temperature due to reductions in canopy cover, in association with higher primary productivity, could promote deterioration of the aquatic habitat (*e.g.*, low levels of dissolved oxygen). An extreme situation can be found in harsh habitats like intermittent headwater streams, where fish are concentrated in shrinking pools during extended dry periods (Godinho *et al.*, 1997, Magalhães *et al.*, 2007).

Riparian vegetation is also important for the stability of the riverbank and its removal could result in high turbidity and siltation due to increased bank erosion (Gregory *et al.*, 1991, Osborne and Kovacic, 1993). Organic matter inputs from riparian vegetation are major food sources for aquatic invertebrates, many of which are eaten by fish (Cummins, 1974), and large woody debris creates complex instream habitats, often related to higher fish diversity (Davies and Nelson, 1994, Gregory *et al.*, 2003).

The relationships between riparian cover, land use and fish assemblage structure and dynamics have been documented in a series of studies (Steedman, 1988; Roth *et al.*, 1996; Allan *et al.*, 1997; Wang *et al.*, 1997, 2000; Klauda *et al.*, 1998; Lammert and Allan, 1999; Schleiger, 2000; Meador and Goldstein, 2003; Hughes *et al.*, 2004; Van Sickle *et al.*, 2004), but complex factor interactions often make it difficult to identify the key mechanisms involved or to quantify their combined impact (Penczak *et al.*, 1994). Nevertheless, a wide range of evidence indicates that the removal of riparian vegetation has a negative impact upon fish communities (Jones *et al.*, 1999; Pusey and Arthington, 2003). The presence of extensive and complex riparian cover at river margins often indicates high stream environmental quality, whereas highly altered riparian zones are associated with impoverished river habitats and fish communities (Karr and Schlosser, 1978; Gregory *et al.*, 1991).

Fish assemblages

Throughout history, river fish have been important for humans as a source of food, commerce and recreation (Shaw, 2003). However, rivers have been profoundly altered by man, particularly in areas where human influence is old, such as Europe. In consequence, many European river fish species are imperilled, particularly taxa with restricted ranges. For example, a recent evaluation of vertebrate conservation status in Portugal (according to IUCN criteria) ranked freshwater fish as the group with the highest number of threatened species, including taxa such as the small-sized cyprinid *Anaecypris hispanica*, an Iberian endemism that is now restricted to the Guadiana River basin (Cabral *et al.*, 2006).

Overall, particular freshwater fish assemblages are associated with distinct aquatic habitats (Moyle and Cech, 1996). Along river systems, from small headwater streams to larger lowland rivers, fish assemblages are organised according to factors such as light, temperature, dissolved oxygen, elevation, gradient, substrate, water velocity, flow patterns, nutrient levels and food availability (Ross, 1997).

Brown trout (*Salmo trutta*, figure 2.2.1) is the typical coldwater species (species that cannot tolerate water temperatures above 25ºC) in many European headwater streams. Typically for salmonids, trout are very sensitive to variations in habitat quality, being particularly intolerant to increases in water temperature. Therefore, in warmer regions such as the Iberian Peninsula, the shade provided by riparian vegetation is important for maintaining the temperature below the critical thresholds for the species. In addition, the importance of riparian vegetation as a source of organic matter in these headwater streams is particularly critical for the production of aquatic invertebrates, the staple food for trout (Klemetsen *et al.*, 2003).

Figure 2.2.1 Brown Trout (*Salmo trutta*) from an Iberian stream (Photo: F. Nunes Godinho).

In contrast to Coldwater Rivers (CR), Warmwater Rivers (WR) – *i.e.* rivers that warm sufficiently to exclude salmonids – vary greatly in size of river channel, flow volume, gradient, width, depth, substrate, aquatic vegetation and riparian cover, and therefore offer a large variety of habitats. In WR, fish assemblages are usually more diverse and include members of several families, *e.g.*, percids, cobitids, esocids and cyprinids. Cyprinids dominate fish assemblages in most European WR, having not only the largest number of species, but also the highest fish biomass.

In WR, riparian vegetation is particularly important for fish because of its influence on the availability and diversity of aquatic habitat. For example, some species of barbel (*Barbus* spp., figure 2.2.2) use holes behind tree roots as a preferred non-spawning habitat. In larger WR, riparian vegetation is also fundamental for maintaining the stability of riverbanks during high flow events.

Figure 2.2.2 Barbel (*Barbus bocagei*) from an Iberian river (Photo: F. Nunes Godinho).

Due to their proximity to areas of high human presence, WR have been particularly affected by deforestation, agricultural and urban development, damming and the discharge of industrial and domestic effluents. As a result, the natural patterns of freshwater fish distribution have changed greatly over time. One of the most notorious signs of alteration has been the successful expansion of introduced fishes over large areas. In Europe, in addition to old fish introductions like the common carp, *Cyprinus carpio,* other species have been introduced since the 19th century and have gained wide distribution, including taxa such as the pumpkinseed sunfish, *Lepomis gibbosus*, the rainbow trout, *Oncorhynchus mykiss* and the largemouth bass, *Micropterus salmoides*. Introduced species, being favoured by altered environments, often interact negatively with native taxa (Godinho and Ferreira, 1998). For example, the most successful fish invaders in Iberia are well adapted to the altered habitat provided by reservoirs (Godinho *et al.*, 1998), an environment where riparian vegetation is absent or is strongly limited by the frequent water level oscillations.

Water permanence can be a problem for fish in some WR, and species living in intermittent streams have to face strong environmental constraints. Intermittent warmwater streams – often small tributaries of larger rivers – harbour fish species that have the ability to respond to drought, either by being able to tolerate the harsh environmental conditions in desiccating pools and/or by moving downstream to places were intermittency is less pronounced (refugia) and colonizing the harsher places in more benign periods. Consequently, the capacity to move freely along the river network could be crucial for the maintenance of fish species/populations and barriers to its movements, like dams, pose serious threats to fish conservation. Nevertheless, human pressure on water resources is likely to continue to increase in these areas, and fish could be competing directly with humans for water availability, requiring a proper balance between ecological and societal needs (Cowx and Collares-Pereira, 2000; Baron *et al.*, 2002).

Fish as indicators of environmental degradation in rivers. The European Water Framework Directive

Due to their reaction to different types of human-induced disturbances, including physical habitat alteration (Ormerod, 2003), freshwater fish are increasingly used as indicators of habitat quality in rivers. In fact, the relationship between fish communities/populations and the quality of their aquatic environments is the basis for using biological monitoring of fish to assess environmental degradation (Fausch *et al.*, 1990).

The indexes of biotic integrity (or ecological status) - derived from Karr's index of biotic integrity (IBI) - usually employ a group of metrics based on fish assemblage structure and function which are integrated into a single numerical index. The index results for a particular site (exposed to some level of disturbance) are finally compared to the index results in a system unexposed to such disturbance, *i.e.*, a reference site (Hughes *et al.*, 1998).

After its widespread use in the USA, the concept of biotic integrity has been adopted in Europe by the Water Framework Directive (WFD, 2000/60/EEC). The directive states that all European rivers should be assessed via a reference condition approach using assessment tools based on biotic elements, including fish. More specifically, the WFD aims to improve the environmental quality of rivers, requiring that: i) all fluvial systems be classified into five quality statuses (high, good, moderate, poor and bad), depending on the degree of degradation, and ii) all except heavily modified water bodies attain at least good ecological status by the year 2015.

In Europe, the FAME R&D project (http://fame.boku.ac.at) developed a standardised fish-based method (European Fish Index, EFI) to assess the ecological status of European fluvial systems. Nevertheless, the FAME project only considered five key physical/chemical parameters, with the key pressure, "habitat disturbance", combining the following indicators: morphological condition, riparian integrity and sediment load. As a result, the index is not adequate for distinguishing the effects of riparian vegetation on fish assemblages and biotic integrity. As stated by Pont *et al.* (2007) the EFI should be improved as regards riparian zone status or land use, mainly by describing anthropogenic pressures more completely. These future developments should improve the capacity of the EFI to detect particular pressures such as those related to riparian vegetation.

Furthermore, since most European rivers are affected by multiple types of pressure, the biological assessment tools should help to identify which pressures most affect fish in order to prioritise restoration measures. This prioritisation should enable river managers to restore riparian vegetation when this is selected as an important factor constraining fish integrity and ecosystem status, thus increasing the probability of success of ecological river rehabilitation/restoration schemes. These aspects are particularly critical for achieving at least good ecological status in European rivers by the year 2015, as required by the WFD.

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Paulo Sá Sousa

AMPHIBIANS AND SEMI-AQUATIC REPTILES

Amphibians

European amphibians comprise two differented groups: the tailed *Caudata* (salamanders and newts) and the tailless *Anura* (toads and frogs) (Arnold, 2003; Griffiths, 1996) . The life cycle of amphibians has a compulsory aquatic phase that often starts during the mating season when spawning occurs and larval development takes place. However, depending on each species, adult individuals predominately spend their period of activity either in aquatic habitats (newts and frogs) or in suitable terrestrial habitats (salamanders and toads). In ecological terms, amphibians tend to avoid aquatic overlap with freshwater fish, which often eat amphibian spawn (eggs and larvae/tadpoles). Thus, temporary freshwater bodies are common aquatic habitats for most amphibians. However, the various linear wetlands that may be preferred by European amphibians are grouped here below into the following three types: mountain streams, ponds in lowland rivers and temporary streams.

Limpid, oxygenated cold streams and cool small rivers

Brook Newts of the genera *Calotriton/Euproctus* prefer clear, oxygen-rich streams, lakes or ponds in mountain areas. The Pyrenean Newt, *Calotriton asper*, uses rocky substrates and avoids muddy waters. The Corsican *Euproctus montanus* and the Sardinian *E. platycephalus* have an aquatic lifestyle, living exclusively in small mountain rivers and unpolluted running waters. These newts may be found under stones or felled trees, but mainly inhabit the root zone of trees and bushes. Their terrestrial habitat is always situated close to the water, whether in wasteland, macchia or woodland. The Iberian lungless salamander *Chioglossa lusitanica* usually lives along the borders of streams with overhanging vegetation and moss-covered rocks (Barbadillo *et al.*, 1999). Its larvae live hidden between stones or in small holes and crevices in permanent rapidly flowing streams with highly oxygenated water. Several Brown Frogs *(Rana)* are found in cold streams. *Rana dalmatina* is widespread in Europe, but in the south of its range the species reproduces not only in stagnant but also in slowly running waters. The rare *Rana pyrenaica* is a mountain stream dweller which does not inhabit ponds or lakes. *R. iberica* is also usually found in cold streams and small rivers in NW Iberia, with a preference for places with abundant riparian vegetation. The Apennine R. italica is a mostly montane species associated with fast flowing streams that have a rocky substrate and some vegetation. *Rana latastei* breeds in permanent and temporary water in wooded areas, sometimes including slow-moving rivers, from northern Italy to southern Switzerland. The Balkanian *R. graeca* inhabits clear streams, springs and small rivers that have running water during the whole year, located mostly in deciduous and mixed forests, but also in hilly and mountainous valleys (Gasc *et al.*, 1997).

The main threats that affect all these species are aquatic habitat loss or damage through infrastructure development (hydroelectric projects) and pressure from tourism-related development in mountain areas. The introduction of predatory trout (salmonids), other non-native fish and exotic mammals (Mustela vison) also constitute a severe threat, leading to local population extinctions.

Ponds created in the margins of small rivers and streams in the lowlands

Many newts of the genera *Triturus* and *Lissotriton* clearly prefer standing waters, and this type of pond is often available in the flood margins of small rivers and streams. During their terrestrial stage newts can be found near ponds, hiding in humid and shady places such as under roots, stones, moss and trees, stone walls and logs. Newts must migrate across land on rainy days to find new aquatic living sites. The Iberian *Lissotriton boscai* prefers small shallow ponds with vegetation. In Atlantic Europe, *L. helveticus* may occur in forested margins of rivers, as may *L. vulgaris*, a eurytopic species. *Lissotriton italicus* is an endemic species of central and southern Italy and it too occurs in slow moving streams, where it lives in the shallower parts of the water to avoid predation. The great newts (*Triturus cristatus, T. dobrogicus, T. karelinii, T. marmoratus,* and *T. pygmaeus*) are found in aquatic habitats near coniferous, mixed and deciduous forests, in their glades and edges and in bushlands, flooded meadows and swamps, including those in river valleys overgrown with large herbaceous and brush vegetation. Aquatic habitats used for breeding and larval development include traditional farmland areas and other slightly modified habitats (*i.e.* lagoons, irrigation ponds and channels, ditches, drinking troughs, wells, oxbows and abandoned quarries). The Eurasiatic Fire Salamander (*Salamandra salamandra*) (figure 2.3.1) takes a variety of forms and is widely distributed through Europe. The terrestrial adults mainly inhabit deciduous and mixed forests and sometimes also conifer forests. The species is typically viviparous, and the female releases the young into water, usually in shallow brooks.

Figure 2.3.1 The Euroasiatic fire salamander *S. salamandra* (Photo: Marco Caetano).

Tree Frogs (*Hyla arborea, H. intermedia, H. savignyi* and *H. sarda*) are found within the vicinity of pools, ponds and streams, generally associated with open, well-illuminated broadleaved and mixed forests, bush and shrublands, meadows and low riparian vegetation; they are also found in anthropogenic landscapes like gardens, vineyards, orchards, parks and lake shores. Dark, dense forests are avoided. Spawning and larval development take place in stagnant waters such as lakes, ponds, swamps and reservoirs, in slow flowing brooks and sometimes in ditches and puddles. Green Frogs *(Pelophylax (ex-Rana) bergeri, P. epeirotica, P. esculenta, P. grafi, P. lessonae, P. perezi* and *P. ridibunda)* are often highly opportunistic and abundant anurans, being semi- or quasi-aquatic species (figure 2.3.2).

They inhabit (and breed in) a wide variety of temporary and permanent waterbodies (pools, slow moving rivers, streams, brooks, ditches, irrigation canals, reservoirs, and marshes etc.), often with rich vegetation at the edges, since these frogs prefer open, well-warmed areas with abundant herbaceous vegetation.

Figure 2.3.2 The Iberian Green frog *Pelophylax (ex- Rana) perezi* (Photo: Marco Caetano).

The major threats to all these species are drainage or canalization of waterbodies for building, tourism and agricultural intensification, or agrochemical and industrial pollution of breeding waterbodies. Predation by invasive species, like fishes (E*sox lucius, Lepomis gibbosus, Macropterus salmonoides*), the Louisiana crayfish (*Procambarus clarkii*) and large frogs (exotic *Rana catesbeiana,* alocthonous *Pelophylax ridibunda/esculenta*) constitutes another severe threat. In some European regions, commercial capture for food (frog-leg trade with *Pelophylax*) or pets (*Lissotriton, Triturus, Hyla*), can potentially threaten local populations.

Temporary streams that frequently recede in summer

Amphibian diversity in the Mediterranean basin is much lower than in Atlantic-influenced Europe, this being largely a reflection of the extent to which arid and semi-arid habitats predominate in large parts of the region (Cox *et al.*, 2006). One family, the *Discoglossidae* (painted frogs and midwife toads), is almost endemic to the Mediterranean region, and two of the three species of *Pelodytidae* (parsley frogs) are endemic. All four members of the Pelobatidae (Eurasian spadefoots, Pelobates sp.) also occur in this region, two of them being endemic. Midwife toads (*Alytes*) are clearly terrestrial, *A. cisternasii* (figure 2.3.3) being associated with xeric Mediterranean open *Quercus* forests. Adults of *A. dickhelleni* are usually observed on eroded soils near water or found under stones. The Western European *A. obstetricans* lives in terrestrial sites near its stream breeding sites: slopes, walls, embankments with many small stones, stone slabs or sand, normally with sparse vegetation are preferred. The critically endangered *A. muletensis* barely persists in some mountain canyons/ponds in the Sierra Tramontana (Majorca). In general all these toads live in the vicinity of temporary streams and creeks which are not too fast-running and permanent waters, where they spawn and their tadpoles often over-winter in the water. Painted Frogs (*Discoglossus*) are mostly found in or in the direct vicinity of water: stagnant waters, swampy lands, mountain streams and even brackish waters. *Discoglossus galganoi* and *D. jeanneae* are both Iberian endemics, separated by the River Guadalquivir. Both *D. montalentii* and *D. sardus* are restricted to the Tyrrhenian area, particularly the Corsican and Sardinian archipelagos.

Figure 2.3.3 The Iberian Midwife toad *Alytes cisternasii* (Photo: Marco Caetano).

The irregularity of the annual Mediterranean rainfall constrains the pattern of amphibian activities. Some 70% of Mediterranean water is used for agriculture. Many wetlands have been lost through drainage and diversion (*e.g.* 65% in Greece) with implications for amphibians. Many artificial water bodies that are suitable for amphibians (*i.e.* catle troughs, wells, reservoirs) were supplied by the traditional extensive agriculture. Nowadays, low rainfall combined with more intensive, unsustainable water-dependent farming are concomitantly responsable for a high level of threat (25.5% of the Mediterranean amphibian species are threatened). Invasive alien species have the next-largest impact. Natural disasters, human disturbance and disease susceptibility (*i.e.* Alytes) are also significant for some species.

Semi-aquatic reptiles

Few reptiles are stream residents and only some are visitors of the riparian edges. Palearctic freshwater turtles (or terrapins) like *Emys orbicularis* live in and around slow-flowing water in streams and rivers with dense riparian vegetation. *Mauremys* terrapins – the Ibero-Maghrebian *M. leprosa* (figure 3.3.4), the Southwestern Balkan M. rivulata and the Southwestern Balkan/Caspian *M. caspica* – inhabit more open riversides or reservoirs. These turtles can only feed in water, so they are completely dependent on water bodies. They also need exposed, sunny places for basking *e.g.* deadwood or shores, so the occurrence of suitable basking sites can be a limiting factor.

Figure 2.3.4 The Ibero-Maghrebian terrapin *Mauremys leprosa* (Photo: Marco Caetano).

Among the Green Lizards, the Iberian *Lacerta scheiberi* inhabits river and stream sides and the Greek *L. trilineata* can also be found close to streams and ditches. The four lizard species of the secretive genus *Algyroides* are found in forested areas of sparse grass and rocky habitats near stream/river valleys, where they can be found close to water on rocks, tree trunks and cliffs. The Spanish *A. marchi* is restricted to the Alcaraz, Cazorla and Segura mountain ranges; *A. fitzingeri* is endemic to Corsica and Sardinia; *A. nigropunctatus* spreads around the coastal eastern Adriatic and *A. moreoticus* is endemic to the Peloponnese (Greece). Two limbless lizards, the European *Anguis fragilis* and the Balkan *A. cephalonnica*, are visitors of hedgerows and wooded stream sides, where they tend to take refuge under stones, planks of wood, etc.

Two snakes, *Natrix maura* and *N. natrix,* may be found close to or within almost all types of water bodies, such as streams and ponds, in Western Europe; however, *N. natrix* is less frequent at watersides than *N. maura* and often occurs at a distance from the nearest water body.

Major threats for these reptiles are caused by habitat loss, largely through deforestation, stream bank erosion, water abstraction and forest fires. Some exotic terrapins (*Trachemys scripta* or *Pseudemys picta*) are competitive displacers of the autochthonous freshwater turtles.

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Jean Roché
Bernard Frochot

RIPARIAN BIRDS

Riparian landscapes and bird communities

Birds perceive the environment as a landscape and watercourses appear in a patchwork of terrestrial and aquatic habitats. Because they are highly mobile, birds can use the different parts of the river system not only during the nesting season but throughout their life-cycle.

Bird communities in different habitats

Flat banks

In the Mediterranean region, the uneven rainfall pattern means that sand and gravel banks cover a large part of the watercourse bed. Few species nest on them: essentially Little Ringed Plover (*Charadrius dubius*) (figure 2.4.1), less frequently Stone Curlew (*Burhinus oedicnemus*), Little Tern (*Sterna albifrons*) and Common Tern (*Sterna hirundo*). These species require bare spaces. They nest on the ground and prefer extensive banks above the normal high water levels, or spots surrounded by water for better protection from predators. During the migration period, particularly in autumn when rain revives the Mediterranean watercourses, these margins can attract a number of wading species that use them as a staging post to rest and find food (Common Sandpiper (*Actitis hypoleucos*), Green Sandpiper (*Tringa ochropus*), Egret, etc.). They hold less interest in winter, when many are under water.

Figure 2.4.1 Little Ringed Plover, *Charadrius dubius*, breeds on gravel banks (Photo: Jean Roché).

Steep banks

These are associated with active fluvial dynamics. When the sediment is sufficiently soft, the bank sides offer nesting sites to several hole-dwelling species that dig their burrows in them: Kingfisher (*Alcedo atthis*), Sand Martin (*Riparia riparia*) and European Bee-eater (*Merops apiaster*). Old or unused holes may be occupied by other species that do not excavate their own nest-holes: Little Owl (*Athene noctua*), Jackdaw (*Corvus monedula*), or sparrows (*Passer* spp.). Length and height make the bank more attractive for nesting, particularly for colonial species (sand martins, bee-eaters). This habitat is deserted by birds during the migration and winter periods.

Riparian woodlands

The breeding avifauna in Mediterranean forests is largely composed of different species to those of the temperate regions of Europe (Blondel, 1990). The same is true of riparian woodland birds. Riparian bird communities can be divided into three groups. The first is composed of woodland species that live and feed in the riparian forest. They are not very numerous and are rarely abundant in these latitudes. The most frequent species are Great Tit (*Parus major*), Blue Tit (Parus caeruleus), Wood Pigeon (*Columba palumbus*), Short-toed Treecreeper (*Certhia brachydactyla*) and Great Spotted Woodpecker (*Dendrocopos major*). This group is mostly based on resident species. The second group is composed of edge species and is better represented. The linear form of this habitat increases the interface between the woodland and the river on one side and the woodland and the valley on the other. Additionally, riparian woodlands are more or less reshaped by freshets and often have clearings that increase the 'internal edges'. Apart from some typical year-round inhabitants (Cetti's Warbler *Cettia cetti*, figure 2.4.4), the breeding birds include numerous migrants (Blackcap *Sylvia atricapilla*, Nightingale *Luscinia megarhynchos* Greenfinch Carduelis chloris), including some with Mediterranean affinities (Melodious Warbler *Hippolais polyglotta*, Serin *Serinus serinus* and Golden Oriole *Oriolus oriolus*). The last group is made up of water birds that use the riparian woodlands and edges as nesting sites but range further to feed, along the water course, in its oxbows or on other water bodies in the valley. Most are large species (Black Kite *Milvus migrans*), often colonial (tree-dwelling herons, storks *Ciconia* spp.), which despite their vast range show a liking for riparian woodlands surrounded by wetlands, as they provide a certain measure of security and, particularly, sources of food nearby that can be taken with little expenditure of energy (figure 2.4.5). In autumn, riverside woods acquire a greater proportion of migrating birds *(Fringillidae, Sylviidae, Turdidae*) which take advantage of the availability of berries (Bay Trees, Dogwoods, Spindle Trees, Hawthorns, etc.). In winter, the composition of the bird community has a more clearly northern affinity, because species that are scarce during the breeding season move south (Blackbird *Turdus merula,* Robin *Erithacus rubecula*, Chiffchaff *Phylloscopus collybita*, Wren *Troglodytes troglodytes*).

Wetlands

When they do not dry out, wetlands are good nesting places for birds that prefer standing waters (Moorhen, *Gallinula chloropus*, Coot, *Fulica atra* and Mallard, *Anas platyrhynchos*). These habitats are also of interest to woodland birds because of the abundance of invertebrates and also because of the amount of dead wood accumulated if the woodland is not managed. Those which are fringed by willows and by large heliophytes can harbour a rare, yet typical species: the Penduline Tit (*Remiz pendulinus*). Wetlands can contribute to the security of riparian forests not only by making access more difficult but also because they may favour the occurrence of species which are very sensitive to human disturbance (birds of prey, heron colonies). Depending on their water level and the amount of aquatic vegetation, wetlands can provide stopover sites to several migrating mudflat dwellers and marshland passerines (warblers *Acrocephalus* spp., Reed Buntings *Emberiza schoeniclus*) and winter food resources to a range of water birds (ducks, herons, etc.).

Grasslands

The most remarkable habitats for birds are grasslands that flood. While infrequent in the Mediterranean region, here and there they provide a less disturbed habitat than farmland to bird species associated with open areas (Yellow Wagtail *Motacilla flava* (figure 2.4.3), Skylark *Alauda arvensis*, Lapwing *Vanellus vanellus*). Dry grasslands are more frequent. They are populated by some passerines with southern affinities (Crested Lark *Galerida cristata*, Zitting Cisticola *Cisticola juncidis*). During migration periods and in winter, a multitude of other small passerines can also be seen (wheatears, swallows, wagtails, pipits, etc.).

Figure 2.4.2 The Greater White-fronted Goose, *Anser albifrons,* a cosmopolitan wetlands visitor (Photo: Mats Björklund).

Figure 2.4.3 Flooded grasslands near rivers provide open areas for the Yellow Wagtail, *Motacilla flava* (Photo: Bernard Frochot).

Bird communities and the dynamics of riparian woodlands

It is a well known fact that in all forest formations, bird populations alter radically as a result of environmental succession. When the tree population of an ancient forest is destroyed by a disturbance such as a fire, a storm or felling, its birds immediately abandon it. However, the resulting open area rapidly acquires a new ornithological community, initially composed of species looking for bare ground (White Wagtail *Motacilla alba*, larks, pipits, etc.). The turnover of the avifauna is considerable and can even exceed 90 % if all the trees are removed (Ferry and Frochot, 1970). In subsequent years, the development of the vegetation succession is accompanied by new transformations in the bird community: pioneering species disappear and are replaced by Grasshopper Warbler (*Locustella naevia*) or Common Whitethroat (*Sylvia communis*) in the herbaceous stages, Linnet (*Carduelis cannabina*) or Melodious Warblers (*Hippolais polyglotta*) in low bushes, Garden Warbler (*Sylvia borin*) or Nightingale (*Luscinia megarhynchos*) in thick bushes, then Turtle Dove (*Streptopelia turtur*), etc. before the return of old forest birds (tits, *Parus* spp., Chaffinch, *Fringilla coelebs*, woodpeckers, *Dendrocopos* spp. ...) (Blondel, 1995; Ferry and Frochot, 1990). Generally speaking, the same pattern is also found in conifer or poplar plantations.

Why does the avian population change so greatly during successions? The main reason is specialisation: when birds have adapted to specific plant sizes and shapes, they are particularly demanding in this regard. Depending on the species, they may have specialised in the way they move: some species only ever move on the ground, others climb trees, yet others perch at the end of the branches, and so on. In spring, these everyday needs are joined by breeding requirements: each species chooses a very precise site to install its nest, entailing an environment that it can only find at a particular stage in the woodland succession. Each stage in the development of the forest has its own typical bird community and the age of the tree stands, *i.e.* the years since the last major disturbance, is a factor of some importance for its ornithological community.

Figure 2.4.4 Cetti's Warbler, *Cettia cetti* is one of the more constant breeding birds in Mediterranean riparian corridors. (Photo: Jean Roché).

On the other hand, most European birds are 'poor botanists' in that they inhabit oaks, beeches, chestnuts or other broadleaf trees indiscriminately. However, it is true that they eat little food of plant origin as they are mainly secondary consumers (omnivores) and feed on a wide variety of invertebrates. This gives them a certain degree of independence from the floristic composition of the forest.

Consequently, riparian woodlands harbour similar bird communities, as regards their composition and dynamics, to those of other broadleaf forests (Frochot *et al.*, 2003). Locally, these communities are determined above all by the physiognomy of the vegetation, *i.e.*, by the age and spatial layout of the tree species.

Floods are a major cause of disturbances: they can rejuvenate the tree populations, starting new successions on the sediment they bring down, or have the opposite effect, leaving behind clumps of ageing forest. On a smaller scale, a river segment or a river reach, the riparian forest then becomes a patchwork of all the stages of forest succession, with a very great diversity of plants and birds.

The mature stages of riverside woodlands, while often associated with exuberant primary vegetation, do not in fact harbour any particular avian species. Nonetheless, there is usually a great abundance of some species, including Golden Oriole (*Oriolus oriolus*), Lesser Spotted Woodpecker (*Dendrocopos minor*) and flycatchers. Locally, willow groves are the habitat of Willow Tit (*Parus montanus*) or Penduline Tit (*Remiz pendulinus*).

In earlier stages, where herbaceous plants and pioneering bushes are dominant and the moister soil is accompanied by hygrophilous vegetation, a less common avian fauna may be found: Whinchat (*Saxicola rubetra*), Bluethroat (*Luscinia svecica*), Reed Bunting (*Emberiza schoeniclus*) and Cetti's Warbler, and sometimes *Rallidae, Anatidae* or Snipe *(Gallinago gallinago*).

Riparian bird conservation

Which species have heritage value?

At least 11 woodland species and 8 aquatic species listed in Annex I of the EC Bird Directive nest in riverside habitats. In France, moreover, two-thirds of the 34 species listed in the national Red Book of Endangered Species that nest in that country can inhabit riparian woodlands (Roché, 2002). Nonetheless, it should be noted that riparian woodland birds in the Mediterranean basin are mainly common species and only a few are really noteworthy in this environment (such as Roller *Coracias garrulus*, Penduline Tit, storks or shrikes *Lanius* spp.).

What bird conservation measures are needed?

Riparian bird communities owe their richness and abundance to natural river dynamics. Through the processes of alluvial erosion and deposition, the watercourse maintains and renews the numerous habitats on which birds depend. The first conservation measure, therefore, should be to protect and if necessary restore these dynamics by protecting the natural flow regime and the quality of the water and by keeping the channel free of hard construction.

More locally, complementary measures at specific points are useful for protecting river channel bird breeding grounds, such as keeping steep banks soft and open (so that Kingfisher, *Alcedo atthis*, Bee-eater, *Merops apiaster*, Sand Martin, *Riparia riparia* and Little Owl, *Athene noctua* have suitable breeding locations) and protecting and even keeping a watch on flat banks and islets where colonies nest (particularly terns, *Sterna* spp.) in order to prevent disturbance by visitors in springtime. In riparian woodlands, the ideal is to preserve a patchwork of all the stages of succession. If the habitat is large, the watercourse can be trusted to maintain this diversity by itself through the free play of erosion and deposition. If it is small, as in residual strips of riparian forest, or if the river dynamics have been weakened, localized planting can be used to maintain a balance between early and mature stages. Particular attention could then be paid to conserving dead trees that provide many species

Figure 2.4.5 Wide riparian forests surrounded by wetlands are of great interest for herons like the Little Egret, *Egretta garzetta* (Photo: Jean Roché).

with nesting holes, sources of food or perches from which to hunt or fish. Grazing in riparian woodlands is sometimes practised but is not helpful for the birds, as it destroys the undergrowth where many scrub-dwellers nest. On open land, however, grazing helps to support a rich and diverse entomological fauna and can contribute to maintaining the various stages of woodland succession, assisting numerous species.

At a landscape scale, the role of lines of riparian forests as ecological corridors between the forests at the head of the catchment and those of the plain needs to be preserved and if necessary restored by reconstructing bands or even just narrow strips of woodland. Obviously, these corridors will be even better for birds if they are several dozen meters long, continuous and high (with trees) and if they have a vegetation structure composed of several vertical strata. As regards wetlands, an important food source for birds, the recommendation is to maintain or restore their connectivity with the river channel. This also helps the woodlands that often border them to remain floodable.

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MAMMALS

António Mira

Riparian zones are habitats of huge importance for most European mammal species (Mitchell-Jones *et al.*, 1999; O'Conell *et al.*, 1993). This significance is strengthened in Mediterranean environments, where hot and dry summers put the survival strategies of mammals occurring in these regions to the test.

For species with a semi-aquatic way of life, like the European Mink (*Mustela lutreola*), Otter (*Lutra lutra*), Iberian Desman (*Galemys pyrenaicus*), water shrews (*Neomys anomalus* and *N. fodiens*), Eurasian Beaver (*Castor fiber*) and water voles (*Arvicola sapidus* and *A. amphibious*), riparian areas are key habitats. In fact, these species often feed and breed on them and move for preference along riparian corridors.

The Iberian Desman mainly inhabits small mountain rivers with clean, oxygenated waters, generally associated with riparian vegetation that provides shelter and nesting places. Its global population is decreasing, the main cause being habitat loss and degradation (Palomo and Gisbert, 2002). In Europe it has recently been classified as Near Threatened (NT) in accordance with the IUCN Red List Categories and is legally protected, figuring in annexes II and IV of the Habitats Directive (92/43/CEE).

Water shrews occur in a broad range of wetland habitats, both freshwater and coastal. However, riparian woodlands are among the most significant for both species, which often live their entire life cycle in this kind of environment. *N. fodiens* presents a wide distribution and stable population trend in Europe. However *N. anomalus*, a species with a more Mediterranean distribution, may be declining in some areas of its range.

Many European populations of the Eurasian Beaver are now increasing due to the implementation of conservation programmes in several parts of their range. Beavers can occupy many kinds of freshwater environments; however, they usually prefer aquatic habitats embedded in a woodland matrix where they can construct their burrows or lodges.

Water voles inhabit a wide range of freshwater habitats, including streams, rivers, irrigation ditches, ponds, lakes and marshes. However, their presence at these sites depends on the existence of a tall, dense grassy layer and/or shrubs in the margins, to provide cover, food and nesting sites. The global population trend of *Arvicola sapidus*, the Mediterranean species, is decreasing.

The Otter (figure 2.5.1) is a semi-aquatic carnivore that occupies a variety of aquatic environments, including lakes, marshes, rocky coastal areas and rivers. However, in most parts of its range otter occurrence is dependent on the existence of riparian vegetation. In these areas, otter breeding sites are often associated with the presence of dead trunks and cavities among tree roots, and the availability of these may be a limiting factor for riverbank occupation and breeding.

Figure 2.5.1 The Otter: an important species of European wetlands (Photo: Marco Caetano).

The European Mink lives in densely vegetated banks of rivers, streams and marshlands and is rarely seen away from freshwater environments. It is one of the most threaten European mammals, being classified as Critically Endangered (CR) in the European Union.

The Otter and the European Mink are included in annexes II and IV of the Habitats Directive.

For all the species mentioned above, changes in riparian habitats due to anthropogenic activities are the main cause of local or global population declines. Habitat loss and degradation resulting from clearing vegetation to channelize streams, water extraction, diffuse pollution from agriculture and acute water quality degradation from industry and other human activities are the major factors acting negatively on the populations of semi-aquatic European mammals.

Habitat fragmentation through dam and reservoir construction is also a major problem for species conservation, since it promotes the isolation of some already small populations. Restoring connectivity between fragmented populations through riparian corridor recovery is a major action that needs to take place in order to invert the negative population trends.

However, other mammal species living in different types of habitat may also depend on riparian zones to complete their life cycles or, at least, to facilitate part of this cycle. In fact, the presence of water and shade provide microhabitats and microclimates that promote higher plant and insect diversity and biomass. Many small mammal species, including the wood mouse, the Algerian mouse and the common shrew, can take advantage of these extra resources, so they concentrate at these sites, attracting predators like weasels, polecats, genets and foxes to riparian areas.

Nonetheless, the higher humidity and high abundance of insects may be a limiting factor for wild rabbit establishment in riparian zones. In fact, besides being ecologically poor for rabbits these conditions promote the spread of diseases like myxomatosis and haemorrhagic fever. These diseases are the main factor contributing to rabbit decline in many parts of Europe.

The milder climate conditions of riparian zones when compared with the surrounding habitats (particularly important during the Mediterranean summer) and the availability of refuges (hollows in tree trunks and among roots; stones, dead wood and debris) make them good areas to rest and shelter for some arboreal bats and carnivorous mammals, which tend to use these habitats intensively.

The accumulation of sediments and litter offers suitable soil conditions for fossorial and semi-fossorial species. In some places moles (*Talpa* spp.) and pine voles (*Microtus* spp.) find soft soil with depth enough to construct their underground galleries and in regions with a Mediterranean climate they tend to concentrate in these areas in summer.

The usually linear forms of riparian areas make them natural corridors for the dispersion of most mammalian species and the main paths of genetic exchange. Consequently, their role as routes of connectivity among populations is of incomparable ecological value for biodiversity conservation at all levels.

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3

Assessing the Ecological Quality of Riverine Landscapes

RIPARIAN SYSTEMS AS ZONES OF PERVASIVE ANTHROPOGENIC STRESS

Henri Décamps
Robert J. Naiman
Michael M. McClain

Riparian zones have been affected by multiple anthropogenic stresses, including flow regulation, land use and climate change. These stresses have isolated the rivers from their floodplains, fragmented forest covers, and favored the expansion of species formerly restricted to the terrace or the uplands. As a result, the physical and biological diversity of the riparian systems have declined along most river networks. We summarize here the effects of anthropogenic stresses on riparian systems after our book "Riparia" (Naiman *et al.,* 2005).

An historical approach of riparian alterations

Human attitudes toward riparian zones have changed over the centuries. At first, riparian zones were rather fearful places, made up of inextricable thickets and deemed unhealthy because of the wetlands that they included. They have been transformed and exploited as fertile fields and as pastures, deprived of their vegetation to facilitate towing of boats by ropes, or planted with flexible willows that were cut regularly for local uses (Décamps *et al.,* 1988). During the 19th century, riparian zones were marginalized by dam constructions and river embankments (Petts, 1989). Only recently were riparian zones recognized as being worthy of conservation or restoration.

As a general consequence, the natural relationship between floodplains and the main channels no longer exists for many large rivers in North America and Europe and is rapidly disappearing on other continents. Particularly in Europe, rivers have been harnessed and managed for numerous uses for nearly a thousand years. Some of the first modifications were for waterpower and navigation in the 12th and 13th centuries (table 3.1.1). Flood control, channelization, and land reclamation followed by ca. 1500 AD, and the construction of water supply dams followed by ca. 1600 AD. Concomitant impacts included artisan fisheries and severe pollution, in addition to large woody debris removal from river channels (Maser and Sedell, 1994). Collectively, these and other modifications to rivers and uplands greatly modified riparian communities (table 3.2.2).

Flow regulation

The main responses of riparian zones to flow regulation depend on the type of regulation – dam characteristics, dikes, and diversion – and the local geology and climate. Dams alter fluxes of nutrients and migrations of organisms, dikes and bank stabilization isolate rivers from their floodplains, diversions either de-water rivers or add water to rivers (*e.g.* interbasin transfers), thereby modifying natural moisture regimes.

A worldwide view of flow regulation

Massive hydrological alterations – to ensure water and energy for agricultural, industrial, and domestic purposes or for flood protection – have changed riparian characteristics throughout the world. An estimated two-thirds of the fresh water flowing to the oceans is obstructed by ~45,000 large dams >15 m high (GWSP, 2004), at least 800,000 slightly smaller dams, and literally millions of "minor" diversions such as artificial ponds and roof catchments. The world's dams alone store 10,000 km^3 of water; seven times more than the total volume of water in all rivers and equivalent to a 10 cm layer spread over the world's dry land surface. Additionally, long stretches of many rivers are further constrained by artificial levees and dikes. More than 500,000 km of waterways have been altered for navigation worldwide, and more than 63,000 km of canals have been constructed.

The extent of dam construction and associated flow regulation on a single catchment can be massive (Rosenberg *et al.,* 2000). The Columbia River and its tributaries in the United States and Canada contain 194 large dams, almost 200 reservoirs occupy the Danube River catchment, eleven large hydropower stations and 200 small and large reservoirs (inundating 26,000 km^2 of land) have been built on the Volga-Kama River catchment, and more than 130 reservoirs have been built on the River Don catchment (inundating 5,500 km^2).

Examples of the effects of flow alterations on the extent, duration, and frequency of floodplain inundation are pervasive. After closure of the Aswan high dam, the Nile River showed a reduced annual discharge, truncated annual floods, higher base flow rates, and a shift of several months in the timing of the flood peak. The maximum-to-minimum discharge ratio decreased from 12:1 to 2:1, with far-reaching consequences on floodplain inundation. During the dry season, the Senegal River now frequently ceases to flow, and less than 1 percent of the natural flow of the Colorado River reaches the mouth. The Murray River in Australia now discharges only 36 percent of its natural flow into the sea, flood duration on the fringing floodplains has decreased from two months to a matter of days, and the timing of floods has shifted from spring to late summer. Similar fates have affected the Nile, Ganges, Amu Dar'ya, Syr Dar'ya, and Yellow rivers, and over-pumping of ground water plagues the central United States, California's central valley, China's northern plains, and major portions of India (Postel, 1997 and 2000).

The "terrestrialization" process

Flow regulation affects the integrity of riparian zones by lowering water tables, reducing lateral fluxes of water and materials, accelerating and modifying the processes of plant succession, and stopping the formation of new habitats (Ward and Stanford, 1995). Essentially, the riparian zone undergoes a "terrestrialization" process that undermines its natural ecological vitality. Productive pioneer species tend to be replaced by less productive upland species that invade the floodplain under artificially enhanced conditions of environmental stability (Décamps, 1993). In essence, the overall effect of flow regulation on floodplains is to impose equilibrium conditions on non-equilibrium communities, thus affecting the recruitment, establishment, and survival of many riparian tree species such as poplars and willows (Rood *et al.,* 2003) or favoring the spread of non-native species (Friedman and Auble, 2000). Alterations in flow also affect the associated fauna through the inundation of valley bottoms or the dewatering of streams.

Ecological sustainability

The alteration of flow regimes is a serious threat to the ecological sustainability of rivers and their associated floodplains (Naiman *et al.,* 2002; Nilsson and Svedmark, 2002). The flow regime is a natural key "driver" of the ecological integrity of riparian zones, determining the dynamics of riparian plant communities and ecological processes. Every river has a characteristic flow regime that redistributes organic and inorganic material, thus influencing plant communities in the riparian zones. Therefore, a major challenge for riparian management is to utilize water resources within the framework of the characteristic flow regimes in order to maintain the goods and services of riparian systems for the long term (Richter and Richter, 2000).

Land use change

Land use change has pervasive consequences for riparian zones, particularly through effects on temperature regimes, nutrient enrichment, and invasive plants.

Temperature regimes

Riparian zones clearly influence stream temperatures, with consequences on their biology as shown along many streams. In the H.J. Andrews Experimental Forest in Oregon, forest harvesting increased maximum stream temperatures by 7°C (Johnson and Jones, 2000). This maximum occurred earlier in the summer, and June daily variations increased by 6°C. Stream temperatures gradually returned to pre-harvest regimes after 15 years as the forest recovered, better regulating short-wave radiation and heat conduction from terrestrial soils.

Nutrient enrichment

Alterations to the global N and P cycles result in a decreasing capacity of riparian zones to retain one or more elements, with attendant downstream effects, harmful algal blooms, coastal hypoxia, and fish kills (NRC, 2000). Nutrients added to the inflowing water influence the species composition and productivity of floodplain organisms (Hanson *et al.*, 1994). As ammonium builds up in riparian soils, it is increasingly converted to nitrate by microbial action, a process that releases hydrogen ions, acidifying the soil. The buildup of nitrate enhances emissions of nitrous oxides and also encourages leaching of highly water-soluble nitrate into streams and groundwater. As these negatively charged nitrates seep away, they carry with them positively charged alkaline minerals such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}). Thus, the human modification of the nitrogen cycle not only increases N losses from the riparian soils, it also accelerates the loss of Ca and other nutrients that are vital for plant growth.

Species invasion

Riparian zones are particularly vulnerable to species invasion, and frequently disturbed sites near the active channel contain generally high percentages of non-native species (DeFerrari and Naiman, 1994; Pyšek and Prach, 1994). Along France's Adour River, plant invaders account for one-quarter of the total species richness of 1,558 species and locally can constitute up to 40 percent of all species (Tabacchi and Planty-Tabacchi, 2000).

Despite great differences in climate, species richness, and land use history, the proportion of invasive species along the Adour River is similar to rivers along the Pacific Coast of the United States and to South African rivers (Planty-Tabacchi *et al.*, 1996, Hood and Naiman, 2000). In the southwestern United States, as a result of widespread human-induced changes in hydrology and land use, native cottonwood and willow stands are being replaced by non-native woody species such as Russian Olive (*Eleagnus angustifolia*) and tamarisks (*Tamarix* spp.) (Cleverly *et al.*, 1997).

However, the ecological outcome of any particular introduction is probably impossible to predict. Only a very small percentage of the available species pool has the life history characteristics and physiological tolerances needed for successful colonization. All colonization patterns are characterized by large variance and exceptions.

Climate change

There is an increasing consensus that substantial warming of the Earth's climate would produce more clouds and rain on average but varying drastically from one area to the next. More violent precipitation events locally and regionally are expected with aggravated risk of flooding, whereas severe drying of soils will also occur in many locations (Milly *et al.*, 2002). These projected changes will place additional pressures on already-stressed river and riparian systems.

Changes in temperature regimes

Changes in temperature regimes (*e.g.*, extreme temperatures, their duration, and seasonal rates of temperature change) alter growth and reproduction for many species. In addition, global warming already shifts the potential geographic ranges of species to the north, or to higher elevations in mountain regions, depending on the presence of suitable habitats as well as of dispersal corridors (Poff *et al.*, 2002). It has been suggested that a warming of water temperatures by 4°C in present-day ecosystems would represent a northward latitudinal shift in thermal regimes of about 680 km, with serious consequences for riparian zones (Sweeney *et al.*, 1992).

Higher temperatures increase the rate of microbial activity and thus the rate of decomposition of organic material, which may increase nutrient availability in riparian soils (Dang *et al.*, 2007). Over time, even groundwater will warm, affecting riparian species further. In Northern regions, winter water temperatures are likely to increase by several degrees Celsius, eliminating extensive ice cover and permafrost, and allowing invasion of cool-adapted species (Poff *et al.*, 2002).

Changes in precipitation and runoff regimes

A modified seasonal pattern of runoff in response to climate change will alter riparian composition and system productivity – and the timing and magnitude of flooding are central in this process (Poff *et al.*, 1997; Meyer *et al.*, 1999). Many of the life history characteristics (*e.g.* reproductive strategies) of both aquatic and riparian species have evolved to avoid or take advantage of predictable high spring flows. For example, successful reproduction by cottonwood trees depends on snowmelt that creates high spring flows inundating the floodplain habitat (Rood and Mahoney, 1990; Auble *et al.*, 1994).

Another significant consequence of shifting from snow to rain at high elevations or in northern basins is the reduction of discharge in late summer. This is expected even if winter precipitation increases in northern latitudes because excess precipitation will not be stored as snow, which provides a source of runoff to sustain late summer base-flow in arid highlands. Less water in the stream channel means less water flowing into streamside groundwater tables, which are important for sustaining riparian tree communities (Stromberg *et al.*, 1996; Scott *et al.*, 1999). As a consequence, riparian communities are likely to experience conspicuous changes in species composition and productivity.

Even if flooding increases in magnitude and frequency, earlier snowmelt and higher temperatures could still result in lower summer discharge in many areas. In addition, some areas could become generally drier and thereby become particularly stressful for river and riparian systems. Many aquatic communities in large rivers are partially dependent on riparian floodplains, either as a nursery habitat for fish or for seasonal export of nutrients from floodplain wetlands to the river. If these floodplains become disconnected from the main rivers because of reduced discharge, it is obvious that aquatic productivity and diversity would decline.

Conclusion

Human intervention in the global water cycle through land cover change, urbanization, industrial development, and water resources management has hydrological impacts beyond the greenhouse effect alone (Rosenberg *et al.*, 2000, GWSP, 2004, Kabat *et al.*, 2004). The cumulative impact of these factors is certainly important, and one critical uncertainty in projecting future aquatic ecosystem response to a changing climate is how humans will interact with changing river and riparian conditions. Human activities have changed many aquatic and riparian ecosystems by diversion, groundwater pumping, and the building of dikes, levees, and reservoirs. These changes have modified natural processes and fragmented the aquatic landscape, making dispersal between ecosystems more difficult and increasing system vulnerability to the additional stresses associated with climate change. Sustainable management, conservation and restoration of rivers and their riparian environments is a major challenge for this century.

Table 3.1.1 Development of River Regulation in Europe (from Petts, 1989).

Year	Historical Sequence	Significant Developments	Other Impacts
1250	Weirs for water power	Stanches widespread in Flanders, Germany, France, Italy, and England	
	River improvements for navigation	1398 First summit canal (R. Stecknitz) 1400 Bertola designed channelization of R. Adda 1497 Leonardo designed pound-lock with mitre-gates Verona (R. Adige) and Florence (R. Arno) established river authorities 1550 Lupicini designed flood-defences for R. Po	Artisanal fishery
1500	Flood-control and land reclamation	Dredging using endless chain technology developed by 1561 Pound locks widespread Small rivers channelized (*e.g.*, Yevre and Havel)	Artisanal fishery
	Science of regulating rivers established	1577–1643 Castelli (Founder of modern hydraulics) 1594 Alicante dam (41 m-high masonry) 1692 Completion of Languedoc canal Guglielmini (1697) and Baratteri (1699) scientific approach to river regulation	1616 R. Thames pollution problems
1750		Large rivers channelized (*e.g.*, R. Oder) R. Guadalquivir: length to Seville reduced by 50 km (40 percent)	Commercial and artisanal fishery
		Earth bank water-supply dams spread in headwater catchments	Pollution
1850	Extensive floodplain reclamation	Major rivers channelized (*e.g.*, Alsatian Rhine and Alpine Rhône) 1845 R. Tisza (Theisz) shortened by 340 km, 12.5 x 106ha reclaimed 1849 R. Danube 4 x 106 ha floodplain reclaimed along 230 km reach Masonary headwater supply dams (50 m high) common	River Thames severely polluted
	Water supply dams spread	1898 Hydroelectric power dam at Rheinfelden	Overfishing
1900	Hydroelectricity dams	1937 First 1,000 x 106 m^3 reservoir: Ivankovo, R. Volga (1,120 x 106 m^3) 1941 First 25,000 x 106 m^3 reservoir: Rybinsk, R. Volga (25,400 x 106 m^3) 1950 First 150 m high dam: Noce-Aldigo, Italy	Severe pollution widespread
	River regulation dams	1955 First 50,000 x 106 m^3 reservoir: V. I. Lenin dam, R. Volga (58,000 x 106 m^3) 1957 First 200 m high dam: Mauvoisin dam, Switzerland (237 m high) 1961 First 250 m high dam: Vaiout dam, Italy (262 m high)	
	Impounded rivers	1962 Grand Dixence 285 m high dam, Switzerland	Conservation

Table 3.1.2 Major Types of anthropogenic environmental change and their principal effects on riparian systems (from Naiman *et al.*, 2005).

Environmental Change	Principal Effects on Riparian zones
▪ Flow Regulation	
▪ Flow Regime	▪ Alters community composition and successional processes; loss of life history cues
▪ Dams	▪ Lotic to lentic; inundation above dam; altered flow, nutrient, sediment, and temperature regimes below dams
▪ Withdrawals	▪ Lowers water table; alters flow regime; decreases alluvial aquifer recharge; system simplification
▪ Channelization & Dredging	▪ Lowers water table; desiccates riparian forest causing terrestrialization and change in community composition; possible decline in biodiversity
▪ Levees	▪ Isolates river from floodplain, thereby reducing hydraulic connectivity laterally and vertically. Constrains channel migration; alters riparian successional trajectories
▪ Land Use	
▪ Vegetative Cover	▪ Modifies albedo and feedbacks to climate; changes local microclimate and successional trajectories
▪ Invasive Species	▪ Introgression and hybridization; increased competition for space and resources; may reduce biodiversity
▪ Resource Management	▪ Usually alters successional trajectories and community composition
▪ Flow Regulation	
▪ Precipitation	▪ Modifies entire flow regime, groundwater-surface water exchanges, and channel morphology and stability; loss of life history cues
▪ Temperature	▪ Spatial patterns and phenology of riparian species are changed

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ANALYSING THE LANDSCAPE AND THE STRUCTURING ROLE OF RIPARIAN CORRIDORS

Teresa Pinto-Correia

Introduction: understanding the role and the concept of landscape

The need to assess and manage Europe's specific landscapes from the perspective of both the natural and the cultural heritage has been pointed out since the beginning of the 1990's in strategic documents such as the Dobris Assessment (Stanners and Bourdeau, 1995), the Pan-European Biological and Landscape Diversity Strategy (Council of Europe, 1996), the Action Plan for European Landscapes (ECNC, 1997) and the European Landscape Convention (Council of Europe, 2000). Recently, the need to recognise and respect the character of the landscape in each specific place has been stressed, in combination with the need to involve local actors and to integrate objectives at different levels in order to maintain or create multifunctional landscapes (O'Riordan and Voisey, 1998; Council of Europe, 2000).

The concept of landscape is considered in different ways depending on the many different disciplines and approaches that deal with it. Landscape ecology, as an integrated approach, considers the landscape as a complex, permanently dynamic system where different natural and cultural factors influence each other and change over time, determining and being determined by a global structure (Forman and Godron, 1986; Naveh and Lieberman, 1994; Zonneveld, 1990). However, besides the more material or objective characteristics, the landscape also has a subjective component, more connected with the observer and his or her impressions (Nassauer, 1997; Palang and Fry, 2003), and the holistic understanding of the landscape also includes the perceptive aspect (Antrop, 1999). The landscape combines both natural and cultural aspects, expressing and at the same time supporting the spatial and temporal interaction of humans with the environment, in all its diversity and creativity (Green, 2000; Wolters, 2000).

In analytical terms, it is important to consider different dimensions and to differentiate between them (Brandt, 1998; Lorzing, 2001), as expressed in figure 3.2.1: (a) the potential landscape, related to natural biophysical characteristics; (b) the landscape of human activities, connected with land use systems and options; and (c) the landscape of the mind and interests, the "mindscape". Even though they should all be integrated in landscape management, considering its multifunctionality, it is often the case that each discipline focuses on just one of these dimensions.

Figure 3.2.1 The concept of landscape: different dimensions and levels of approach (adapted from Brandt, 1998).

Analysing the landscape and its components

In landscape ecology, analysis is very often focused on the dynamics and spatial arrangement of the land cover, including its causes and consequences, so an understanding of pattern is fundamental (Haines-Young, 2005). Land cover is interesting as it is highly dynamic and expresses human activities, shaping the materiality of the landscape through land use. In the widely-adopted patch-corridor-matrix model (Forman and Godron, 1986; Forman, 1995), landscapes are represented as matrices (figure 3.2.2, left) constructed of 1) mosaics, consisting of collections of discrete patches, and 2) networks, consisting of collections of corridors. Many of the fundamental ideas, tools and methods of landscape ecology are constructed according to this paradigm (McGarigal and Cushman, 2005). These concepts are mainly based on studies of agricultural landscapes with intensive, specialised land use in North America and northwest Europe, not in the Mediterranean and other complex landscapes which depart from this more simple structure (Haines-Young, 2005). Land cover is usually mapped using categorical maps, classifying it into discrete land cover classes and delineating it accordingly, as patches and corridors, through visual interpretation of aerial photographs.

However, in fuzzier landscapes with continuous gradients in terms of land cover, *e.g.* the agro-silvo-pastoral landscapes of the Iberian Peninsula (figure 3.2.2, right), defining patches through a discrete classification is more a matter of judgement and interpretation than of a restrictive methodology based on objective parameters (van Doorn and Pinto-Correia, 2007). Here, the delineation of categorical classes of land cover risks being a poor representation of the true heterogeneity of the landscape (McGarigal and Cushman, 2005), but tools for the adoption of a gradient approach for mapping land cover are generally unavailable or not yet well developed (Haines-Young, 2005).

Figure 3.2.2 Landscape description: differences between intensive, specialised land use landscapes with clear borders and a well defined matrix of patches and corridors (left) and extensive, fuzzy land use system landscapes where the matrix is not clear and the patches composing the mosaic have unclear borders and have to be identified through analysis with pre-defined criteria (right).

In all types of landscape patterns, both those with clear boundaries and those which are fuzzier, riparian corridors are always recognisable elements, differentiated from their surroundings by their shape and texture and their overall structure as a network. At different scales, these are corridors that shape and structure the landscape and through which important fluxes of energy, matter and species are processed (Saraiva, 1999).

Riparian corridors as diversifying and structuring landscape elements

Different types of watercourses, together with associated riparian corridors, have a series of important regulation, habitat and production functions in the landscape (de Groot, 2006), particularly for drainage, water retention, transport and storage of matter, energy storage and flow, support of genetic resources, self-cleaning, providing habitats and helping to balance out climatic differences (Bastian and Steinhardt, 2002). The more significant the water body and the riparian corridor, the more significant these functions are as well. A comprehensive landscape ecology analysis of a body of water starts with the source and catchment areas and examines the entire course with all its influences, involving both biotic and non-biotic elements.

Furthermore, as watercourses are structured as a network, they contribute to connectivity at the landscape level, which is relevant for almost all animal species. When well developed and preserved, riparian corridors have a diversified structure, an inner and outer part and several components, including the presence of water, which all in all increases their ecological interest and contribution to connectivity, compared to simpler corridors such as hedgerows. Corridor efficiency depends first and foremost on the species concerned but in general, the vegetation structure (herb, shrub and tree layers), corridor width, edge structure and species composition are all important. The density of corridors and the number of intersections is also highly relevant, independently of the landscape context. Nevertheless, the importance of corridors is more easily assessed in a matrix-patch-corridor mosaic type and previous research has shown that the higher the fragmentation, the more relevant the role of corridors (Burel and Baudry, 1999). However, it must be pointed out that there is still a need for greater knowledge concerning the exact role of corridors in terms of reducing the effects of fragmentation in different landscape patterns, particularly fuzzy patterns, where gradient may be more relevant for species behaviour than the distribution of patches and the connecting corridors (Haines-Young, 2005). As mentioned above, landscape ecologists should consider pattern, including patches and corridors, more as an explanatory variable and start its analysis by considering ecological processes (Wu and Hobbs, 2000). Even with these limitations, however, the role of riparian corridors has proved to be relevant to the behaviour of many species, both as a habitat and as a connecting element (Burel and Baudry, 1999).

From another perspective, riparian corridors also secure a multitude of information and carrier functions, as classified by de Groot (2006): they have an aesthetic, ethical and social role since they contribute, often in a remarkable way, to the beauty and diversity of the landscape and, in this way, to its appreciation by several types of users; they are also involved in education and training and used for recreation in many ways (Bastian and Steinhard, 2002). Especially in open and semi-open rural landscapes, the presence of a well constituted riparian corridor increases the diversity of the mosaic and is a structuring element that improves landscape attractiveness. This applies not only to agricultural landscapes, but also, clearly, to urban-dominated landscapes, where this kind of corridor is often the only one of the previous natural elements that remains. Watercourses and their riparian corridors, with their network structure closely related to the relief and morphology and to land capability and use, can be seen as the backbones of the landscape. In this way, the presence of the riparian vegetation in different types of contexts helps the observer to read and understand the landscape, besides contributing to its aesthetic quality.

Concluding remarks: the multifunctionality challenge in integrated landscape management

Multifunctionality has emerged as a key concept in recent years. It reflects the transition from a productivist to a post-productivist understanding of the rural environment (Wilson, 2000). Rural landscapes have turned from production areas into consumption areas. In addition to the traditional roles of food and fibre production and a place for the rural population to live, increasing expectations concerning rural landscapes have developed in several sectors of society, and other functions such as preserving biodiversity and water quality, offering spaces for recreational activities and maintaining cultural identity are also now acknowledged. These functions, which are secured by various spatial units, in combination or separately, can be summarized as the goods (removable) and services (non removable) provided by the landscape which fulfil human needs, demands and expectations, in a broad sense, and are valued by society (de Groot, 2006). In this way, through social demand for these different functions, multifunctionality has emerged as a new paradigm for landscape strategies and management, often based on the assumption that the result of more multifunctionality will be higher sustainability, even if the relation between the two is rarely explicitly mentioned in the research (OECD, 2001).

Riparian corridors make a positive contribution to the majority of the above-mentioned functions of the landscape. The network density and the state of the corridor, where vegetation structure, diversity and continuity and water quality are the main concerns, are both relevant factors for increased multifunctionality. As such, integrated management strategies that aim for landscape multifunctionality should pay particular attention to riparian corridors, considering all their dimensions and their spatial and temporal variations in an integrated way (Saraiva, 1999).

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Stamatis Zogaris, Ronald Bjorkland
Rhema H. Bjorkland, Yorgos Chatzinikolaou
Sofia Giakoumi, Alcibiades N. Economou
Panayotis Dimopoulos

RAPID VISUAL ASSESSMENT PROTOCOLS FOR MONITORING IN RIPARIAN ZONES

Introduction

The continued deterioration of river corridors has focused attention on the need to assess their biodiversity and ecological integrity (Postel, 1998; Baron *et al.,* 2002). Protection of rivers and their riparian zones depends on effective management (Gordon *et al.,* 2004), which in turn relies on accurate and concise information on the condition of these systems (Holling, 1978; Ringold *et al.,* 1996). Additionally, water and riparian resource issues are likely to become more complex in the future (Simonovic, 2002) and will require assessment and management efforts appropriate in scale (Verdonschot, 2000). While current laws and practices endeavor to regulate those human activities that impact river systems, inadequate knowledge about river corridor ecology, competing interests, ineffective policies, and inefficient infrastructure and institutions often limit these governance tools (Page and Kaika, 2003).

One of the problems encountered in protecting river and riparian areas is the lack of relevant ecological information about these systems at the scale of the river corridor site, where most management and restoration activities take place (Palmer *et al.,* 2005). Site-based information refers to data on the attributes of particular river corridor reaches or segments such as forest structure, species richness, anthropogenic alterations etc. Traditionally, long-term field studies have been conducted to collect and map such information, particularly focusing on protected areas. But riparian zones may cover extensive linear networks that often are outside protected areas; hence many riparian areas remain unstudied and poorly managed, and their conservation values discounted. Also, specific area studies are static compilations of data and do not reflect the dynamic features characteristic of riparian zones. Consequently, monitoring schemes are often needed to track trends in natural variability and conservation attributes and anthropogenic impact over time.

Over the past two decades many techniques encompassing rapid field surveys have evolved. These techniques detail the standardized procedures for the acquisition and compilation of relevant physical, chemical, and biological data through the use of visual estimations and measurements by trained personnel. Rapid assessment protocols are useful both for a one-time reconnaissance project and for repeated monitoring surveys. In fact, use of rapid assessment procedures probably has helped shift the monitoring focus from intensive area studies to wider multi-site regional assessments (Goldsmith, 1991; Norris and Thoms, 1999).

While recognizing their limitations for providing in-depth information for research applications, rapid visual assessment methods were developed primarily as an easy-to-use and cost-saving mechanism (Resh and Jackson, 1993; Lenat and Barbour, 1993; Resh *et al.,* 1995; Sayer *et al.,* 2000). Most rapid assessment protocols attempt to address conservation-related assessment questions and focus on critical unmet information needs that cannot be gleaned from remote sensing, desk studies or spatial analysis techniques. Furthermore, rapid assessment protocols provide basic site-based information and generalizations that are more readily understood by resource managers, decision makers, and the general public (Growns *et al.*, 1997; Bjorkland *et al.,* 2001). The use of easy-to-use rapid assessment protocols by non-government organizations and trained citizen volunteers for monitoring, education, and public awareness plays an important role in conservation campaigns (Newton, 2001; Middleton, 2001; Palmer *et al.,* 2005). Site-based rapid assessments of riparian conditions can provide relevant information to help prioritize river corridor reaches that require specific management, protection, or restoration actions (Greenwood-Smith, 2002; Gibbons and Freudenberger, 2006).

This chapter reviews some aspects of rapid assessment procedures for monitoring riparian systems. These are confined to procedures that can be undertaken rapidly, on the ground, and employ site visits at the scale of river corridor reach or site. The following aspects are discussed: a) definitions of rapid assessment and monitoring; b) ecological information categorization; c) protocol design; and d) data management and communication approaches.

Rapid visual assessment in riparian systems

Studies of riparian areas may include collecting data on the physical, chemical, and biological properties to describe biological communities, geomorphic composition and processes, ecological relationships, and the impact of anthropic influences. However, systematic studies of these areas are complicated by core factors that influence their structure and function: spatial and temporal heterogeneity at multiple scales; the dynamic nature of these systems; and the influence of extrinsic or external processes, often at a broader scale (Odum, 1990). As a result, site-specific information is often lacking and management decisions that affect riparian health and integrity are made in the absence of sound ecological data; this situation is particularly acute outside protected riparian areas (Petersen, 1992; Munné *et al.*, 2003; Gordon *et al.*, 2004).

Rapid assessments can provide snapshots of the condition of the environment, often with minimal resource commitment, and obtaining information from site visits is very important even if it is not thorough or includes only a few key parts of the system (*e.g.*, alien species occurrence, woodland buffer species composition, or disturbance regimes). While remote sensing and Geographic Information Systems (GIS) are routinely used nowadays to capture a synoptic view of the area of interest and to facilitate the analysis and communication of the information, site-specific information can greatly augment general environmental data on conservation values that cannot be assessed solely through the use of these tools (Feinsinger, 2001).

Use of trained "expert judgment" is central to many aspects of rapid assessments, and visual cues of specific indicators form the basis of this judgment-based assessment procedure. Assessments based on visual cues differ in three ways from other site-based methods that focus only on quantitative measurements. First, these assessments tend to be comprehensive, incorporating many riparian and/or river attributes. Second, they are systematic and standardized over a wide range of conditions and environments. Third, the data is consistently aggregated so that it can produce a qualitative or semi-quantitative descriptor (or score) of the condition of the riparian and/or river system (Winger *et al.,* 2005; Sutula *et al.,* 2006).

Visually-based rapid assessment methodologies use benchmarks (references) to characterize quality levels in order to evaluate riparian conditions. It is assumed that specific measures of visible ecological conditions can be evaluated in relation to a specified standard or reference condition (Sutula *et al.*, 2006). Therefore, this "reference condition approach" requires baseline information on the structure and functioning of different types of riparian zones in their "natural" state. If natural riparian zones do not exist, minimally-disturbed and near-natural riparian systems provide reference conditions. Reference-based assessment procedures systematically aggregate variables into a scoring system, calibrated to an upper boundary (the reference condition) that characterizes the near-natural or best attainable condition of a particular system (Ferreira *et al.,* 2002). Knowledge of reference conditions is therefore a prerequisite for employing benchmarks in indicator-based assessments.

Rapid assessment protocols differ in their focus on the geographic domain and features of interest. For example, some protocols focus only on the riparian vegetation while others evaluate both in-stream and riparian characteristics in order to provide a general summary of the river corridor's health. All rapid visual assessment procedures involve site data collection, during which visual estimates and measurements are made along a pre-selected reach of the river corridor. The assessed site is a particular point next to the river or a longitudinal plot (or transect) and may range from 50 meters to 500 meters in length. Most field assessments can be completed within 20 to 50 minutes per site.

Visual assessments often involve subjective or semi-quantitative estimations instead of precise measurements. Relative to other more detailed measurement procedures, rapid assessments may be less precise or may sacrifice detailed ecological information; nevertheless, they are usually more effective for detecting conditions or trends within a wider geographic area than other in-depth study approaches (Ward *et al.*, 2003; Winger *et al.*, 2005). Rapid assessments provide some of the most valuable tools for monitoring riparian areas because they are portable to many different types of riparian environments, standardized, structurally simple, and conservative in resource requirements.

Table 3.3.1 Simple categorization of popular rapid assessment protocols.

Types	Characteristics	Application examples	References
▪ Inventory surveys	▪ Biotic attributes inventory	▪ *e.g.* species assemblage inventories	▪ Vegetation sampling (Mueller-Dombois and Ellenberg 1974; Brown 2000); ▪ Riparian reference conditions (Ferreira *et al.* 2002)
▪ Bioassessment	▪ Index-based bioassessment	▪ indices of biotic integrity	▪ Wetland Index of Biotic Integrity (IBI) (USEPA 1998; Karr and Chu 1999)
▪ Hydrogeomorphic Assessments	▪ Abiotic attributes inventory/ Index-based abiotic protocols	▪ fluvial geomorphic inventories/ stream bank erosion surveys	▪ Hydrogeomorphic Assessment (HGM) (Brinson 1996)
▪ Hybrid Assessment	▪ Index-based hybrid protocols	▪ riparian and aquatic condition surveys	▪ Riparian, Channel and Environmental Inventory (RCE) (Petersen 1992) ▪ River Habitat Survey (RHS) (Raven *et al.* 1998) ▪ Riparian Forest Quality (QBR) (Munné *et al.* 2003) ▪ Stream Visual Assessment Protocol (SVAP) (Bjorkland *et al.* 2001)

Monitoring: definitions

Monitoring is an assessment scheme involving both a spatial and temporal dimension (Brown, 2000) and may be thought of as a natural extension to a rapid assessment procedure. However, the many different definitions of monitoring have created confusion, especially in conservation and management policy literature (Spellerberg, 1991; Irvine, 2004). To help simplify the different monitoring definitions, two general "categories" of monitoring can be considered. The broad definition is loosely used to describe simple periodic measurement or observations of a process or object (Roberts, 1991; Comiskey *et al.*, 1999); this is called surveillance monitoring. In contrast, a stricter and narrower definition articulated by Hellewell (1991) defines monitoring as "intermittent surveillance on a regular or irregular basis carried out to determine the extent of compliance with a predetermined standard or the degree of deviation from an expected norm". This latter definition involves a hypothesis-driven research approach that imposes a higher degree of discipline and structure, since it is monitoring against a pre-determined standard, and is commonly referred to as compliance monitoring (Brown, 2000). For example, bird counts in riparian forests are a type of surveillance monitoring, while a hypothesis-driven bird count scheme designed to assess riparian restoration through bird habitat use is compliance monitoring. Compliance monitoring does not always reveal the exact value of the features measured; it often only indicates if a standard has been met.

Compliance monitoring presupposes that one already has an idea of the possible output data and a good base-line reference in order to gauge sampling results.

Some researchers regard compliance monitoring as "the norm" and the only true form of scientific monitoring (Goldmith, 1991; Hellewell, 1991); moreover, they often refer to all other monitoring-like schemes as "survey" and "surveillance". This dichotomy is artificial because repeated surveys can provide data to detect patterns and changes over time, and both monitoring categories use similar or identical data-gathering procedures (Elzinga *et al.*, 2001). However, making the distinction between surveillance monitoring and compliance monitoring is useful; for example, when it is necessary to prevent a monitoring project which focuses on policy-relevant compliance from expanding its data collection far beyond its specific purpose (Feinsinger, 2001). In contrast to compliance monitoring, surveillance monitoring is usually much simpler; it can be employed within a variety of data gathering procedures and is usually used to help collect a wider array of environmental information, such as baseline biological information. Rapid assessment methods can support both surveillance and compliance monitoring data needs.

Why Monitor?

Monitoring should be an important part of conservation management because of the timely information it provides. The success of a monitoring effort depends on a clear understanding of its goal and specific objectives (Johnson, 1999), strategic planning, and appropriate design. Reasons for monitoring include:

1) Assessment of the effectiveness of policy or legislation (*e.g.*, restoration value)

2) Assessment of performance, functioning or condition (*e.g.*, condition of a habitat)

3) Detection of change; monitoring of early warning signals (*e.g.*, ecological degradation)

4) Long-term ecological understanding (*e.g.*, change of species assemblage, natural variability).

These four reasons are not mutually exclusive. When clear goals and objectives are established, some tasks will have a higher importance or value than others, even in the light of differences in opinion among scientists and stakeholders (Goldmith, 1991). Monitoring objectives and strategies should be developed through the participatory involvement of all major stakeholders and should have short-term and long term value (Nichols, 1991).

Defining monitoring objectives and "ecological information types"

Managers and conservationists frequently have to address multiple and competing needs. Many types of information are often needed concurrently in order to make management and conservation decisions. Careful attention to these competing needs will help guide the monitoring design schemes. Monitoring programs that will become part of a management plan should address the following six questions (Goldsmith, 1991; Noss, 1999; Sayer *et al.*, 2000):

1) Purpose: what are the specific goals and objectives of the monitoring effort?

2) Method: how can these goals and objectives be achieved?

3) Analysis: how will the data be handled?

4) Interpretation: how will the data be used?

5) Dissemination: how will the results be communicated?

6) Fulfillment: what are the signals that the goals and objectives have been met?

The challenge of deciding what information to collect and how to use it is not a simple task. An understanding of different information categories is important to create an effective protocol for relevant information gathering. Figure 3.3.1 shows a hierarchical relationship of five types of relevant "ecological information types", and each information category is described below.

Figure 3.3.1 "Ecological information pyramid" showing a hierarchical relationship among five forms of "ecological information types". Each level provides a necessary type of information for the development of the next higher level. "Assessment" represents the highest, most integrated level of ecological information for evaluation and interpretation (Adapted from Innis *et al.*, 2000 and Heywood, 1997).

Natural history knowledge

Many conservation biologists emphasize the need for base-line natural history knowledge as a framework for ecosystem assessments (Janzen and Gámez, 1997; Rivas, 1997; Futuyma, 1998; Karr and Chu, 1999). Even incidental natural history details may help establish a knowledge base from which a conceptual framework of ecosystem patterns and processes can begin to evolve. Incidental biodiversity data may build important baselines concerning key biophysical attributes of systems (*e.g.* the species' migratory patterns).

This type of data gathering may help produce important sources of information about elements such as "historical" reference conditions, habitat-type definitions, habitat distributions, species requirements, species rarity, population trends, and other region-specific ecological patterns. Natural history information may be compiled while completing field datasheets within a rapid assessment framework (*i.e.*, by including special data fields in the formal protocol for pertinent natural history data such as rare species occurrence, alien species, etc). These field observations and interviews can later be systematized and analyzed to provide important conservation-relevant knowledge baselines (Bibby *et al.*, 1998).

Inventory

An inventory is a systematic form of ecological and natural history data compilation in which lists of occurrences or observations of interest are recorded. Inventories catalogue observable features, including physical, chemical, biological, habitat and landscape elements (Innis *et al.*, 2000). Inventory results usually apply to the cataloguing of quantitative data collected as a "snapshot in time". Standardized inventory procedures are a natural extension of natural history knowledge bases. These data are easily organized in databases and on maps. An example of a "rapid" approach to biodiversity inventories are the methods used to collect plot-based vegetation and habitat type data systematically; these methods have been employed successfully for a long time (Mueller-Dombois and Ellenberg, 1974; Dimpoulos *et al.*, 2005). Most assessment procedures or monitoring efforts require a knowledge-base with which future change may be compared, and inventories may help develop these baselines.

Classification

Classification groups ecological information based on common environmental or biotic attributes (Innis *et al.*, 2000). Some system of classification or stratification of inventoried sites is vital in survey or monitoring schemes. Because riparian systems exhibit a very high natural variation, a well-structured classification procedure is necessary to compare sites within similar riparian types. O'Keeffe *et al.*, (1994) demonstrated that classification greatly assists in the organization and understanding of complex systems. A classification system clarifies differences among varied sites, and the criteria used to show differences among groups or elements should be selected with the end user and purpose identified (Gordon *et al*., 2004). Classification schemes are an important step towards organizing information and their development must be guided by a specific purpose. For example, classification systems are usually a prerequisite for developing type-specific reference conditions, calibrating and adapting indices and applying assessment procedures.

Indicators and indices

Indicators are discrete biotic or abiotic parameters that are used to evaluate environmental conditions and detect changes (Comiskey *et al*., 1999). Measurement values of one or more related indicators (or metrics) may be combined to provide a single composite assessment score or index (Williamson *et al.*, 1982). Multimetric indices, therefore, comprise the sum of the responses of individual metrics and may be used as quantitative tools to simplify the relative weights of multiple indicators (Karr and Chu, 1999).

In order for indices to fulfill a legitimate role as a quantitative tool, attention must be given to the selection and use of the proper indicators and to ensure they adequately represent the structure, function, and composition of the system of interest (Dale and Beyeler, 2001). In the worst-case scenario, use of inappropriate indicators can support decision-making that is incompatible with conservation goals (Boháč and Fuchs, 1991; Butterworth, 1995; Comiskey *et al.*, 1999; Dale and Beyeler, 2001). Characteristics which are important in the selection of indicators include:

a) Ecological relevance - indicators must provide scientifically sound assessments of the key ecological factors they are selected to measure or detect, such as disturbance or sources of stress.

b) Sensitivity - indicators must be sensitive to subtle changes in key ecological factors.

c) Speed - indicators must be able to respond promptly to changes in key ecological factors.

d) Measurability and standardization - indicators should be easy to detect and measure in a wide range of environments.

e) Easy-to-understand - indicators should provide unambiguous results.

f) Cost-effectiveness - includes relative ease of application and minimal commitment of resources to obtain results.

Although many versions of the widely replicated Index of Biotic Integrity (IBI) have been applied successfully to streams, their use in riparian and terrestrial systems has been more challenging (Andreasen *et al.*, 2001). The unique spatial and temporal heterogeneity of riparian environments may necessitate use of region-specific indicators; this, in turn, requires testing, validation and standardization of the index to produce reliable data about the environmental and ecologic conditions of interest (Keith and Gorrod, 2006).

Assessment

Assessments that provide ecological information are the most integrated level of information about natural systems. They represent integrated statements about the current state of a system and the factors that contribute to that state (Innis *et al.*, 2000). They must be based on knowledge of the ecology of a site and consideration of its physical, chemical and biological properties and their inter-relationships in space and time (Mattson and Angermeier, 2007).

Drawing on the analogy of preventative medicine, Irvine (2004) compares assessments to occasional health check-ups. Assessments can identify water bodies at risk of failure to meet predetermined criteria. Like medical check-ups, they depend to some degree on expert judgment and well-defined indicators.

Reference conditions or standard baselines are central to assessments; they represent the collective set of conditions that are to be expected in the absence of anthropogenic impact (Nijboer *et al.*, 2004). Reference conditions serve as benchmarks against which to measure the extent of impairment of ecological systems or habitats as a result of human activities. Although there are many methodologies used to establish reference conditions, the most common practice is to develop a spatial framework using natural undisturbed or minimally-disturbed study sites that are representative of the ecosystem types under consideration and where the biological and environmental attributes are known.

Designing, developing or adapting a rapid assessment protocol

Strategic design of a rapid assessment protocol is fundamental to obtaining useful and high quality information for conservation, policy compliance, or other management needs. In the absence of careful planning, inadequately designed protocols may provide information that lacks precision or specificity or information that leads to inaccurate conclusions (Droege, 1999; Dale and Beyeler, 2001).

Protocols that are not well thought-out waste time, effort, and other resources and may delay the start-up of conservation activities. Therefore, before initiating development or adaptation of an existing protocol, the following preliminary questions should be addressed:

1) What are the objectives of the assessment program?

2) Is there a hierarchy of objectives? If yes, what is it?

3) What indicators are to be monitored?

4) How will the information be used?

5) What protocols already exist and what modifications are necessary to make them applicable to the conditions and needs of the area of interest?

There are many good examples of available protocol designs complete with sample field data sheets and guidelines for data collection and analysis. Therefore, in the interest of economy of effort, existing protocol models should be reviewed. If a suitable one is identified, a pilot project can help determine if it can be adapted to meet the specific needs and site conditions; this exercise may also serve as an important learning activity for technical and management staff. Other considerations (USEPA, 2005; BCMOF, 2002; Vives *et al.*, 1996) that should be entertained before developing a protocol include:

a) Scope of the protocol: should it have regional bias (targeted to a specific region) or universal bias (applicability to a wide range of physiographic and environmental conditions)

b) Data review and identification of gaps (informational, temporal, spatial)

c) Performance criteria for data acceptability (accuracy, precision, representativeness, bias, comparability and detection limits)

d) Field measurements and other parameters or covariates to be assessed

e) Timing or scheduling of assessments

f) Sampling network design (targeted or probabilistic)

g) Methods employed for analyzing samples

h) Data quality assurance and quality control plans

i) Data management

j) Project leadership and supervision

k) Training of personnel in protocol application

l) Resource availability, including financial, personnel, material, logistic and programmatic

Once the protocol adaptation or design has been completed, basic management guidance can significantly help improve the quality of the information collected during the project (Somerville *et al.,* 2004; Sutula *et al.,* 2006). These additional steps include, but are not limited to:

1) Training and review of protocol for all personnel involved with the project

2) Repeated visits to the same sites to test different protocol applications

3) Rigorous field-testing to ensure that measurements are repeatable with similar levels of precision among landscapes and field personnel.

4) Transparency in methodology and data through dissemination in literature and other media.

Limited funding is usually a major challenge for rapid assessment projects, and resource commitment, including direct and indirect expenses, must be factored into the design.

The full range of assessment costs often are not recognized and are grossly underestimated (Caughlan and Oakley, 2001). Additionally, other "more robust" protocols may follow or be used in tandem with rapid assessment procedures (*e.g.*, EU WFD monitoring), thereby necessitating an evaluation of the relative importance of the rapid assessment, its placement in the overall management scheme, and its resource requirements. Use of the appropriate set of ecological indicators, therefore, should be guided by costs as well as by the scientific needs.

In conclusion, rapid assessment and monitoring protocol development can be characterized as having four major stages, as outlined in figure 3.3.2.

a) Baseline study and information needs (*e.g.,* extent of riparian area?

b) Purpose-based assessment questions (*e.g.*, anthropogenic or natural impacts of interest)

c) Field protocol design (*e.g.*, specific indicators or metrics to be employed)

d) Protocol finalization (*e.g.*, field testing, validation, fine-tuning the protocol).

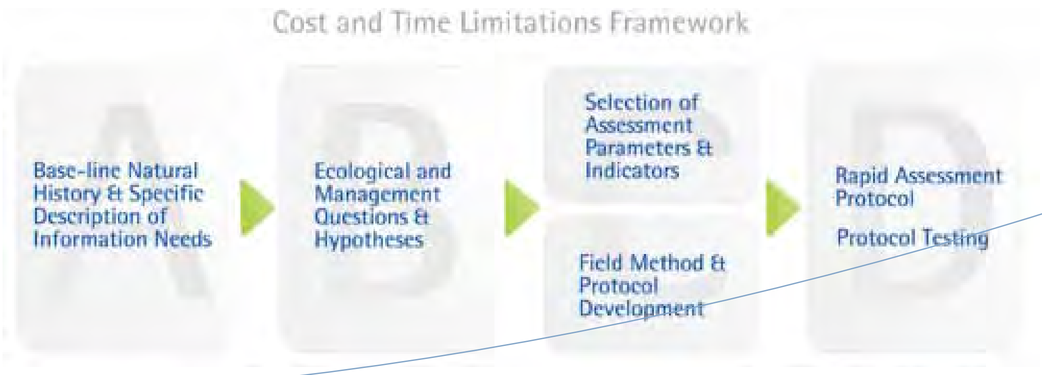

Figure 3.3.2 Simplified scheme for rapid assessment protocol development. A: Information needs; B: Purpose; C: Protocol design; D: Finalization (adapted from Catsadorakis, 2003).

Considerations in the use of rapid assessment and monitoring

Despite the availability of a suite of different assessment protocols for riparian, river and wetland environments, most are not widely used. Additionally, the failure of many assessment and monitoring projects to provide applicable and readily useable information has promoted the use of ad hoc approaches to acquire information about these environments (Innis *et al.*, 2000; Gibbons and Freundenberger, 2006).

Although a wide range of biological and ecological attributes can be collected and evaluated by visual assessment procedures, only a limited number have proven useful in providing information about the impact of anthropogenic actives on biological systems or in addressing specific monitoring questions (Goldsmith, 1991; Ward *et al.*, 2003). The output from assessment and monitoring efforts constitutes key ingredients in decision-making and should reflect specific conservation management priorities (Clewell and Rieger, 1997). In order to ensure that the assessment and monitoring component is compatible with the conservation and management goals, the following generic questions should be considered (Brown and Rowell, 1997):

a) What are the "best" or most "meaningful" attributes to monitor?

b) What are the best or most appropriate methods to use for assessment or monitoring, and will these procedures create secondary problems (*e.g.* damage to habitats and species; loss of critical information)?

c) How are the conclusions checked for accuracy, precision, and applicability to the issues and areas of interest?

d) Are the requirements of the assessment or monitoring program within the financial, administrative and logistics guidelines and means of the sponsoring agency?

e) Will the information be available in a timely fashion to support decision-making or does the situation require immediate intervention?

Rapid assessment and monitoring programs can be viewed as a type of applied ecological study (Pickett *et al.*, 1997), and as such they must adhere to rigorous standards in all their phases, including field operation, sample handling and data management. They should be designed with a priori knowledge of the type of analysis and statistical tests used (Elzinga *et al.*, 2001), and implemented by trained personnel. Finally, it should be stressed that rapid assessments and monitoring should not be a substitute for in-depth ecological research, which often is needed to understand the structure and function of the natural systems of interest.

Much of the success of rapid assessment programs rests on expert judgment: selection of appropriate indicators; development of metrics; scoring and data interpretation; and evaluation and weighting of the results (Karr and Chu, 1999). Expert judgment, in turn, is dependent in part on an understanding of the natural history of the area including its inherent variability of conditions and community composition (Futuyma, 1998; Andreason *et al.,* 2001) of the organisms.

Finally, management decisions may require information on a spatial and temporal scale that cannot be achieved by short-term or site-specific rapid assessment activities alone. Information from broader scales, using remote sensing and spatial modeling is increasingly utilized effectively. The ultimate challenge is to integrate these multiple layers of research into a holistic framework that provides relevant information efficiently and economically. Rapid, site-based assessment and monitoring methods are a part of this larger network of information inputs. We must not ignore the outputs and dissemination of this work.

Data management

Integration of assessment and monitoring data into policy-relevant conservation action is in large part an exercise in information management (Janzen and Gomez, 1997). All phases of information management, including data-entry, quality assessment, archiving, and documentation carry risks of error (Michener and Brunt, 2000). Nevertheless, control checks can be incorporated into the program's design to protect against mechanical (*e.g.*, inaccurate or incomplete information) or judgment errors. Effective information management procedures will also help guide the efficient and appropriate use of the information to achieve conservation goals. Major potential sources of error include initial recording of data, the transfer of information from field data sheets to the computer database, and inappropriate statistical analysis. Quality checks may include instrument calibration, checklists, or computer double-entry procedures (Shampine, 1993; Barbour *et al.,* 1999). The data should be organized in a format that ensures it is readily retrievable, accessible for analysis and secure, and that it has flexibility to accommodate future uses (Jenkinson *et al.,* 2006). Application of GIS and simple databases facilitates the analysis and storage of the data (Sayer *et al.*, 2000).

The costs of proper data management are often underestimated or not accounted for in many assessment and monitoring projects (Caughlan and Oakley, 2001). Planners must incorporate all data management costs into the budgets, including expenses to support quality assurance. This investment will increase the overall cost-effectiveness of a project since quality assurance will eliminate or minimize the amount of information lost or the need to repeat data management steps (Shampine, 1993). In order to maximize the effectiveness and economy of the information management component, expertise in this area should be included at the start of the program.

Basic communications

Clear, concise and unambiguous communication is central to the success of riparian conservation activities (Bell and Morse, 1999; Baron *et al.,* 2002; Naiman *et al.,* 2005). Most rapid assessment protocols are designed to promote an exchange of information between field investigators and the general public

(Bjorkland *et al.*, 1998; Gibbons and Freudenberger, 2006). Researchers need to articulate the results of assessment projects and their conservation relevance, and to identify areas where data are insufficient or there is a lack of understanding. The success of conservation efforts ultimately depends on the local community, not just on the scientists and managers who have a professional investment in the resources or the area.

The prospects of success of the conservation efforts are enhanced when scientists and managers take a proactive approach in their communication and provide the communities with useful information (Feinsinger, 2001). Currently, the need to disseminate and popularize scientific environmental information has become very important; for example, the EU-WFD policy requires "effective consultation with interested parties and stakeholders" (Irvine, 2004). Failure to effectively communicate to decision-makers and the broader community risks alienating segments of the community and ultimately may contribute to the deterioration of social networks which support conservation and research. Successful outreach and education programmes depend on effective integration of science, education and decision-making, which in turn, rely on deliberate, transparent and organized communication between decision-makers, scientists, managers, and other stakeholders.

To this end, a well conceived and easily applied rapid assessment protocol can be an important community education and outreach tool in itself. When employed by volunteer groups through an organized program such a "site caretaker" or "adopt-a-stream" initiatives, simple assessment protocols allow the community to assume stewardship of the area of interest and help to foster a better understanding and appreciation of the natural history and its linkage to the cultural heritage (Newton, 2001; Middleton, 2001).

Table 3.3.2 Simple communications matrix for maximizing the impact of assessment monitoring or surveys (modified from Bibby *et al.*, 1998).

Audiences	Message	Delivery
▪ Local Communities	▪ We are interested in this area because... ▪ Our interests are not a threat to you because... ▪ Are you interested in "adopting" a riparian area as a local caretaker?	▪ Clear verbal ▪ Tactful and respectful attitude ▪ Openness; participatory approach. ▪ Press release / fact sheet / popular article to local media ▪ Specialized outreach tools (training courses, manuals, field-guides etc)
▪ Regional and national technical	▪ Here is some information that you may find useful... ▪ This assessment is policy-relevant and proposes...	▪ Good diplomacy ▪ Clear and simple written reporting suitable to particular needs
▪ Scientific – NGO or government, national or international	▪ Here is a report on a recent rapid assessment of...	▪ Scientific publication ▪ Unpublished report ▪ Archived data

Conclusion

Successful rapid assessment and monitoring efforts must be relevant to ecological theory, statistically reliable, cost-effective, and able to promote effective communication. Riparian zones are complex systems covering extensive linear networks over the landscape; their widespread distribution and heterogeneity often confound conservation and restoration plans. In order for decision-makers to be more effective in managing riparian zones, adequate and appropriate information on the ecological attributes and the environmental conditions of the systems is important. Simple and scientifically rigorous field survey procedures for inventorying, classifying and assessing riparian environments at the site-scale are needed because most management and restoration actions take place at this spatial scale.

Conservation has been described as a "crisis discipline" that usually does not have enough time or resources to accommodate in-depth ecological and environmental studies. Additionally, data on site-specific natural or anthropogenic events impacting an area of interest are frequently lacking, even though such information is an important requirement for conservation planning (Janzen and Gomez, 1997). In order to bridge this information gap, rapid assessment protocols for riparian areas have been used successfully. Rapid assessments are usually cost-effective; they provide a preliminary snap-shot that can be used as a preliminary or first-tier approach in assessment and monitoring schemes.

Also, they can be used in parallel with more rigorous assessment protocols and mapping tools, and can serve as an important means to involve the public in a stewardship role. Citizens can contribute and learn about ecological systems by using simple rapid assessment protocols. Research organization and non-governmental environmental groups both face unique opportunities for growth, if they are willing to invest the resources needed to employ appropriate rapid assessment protocols. It is important for this endeavor to provide not only good scientific data but also useful and practical information that can be utilized in specific conservation activities or environmental decision-making. The use and development of rapid assessment procedures should continue to play an important role in addressing riparian conservation challenges.

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LANDSCAPE AESTHETICS: ASSESSING SOCIAL PERCEPTION

Maria da Graça Saraiva

Introduction. Landscape aesthetic assessment and evaluation

Aesthetic appreciation and evaluation has become an important concern in the field of environmental awareness and planning. The balance between natural and human environments has always been a field of interest in human societies, which seek beauty, delight and an equilibrium between human works and their environment.

As a result, environmental aesthetics is becoming an interdisciplinary field of research, incorporating disciplines as diverse as geography, planning, landscape architecture, psychology and philosophy, among others (*e.g.* Breackwell, 1992). This recognition shows that aesthetic values in the environment are a growing issue, as an important complement to areas of research such as sustainable development, planning and resource management (Berleant, 1997).

Physical settings influence human inhabitants and contribute to their well-being and satisfaction, while the beliefs, values and attitudes of humans shape their environment and their degree of satisfaction with it. Public perception of the landscape and river landscapes and public involvement in the management process are critical issues when considering sustainability as a target for river rehabilitation and for riparian zone management.

Aesthetic values and their social esteem can be assessed through different approaches and motivations. In the literature, several approaches that take the expert or professional point of view can be identified, addressing technical aims and integration into the planning and design process. Others spring from the social sciences, mainly environmental psychology, including behavioural studies related to public perception and public preferences for scenic and aesthetic values. A further group, largely humanistic or phenomenological, are more concerned with the intangible, sensory and emotional aspects of landscape appreciation. The underlying paradigms of these approaches were reviewed at the beginning of the eighties, an important stage for synthesizing the motivations and methods underpinning the complex framework of landscape and scenic evaluation (Zube, 1984; Daniel and Vining, 1982; Porteous, 1982).

Recent developments in this field show the need to combine and integrate these different approaches in order to attempt as close as possible an approximation to the complexity and subjectivity of aesthetic values. The use of mixed methodologies has been recommended, combining expert approaches with others involving public surveys and measurable parameters with subjective, intangible assessment (Bell *et al.*, 2001; Porteous, 1996; Saraiva, 1999).

River Landscapes aesthetic evaluation – a review

River landscapes are generally more appreciated by the majority of the public than other scenic features of the landscape. The attraction and interest of water in landscape appreciation has been pointed out by several authors in the literature on landscape perception and assessment (Herzog, 1985; Litton *et al.*, 1974; Lee, 1979; Pitt, 1989; Gonzalez Bernaldez, 1988; Saraiva, 1999).

Nowadays, the search for a sustainable management of river landscapes requires consideration of public perceptions and values, tools to promote healthy, adequate functioning of the ecosystem and resource provision. This target becomes even more demanding in the case of Mediterranean regions, where the dryness of the climate during part of the year causes irregularity in flow magnitudes and high variability in hydrological regimes, affecting the biotic and non-biotic components of the landscape, increasing its fragility and reducing its resilience.

Several approaches, ranging from expert methodologies to cognitive assessments as well as public preference studies, have tried to identify the most representative parameters that influence river landscape quality and its social perception. Since the end of the sixties, many studies have focused on this aim, trying to incorporate aesthetic evaluation into the whole assessment process and seeking better management of natural resources and processes together with increased, effective public involvement and participation. Classic references include Leopold and Marchand (1968), Litton *et al.* (1974), Kaplan and Kaplan (1978), Lee (1979) and Herzog (1985), among others. Table 3.4.1 summarizes some of the main factors or criteria applied to the aesthetic evaluation of river landscapes in the literature.

In recent research on the aesthetic evaluation of urban rivers conducted as part of the URBEM research project (Urban River Basin Enhancement Methods, www.urbem.net), a method for assessing the aesthetic

Table 3.4.1 - Synthesis of main factors or criteria used for aesthetic evaluation of river landscapes.

Author	Approach	Criteria for evaluation and preference of river landscapes
Leopold and Marchand (1968)	Expert assessment	Physical and chemical factors– width, depth and bed slope, flow speed, valley and floodplain width, order, basin area, etc. Biological factors– diversity, presence of fauna and vegetation, etc. Factors of use and human interest - aesthetic interest, accessibility, degree of development, etc. Index of unique character
Nighswonger (1970)	Expert assessment	Contrast and Diversity
Litton *et al.* (1974)	Expert assessment	Variety and Vividness
Jones *et al.* (1975)	Expert assessment	Vividness and Integrity
Dunne e Leopold (1978)	Expert assessment	Assessment of landscape, based on physical factors – riverbed width and depth, valley width and slope and on human interest factors – land use, views, presence of riffles, etc.
Lee (1979)	Public perception Survey	Legibility Complexity Spatial definition and Mystery Distinctive elements and Disturbance factors
Ulrich (1983)	Public perception Survey	Complexity Focal incidence and composition Depth and Texture Absence of perceptible risk
Herzog (1985)	Public perception Survey	Identifiability Coherence Spaciousness and Complexity Mystery and Texture
Pitt (1989)	Mixed	Symbolism and Mystery Naturalness Complexity and Multiple spatial organization
House and Sangster (1991)	Mixed	Quality of water Attractiveness Vegetation diversity and Naturalness
Saraiva (1999)	Mixed	River and riparian buffer morphology and diversity (landscape units) Degree of human impact and landmark presence Unity/ uniqueness, variety, vividness, integrity Coherence, legibility, complexity, mystery
Saraiva and Monteiro (2004)	Mixed	Relations between the criteria described above with visual and scenic characteristics, such as diversity, contrast, texture, spatial definition, heterogeneity, disturbance. Compilation of an index considering these variables

values of rivers in an urban context was developed (Silva *et al.*, 2004, 2005). This method, based on both expert assessments and public surveys, is intended for inclusion in the wider framework of a decision-making support system for river rehabilitation. It is designed to incorporate the specific context of rehabilitating rivers in urban locations, based on a three-dimensional approach that considers the interrelation of the main components concerned - the river itself, the town or city that surrounds it and the people that experience these two environments and influence them with their values, perceptions, attitudes and behaviour. A list of different points of view that potentially contribute to the perception of aesthetic quality in rivers running through cities is selected and organized according to these three dimensions. The partial conclusions for each point of view are assessed through a chosen set of indicators and descriptors (Silva *et al.*, 2004, 2005).

The points of view and indicators are described in the reports cited, as is the methodology for integrating the criteria, which aims to establish an "aesthetic performance profile" of each river landscape which can then be compared with the situation "before" or "after" the rehabilitation scheme or with other rivers in a similar ecological or geographical situation. It can also show which dimension – river, town/city or people's perceptions or values – can be enhanced or improved by a rehabilitation

Criteria for assessing river landscape aesthetics from a social perspective

For more generic river landscapes, a large set of criteria based on the approaches mentioned above can be adapted, expanded, and applied to each specific context.

One important aspect to consider is the scale of the approach, which can be seen from a top-bottom point of view – eco-region, river basin/watershed, landscape unit, reach/stretch, section/habitat – depending on the spatial context of the area assessed (figure 3.4.1). It is very important to consider this spatial context and take into account the interrelation of geomorphologic, hydrological and ecological factors that influence the river's behaviour and shape its environment.

An adequate assessment framework should consider three dimensions of analysis, as in the method described above: the natural feature – the river, the surrounding environment – the riparian buffer, where human disturbances and uses can be more or less evident, and the social component – the people, considering the perceptions, values, attitudes and behaviour of the "social actors", *i.e.* the users,

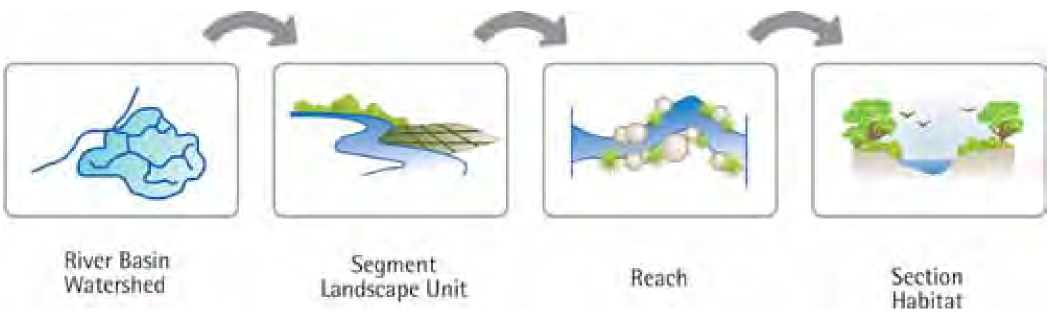

Figure 3.4.1 Scale of river landscape assessment approach – from river basin to local context (adapted from Moreira *et al.*, 2004).

managers, decision-makers and the general public (figure 3.4.2). Within this framework, the criteria that influence the aesthetic value and experience of each river landscape can be selected for each specific case, according to its physical and human setting.

Table 3.4.2 shows a list of the criteria that are applicable according to the literature reviewed. Rather than being intended as a complete checklist, it tries to identify the main factors or attributes that influence aesthetic perception and evaluation. The applicable set of criteria can be chosen to suit each case or situation, as each is unique and needs to be assessed according to its own character and context.

Other parameters can be added or adapted to this framework and they can all be used to a greater or lesser extent depending on the availability of data and resources. "River" and "riparian buffer" aesthetic values can be assessed mainly through expert methods. The "People" dimension usually requires public surveys and interviews. Integration of these descriptors requires the use of multiple methodologies or evaluation techniques, such as building an aesthetical profile (Silva *et al.*, 2004). This kind of approach is able to reveal the diversity of characteristics of each river and its surrounding landscape. Some can be related more to a social or cultural context, others more to natural or pristine conditions.

Figure 3.4.2 Framework for assessing river landscape aesthetics. Adapted from Silva *et al.*, 2003.

Discussion and final comments

A wide array of methods, criteria, parameters and indicators are used for aesthetic evaluation of rivers and river landscapes, showing the high level of subjectivity that this process demands.

The list of criteria and the assessment framework described above are based on the main concepts and approaches reviewed in the literature. They attempt to incorporate not only biophysical and measurable indicators, but also inputs from public surveys that allow an understanding of social values and of people's perceptions, motivations and views.

Nowadays, aesthetic evaluation of landscape requires the integration of expert assessments with public surveys, involvement and participation. By providing a better knowledge of the views and attitudes of social groups concerning their river landscapes, these comprehensive approaches may help to strengthen a sustainable relationship between society and nature.

Acnowledgements

To Isabel L. Ramos, Fátima Bernardo and Jorge B. Silva, as partners at the research developed about aesthetical evaluation, in Work Package 4 for the URBEM project, as well as for their comments and suggestions for this manuscript.

Table 3.4.2 - List of criteria for aesthetic evaluation of river landscapes (Adapted from Silva *et al.*, 2003).

River landscape aesthetic evaluation	
River	
Morphology	River dimensions (width, depth, slope, etc.), Valley and floodplain morphology, Disturbance of the natural dynamics, Sinuosity; Type of Bank Shape, Presence of elements in the channel (pools and riffles, etc.).
Hydrology	Flow regime, speed.
Water Quality/Pollution	Colour, reflexion, Visibility of trash or pollution
Natural and Technological Hazards	Flood vulnerability, Bank erosion, landslide risk.
Riparian Buffer	
Riparian Vegetation/Biodiversity	Biodiversity, Riparian vegetation in river banks – width, composition, distribution, diversity.
Land Uses	Typology / Diversity, Degree of disturbance
Activities	Attractiveness of riparian fringe and riverfront activities, Recreation, leisure, Degree of disturbance.
Space Quality	Visual permeability, Intensity of development.
Cultural Heritage	Cultural heritage (landmarks, belvederes).
Accessibility	River crossing (bridges), Surface of parking, Public transport, Walkways and bike tracks, Anchorage places, Navigability.
Pollution/Trash	Trash visibility, Pollution.
People	
Formal Attributes	Colour, contrast, texture, pattern, Unity/ uniqueness, , variety, vividness, integrity, Diversity, spatial definition, etc.
Preference pattern (Kaplan and Kaplan, 1978)	Coherence, legibility, Complexity, mystery.
Place Identity (Breakwell, 1992)	Continuity, Self-esteem, Self-efficacy, Distinctiveness.
Restorative Capacity (Kaplan, 1995)	Being away, Fascination, Extent, Compatibility.
Symbolism	

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REMOTE SENSING APPLICATION IN RIPARIAN AREAS

Adélia Maria Oliveira de Sousa
Kasper Johansen

Introduction

Riparian buffer areas have been recognized as important landscape features that provide unique habitats for many wildlife species (Iverson *et al.*, 2001). Riparian vegetation, including that of floodplain forests as well as rivers, is recognised as an important part of river ecosystems and there is an increasing demand for riparian vegetation parameters to be assessed in conservation, restoration and management projects (Muller, 1997). The management of these areas is a field of increasing relevance, as human modification of the landscape continues unabated (Goetz, 2006). Approaches are needed for mapping biophysical properties in riparian areas, monitoring the changes taking place, targeting restoration activities and assessing the success of previous management actions. For large spatial extents (> 100 km of stream length) it can be difficult to achieve these targets using the traditional techniques based on visual interpretation of analogue aerial photographs and field visits.

Remote sensing is the observation of objects and features without any contact and includes mapping and digital image processing techniques using aerial photography and satellite images. Remote sensing provides up-to-date, detailed information about land condition and land use, and uses instruments mounted on airplanes and satellites to produce images of the Earth's surface (Rowlinson *et al.*, 1999). This technique provides a different view of the terrestrial landscape and is used for inventory, monitoring, and change detection analysis of environmental and natural resources (Narumalani *et al.*, 1997). To produce maps of riparian zone features from remotely sensed images, field survey data obtained coincidently with the image capture are required to build relationships and models between quantitative field measurements and the spectral reflectance and to validate the map outputs. These spatial data can be incorporated into a geographic information system (GIS), which facilitates the management of water resources, land use and land cover as well as urban planning (Rowlinson *et al.*, 1999).

Remote sensing has made significant progress in the last decade. The use of remote sensing imagery has increased, mainly caused by development of new techniques for image information extraction, but also because of advances in commercially available airborne and satellite imagery at high spatial resolutions (pixels < 4 m x 4 m) (Lillesand *et al.*, 2008). In the last few decades, a number of studies have used satellite images with the aim of obtaining land cover type mapping for the management of riparian buffer areas. Recent advances in remote sensing have the potential to aid riparian management substantially. High spatial resolution imagery provides a basis for consistent assessments for regularly, accurately, and cost-effectively mapping and monitoring riparian areas (Congalton *et al.*, 2002).

Mapping riparian zones from moderate spatial resolution imagery

The Landsat (http://landsat.gsfc.nasa.gov) project is a joint initiative of the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS). The first of the Landsat (Land satellite) series was Landsat-1, launched in 1972 with the Multi-spectral Scanner Sensor (MSS), which was also used subsequently on Landsat-2 and 3. This sensor had four spectral bands, two in the visible and two in the near-infrared part of the spectrum, with a spatial resolution of 68 m x 83 m, usually resampled to approximately 60 m. The size of each image is 185 km x 185 km. The main applications of Landsat MSS images have been in agriculture, environmental monitoring, forestry and land use planning (Lillesand *et al.*, 2008). The most recent of the series is Landsat-7, which was launched in April 1999 with the Enhanced Thematic Mapper Plus (ETM+) sensor onboard. This sensor has seven multi-spectral bands, three in the visible, one in the near-infrared, two in the mid-infrared and one in the thermal infrared part of the spectrum. The sensor collects data with a spatial resolution of 30 m in the visible and short-wave infrared bands and it has a revisit cycle of 16 days. As with the MSS sensor, a full scene covers 185 km x 185 km.

One of the most common applications of Landsat imagery has been the development of land cover type maps. These types of images have also a wide application in estimating the amount of different cover types within riparian zones (Goetz, 2006) and have often been used in recent years. Land cover / land use (LCLU) data are frequently employed in watershed studies, but the source of the images and the processing method are rarely considered during their interpretation, making comparison of results impossible.

Apan *et al.* (2002) developed a method to produce a LCLU map of riparian areas using two images of the Locker Valley in Queensland, Australia: one from Landsat MSS (1973) and another from Landsat TM (1997). They used a normalised difference vegetation index (NDVI) image to help quantify the relative vegetation greenness and biomass, and classified the 1973 and 1997 images by adopting a post-classification change detection method. This method used spatial masking and supervised classification techniques, and created a map overlay in GIS to develop a thematic map depicting all the possible combinations of changes in land use between the 1973 and 1997 images. However, this paper did not validate the accuracy of the change detection because of the lack of field data. Their mapping results identified changes in the riparian vegetation, and they concluded that the riparian landscape had changed significantly during the 24-year period under study. Information about the landscape structure can be useful for the management of these areas, particularly for identifying and prioritising stream segments for rehabilitation and preservation. Hewitt (1990) also used Landsat TM data to map riparian areas associated with rivers, lakes and wetlands along the Yakima River of central Washington. The resultant classification had an overall accuracy of 80% in the detection of three land cover types, *i.e.* water, riparian zones, and others.

Another satellite used in LCLU studies is the Systeme Pour l'Observation de la Terre (SPOT: http://www.spot.com). The SPOT programme began in 1986 with the Franco-European satellite SPOT 1, under the responsibility of the Centre National d'Études Spatiales (CNES) in France. SPOT 2 was launched in January 1990 and SPOT 3 in November 1993, but the latter failed after a year. These three satellites carry a Visible High-Resolution sensor (HRV). This sensor acquires images in panchromatic mode (one band in the visible part of the spectrum) or multi-spectral mode (XS - green, red, and infrared parts of the electromagnetic spectrum). The pixel size is 10 m in panchromatic mode and 20 m in multi-spectral mode and the swath width is 60 km. SPOT 4, launched in March 1998, has Visible and Infrared High-Resolution (HRVIR) sensors, which are very similar to the HRV sensors of the previous generation. The most recent satellite sensor in the series is SPOT 5, which was launched in May 2002. The main difference in the SPOT 5 sensors compared with the previous generations is the high spatial resolution of 5 m and 2.5 m (instead of 10 m) in panchromatic mode and multi-spectral bands of 10 m pixels. SPOT multi-spectral imagery has been used to map a multitude of small features such as vegetation, soil erosion, urban environments, and forest properties because of its higher spatial resolution.

Pinheiro *et al.* (2008) classified LCLU in riparian zones of the Concordia River in south Brazil using SPOT-5 images. The aim of this approach was to analyze the relation between LCLU in riparian zones and the quality of water by using three representative parameters: transport and dispersion of fertilizers; content of organic compounds; and pathogenic organisms. Buffer strips of 20, 30, 50, 100 and 200 m widths along the river were considered and information about LCLU was extracted from the SPOT-5 satellite images at a spatial resolution of 10 m (multi-spectral bands) and 2.5 m (panchromatic band). It was found that LCLU in riparian zones can explain the variability of water quality indices and total pathogen concentrations.

SPOT multi-spectral imagery clearly provides adequate data for accurately mapping broad vegetation types at a landscape scale (Arbuckle *et al.*, 1999). However, because of limited spectral and spatial resolution of SPOT multi-spectral data and the complex topography of riparian terrain, more detailed mapping of riparian vegetation types and structure require higher spatial resolution imagery to be used.

Integration of multiple image datasets for mapping riparian zones

Several studies have used multiple types of image data to analyse and map riparian zones. Mouat and Lancaster (1996) investigated the relationship between LCLU data derived from aerial photographs and Landsat TM imagery and water quality parameters, but they did not provide a formal comparison of the two data sources. When comparing these data, a number of factors have to be considered (Turner, 1989; Collins and Woodcock, 1996), including: (a) spatial resolution; (b) spectral resolution; (c) radiometric resolution; (d) temporal resolution; (f) spatial extent; (g) methodology of classification; (h) number of LCLU classes; and (i) accuracy assessment methodology.

Iverson *et al.* (2001) conducted a survey of the Vermilion River basin in east central Illinois, USA. They used three data sets to evaluate 300 m of land cover on either side of the streams: (i) the US Geological Survey's data on land use and cover, (ii) land cover manually digitalized from the National High Altitude Photography program, and (iii) Landsat TM data classified as land cover using unsupervised classification. The resulting information was assessed for spatial distribution and, with the aid of aerial photographs and quadrangular maps, assigned to land cover types. In most cases, many clusters were grouped together to represent one land cover type. TM data proved to provide reliable information for this purpose. TM and other readily available satellite data, once classified, can be easily processed for this ranking scheme. The authors compared the three results and concluded that TM data can be useful for inventorying riparian forests.

Lattin *et al.* (2004) compared Landsat derived image maps with colour infrared aerial photographs specifically commissioned for the study of riparian buffer areas of the watersheds of Oregon's Willamette Valley. They concluded that finer spatial resolution data (aerial photographs) provided better mapping precision of narrow riparian vegetation adjacent to agricultural lands, than the coarser TM data. The multi-temporal TM data were better for distinguishing row crops adjacent to riparian zones. Human induced activities and disturbance in areas adjacent to riparian zones are important to map, as they may provide an indication of water quality, because of potential sediment, nutrient and pollutant inputs caused by runoff. Despite their very different nature, the Landsat images and the aerial photographs proved to be good analytical tools when correlating LCLU types with selected stream quality assessment indicators such as the fish Index of Biotic Integrity or water nitrate contents.

Rowlinson *et al.* (1999) conducted a survey to identify and assess different remote sensing data sources that are applicable to mapping alien vegetation in riparian areas using aerial videography, aerial photography and satellite imagery for a small sub-catchment area in the KwaZulu-Natal midlands in South Africa. Aerial videography is a new technique that has been incorporated into traditional remote sensing techniques in order to reduce the time required for data processing. The results of this study showed that manual techniques for riparian vegetation identification from fine spatial scale black and white aerial photographs produced the most accurate and cost-effective results, whereas analysis of aerial videography and Landsat TM data produced the lowest mapping accuracy.

Mapping riparian zones from high spatial resolution satellite imagery

Most current studies of remote sensing systems have been relatively coarse in spatial resolution (*e.g.* Landsat TM (30 m pixels); SPOT HRV multi-spectral (20 m pixels)). Sensors with moderate spatial resolution (> 4 m x 4 m) may be inadequate for the detection and analysis of riparian zones since the pixel size often exceeds the physical dimensions of these areas, prevents analysis of individual features, and reduces the level of variability present within riparian zones because of their heterogeneous nature at a scale smaller than moderate spatial resolution pixels. However, it is expected that as the spatial resolution of satellite sensor systems improves, remote sensing will be an invaluable data source for frequent, detailed studies of the streamside vegetation, landform, and impact of non-point source pollution on water resources.

Two satellites with improved high spatial resolution are IKONOS (http://www.geoeye.com) and Quickbird (http://www.digitalglobe.com), which have proved more feasible for mapping biophysical and landform characteristics of riparian zones than moderate spatial resolution sensors (Johansen and Phinn, 2008). The high spatial resolution imagery from the IKONOS satellite sensor is useful for many resource management applications, including riparian buffer areas. The IKONOS satellite sensor is a high spatial resolution system operated by GeoEye. IKONOS was the first commercially owned satellite providing panchromatic and multi-spectral imagery with pixels < 1 m and < 4 m respectively (Dial *et al.*, 2003). This sensor can provide relevant data for nearly all aspects of environmental studies. Using these images, Antunes *et al.* (2003) presented a high spatial resolution image classification based on object-oriented image analysis. The objects were produced from multi-resolution segmentation through merging of adjacent pixels into homogenous objects using the IKONOS imagery. Object-oriented image analysis has proved feasible for analysis of imagery with high spatial resolution suitable for riparian zone mapping. In high spatial resolution imagery, individual features are larger than the pixels. The pixels making up a feature, *e.g.* a tree crown, may exhibit large variation in spectral reflectance. This variability reduces the ability to successfully map individual features. Object-oriented image analysis reduces the level of reflectance variability of individual features through merging of the pixels into objects. The classification by Antunes *et al.* (2003) was based on fuzzy rules through contextual descriptors such as shape, texture, relations between objects and sub-objects, and location of land-cover classes in relation to each other. Different classification approaches were assessed: semantic network, selective and context change classification. The site tested was an agricultural area near the town of Nova Esperança, Paraná, Brazil with the purpose of mapping the riparian vegetation along the Porecatú River. Considering the complexity and the different vegetation structures riparian forest, eucalyptus and swamps multi-resolution segmentation was found to be well suited to generating images of objects and building up spatial relations.

Another study using IKONOS imagery was carried out by Goetz *et al.* (2003), who developed an alternative to interpreting aerial photographs to update the forested lands map, as well as to map changes that had occurred in land use, particularly residential development and intensification of impervious surface areas. Related applications include the use of these data to train sub-pixel algorithms of tree cover and impervious surfaces using coarser resolution imagery (*e.g.* Landsat). This study shows the practical utility of IKONOS imagery, particularly for mapping impervious surfaces, tree cover and riparian buffers, all of which are related to the condition of streams.
The integration of field and remotely sensed image data is important for the development of models that explain biophysical properties of riparian zones and for validating the mapping results. Several studies using high spatial resolution imagery have identified the challenge of accurate co-registration of these two data sources. The level of geometric accuracy required for integrating the field and the high spatial resolution image data can generally not be obtained from conventional global positioning system (GPS) receivers. New approaches such as identification of ground control points or transition areas between LCLU classes easily recognisable in both the field and image data can be used to correctly georeference the two types of data for precise overlay functions (Johansen and Phinn, 2008; Johansen *et al.*, 2008).

In Australia, suitable methods for measuring and monitoring the condition of riparian environments are being investigated by local, state, and national government agencies responsible for maintaining these environments (Johansen *et al.*, 2007; Johansen and Phinn, 2008). Johansen *et al.* (2007) compared two riparian condition assessment approaches, the Tropical Rapid Appraisal of Riparian Condition method, developed for rapid on-ground assessment of the environmental condition of riparian areas of the savannah, and an image based on a riparian condition monitoring scheme (figure 3.5.1). The measurements derived from these two approaches were compared

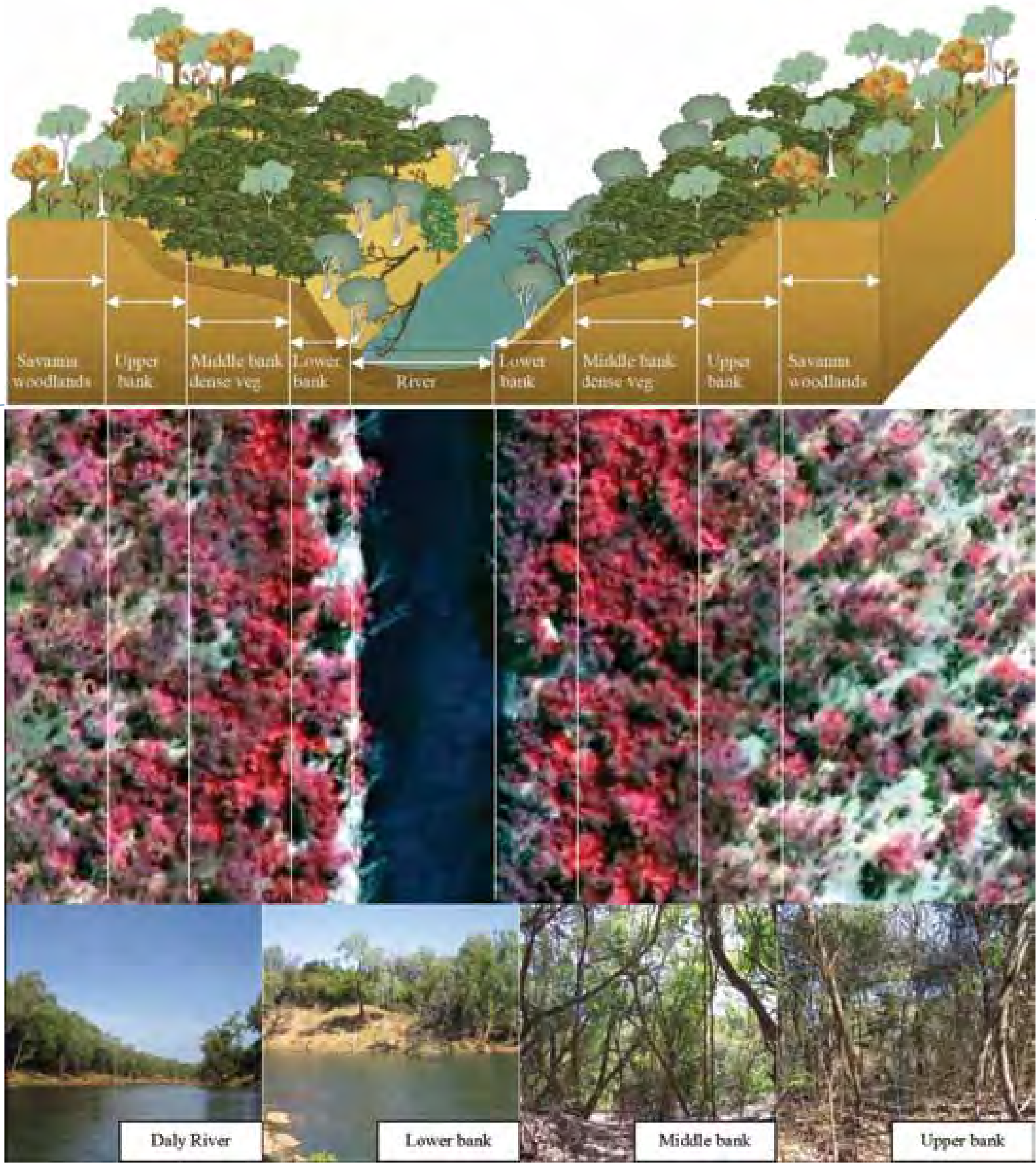

Figure 3.5.1 Sketch, pan-sharpened QuickBird image subset, and photos of the different stream bank sections identified along the Daly River, Northern Territory, Australia. Characteristic widths of this river system's riparian subzones are shown on the image subset. Source: Johansen *et al.,* 2007; Symbols for diagrams courtesy of the Integration and Application Network, University of Maryland, Centre for Environmental Science (http://ian.umces. edu/symbols/).

and correlated. The satellite data used included two 2.4m pixel multi-spectral QuickBird images, captured one year apart. The QuickBird sensor is a high spatial resolution satellite owned and operated by DigitalGlobe. These satellite images are an excellent source of environmental data, useful for analyses of changes in land use, agricultural and forest. The field measurements of percentage canopy cover and canopy gap distribution were derived from upward looking field photos taken with a digital camera, while organic litter was measured on the ground. These field measurements were used to calibrate and train the image-derived measurements and to validate image classifications. In this study, spectral vegetation indices suited to riparian environments were used, including NDVI, the Enhanced Vegetation Index (EVI), and the Soil-Adjusted Vegetation Index (SAVI), calculated and converted to percentage canopy cover and organic litter based on best-fit regression models between field measurements and corresponding spectral vegetation index values. The authors found that stream order, width of the riparian area, spatial variation in riparian condition, shape of the river system, and accessibility are important factors for determining the benefits of the field versus image based approaches. The multi-temporal analysis was more accurate and cost-effective for stream lengths > 200 km using the image based method due its higher precision compared to field based visual assessment.

Mapping riparian zones from airborne sensors

Remote sensing has been used, to a limited extent, to map and monitor characteristics of riparian areas, with classification of dominant vegetation species and mapping vegetation structural parameters as the main focus (Nagler *et al.*, 2001; Davis *et al.*, 2002; Dowling and Accad, 2003; Johansen and Phinn, 2006). The spatial resolution of the data indicates the minimum potential mapping unit. Airborne image data usually have higher spatial resolution than even the latest high spatial resolution satellite imagery available to the public (*e.g.,* IKONOS and Geoeye-1, Geoeye, and QuickBird, Digital Globe). With this level of detail available from airborne imaging systems, riparian zone metrics, beyond general classification of vegetation, can be assessed. These types of metrics may include assessment of large woody debris, bank stability, and stream properties.

The scale factor is of significant importance for studying riparian vegetation. The spatial resolution of the remote sensing data imposes a scale for analysing the vegetation. In forest studies, White and Mac Kenzie (1986) considered that the main target was to find a scale at which one pixel integrates the relevant heterogeneity within a unit to be mapped without causing any blurring across boundaries of major cover types. They considered that the optimum spatial resolution depends on the target of the study and on inherent characteristics of the landscape, *i.e.* size of tree crowns, canopy roughness, number of species within the types of vegetation, shape and extent of patches in a type of forest, spectral contrast with the matrix around the forest, and heterogeneity produced by patchiness within the forest (Muller, 1997).

Bryant and Gilvear (1999), Ferreira *et al.* (2005) and Milton *et al.* (1995) used multi-temporal remotely sensed data for change detection purposes of riparian zones. These studies used multi-date aerial imagery or photography. With an expanding market for airborne digital sensors providing very high spatial resolution (< 0.5m x 0.5 m pixels), these image data are likely to be used for riparian mapping and monitoring. Johansen *et al.* (2008) highlighted advances of digital airborne sensors such as the Vexcel Ultracam, Leica ADS, and Intergraph DMC sensors over satellite derived data. These included the ability to mobilize quickly at opportunistic times and at user-specified locations, increasing the likelihood of obtaining cloud-free images. Recently, airborne digital sensors have become increasingly competitive to satellite imagery in terms of costs, accuracy, and flexibility of use.

To obtain more detailed information, a new approach that considers the sub-pixel information in order to obtain land cover maps has emerged. It considers

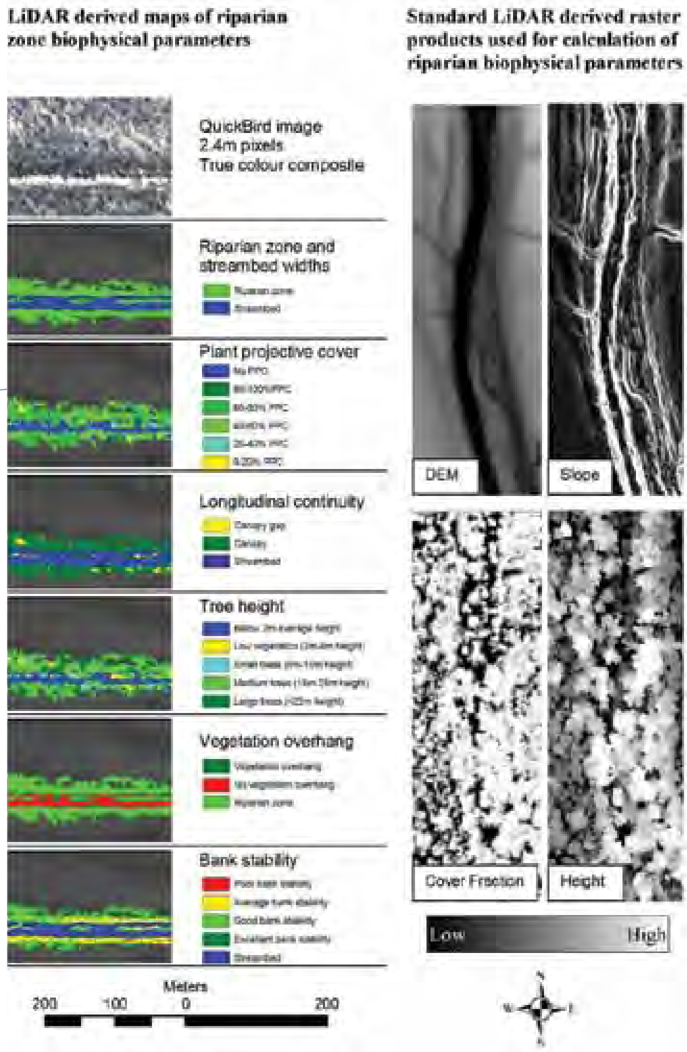

Figure 3.5.2 Standard LIDAR derived raster products and examples of associated riparian biophysical and landform maps derived from an Australian tropical savanna environment (Adapted from Johansen *et al.*, (in review)).

the proportion of each pixel occupied by any given land cover type. This information is mainly obtained using a tree algorithm type of classification that outputs continuous estimations of a given land cover type (Hansen *et al.*, 2002). A decision tree analysis is a non-parametric classifier that divides an image into regions (Oliver and Hand, 1996), by constantly dividing the image data into increasingly homogeneous regions using rules. Laser-based remote sensing is an advance in this field, providing even more detailed information about the properties of buffer areas, such as refined topographic derivatives and multidimensional vegetation structure.

Another type of remote sensing data used in recent years is light detection and ranging (LiDAR) systems (Lefsky *et al.*, 2002). These systems have been used in development and research applications for many years. Airborne LiDAR sensors derive information on the elevation and reflectance of terrain and vegetation from a pulse or continuous wave laser fired from an airborne transmitter, for which its position is precisely and accurately measured. Processing of the reflected LiDAR signal provides an accurate measure of distance between the transmitter and reflecting surfaces based on the time of travel of the laser and position of the sensor (Lefsky *et al.*, 2002). LiDAR data can provide detailed information on the heights of riparian canopy and understorey surfaces with vertical and horizontal accuracy within a few centimetres. LiDAR products provide improved definition of stream networks and catchments through elevation grids, while topographic definition within buffer areas can be derived and used with associated vegetation information for improved characterisation of the physical properties of buffers (figure 3.5.2).

Antonarakis *et al.* (2008) classified five types of riparian forest along three meanders of two rivers in France with accuracies between 66% and 98% using elevation and intensity information derived from LiDAR data. Frontier technologies for mapping riparian zones will show how LiDAR data, in particular full waveform data, can be used to quantify biophysical and landform parameters from elevation and intensity information and assess multi-temporal changes in two and three dimensions. Other leaps likely to occur in the future is the use of high spatial resolution imagery for partial automation of mapping riparian biophysical and landform parameters to generate more consistent maps suitable for planning and natural resource management.

Concluding remarks

Remote sensing is a cost- and time-effective technique to identify different types of vegetation in riparian areas and the remote sensing data can be incorporated into a GIS which can be used as a tool for the management of riparian areas. To date, the main application of remote sensing data in riparian areas has been the mapping of land-cover classes. These are used mainly to manage riparian areas. The traditional methods of land-cover classification with remote sensing data used in riparian areas are pixel based supervised and unsupervised algorithms, decision tree analysis, and thresholding of vegetation indices. In recent years, high spatial resolution remote sensing imagery has become more readily available from airborne and satellite sensors, providing imagery more suited for detailed assessment of riparian biophysical and landform characteristics. This has allowed improved characterisation of the properties of riparian areas than before. With increasing spatial resolution imagery available from airborne and satellite sensors (Johansen *et al.*, 2008), object-oriented image analysis using fuzzy rules has become a more appropriate approach for reducing the within-feature reflectance variability, but still achieve the high level of detail required for riparian zone mapping. This progress is likely to expand rapidly in the near future, especially with the increasing availability of full waveform small footprint LiDAR sensors and software packages currently being developed for multi-temporal three dimensional assessment of LiDAR data and for partial automation of mapping routines. Future research of mapping riparian zones is also likely to take advantage of the increasing data dimensionality through integration and combined processing of different image datasets such as high spatial resolution satellite/airborne imagery and airborne LiDAR data.

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Joao Rabaça
Carlos Godinho

BIRDS AS BIO-INDICATORS OF RIPARIAN ECOSYSTEMS

Monitoring biodiversity has received increasing attention in the last decade, following the entry into force of the Convention on Biological Diversity (see http://www.cbd.int). Concepts like biodiversity, sustainable development, nature conservation and bio-indicators have been increasingly focused on in the media and are becoming widely known among the public. However, there is often a gap between the theoretical framework of these concepts and their being fully understood by citizens. This can create several constraints on land use and territory management, particularly if local, regional or national technicians and decision makers are involved. The question, then, is how to take the step from theory to field work. This chapter provides a brief focus on the use of riparian and aquatic birds as bio-indicators and will (1) try to clarify what a bio-indicator is and what it can tell us, (2) give a few examples with reference to birds and (3) suggest a stepwise procedure for assessment of the birds associated with a river stretch.

What is a bio-indicator?

The term bio-indicator in its broader sense can be defined as organisms or clusters of organisms (*e.g.* communities, guilds) used to monitor environmental changes in habitats or ecosystem conditions. Bio-indicators can be used in different fields of biology and environmental sciences, employing different assessment methods depending on the range and the organisms involved. In order to achieve their goal, bio-indicators must be both reliable and indicative of a particular state of habitat/ecosystem situations.

Indicators summarize data on complex environmental issues to indicate overall biological diversity status and trends. They are generally used to simplify, quantify and communicate the state, changes and trends of particular areas of interest. They can be used at different geographical scales, from local to global, from regional to European (Delbaere, 2002), depending on the goals considered.

There are several approaches to generating an indicator of the state of the wildlife. Most often, the common procedure is to measure diversity using species loss or gain to estimate or measure the trends in biodiversity (Gregory *et al.*, 2003). For this approach to be used successfully, considerable attention must be given to selecting the appropriate set of indicators. An indicator must be quantitative, simplifying, user driven, relevant to policy, scientifically credible, responsive to changes, easily understood, realistic to collect and susceptible to analysis (*e.g.* Carignan and Villard, 2001; Gregory *et al.*, 2003). As mentioned by Delbaere (2002), getting from science to practical policy implementation is fundamental for obtaining the best indicators, as it strongly influences essential steps of the data production process such as monitoring and data management. Nevertheless, it is not always easy to apply science in a policy world.

Birds as bio-indicators

Among terrestrial vertebrates, birds have often been used as bio-indicators (*e.g.* Burnett *et al.*, 2005; Gregory *et al.*, 2005; Padoa-Schioppa *et al.*, 2006). Birds occupy a large number of habitats all over the globe and usually occur in large numbers (Tucker and Heath, 1994). Several species are rather sensitive to environmental changes and are faster reactors. Additionally, birds are frequently used as indicators of changes in other groups (Tucker and Heath, 1994). Furthermore, birds are the best-known biological group, considering the amount of information available. The shifts in distribution and population trends of several species or clusters of species are currently known. Moreover, birds are the only group for which extensive nationwide or continental atlases and data bases of trends are available. Compared with other terrestrial vertebrates, bird numbers are relatively easy to gather and can be recorded in a systematic way over time, so it is rather easy to obtain temporal series. Another important trait of birds is their popularity among the public of all ages, providing a vast body of volunteers who are interested in participating in monitoring programs. Currently, the easiness of monitoring birds using simple survey protocols is probably the main reason why using birds as bio-indicators is so attractive. Additionally, the longer life span of birds compared with other organisms often used as bio-indicators (*e.g.* diatoms, invertebrates or fish) increases their sensitivity to cumulative impacts on the environment. In the European Union (EU), an outstanding example of the use of birds as bio-indicators is the Farmland Bird Index, which is one of EUROSTAT's structural indicators for the environment. This EU index is based on trend data provided by 18 Member States that conduct national breeding bird surveys annually under the Pan-European Common Bird Monitoring Scheme (see http://ec.europa.eu/eurostat). The index provides a reasonable approach to population trends in farmland birds (figure 3.6.1) and clearly shows that in Europe's agricultural landscapes, common farmland birds have declined over recent decades.

However, certain drawbacks prevent birds from constituting a panacea for monitoring environmental changes or ecosystem conditions. Their various disadvantages include their mobility, which makes it difficult to establish site-specific causes when high mortality levels or a rapid decrease in population numbers are detected, since the factors involved could be operating elsewhere (even in different geographic areas where migratory species are concerned). In order to mitigate the effects posed by the spatial volatility of birds, ornithologists have often suggested that their quantitative study should focus on the breeding season, due to the relative spatial constancy recognized in most species and imposed by territorial behaviour (nonetheless, different territory types have been described in birds, making this a tricky process).

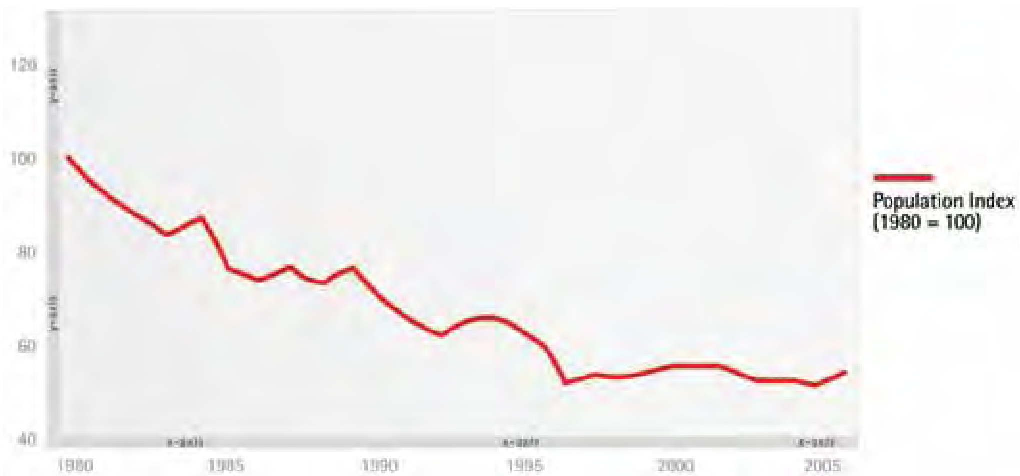

Figure 3.6.1 Population trends of common farmland birds (European Bird Population Index) for the period 1980-2005 (Source: http://www.ebcc.info/index.php?ID=299).

Application to aquatic ecosystems

The use of aquatic organisms to assess the biotic integrity of riparian ecosystems has become a common procedure in recent years. Several indices have been developed for different taxa, namely fishes, macro-invertebrates, macrophytes and diatoms. So far as birds are concerned, several attempts have been made to produce indices that somehow relate ornithological attributes (species composition, richness, densities, diversity, trophic categories) with aquatic and riparian features of the river stretches being sampled (water quality, type of flow, bank slope, substrate, density and structure of riverside vegetation). Based on assessment of breeding bird communities by a point count method, Roché and Frochot (1993) documented the existence of ornithological zones along the upstream-downstream gradient in three rivers in France. Their model has four zones from the headwaters to the mouth, each characterized by a bird species: the first sector is illustrated by the Dipper (C*inclus cinclus*), the second by the Common Sandpiper (*Actitis hypoleucos*) and the third by the Common Tern (*Sterna hirundo*), while the last is best characterized by the Coot (*Fulica atra*). Another interesting finding by these authors is that these ornithological zones are analogous to previously-described fish zones, thus suggesting a general model that incorporates river channel patterns such as waterfalls, braiding, anastomosis and meandering (Roché and Frochot, op. cit.).One of the best-known vertebrate indicators of water quality is the Dipper (*Cinclus cinclus*), an aquatic passerine of the Cinclidae family, which includes freshwater birds which are rather unique in their ability to dive and swim underwater (figure 3.6.2). The species distribution in Europe is closely associated with fast-flowing rivers, often in upland areas, with cold, clear waters where they can feed on the nymphs or larvae of insects, shrimps or small fishes (*e.g.* Cramp and Simmons, 1988).

Dippers are monogamous and highly territorial throughout the year, establishing their territories

Figure 3.6.2 The Dipper (*Cinclus cinclus*), a specialist riverine bird, is commonly considered a good indicator of water quality (photo: Jean Roché).

longitudinally along the river. Ormerod *et al.* (1987, 1991) documented a strong association between the occurrence of Dippers and low acidity stream waters in the UK. Sorace *et al.* (2002) conducted a study in central Italy to ascertain whether the occurrence of the Dipper was affected by stream pollution. They sampled 47 stretches of 35 watercourses and found that in 93.3% of the cases Dippers occurred in unpolluted reaches and were absent from 93.7% of the polluted streams. Moreover, they were able to trace the disappearance of Dippers in a few streams following degradation of the water quality. According to the authors, this species not only tracks changes in water quality over time but is also sensitive to stream pollution, reinforcing its role as a good bio-indicator (Sorace *et al.*, 2002). Although the above example demonstrates why a particular bird species can be a good bio-indicator, the composition of bird assemblages associated with river stretches is often used as an indicator of river channel and riverside habitat features and modifications induce by human activities (*e.g.* changes in bank slopes, vegetation cutting and livestock grazing). This is based on the fact that birds respond to changes in vegetation density and type, both in the river corridor and in the surrounding matrix. Bryce *et al.* (2002) tried to assess human impacts on stream reaches in Willamette Valley (USA) using a bird integrity index (BII) that uses information on bird assemblages obtained through bird surveys. In essence, they carried out a systematic evaluation of several avian metrics (*e.g.* richness, total abundance, long-distance migrants, foraging guilds, tolerance to human disturbance, nesting strategies) for their value as indicators and combined those selected into an index of ornithological integrity to assess the condition of river stretches. They concluded that the BII appears to be a useful management and monitoring tool for assessing riparian integrity.

Although several constraints make it advisable to exercise some caution in using riparian birds widely as bio-indicators, it is important to highlight that some key information on the ecological traits of riparian landscapes can be obtained from ornithological assessment. Water birds (waterfowl and waders) can provide useful information on the integrity and dynamics of river channels, while woodland birds associated with riversides can be used in the study of all stages of riparian vegetation.

How to carry out an assessment of bird communities in riparian ecosystems

Human pressure in riparian areas is increasing and most of these areas are being lost or modified (Kaufmann *et al.*, 1997; Rottenborn, 1999; Nilsson *et al.*, 2005). The long history of intensive land use and human disturbance (Décamps *et al.*, 1988; Corbacho *et al.*, 2003) underlines the need to speed up actions for their recovery.

Considering the attractiveness of birds and the user-friendly quality of most survey protocols, this section suggests a simple stepwise procedure for assessing the bird communities associated with a watercourse reach where recovery may be planned. In time, this will make it possible to detect changes in species composition and abundances, and relationships with habitat features might be established. The necessary steps are as follows:

a) Description of the initial state – data on birds and habitats must be collected prior to recovery action. Information about potential species must also be gathered. This information is fundamental for delineating the time and place of the action to be taken according to the distribution and ecology of the species and for evaluating the effectiveness of future rehabilitation

b) Choosing bird assemblages – if possible, a community approach rather than a single-species approach is recommended. In this way, natural fluctuations in single species populations and the misleading effect of factors other than alterations in riparian habitats will be avoided

c) Control areas – a control area without intervention in the same watercourse or in another with similar habitat features (possibly from the same watershed) is quite useful in order to evaluate the effect of the actions being undertaken. It also helps to avoid any delusions about the results

d) Definition of survey method and sampling places – the adoption of a standardized method is recommended. This will allows future comparisons with other works and replication of the surveys in an almost unlimited time span. A point-count methodology (*e.g.* Blondel *et al.*, 1981) with limited distance, 25m bandwidth, and a survey time of between 10 and 20 minutes split into 5-minute frames is recommended. The adopted bandwidth must be related to the width of the river and consistent throughout the survey area. In the RIPIDURABLE project (see www.ripidurable.eu), two bandwidths (25 and 50m) were used in rivers with a 5-15m wide river channel, but in larger rivers the observation bandwidth can be increased. The number and location of the sampling stations varies in each case. Nevertheless they must be separated so as to allow independent observation (*e.g.* 250 m apart) and systematically spaced

e) Interpretation of results – bird surveys must provide information on the actions taken, based on bird-habitat associations. Therefore, particular attention must be given to the environmental variables related with habitat features. Bird surveillance must reflect recovery actions and the development of the measures undertaken. The use of environmental variables, bird species richness and abundances make it possible to build predictive models that can be useful to the restoration plan. The results must be used to make adjustments to the restoration plan if necessary and also to undertake public information and educational activities

f) Replicable – In order to evaluate the success of the rehabilitation procedure, it is necessary to monitor over time. This is why it is so important to employ a replicable method. Depending on the spatial scale of the project and the logistics, monitoring surveys can be conducted on an annual basis or every two or three years.

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4

Developing and Implementing a Project

PLANNING

Gonçalo Leal
António Campeã da Mota
Ilidio Moreira
Maria da Graça Saraiva
Ana Mendes

Introduction

The methodology of a project comprises several phases and steps designed to attain the defined objectives. The sequence of actions includes collecting the fundamental data for analyzing and characterizing the present situation, which makes it possible to diagnose and assess problems; defining the objectives; defining the types of reaches involved in the restoration project, as shown in the following flow chart:

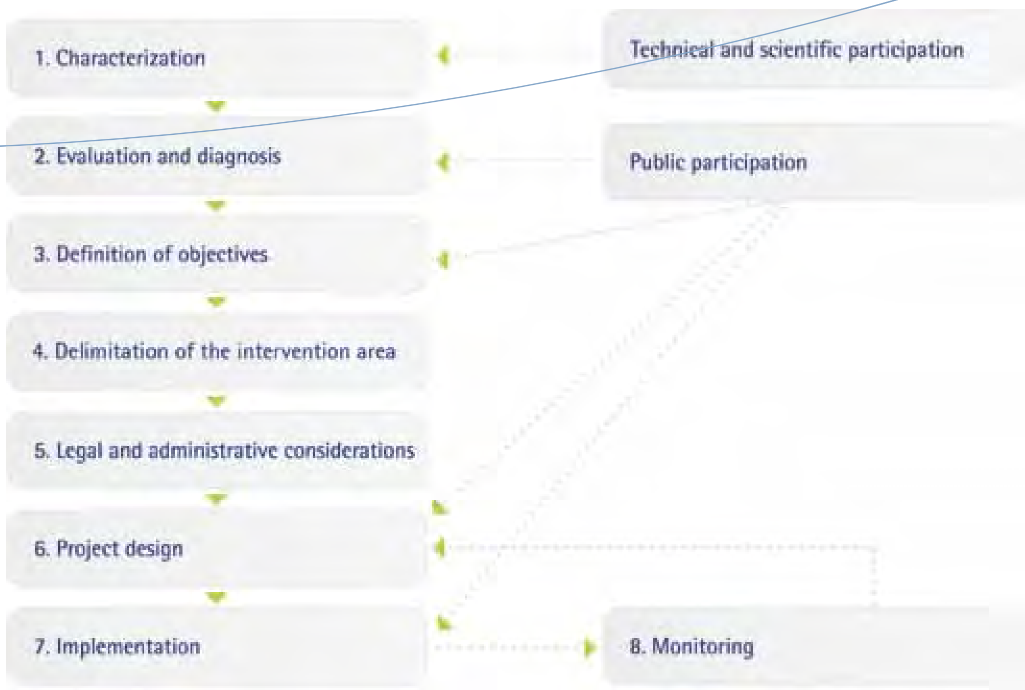

Figure 4.1.1 Flowchart of a fluvial system recuperation project.

Characterization

Characterization of the array of factors that contribute to the diversity and the functions of fluvial systems is fundamental, making it necessary to study the various components of these systems. This requires a multidisciplinary approach and the collection of data on a variety of specific parameters in order to analyze the ecological integrity of the river.

Other aspects that are essential for the exhaustive study of situations which require action are listed below. The list indicates some of the factors and parameters that need to be taken into account in projects of this nature:

A. **Characterization of the reach**

1) Situation within the river basin
2) Topographic characterization
3) Width, length and other measurements
4) Degree of linearity

B. **Hydrology**

1) Precipitation data
2) Annual flow values
3) Seasonal flow values
4) Flood/spate peaks (5, 10, 50 and 100 year return periods)
5) Minimum flow values
6) Runoff behaviour
7) Catchment form and dimensions

C. **Erosion and sediment transport**

1) Characterization of erosion processes
2) Quantification of superficial erosion
3) Characterization of torrential erosion

D. **Fluvial processes**

1) Channel form and dimension
2) Substrate composition
3) Transversal relations between channels in minimum discharge and bankfull conditions
4) Evidence of landslides or slippage
5) Bank erosion
6) Channel-forming discharge (bankfull conditions)
7) Channel mobility
8) Types of sediment

E. **Water quality**

1) pH
2) Conductivity
3) Colour
4) Temperature
5) Dissolved oxygen
6) 5 day Biological Oxygen Demand (BOD5)
7) Chemical Oxygen Demand (COD)
8) Sediments in suspension

F. **Riverine vegetation**

1) Type of community
2) Distribution of community
3) Degree of coverage
4) Degree of continuity

G. **Plant and Animal species**

1) Aquatic species
2) Riparian species
3) Indigenous vs. exotic species
4) Rare endemic or endangered species
5) Macroinvertebrates or vertebrates that act as water quality indicators

H. **Ecological integrity of the river system**

Definition of the technical/scientific team

The characterization phase of a restoration project is crucial for the future viability of its implementation. It requires technical expertise and considerable experience. The early inclusion of a multidisciplinary consulting team is vital. As far as possible, the team involved in the characterization phase should take part in the project design and implementation phases. The team should comprise both biologists and engineers with knowledge of terrestrial and aquatic ecology, hydrology, hydraulics, geomorphology and sediment transport.

Evaluation and diagnosis

In this phase it is important to involve all interested parties, thereby ensuring public engagement in the development of the project. The real success of this type of operation is highly dependent upon acceptance by and information from all parties with an interest in the river and its riparian zone; therefore, consensus needs to be created between stakeholders (*e.g.* landowners, local authorities, users) and the project's technical team so that the subsequent phase takes the needs of all parties into account.

It is often important to consider relevant aspects such as the limits of intervention (reach or catchment scale), since these will influence which jurisdiction applies to the project: one might be talking about just one or two landowners or it could also involve the local, regional, or even central government.

Consequently, it is important to form an advisory group, which should include private citizens, public interest groups, economic interest groups, official organisations with jurisdiction within the area and environmental and heritage NGOs. This advisory group should meet periodically in order to: (FISRWG, 2001)

a) Identify the various public interests in the project.

b) Provide various points of view and propose objectives to decision makers.

c) Ensure that local values are taken into account during project implementation.

d) Plan best alternatives for activity development in accordance with all participating parties' interests.

The advisory group must be conscious that its role is to advise and that decision-making power resides with the project initiator. Although group members play an important role in project planning and implementation, they do not take final decisions.

During the evaluation and diagnostic phase, it is important to involve these advisory groups in order to guarantee public participation in the whole project. Establishing such groups is often very difficult. Public announcements are a good way of generating interest, as are advertising, writing to institutions with a potential interest or even contacting potentially cooperative parties such as landowners directly.

Definition of Objectives

Following the initial characterization phase, once a general overview of the situation has been aquired, the objectives and scope of the project should be established. It can be helpful to invest a few hours in giving some thought to general restoration ecology concepts, *e.g.* the definition of 'restoration', and determining reference conditions and possible future scenarios. An exhaustive definition of these concepts and a description of their usefulness in deciding the project objectives are given in Part 1, chapter 2 and in Part 3, chapter 3 of this book.

Delimitation of the Intervention Area

The delimitation of the intervention area is always a complex theme, since it is directly related to the definition of objectives and the active participation of advisory groups, as well as to the technical requirements of the project.

In an initial phase, the technical personnel define the geographical intervention limits (via analysis of the data collected during the characterization phase), following the previously defined objectives. In a second phase, these intervention limits need to be revised by the advisory group in order to reach consensus with all the social groups participating in the process, and also to ensure that all stakeholders are absolutely clear about the proposed objectives.

From the technical point of view, it is important to emphasize that the geographical limits which are defined should be a direct reflection of relevant ecological processes. These limits should reflect the various spatial scales through which ecological processes influence river systems.

Once the location of the project has been decided, it is necessary to identify the priority intervention reaches and their limits, as it also is, to identify landowners in the area where the intervention measures are planned. The type of intervention will vary with the type of landowner and the legislation concerning the land bordering the river. It may be necessary to act differently in order to attain the proposed objectives, including public participation.

At this point, it must be stressed that without having fully informed the interested parties, such as landowners and other users of the reach to be restored, and without public participation, intervention measures run the risk of failure in the long term. This can be ascribed primarily to the lack of information among the local population: imposing measures that have not been previously agreed upon or that do not have public consensus may reduce the viability of their duration in the field.

Generally speaking, the types of combinations of land ownership and national or local administrative classification of the land where the intervention is to be carried out may be defined as follows: (FISRWG, 2001)

a) A single landowner in a rural area

b) Several landowners in a rural area

c) A single landowner in an urban area

d) Several landowners in an urban area

e) A single landowner in a protected area or natural park

f) Several landowners in a protected area or natural park.

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LEGAL AND ADMINISTRATIVE GUIDELINES FOR THE RESTORATION OF RIVERS AND WETLANDS

Pedro Brufao Curiel

Introduction

The restoration of rivers, riversides and wetlands in Spain has been approached mainly from a technical point of view (including the concession of public works) and at most from a social perspective, aimed at involving local populations.

In order to comply with the Water Framework Directive, to develop the programmes envisaged by the National Plan for River Restoration, and to carry out the greatest possible number of private and official activities of fluvial ecosystem recovery, it is necessary to take a series of previous legal and administrative steps to guarantee juridical certainty. When dealing with river restoration projects, some of the legal issues may include: distinguishing private property from public property; expiry and renewal of concession periods; rights affecting adjacent land and its legal uses; legislation governing natural spaces; potential environmental impact studies; acquisition of land through private transactions or compulsory purchase; relations between different administrative levels; allocation of competences; or the use of alternative legal figures, such as the "river agreements".

The present chapter summarises how national and EU legislation can contribute to the vital effort of recovering our deteriorated fluvial ecosystems. The topic is discussed at length in the author's forthcoming "Manual jurídico para la restauración de ríos y terrenos ribereños" ["Legal manual for the restoration of rivers and their surrounding areas"], to which reference shall be made.

General considerations

When a private person or the public administration considers the restoration of a river or a wetland area, the first issue that must be addressed is land ownership. One of the main purposes of the rule of law is to guarantee juridical certainty, which in this case would apply to an environmental project, and it must be totally clear from the outset who the public or private owner of the relevant land is, and what the exact boundaries of that land are.

In countries that follow the tradition of Roman law, like Spain, rivers and wetlands are generally public spaces, although various specific conditions may apply, such as different ownership regimes of riverbeds and water rights. Boundaries are another issue, since exact property limits are sometimes not clear, or have serious environmental implications (as when water courses have been channelled to avoid flooding of private land). In addition to ownership issues, the legal circumstances of the property must also be examined, as the use of the land might be restricted or controlled by other owners, such as in the case of servitudes and leases.Furthermore, municipalities and other public bodies own thousands of square miles of land under a wide range of juridical regimes, one of the most important of which is communal ownership. To make matters more complicated, it is often impossible to determine who the landowner is, since the property is not registered or the relevant details are not correct. Many other problems may also hinder land restoration work: inheritances, public concessions (generally associated with hydraulic and mining activities), and litigation over boundaries or infrastructural projects (it is not unusual for recently reforested areas to be devastated by new highways or urban developments).

We reiterate the enormous importance of juridical certainty. To ensure the latter, a good project must have its corresponding administrative file, describing the conditions of availability of the relevant fluvial and riverside areas. In Spain, this makes it indispensable to examine the Property, Land; and Water Registries, the Private Water Catalogue, the Registry of Mines, and the town planning archives, and ascertain potential restrictions in protected natural spaces. Together with legal analysis, we must pay close attention to the many illegitimate and clandestine uses of water, which may hamper the success of our restoration efforts. It is indeed a well-known fact that only a small part of underground water is extracted legally, and that the use of surface water for irrigation is often illegal; the same applies to hydroelectric plants and industrial uses. As regards these matters, the rule of law is far from being duly upheld in Spain, where a situation of true 'hydrological disobedience' holds sway. One of the first steps to be taken, therefore, is to enforce the law by means of the relevant penal and administrative measures that our legislation makes available to us.

Lastly, we must consider essential flow-volume availability, since it is obvious that no restoration project can be properly carried out without a natural water regime, or at least an acceptable regime of maintenance flow volumes. In addition to land ownership and property availability, an adequate regime of water that is as natural and clean as possible is clearly necessary for successful restoration to take place. To this end, details regarding dates of expiry and renewal of water concessions or authorisations (both in terms of volume, hydraulic regime, and quality) must be known, and work such as the potential demolition of dams and hydraulic infrastructures that may hinder restoration objectives should be duly contemplated and planned for. The best available water-treatment techniques must also be used when necessary. The different reports and books regarding these issues have been published on line at www.riosconvida.es.

Specific legal techniques

Restoration projects on publicly owned land will generally be carried out by the relevant environmental and water administrations, with great savings in terms of the cost of transactions with private individuals and companies. We will thus focus our attention on measures coming under administrative law, without forgetting potential figures of private law. When projects result from private initiatives, private measures such as leases, servitudes, purchases and sales, and permutations, must be borne in mind, since activities will centre on riverside areas especially, and not so much on public water domains, unless special agreements with the competent authorities exist.

The first administrative measure should be aimed at finding out what agency or official body is competent in the area of choice, something which in principle is not easy. Permits must not only be secured from the river-basin authority, but also from the local council and other territorial administrations. Environmental impact reports, or official exemptions from such administrative requirements, are necessary as well. In the case of Spain, the Hydrographical Confederations and other river-basin authorities, like the regional and municipal administrations, are competent in environmental matters, and can therefore carry out interventions such as those described in the present paper. It is also quite common for agreements to be reached between administrations, or for consortiums or other bodies to be created in an effort to add public thrust to these activities. The main legal figures that can then be put to use are the following:

1) Administrative eviction: ejectment of illegal occupants of public property.

2) Expiry, waiver, or restricted renewal of water and mining concessions and authorisations.

3) Restitution to original status as public water domain, or restitutio in integrum

4) "Domain reserves", or rivers and wetlands with respect to which no authorisations or concessions may be granted, as is the case in the US under the Wild and Scenic Rivers Act.

5) Compulsory purchase of land.

6) Lease, usufruct or surrender for environmental purposes.

7) Compulsory surrender of land in urban development projects and land-plot concentrations.

8) Planning in conservation areas and urban developments.

Private law also offers a comprehensive series of legal figures. Some of the most important are:

1) Purchase of property: donation, purchase and sale, permutation and acquisitive prescription (access to ownership over time)

2) Use agreements: leasing, civil servitudes and conservation easements, and conditioned private agreements.

One vital issue is the acquisition of domain and ownership of other rights with a view to creating vast areas that are environmentally and legally protected. In terms of comparative law we have the great examples of the National Trust in the UK, and of private reserves in the custody of foundations and private NGOs. In Spain, one of the pioneer organisations was the Fundación Territorio y Paisaje [Land and Landscape Foundation], which owns some riparian land. From the public point of view, mention must be made of urban planning restrictions ("non-developable" and "non-developable, specially protected" land) and conservation areas or protected spaces; among the latter, energetic efforts should be put into the creation of a network of protected spaces, along the lines of the above mentioned Wild and Scenic Rivers in the USA. Together with the execution of the Plan Nacional de Restauración de Ríos [National River-Restoration Plan], another "conservation" plan is indispensable, to protect fluvial spaces that are currently under serious threat, since very few rivers are in good ecological conditions.

Conclusions

This paper is but a brief overview of the different legal and administrative possibilities that are open to us when executing river restoration projects.

We must also ensure that adequate funding is available, and increase political awareness of the problem, since restoration programmes are in many instances considered mere 'compensation' to make up for the damage caused by infrastructural or urban projects with a high environmental impact.

These programmes should not be limited to the public sector. Private enterprise can also promote similar interventions with adequate public support (agroenvironmental measures, for instance) and the use of fiscal incentives for riverside landowners engaged in farming activities. Conservationism is certainly not limited to officialdom.

Ana Mendes

PROJECT DESIGN

This chapter is based on the FISRWG's publication Stream Corridor Restoration Principles, Processes, and Practices (2001) and on the experience acquired in the course of the Ripidurable project

Definition of the technical team and the decision making processes

The team that will be responsible for designing the restoration project must be capable of handling the very different aspects involved in such a complex process. The team should comprise technically-skilled members with a wide range of interdisciplinary experience in engineering, biology, the social sciences and economics; particular emphasis should be placed on skills in the following areas:

1) Biology
2) Forestry engineering
3) Hydraulic engineering
4) Biophysical engineering
5) Geology
6) Landscape planning
7) Social sciences and economics

The technical team should be responsible for a number of decision-making processes, such as:

1) Procuring finance for the project

2) Coordinating public sessions

3) Adducing the scientific bases for the restoration work

4) Adducing the legal bases for the project to be operational

5) Providing support for the necessary bureaucratic processes such as obtaining licences and permits

6) Implementing the project (scheduling and coordinating activities involving machinery, machine operators and technical personnel)

7) Providing alternative remedies when any of the original solutions becomes difficult to implement in the real situation on site

8) Monitoring

One important aspect of teamwork that needs to be taken into consideration is setting out the team rules for specifying and monitoring the work in progress. This document should be drawn up at the first meeting and should cover important aspects such as:

1) Meetings: periodicity, compulsory attendance, place, agenda, identification of a mediator, drawing up and approving the minutes of the meeting.

2) Decision making process: defining the decision process (votes, consensus and advice), delegating decisions

3) Resolving problems: approaching and resolving impasses

4) Communication and information: definition of public relations measures, communication between team members

5) Leadership: definition of decision makers and managers (N.B. there must be someone with overall responsibility for project implementation who makes decisions at key moments during the project).

In parallel with the creation of the technical team, a consultation body should also be set up to meet specific needs of the restoration initiative.The skills of each specialist on the consultative body can significantly increase the long term chances of project success; the following list is not exhaustive:

1) Lawyer
2) Microbiologist
3) Botanist
4) Economist
5) Archaeologist
6) Sociologist
7) Land surveyor
8) Topologist.

Creating public participation groups

Public participation in restoration projects, while it needs to be well-managed, has an important role to play in garnering and pooling knowledge and is a fundamental element in the success of these initiatives over time. The creation of public participation groups brings scientific and technical know-how together with social, political and economic information, which all influence restoration project management and, indeed, affect the definition of realistic long term objectives.

It is important for the public participation group to be made up of several interested parties and users of the area where the restoration initiatives will take place. However, these groups tend to comprise organizations with differing interests and it is important for the group members to decide together upon a series of protocols that will facilitate decision making and communication. Within each interest group, it is important to take the following into account:

a) Each group should select a representative

b) The group should establish decision-making rules

c) People with communication and data-synthesis skills should be chosen (this is important for the development of a collective group-work consciousness, which will temper unfavourable group dynamics that can result in possibly extreme positions)

d) All procedures should be documented (drawing up and approving minutes).

It is important to keep the public participation groups informed during the whole process from design to implementation, allow them to share problems that may occur during implementation and ensure information-sharing between them and decision makers.

Special attention should be given to private landowners with land adjacent to the river margins. As an integral part of the restoration process, it may be necessary to restrict use of the margins (*e.g.* increase the area of the riparian gallery with consequent loss of agricultural land, or restrict the passage of cattle or their drinking points) which may result in loss of income for the private landowners. For these reasons, it is fundamental to include landowners in the decision making group.

In order to facilitate the setting up of public participation groups, it is important to develop an effective communication plan that seeks to bring together diverse points of view. The following means can be used to publicize the establishment of these groups:

1) Internet websites
2) Local radio talk programmes
3) Brochures
4) Information bulletins
5) Press-releases
6) Open sessions
7) Seminars
8) Regular scheduled meetings
9) Study visits

Economic analysis versus objectives

When preparing for a restoration project, the most suitable and economically viable techniques for meeting the project objectives need to be considered. This includes carrying out a feasibility study of the selected techniques in order to determine whether or not it would be more appropriate to use a passive method or to undertake more direct intervention on the system, such as biophysical engineering techniques, at a given moment. Consequently, it is important to analyze the expected objectives and their relation with:

1) The causes of degradation, in order to verify which perturbation factors, if allowed to remain, will prevent the planned actions from having the desired effect. Thus, it is important to weigh up the intervention in terms of totally removing or just reducing the perturbation factors.

2) The effects of degradation, in cases when it is not possible to act upon the causes of degradation and re-establish the system's natural conditions. In many projects it is only possible to act upon the symptoms. In this phase it is important to define which mitigation measures and techniques can be used in the expectation of obtaining results that are economically advantageous.

3) The reach / river / corridor / catchment / landscape/ region: since it is virtually impossible to act upon all of the human impacts that influence a restoration project which is being drawn up, it is important to weigh up selected techniques and suitable solutions that will ensure fluvial continuity and at the same time meet economic and social objectives; although difficult to quantify economically, these factors should always be taken into consideration.

According to the Federal Interagency Stream Restoration Working Group (2001), in order to analyze the economic efficiency of the suggested solutions it is necessary to:

1) Draw up a list of techniques that allow defined objectives to be met

2) Draw up a list of probable ecological benefits

3) Draw up a list of probable costs

Quantification of probable ecological benefits can be difficult since medium and long term benefits can be hard to measure, as can impacts at the spatial level of reach and basin. In these cases, the ideal approach will be to try to convert the benefits of their impact upon the population into economic terms; for example, the benefit of flood prevention can be calculated in terms of land costs. It is important to note that probable technical costs do not refer only to implementation costs but also to design costs, land purchase, licences etc. Cost benefit analyses are not exact, so it is necessary to consider the following two rules for classifying inefficient techniques:

1) For the same benefit, there is a cheaper alternative

2) With another technique, more benefits could be obtained for the same price

Cost benefit graphs and higher-cost analyses can facilitate the choice of the most suitable technique. However, accurate economic analysis depends upon the data employed and explicit, exact quantification of the costs and comparison of the cost and benefits of each technique are vital for the correct choice of a suitable solution. For example, action to control erosion resulting from cattle crossing at a particular point on a river could use the following techniques:

1) Constructing a cattle ford to minimize trampling

2) Restricting cattle to crossing at a single point, using fencing to limit access to other areas.

3) Restricting cattle to crossing at a single point and planting vegetation

4) Totally prohibiting cattle crossing

The following table (table 4.4.1) summarises the benefits and cost of each course of action.

Table 4.4.1 Cost-benefit analysis of an erosion control action.

Technique	Benefits %	Cost (euros)
A	80	4000
B	90	1000
C	90	2000
D	1000	6000 (compensation)

The value of this type of analysis is totally dependant on the criteria employed to assess the benefits and on the number of factors assessed. For instance, this example only takes into account one factor, erosion control, so technique B will be the most effective solution as it has the best cost/benefit ratio. However, if the course of action is evaluated globally, factoring in the environmental benefits provided by the vegetation and the environmental and landscape impact of installing permanent structures such as fencing, then the cost/benefit ratio is likely to produce a different result.

An economic analysis can only be considered complete if it includes a risk assessment study, examining the possibility that the restoration process may fail due to external factors that were not quantified or cannot be controlled during project implementation. For example, in a replanting project it is assumed that the plants will root successfully and it will be 5 years before they attain the capacity to resist flood events. However, a 50 year flood event occurs during the first 5 years of the project, wiping out all the work that has been carried out. This shows the importance of an analysis by the project manager of the potential risks that could occur when implementing a given action.

Project documents

When drawing up a project, various documents need to be prepared as a basis for allocating the tasks to the various companies and to support the responsible supervisor by ensuring that the contractors responsible for carrying out the work comply with the necessary technical specifications in order to meet the proposed objectives and minimise the negative impacts associated with this type of intervention. Thus, an outline of the work should be drawn up with the following details.

1) Location and recent history

2) Morphology

3) Hydrology and climate

4) Flora and fauna

5) Intentions and objectives

6) Proposal (preparatory work, drainage and terrain modelling, vegetation)

The works plan should specify all of the following details:

a) Preparatory work (depot installation, preparation of access and storage areas, measures to minimize negative impacts, delineation of intervention area, demolition and removal)

b) General modelling of the terrain (excavations, disposal areas, borrow)

c) Planting (general preparation of terrain, planting of trees, bushes, aquatic vegetation and herbaceous plants)

d) Dismantling work depot

e) Responsibilities and guarantees

The following design documents should accompany the list of the tasks to be undertaken:

1) Topographical study

2) Hydrological study

3) Altitude measurements

4) General plan

5) Planting plan

6) Detail drawings

Scheduling

Proper sequencing and scheduling of each activity to be implemented as work gets underway is vital for the success of the project. Specifications regarding the most suitable seasons for moving earth, clearing, selective cutting and planting should be met, not only to ensure that each task succeeds but also to minimize negative impacts. In this regard, special attention should be paid to projects that include plantings. Nurseries usually do not carry stocks of the required species and ecotypes from the specific biogeographical region where the project is to be carried out and it is often the case that inappropriate specimens are introduced because they were the only ones available at the moment of planting. This problem could easily be avoided with a well-designed plant propagation schedule (see chapter 4.7 of this book).

The project manager must ensure that the projected schedule is adhered to and must subcontract in accordance with any limitations that may affect project timing. This is important and decisive for the choice and continued employment of the company contracted.

Quotes

Restoration project cost estimates must be based as much as possible upon requested quotes that are as detailed as possible, thereby minimizing the chance of failing to meet implementation objectives due to lack of funds.

Generally speaking, the following costs should be considered:

1) Generally for each phase: contracting specialized technical teams, equipment purchase or hire, travel expenses, board and lodging

2) Characterization: sub-contracting specialized technical teams for specific tasks (fish sampling, bird census, statistical analyses)

3) Evaluation and diagnosis: setting up a public participation team, room hire, advertisements, contractual costs of public participation team leader, design and publication costs of pamphlets and websites, maintenance costs, costs for seminar preparation and organization

4) Definition of objectives: technical team and public participation group meeting costs, costs for sub contracting a sociologist, incentives to participate in meetings

5) Administrative and legal measures: sub contracting a solicitor to advise on the necessary administrative procedures (licences) and to establish contact with landowners about implementing the actions planned

6) Project design: meeting room hiring costs, environmental impact studies.

7) Implementation: contracting a project manager and a works supervisor, installation and construction works, final cleaning and clearing of site, planting and irrigation works, purchase or propagation of plants.

8) Monitoring: field sampling costs, data base construction, data management and treatment, report writing.

It is essential to contract companies to carry out particular project tasks since most organisations that implement this type of initiative do not possess heavy machinery or personnel who are skilled in such a specialized area of intervention. Only a few companies specialize in this type of work, so it is advisable to draw up highly-detailed technical specifications for the planned tasks. Contracts with companies demand constant supervision in order to ensure that work is concluded according to specifications. To ensure the fulfilment of project specifications and minimize the risks of incorrect execution of tasks by the contractor, the project manager must hold prior field meetings: these are necessary for all-round correct comprehension of goals. The contract should be drawn up by a lawyer, safeguarding the following aspects:

- Final terms of the contract
- Technical definition of the tasks
- Schedule of tasks
- Responsibility for necessary licences and studies
- Definition of relation between works contractor and subcontractors
- Registration and reporting of activities to be performed

Funding

Given the expected benefits of implementing riparian corridor restoration in terms of improved ecological and landscape quality, several countries have established mechanisms to compensate farmers for loss of income due to the restrictions imposed on agricultural activities in the areas immediately adjacent to the river. In the past, in Portugal, this form of compensation was provided for in the 2002-2006 RURIS Programme (Rural Development Plan) agro-environmental package under the "Riparian belt" measure (measure 4.2).

The objectives of this measure included "environmental management of areas that are marginal for the farmer, but fundamental as semi natural systems" and "the maintenance of riparian vegetation as an element that contributes to water quality, conservation of the riverbank and biodiversity" (DGDR, 2000).

Application of this measure required a management plan for the area of influence of the watercourse and individual management plans on the part of the farmers, with undertakings to implement the management of these areas under conditions that favour the development and maintenance of riverine vegetation and its environmental functions.

The "Riparian Belt" measure therefore represents an important example of funding for the integrated protection and conservation of rivers and riparian corridors, and its successful implementation will be of great environmental interest. It is important to take the necessary steps to monitor the success of this initiative.

Besides this example, the Water Framework Directive (WFD) requires the ecological quality of rivers with low ecological status to be improved by 2015. The new community funding framework (2007-2013) offers EU member states various opportunities to submit projects involving the restoration of watercourses. There are reference frameworks not only for each Member State but also for European-level interregional cooperation projects to carry out pilot studies of riparian gallery restoration, exchange experiences and promote a wider vision of restoration project implementation.

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Gonçalo Leal
António Campeã da Mota
Carlos Freitas
Kátia Morgado
Ilídio Moreira

SELECTION OF TECHNIQUES

Site preparation

Site preparation is the first essential on-site step in restoration project implementation. The various intervention measures should be set out on site using stakes and coloured tape in order to make it easier for the manager and the works supervisor to follow the progress of the work. It is also necessary to define access zones and areas for storing materials, which should be close to access roads, at some distance from sensitive habitats, and should avoid the need to cross the river, as well as potential flood zones or areas with steep slopes.

Occupational, environmental and transport safety requirements such as fencing, signs and waste management need to be considered, in accordance with the existing legislation in each Member State, when installing and subsequently demolishing temporary constructions like depots and workshops. Dismantling these kinds of structure should include, amongst other tasks, the total removal of materials and equipment and general cleaning and recovery (soil loosening and landscaping) of the affected area.

Selective cleaning techniques

Aquatic and riverine vegetation control

Some aquatic or riverine plant species can be invasive, growing uncontrollably and thereby negatively affecting natural biotic communities, resulting in physical and chemical alterations of the immediate habitats. The origin of these phenomena is basically related to the deliberate or accidental introduction of exotic species. In the absence of natural control mechanisms such as the presence of competitors or extremely favourable ecological conditions (*e.g.* nitrophilous species in eutrophized water bodies), these exotic species spread uncontrollably, replacing native ones, and result in the replacement or elimination of natural floristic community diversity.

Examples of such situations in river habitats include acacias such as Mimosa (*Acacia dealbata*), the Tree of Heaven (*Ailanthus altissima*) and the Giant Reed (*Arundo donax*).

There are also cases of aquatic vegetation becoming invasive, causing a swathe of problems that need to be controlled (see box 4.4.1).

Box 4.4.1 Problems caused by abnormal and excessive aquatic plant growth

- Diminished water quality – some algae release toxins
- Anoxia – the destruction and decomposition of large amounts of aquatic vegetation consumes oxygen, causing fish and macroinvertebrate mortality
- The dominance of exotic species (*e.g.* Water Hyacinth, Eichhornia crassipes, and Parrot Feather Watermilfoil, Myriophyllum aquaticum) leads to the elimination of native plants, resulting in an impoverished ecosystem
- Diminished water flow
- Increased sedimentation caused by reduced flow. The sediments result in a greater expanse of vegetation

In headwater areas it is not normally necessary to control aquatic vegetation growth, as they have better water quality (lower nutrient contents), higher flow velocities and a predominance of coarse substrates in the riverbed. The situation on downstream reaches is precisely the opposite and can be worsened by greater exposure to the sun and higher water temperatures, which encourage plant growth.

During aquatic plant cutting and removal, there is a natural tendency to remove as much vegetation as possible. In the case of invasion by a single species (*e.g.* Water Hyacinth or Parrot Feather Watermilfoil), this is, in fact, the best approach. However, when several species are present a radical clearance method impoverishes the ecosystem and facilitates subsequent invasion by a single species (the least-affected species or the species that recovers most rapidly). Clearance operations should adopt the 'little and often' approach.

Aquatic plants can be grouped according to their growth behaviour: submerged, floating or emergent. The control method should obviously be appropriate for the target type(s) of plant(s). The principal control methods can be divided into 4 groups: mechanical, chemical, biological and environmental (box 4.4.2).

Box 4.4.2 Aquatic plant control methods

- Mechanical – cutting, uprooting and dredging
- Chemical – application of herbicides
- Biological – fish, insects, grazing
- Environmental – shading, increased flow rate, nutrient reduction

Mechanical control

Most submerged, floating and emergent plants are effectively controlled by cutting. Depending on water depth, specially prepared boats or a mechanized cutter/harvester can be used, with or without a collecting receptacle or mowing bucket.

Figure 4.4.1 Water Hyacinths manual removal from margins (Photo: I. Moreira).

If a mowing bucket is employed, the plants are cut and collected in a single operation. Under such circumstances work should be carried out in a downstream–upstream direction. Under other circumstances, operations are carried out in an upstream–downstream direction in order to facilitate the collection of cut material. In either case, this should be collected as rapidly as possible in order to prevent (i) the spread and recolonisation of the species to be controlled (ii) blockages in aqueducts bridges and culverts and (iii) rotting of plant material, causing anoxia.

In order to avoid these problems and make it easier to collect the cut material, the normal practice is to put nets in the infested reaches. Removal is then carried out using a mechanical digger equipped with a perforated shovel (see figure 4.4.2).

Figure 4.4.2 Perforated shovel that can be used for Water Hyacinth removal (Photo: I. Moreira).

Less frequently, submerged or floating vegetation can be removed by dredging the riverbed, followed by removal with a perforated shovel. In other cases, large scale clearance can be carried out at the same time by digging with a cleaning shovel.

The following practices are recommended with the aim of minimizing impacts caused by mechanical removal of aquatic vegetation:

1) Work on alternate river reaches or riverbanks, guaranteeing (i) that the water course never becomes completely denuded of vegetation and (ii) rapid recolonisation by plants and animals.

2) Conserve small plots of previously identified vegetation, selected for their floristic or structural value.

Chemical control

In many situations mechanical control is not an efficient method and the application of herbicides can constitute an alternative method for eliminating aquatic plant infestations. However, most herbicides are not selective and can also eliminate desirable species. The use of herbicides close to streams and rivers is highly restricted and it is important to consult European and national legislation in order to minimise the negative effects of this type of intervention.

In deciding to use herbicides, a sound knowledge of product characteristics and application is necessary, including all the restrictions designed to minimise the negative effects and maximise the advantages gained by its use. It is important to emphasise that resorting to the use of herbicides should be considered only when all alternative methods have been proved unviable.

When choosing herbicides, the toxicity, persistence, degradation by-products, hydrodynamic mixing properties and application frequency, timing and methods need to be taken into consideration.

When applying directly onto water, the herbicide used should be non-persistent, with a short degradation time and/or rapid absorption.

The same active substances are used for terrestrial and aquatic plants, differing only in formula, dosage and modes of application.

Depending upon the situation on site, several types of herbicide application methods exist. Treatment manuals should be thoroughly consulted and in all cases the herbicide packet label instructions for correct application of the EU-approved uses must be followed.

In choosing an herbicide, care should be taken to consult the competent official services, use only the active substances that have been approved for use in riverine areas and comply with any restrictions concerning their use.

Although herbicide application is a rapid process, plant die-back can take up to several weeks. Hydraulic benefits will therefore take some time to become apparent.

The use of herbicides must be carefully thought-out and is not always the best solution. The extent and period of application must be carefully calculated since submerged vegetation can decompose after treatment and cause anoxia.

Each type of herbicide is recommended for a particular range of infestants and situations. If there is a plant species in the same category that one wishes to preserve, mechanical control methods should be used. In each situation, rare species that may be affected by the selected herbicide should be identified and specialist advice should be taken.

It is important for staff responsible for applying herbicides to be trained and experienced and for operations to comply with current regulations.

In all cases, the use of chemical control should first be confirmed as the best effective solution. Advice concerning the choice of herbicides is only an aid to choosing the most suitable product, with the protection of the watercourse as a priority. Doubts concerning products should be addressed to the regional or local Agriculture Department.

While there is a safety margin between the herbicide concentration which is suitable for infestant control and the concentration that may cause harm to fish and other wildlife, situations may arise where a combination of a limited safety margin and the occurrence of complex interactions results in fish mortality. Therefore, a careful approach is recommended, based on a series of localised applications where only a small portion of the infested surface is treated.

The control of truly aquatic species requires specific precautions to ensure that riparian vegetation is not affected when the treatment is applied from the bankside.

It is important to take into account the time of year when herbicides can be applied and it may be necessary to wait for the most suitable development stage of the infestants earmarked for eradication. Such suggestions are normally given on the product package label; however, the following precautions are recommended:

1) Most floating and emergent infestants are treated by direct application to the leaves. Therefore, treatment should only be carried out once the leaf area has reached a significant stage of development. Applications made during mid to late summer minimise the disturbance to the fauna, since most birds and insects have already completed their breeding cycle by then.

2) Algae and other underwater infestants are generally treated during the spring or at the onset of summer. At this time of year, these plants are not yet fully developed and are more susceptible to herbicides. The risk of anoxia is also reduced due to the lower water temperature and the lower levels of total biomass.

There are special cases where mechanical control is used in tandem with chemical methods, such as the control of Giant Reed, where springtime and autumn applications of glyphosate have proved more successful on reeds that had previously been cut during the autumn or at the end of the summer, respectively.

In the USA, where Giant Reed proliferation is a problem, a combined approach has been used successfully in situations where cane infestations are surrounded by indigenous plants. The method consists of two successive cuts of the stems, the first at 30-60cm above the soil during the growing season and the second when new shoots reach 60-90cm above ground level, followed by a direct application of glyphosate onto the cut section. Applying the herbicide at the onset of autumn has been found to be more effective.

Biological control

Methods include:

1) Bovine or ovine grazing of emergent and floating plants. This method depends on the palatability of the plant species, access to the watercourse by cattle and their efficiency in controlling excessive growth. These factors must be weighed against negative factors, particularly trampling of the riverbed and margins.

2) Grazing by ducks, geese and swans can give significant beneficial results. However, it can be difficult to control these animals, which frequently result in reduced plant diversity.

Environmental control

Environmental control techniques comprise manipulating the environmental conditions in such a way that they become less favourable to plant growth. The principal techniques are (i) nutrient reduction; (ii) manipulation of watercourse hydraulics and (iii) increasing the shade.

Table 4.4.1 summarises the characteristics, advantages and disadvantages of each of these techniques.

Table 4.4.1 Advantages and disadvantages of environmental control techniques

Technique	Description	Advantages	Disadvantages
▪ Nutrient reduction	▪ Removal of nutrients (in particular phosphates) from effluent discharges into watercourses	▪ Environmentally more sustainable and desirable. ▪ Reduces invasive plant proliferation and the formation of dense vegetation mats ▪ Savings in the classic control of infestants (long term)	▪ Costly ▪ Reduced short term effects due to the presence of nutrients in the sediments
▪ Modification of river cross section	▪ Deepening of the channel mid section, increasing flow velocity and reducing sediment deposition	▪ Creates a self cleaning system ▪ Increased habitat diversity ▪ Ideal in low flow rate conditions	▪ Does not solve the problem of excessive vegetation growth on lateral platforms
▪ Shading	▪ Planting of bushes and trees on the south margin	▪ Not costly ▪ Savings in the classic control of infestants (long term) ▪ Alternating with open areas results in increased habitat diversity	▪ Little short term effect (during tree growth phase) ▪ Occupies a strip of land on the riverbank ▪ Maintenance access is limited to north bank face

Control of herbaceous vegetation on the riverbank

Control of riverbank vegetation and vegetation on the inner bank of dykes presents the following advantages:

1) Encourages the establishment of vegetation cover with well-developed roots, minimising the erosive effects of runoff

2) Minimizes riverbed roughness, maximising the drop in water level following flood episodes (reducing the probability of flooding and the possibility of dykes bursting).

From an environmental point of view it is preferable to have a covering of vegetation in order to improve the feeding and shelter conditions of a number of mammal, bird and insect species. However, there may be situations where selective control of herbaceous plants is necessary and some recommendations are therefore given.

The three methods for controlling the growth of river bank vegetation are grazing, cutting and herbicides. Herbicides should only be used in exceptional circumstances, such as in the control of reeds or exotic invasive species, and applicationsm should be limited to small areas. Herbicides should not be used as a routine control method.

The remaining two methods can be used to maintain suitable vegetation cover. There are spots where it is not practical to cut herbaceous vegetation and others where there is no livestock. The greatest disadvantage of cutting is the abrupt change in habitat, whilst grazing could be an environmentally hazardous method due to the effects of trampling and the presence of excreta.

In terms of vegetation structure, the results obtained from grazing obviously depend on livestock management, especially the species, the number of heads and the time of year. Specific details of these questions exceed the scope of this work, but appropriate livestock management should avoid overgrazing. The principal objective of grazing is to allow visual inspection of the riverbanks, reduce the predominance of some herbaceous species and encourage floral and faunal richness. For reproduction and trampling reasons, bankside grazing should not take place before July.

Removal of slope and riverbank vegetation results in a sudden, radical change to the plant communities and to the habitat structure of invertebrates, birds and mammals. The timing, frequency and extent of cutting must be carefully chosen to minimize its impact. The recommended timing is from mid summer (after July). The advantages of this procedure are:

1) Conservation of shelter necessary for animal reproduction

2) Availability of seeds and fruits as a food source for birds and small mammals

3) No stimulation of plant growth, which would occur if cuts were made during the spring.

Cutting in alternate areas (in rotation) results in substantial improvements in plant diversity and habitat structure. Although the size and type of the zones which are not cut vary with each specific situation, the following guidelines can be followed:

1) Preserve at least 10% of the area, which will be cut over a longer period of rotation (3-5 years)

2) Cut in rotation, ensuring that no other areas remain uncut for longer than 3 years in order to prevent the development of dominant species, brambles or scrub which would inhibit the growth of other species.

Cutting areas alternately satisfies hydraulic function requirements in watercourses. It should be remembered that limited areas in more developed stands of vegetation do not have any significant effect on riverbeds over 2 metres wide. The cut materials must be removed from the riverbed and deposited in dry areas, providing food and shelter for insects, reptiles and small mammals. Burning this material is not recommended for environmental reasons (see box 4.4.3).

Box 4.4.3 Effect of burning

Burning is not an ideal way of controlling vegetation for both hydraulic and environmental reasons:

- Risk of fire spreading uncontrollably and possibly affecting the riparian gallery
- Destruction of bankside and bank face vegetation cover, leading to the risk of erosion
- Habitat damage or destruction and the indiscriminate loss of species and plant communities
- Soil damage
- Release of nutrients into the soil and watercourse leading to the dominance of more competitive species and the increased growth of aquatic species

Control of shrubs and trees

Margins

In most cases there is no hydraulic justification for removing shrubs and trees from the margins, since normal flow conditions take place in the riverbed. In flood situations, vegetation on the margins slows the flow and reduces the impact of the flood event. The trees and shrubs that make up the riparian gallery should be the focus of special maintenance attention, since they are the principal structural elements in the natural and landscape value of watercourses and cannot easily be substituted.

When clearance of riparian vegetation on one of the river margins is unavoidable, it is the north margin that should be "sacrificed". The south margin is more important since it provides shade and therefore contributes to the control of water temperature and luminosity. However, trees on the north margin, preferably the largest and most valuable, should be left at regular intervals.

The necessary space for a heavy machine to manoeuvre around the trees varies with the height and profile of the riverbank, the type of machine, the size of the tree and the operator's skills. Generally speaking, it is possible to work with a 10 metre interval between trees, although the spacing may affect the performance of the machine.

Cutting hanging boughs and branches which accumulate waterborne detritus or obstruct the movement of machinery is a routine measure but should not be carried out by non-specialised personnel. Only branches that constitute a flood hazard should be cut.

If machines must work next to existing trees, vulnerable or inconvenient branches should be cut and removed before the machinery goes into operation in order to avoid preventable destruction and possibly extensive damage.

Standing dead trees should have the heaviest branches removed, although the trees themselves should remain in place since they constitute valuable habitats for organisms that need dead wood (fungi, invertebrates, bats and birds).

Tree cutting has one of two primary objectives (i) clearing a group of trees with the aim of selecting a single vertical trunk with the best shape; (ii) total clearance of an area in rotation with other areas along the same watercourse. The latter can be used to produce a series of trees with balanced growth rates based on the life cycle of each species (see figure 4.4.3).

Box 4.4.4 Recommendations for the control of shrubs and trees along the margins

- Cut the riparian gallery vegetation only under exceptional and justified circumstances
- Preferably preserve the vegetation on the south bank, with the aim of maintaining shade
- Leave trees at 10 metre intervals on the cut bank
- Keep dead trees if they are standing

Riverbed and Bankfaces

Management of shrubs and trees on banks within the watercourse (or the inner face of dykes) is necessary for hydraulic reasons. The presence of shrubs within the watercourse increases resistance, increasing the

Figure 4.4.3 Tree cutting operations (Photo: I. Moreira).

water level during flood or spate events. In extreme cases a tree or part of a tree can impede the flow or obstruct bridges and other structures.

Environmental factors may result in maintenance operations on trees or shrubs. Where a uniform population of a species occurs, for example, selective clearing may be of benefit in order to encourage greater structural diversity. Regular pruning of willows can alsp stop them falling and increasing the risk of obstruction.

Dense copses of trees in the watercourse increase the risk of flooding and complicate cleaning operations. Normally, single trees do not present any great flood risk, since they rarely accumulate flood detritus.

Sometimes, the location of trees in certain areas of the riverbed (on the inside of meanders for example) has no impact on flow capacity but pruning of the lower branches may be beneficial since they can impede flow during spate episodes.

Shrubs within the riverbed may require several types of maintenance work, including the simplest approacha: preservation. It is important to evaluate the effect of shrub communities on flood flows in the watercourse. In some situations, where there has been earth slippage or widening of the riverbed, woody vegetation should be kept on at least one side of the watercourse.

In order to maintain a natural system, composed of shrubs and trees, the 'little and often' approach is best. Removing branches that are or could form an obstruction is environmentally acceptable. However, the temptation to remove more than is necessary must be resisted.

During tree clearing, it is best to mark the trees or branches in such a way as to indicate the action to be performed, *i.e.* felling, selective branch removal or pruning. This approach is indispensible when non-specialised personnel are carrying out this task. Uprooting trees is not recommended since it causes structural damage to the bankface.

Whenever possible, pruning and cutting back should be carried out during the winter period, up until March, avoiding the birds' nesting period and periods of greater invertebrate activity. This is also the most suitable period for the tree, since growth activity is at a minimum and it makes a better recovery from pruning cuts.

Maintenance work carried out in the riverbed with standard machinery, using a boat, allows recovery of the intended flow capacity without affecting the shading of the watercourse. Only the lowest branches of the trees on the margins are cut (at water level). Removal of material is carried out through openings in the "tunnel" of vegetation, spaced approximately 100 metres apart.

Woody material that has been removed must be deposited in carefully-chosen areas. Burning should be avoided (see box 4.4.3). The recommended approach is to use a wood chipper. The resulting woodchips can be used as mulch or as a covering for footpaths. Another solution is to use branches as stakes to protect the margins or to make fascines of living/dead woody material.

In many cases, with the consent or cooperation of the farmer that owns the land, the woody material can simply be left in piles. As the material decomposes, it provides refuge for many animal species, from invertebrates to small mammals, reptiles and birds.

Some recommendations should be followed during cleaning operations in order to minimise negative effects:

a) Always bear in mind that the priority objective is to treat the cause and not just address the symptoms. This requires a fundamental understanding of the physical processes involved before defining the intervention measures.

Box 4.4.5 Control of bank face shrubs and trees recommendations

- Trees and branches that disturb flow should be marked for removal.
- Cut 'little and often'.
- Pruning should be carried out during the winter.
- Never physically uproot trees.
- Mechanical work should be carried out in the riverbed itself in order to reduce damage to vegetation along the margins.
- Encourage reuse of woody material.

b) Any intervention must be preceded by a detailed survey of the state of the watercourse, carried out by a qualified technical expert, with the aim of defining areas and types of intervention, taking into account both physico-hydraulic and ecological aspects.

c) The removal and disposal of left-over materials (especially substrates etc) should be carefully pondered. Burying material in lower-lying adjacent areas is not always the best solution, since these are themselves of ecological interest, providing refuge, food and reproduction areas for plants and animal species. Should doubts arise, an aquatic ecologist should be consulted. The use of deposits excavated from the margins to reinforce marginal dykes should be analyzed beforehand in order to verify whether such a measure would prevent drainage from the catchment into the watercourse and affect the ecological value of the margins. Special attencion should be paid to the removal of substrates that contain remains of invasive plants like Arundo donax. This material must be disposed of in authorized sites.

d) If there are agricultural or natural areas of interest on the valley floor that merit preservation, it is important to study the most convenient access route to the watercourse for heavy machinery. Existing access roads should be given priority.

Earth Movement

These are some basic recommendations for earth movement, aimed at reducing the negative effects of these operations: In small/medium sized watercourses without permanent flow, with clearing operations taking place during the summer, it is preferable to operate machinery from the riverbed. This substantially reduces disturbance of the riparian habitats. Disposal of the excavated material requires careful planning. In small watercourses, when it is not possible to work from the streambed, the riverbank selected for works along the reach should be the one of least natural interest, taking into account vegetation cover and areas for animal reproduction. Where there is no difference between the banks, the north (or east) bank should be used for works and the south riverbank (west) preserved, since it provides shade for the watercourse. The choice of machinery, in terms of power and dimensions, is influenced by the width of the watercourse and the type of work to be carried out. More details are given below on aspects that should be taken into consideration in the following types of intervention along watercourses:

- **Transverse reprofiling**
- **Longitudinal reprofiling**
- **Reprofiling of curves**
- **Substrate removal**

Transverse reprofiling

Transverse reprofiling can comprise actions to deepen and widen the riverbed along relatively long reaches with the aim of maintaining the bankfull flow capacity of the channel. When performing this kind of action, attention should be paid to preventing negative effects on the connectivity between the channel and the floodplain. For example, if the channel is simply deepened there is no guarantee that existing habitats will be maintained, since the water level will naturally fall to lower levels, which will tend to be well below the riverbank surface. However, in semi-urban areas or areas with some density of human occupation, space restrictions may exclude other options.

A good alternative to deepening the riverbed is to widen it, especially in areas where the natural value of the margins is compatible with the temporary elimination of vegetation along one bankside.

Sometimes it is necessary to carry out riverbed substrate removal at the same time as cutting back one of the bank faces. This should only be done in exceptional circumstances, since this kind of intervention is not to be confused with fluvial regulation measures. In these cases, replanting operations must be thoroughly planned to ensure rapid regeneration and protect the bank face against erosion.

When widening and deepening operations are unavoidable, combined methods should be used to create transverse profiles that comprise both base flow and bankfull conditions, thereby guaranteeing an effective compromise between (i) the natural values to be preserved within the levels for base flow conditions and (ii) the need to augment the transverse section of the river because of the occurrence of flood events.

The following recommendations are given for transverse reprofiling actions (see figure 4.4.4):

1) Create a non-uniform, asymmetrical riverbed based on consistent geomorphological principles; the proposed profile can be based on exixting reaches in the same watercourse.

2) Widen alternate single margins along each section, resulting in greater sinuosity in very straight sections.

3) Vary the slope of the bank face from steep to very gentle, thereby promoting habitat diversity.

4) Maintain at least some midchannel islands, so long as the dimensions of the section at this point are suitable for avoiding bottlenecks.

5) Create suitable section dimensions and appropriate roughness for tree growth on the bank face, thereby reducing the need for future interventions.

6) Create suitable riverbed dimensions, taking into account a variety of flow conditions – average and summer base flow – not just those of predictable flood events.

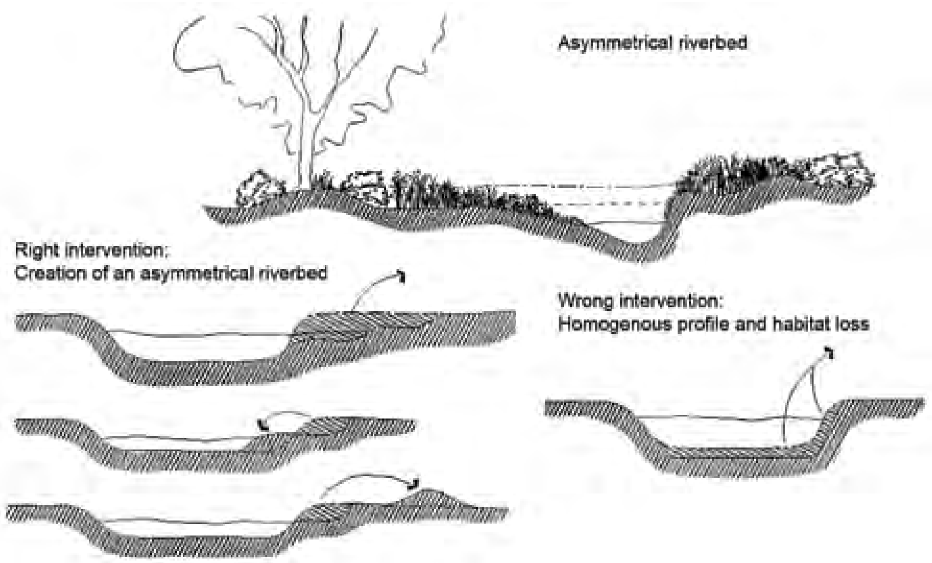

Figure 4.4.4 Transverse reprofiling (chapter authors).

Longitudinal reprofiling

Longitudinal reprofiling of a river reach should take the equilibrium between channel morphology and hydraulic characteristics into account. The watercourse must have a longitudinal slope that corresponds to the different hydraulic parameters of the site, like flow energy and sediment transport. The effects of any variation in longitudinal slope should be considered, especially as regards bed stability (see figure 4.4.5).

The presence and pattern of pools/deeper areas and riffles along the riverbed are the result of the interaction between flow energy and sediment type. As these are transitory features that change following flood events, the removal of these features is pointless in hydraulic terms. Also, in ecological terms, these features result in the presence of gravel riverbeds (essential for fish oviposition) and promote habitat diversity, justifying their preservation.

During small-scale substrate removal, it is possible and desirable to maintain pools and riffles. Where substrate removal is more pronounced, such features are inevitably destroyed. In such cases, recreation of these features is recommended (see table 4.4.2). Stone or staked groynes can be useful for this purpose.

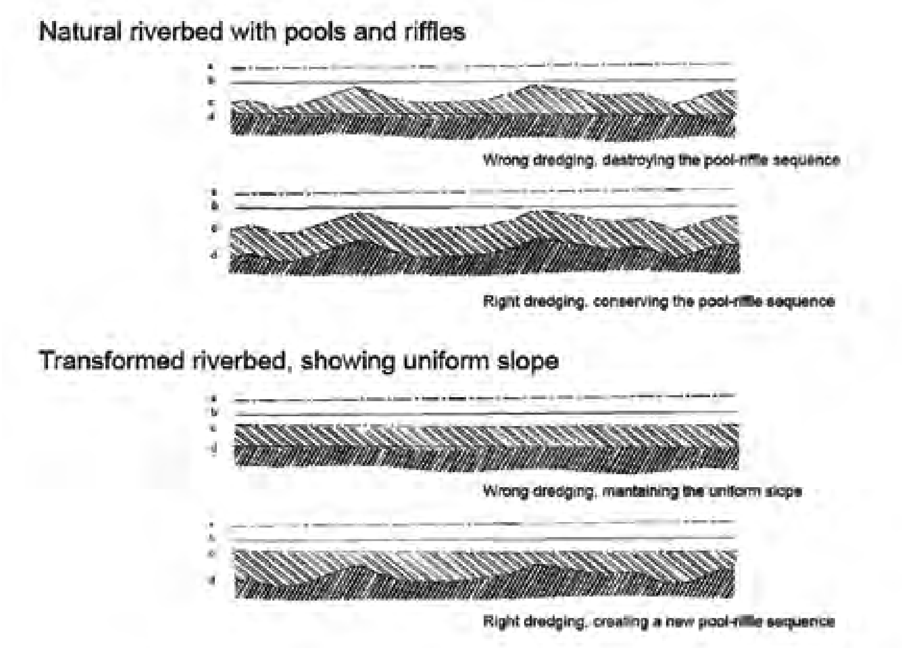

Figure 4.4.5 Longitudinal reprofilling.

Table 4.4.2 Characteristics of pools and riffles.

Characteristic	Pool	Riffle
▪ LOCATION	▪ On the outside of meanders	▪ Diagonal to the axis of the watercourse, at the downstream end of the meander
▪ MATERIAL (Stones, coarse gravel, etc.)		▪ Use pre existing materials
▪ SPACING		▪ Similar to pre existing riffles ▪ 6 times the water width
▪ HEIGHT/DEPTH	▪ Minimum depth 30cm	▪ 30-50 cm above the riverbed
▪ LENGTH	▪ 1-3 times the width of the watecourse	

Reprofiling of meanders

Meanders have scenery value and contribute to habitat diversity on both their sides. From an environmental and conservation point of view, this lotic feature should be preserved. Also, hydraulically speaking it is not advisable to eliminate meanders since this alters the hydrogeomorphological equilibrium of the watercourse, increasing the slope and therefore the erosion and flow rate, especially during higher flow episodes.

In certain cases meanders and bends can become unstable, making it necessary to intervene.
By following the correct criteria, however, these interventions can retain or even improve natural features. They are divided into three types:

Removal of substrate from the inside of the meander

When substrate accumulation on the inside of the meander reaches considerably greater heights than base flow levels, it is advisable to reduce the height, since an increase in the flood flow capacity will favour the establishment of more humid habitats.

Substrate removal from the inside of the meander mainly comprises the removal of deposited sediments, resulting in the water level (under normal conditions) being just below ground level (see figure 4.4.6).

Advantages:
- Increased flood flow capacity
- Favours the establishment of humid habitats on the inside of the meander and the growth of plants typically found in such systems.

Disadvantages:
- None

Construction of a by-pass channel

When flood defence needs include an increase in watercourse drainage, the creation of a meander by pass channel that comes into operation only during flood flow events allows flow regimes suitable for river habitats to be maintained. The by pass channel should slope in a downstream direction and care should be taken to protect the by pass opening from erosion during flooding (using coarse substrate, for example) in order to prevent it becoming a channel with permanent flow (see figure 4.4.7).

Advantages:
- Increased drainage capacity during flood events.
- Favours the creation of new habitats.

Disadvantages
- Decreases area available for agriculture.

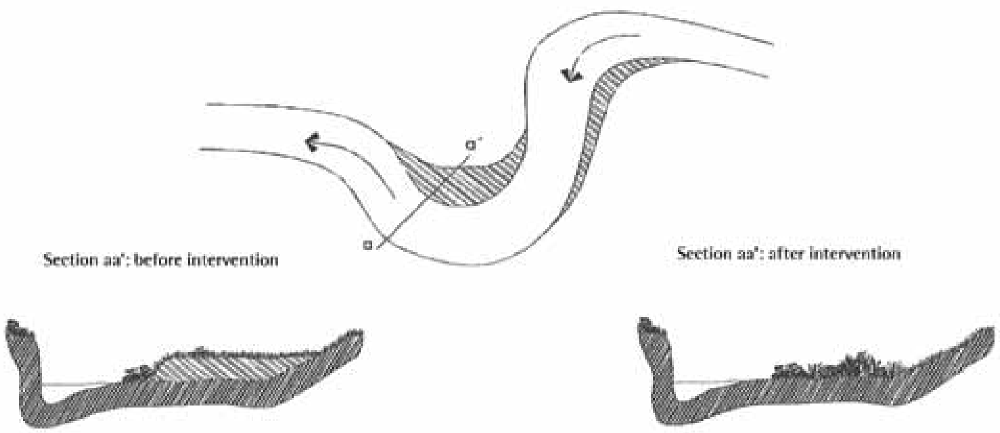

Figure 4.4.6 Transverse reprofiling (chapter authors).

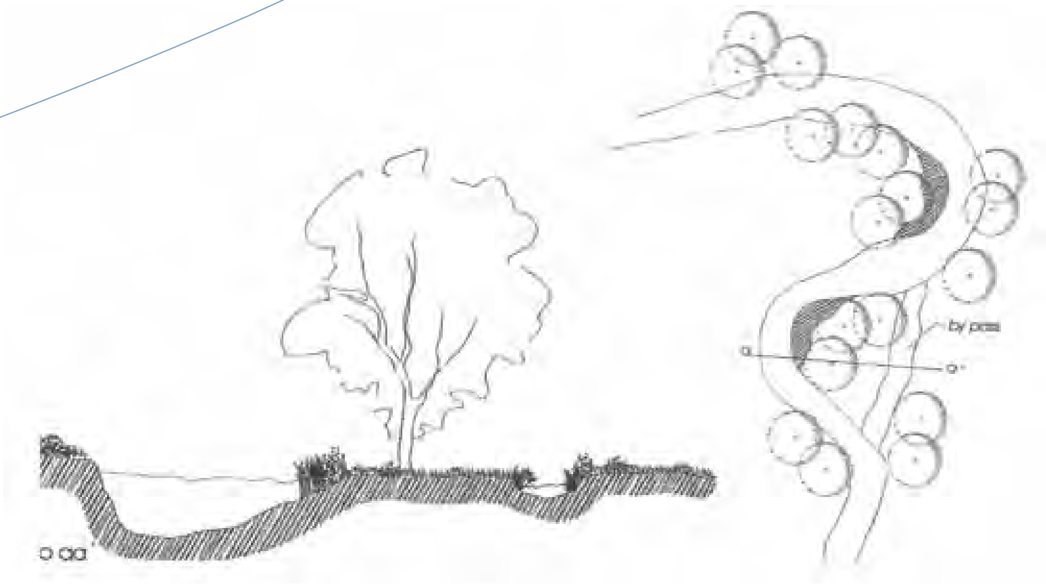

Figure 4.4.7 Transverse reprofiling (chapter authors).

Covering the outside edge of the meander

Covering the outside edge of the meander can be considered in cases where the substrate is not resistant or violent flood flow events destabilize the outer bank face. Rip-rap, gabions or wooden stakes can be used. It increases bank face resistance following fragilisation caused by flood events.

Advantages:

- Reinforces the bank face, reducing erosion of the margins.
- Allows sediment deposition, increasing the umber of ecological niches.
- The use of local materials is more economical.

Disadvantages

- Excessive use of these techniques may lead to artificialisation of the riverbank; this technique should be used together with plant cover.
- This process can become prohibitively expensive when local materials cannot be used.

Rip-rap

The bank face is covered with an assortment of appropriately sized stones. Planting improves rip-rap stability.

Gabions

Gabions are stackable cages made from hexagonal galvanised steel mesh and filled with stones (10-15cm). Typical gabion dimensions are 2.0 x 1.0 x 0.5 m. A variant of this structure, Reno mattresses, are rectangular baskets made of heavily galvanized, double-twisted woven steel wire mesh measuring 2.0 x 5.0 m x 15 to 30 cm thick.

Gabions provide mechanical resistance and flexibility. They are easy to place and long-lasting. The wire mesh eventually ruptures, but only after the stones have become consolidated with the surrounding soil.

Stakes

The vertical bank face is protected by a continuous line of vertical stakes driven into the bed. The stake diameter should be between 5 and 10cm.

Short stakes should be used to prevent slippage of a steep bank face; the top of the stakes should lie level with the bank face surface. The recommended density is 2 stakes per square metre of bank face.

The use of live stakes, using native species, results in replanting of the riverbank and recolonisation of ecological niches.

Substrate removal/dredging

It is preferable not to remove substrate totally from the riverbed, since the elimination of fine organic substrates prevents recolonisation. However, in certain cases, such as the prolonged absence of maintenance work and pronounced substrate accumulation, spot removal of substrates may be necessary. Partial substrate removal can include the removal of shallows and mid channel islands/bars that obstruct the channel. Such types of intervention should take into account the high ecological value of midchannel islands and bars, which provide shelter for plants and animals as a result of their limited accessibility. Such features do not always obstruct flow, since the current is generally greater around them. However, in other cases, an unsuitably-situated mid channel island/bar can result in bank collapse immediately downstream. Partial substrate removal normally involves dredging a deeper central channel. Preferably, in order to create hydraulic and habitat diversity (riffles, backwaters), the width of the deepened channel should not be uniform. This technique is particularly useful where shallow waters have resulted in excessive plant growth, since the increase in depth increases flow velocity and helps to control the plants. In the case of a permanent or semi permanent watercourse that is slow-flowing and wide enough for a boat, it is possible to carry out dredging using pumps. It is sometimes necessary to excavate a pit or depression for the dredged mud, since it is not always environmentally sound to spread it along the margins.

Box 4.4.6 Prior to midchannel island removal

- Comprehend the mechanism that led to the formationof this feature.
- Confirm that it is in fact an obstruction to flow.
- Confirm structure stability
- Evaluate alternatives
- Partial removal
- Widening the section of the watercourse at this point
- Localised deepening of the branches of the watercourse on either side of the feature
- Lowering the ground level of the midchannel island to give increased flow capacity during flood episodes.

Although the techniques used to clear and unblock watercourses cannot be uniform, by their very nature and due to the different types of situation, there are common rules that should be followed. Clearance work should always be carried out in a downstream to upstream direction, wherever possible maintaining bank stability and avoiding damage to existing trees and shrubs. In narrow streams and rivers (up to 5 or 6 metres), work should be carried out along one of the riverbanks, maintaining the other intact, unless bank collapse or erosion has occurred, in which case that bank must be repaired. In wider rivers, work should be carried out in the river channel of the reach in question.

Box 4.4.7 Substrate removal – general rules

1) Consult an environmental specialist on the value of the local ecosystem.
2) Minimize the volume to be excavated except in the case of highly degraded systems (unprotected riverbanks, dominated by brambles and reeds, etc)
3) Preserve bankside vegetation except in very degraded circumstances
4) Maintain variation in the longitudinal profile and cross section along the reach subject to intervention (meanders, pools, riffles etc)
5) Work within the river channel or, alternatively, along one of the river banks.
6) Carefully choose the areas for depositing removed material, avoiding crossing the river or leaving material in sensitive areas.
7) Improve environmental conditions whenever possible (areas of still water, replanting riverbanks or bank face).
8) If it is necessary to cut down trees along the margins for machinery access, adopt regeneration techniques (pruning, live cuttings, etc)
9) Work in a downstream-upstream direction – a practice which is favourable for plant and animal recolonisation.
10) Predict the effects of intervention measures on the reaches situated immediately upstream and downstream.
11) Work should be carried out during the appropriate time of year.
12) Suitable machinery should be used with the aim of minimizing damage to bankside plant communities.
13) Choose heavy machinery access routes that avoid areas of greater ecological value.

Work using the following equipment (i) chainsaws (ii) hydraulic mechanical diggers (90 kW and a reach of approximately 8 metres) and (iii) tractors equipped with bulldozer and ripper attachments (100 kW) should be carried out in immediate succession in the following sequence:

1) Chainsaws, advancing in front of the heavy machinery, cut branches hanging in the river channel and trees at the base of the bank face that are at risk of falling or that that have already fallen into the reach in question.

2) Hydraulic diggers then remove the plant debris to the bankside using an excavation shovel, burying it whenever possible in adjacent land or piling it up for subsequent burial or destruction. These machines also remove substrate and deposit it next to the riverbank or load it into lorries for transport to appropriate disposal sites.

3) Tractors equipped with bulldozers and rippers spread substrate on the land adjoining the margins, filling pits if available. Substrate removal work is carried out in the section of the watercourse and substrates are transported to areas close to the riverbank, from which they are removed by excavators equipped with shovels

In the case of intense substrate removal, the excavators should work in tandem with the buldozers, increasing the efficacy of the operation. The expected efficacy of clearance work using the machinery mentioned above varies with the workconditions, such as the cross-sectional width of the river and the degree of obstruction; three situations can be considered:

Box 4.4.8 Considerations for depositing dredged material

- Can materials containing plants be used for recolonisation of the watercourse?
- Does the material contain remains of non-native invasive plants that could be an environmental problem? (in this case this material must be disposed of in suitable sites)
- Does the material have suitable characteristics and is there any possibility of its being used for borrow? (*e.g.* stones for dyke construction, sand or gravel for access tracks, earth with good geotechnical characteristics for dyke construction, compost for covering berms)
- Can the material be incorporated into agricultural land instead of spreading it along the margins?
- Is there any advantage in transporting the material offsite?
- Did the preplanning identify certain areas for depositing material and other areas that should be preserved?
- Do the areas for spreading material need a covering of compost or can they be seeded directly with a low maintenance herbaceous seed mix?

1) Moderate: some substrate accumulation, no signs of bankside erosion or collapse, some trees with branches hanging in the river channel.

2) Medium: reaches with substrate accumulation, some evidence of bank erosion or collapse, trees with branches hanging in the river channel.

3) Severe: substantial substrate accumulation, vegetation within the river channel, bank collapse and erosion evident.

Table 4.4.3 Clearance operations in watercourses.

Transverse section of watercourse (width in metres)	Amount of obstruction		
	Moderate	Moderate	Severe
3–6	25-30	35-40	35-40
6–15	60–75	90-100	105-110
15–30	120-150	200-300	350-550

BIOPHYSICAL ENGINEERING TECHNIQUES USED IN RIVER RESTORATION

Paola Sangalli

Bioengineering in a fluvial environment

Human activities give rise to a number of impacts on the natural environment, such as erosion or instability, soil degradation, water, ground and air pollution, changes in the vegetation, deterioration in the quality or character of the landscape and the destruction of habitats, among others. To preserve natural resources, remedial or restorative measures designed to avoid negative impacts or minimise their effects on the environment need to be adopted.

Any restoration programme must make it possible to regenerate the biological potential of the land so that its reuse for other purposes or its integration into the landscape of which it is a part will be viable. In general, every restoration project pursues the following aims:

a) **Technical aim**: To protect the soil from erosion, stabilize it and regenerate its productive capacity

b) **Landscaping aim**: To integrate the site into its landscape surroundings and setting

c) **Ecological aim**: To regenerate the habitats.

Establishing permanent plant cover is the best long-term solution for achieving these objectives as it plays an essential part in erosion control, soil stabilization, soil regeneration, visual impact minimization and integration into the landscape. A number of methods for establishing permanent vegetation cover are collectively known as Bioengineering or Soil Bioengineering.

Bioengineering comprises a series of techniques that use live vegetation as an engineering material, alone or in combination with inert structures, for environmental remediation. Soil Bioengineering and Biotechnical Engineering are employed in landscape regeneration and restoration, especially in slope and bank consolidation and to control erosion. Another term that is used is Landscape Engineering.

The German term for Bioengineering is Ingenieurbiologie. The Austrian professor H.M. Schiechtl, who is considered the father of this discipline, defines Bioengineering as the construction discipline that pursues technical, ecological, economic and design goals primarily by using living materials such as seeds, plants, parts of plants and plant communities as construction solutions, alone or combined with inert materials such as stone, earth, wood, iron or steel. These goals are achieved by taking advantage of the many uses of plants and employing construction methods with low environmental impact.

The origins of Soil Bioengineering lie in a combination of forestry techniques and traditional engineering methods, developed principally in Central Europe. This discipline does not replace classic engineering but provides a necessary complement to assist conventional engineering works.

In the field of hydraulic engineering, attitudes towards watercourses have changed in recent years. Instead of a threat from which people need to be protected, rivers are now seen as assets to be preserved and valued. Consequently, the project design needs to adopt a systemic approach to works in watercourses, based on the realization that a river or stream is not a canal where a liquid flows as quickly as possible but a complex ecosystem where every part, living or inert, is related to others and the disappearance of a link can imperil the operation of the entire system.

Soil bioengineering work to restore watercourses and their banks does not only mean controlling erosion through the use of live plants, it can also include actions to increase the morphological variety of the course or the shape of its section and provide specialised niches for fish or other aquatic flora and fauna.

This book highlights the value of using native riparian vegetation in river restoration, and what could be better than to include some examples that show some of their capabilities and possibilities? The methods described in the following pages provide an illustration of this potential. Although many more techniques are available nowadays, these are some of the main ones which are currently in use.

Live Fascines

Description: Horizontal revetement along the river edge consisting of fascines or faggots, stabilizing the toe of the embankment when they sprout.

Use: Method employed to stabilise the toe and repopulate the banks of rivers and lakes, using live fascines made from species that can be propagated vegetatively.

Construction: Branches of woody easy-to-root species with a minimum diameter of 3 cm are cut and assembled into cylindrical bundles measuring 3 to 4 m in length and 30 to 50 cm in diameter. The species most frequently used include *Salix purpúrea*, *Salix elaeagnos* and *Tamarix* spp. A shallow trench is dug and the fascine is placed so that 1/2 or 1/3 of it will be above the mean water level.

Figure 4.5.1.1 Side view of a live fascine (Paola Sangalli).

Figure 4.5.1.2 Front view of a live fascine (Paola Sangalli).

Materials:

- Branches of the above species, minimum stem diameter 3 cm, minimum length 2 m
- Galvanized wire, diameter 2-3 mm, at 50 cm intervals
- Stones for base
- Stakes, wood or corrugated steel, diameter 8-14 mm and minimum length 60 cm

Limitations: Fascines along the toe of the bank narrow the channel, so water flow space requirements need to be taken into account.

Figure 4.5.1.3 Building a fascine from willow twigs (Photo: J. P. Fernandes).

Figure 4.5.1.4 A fascine serving as a fine material retention structure in a log cribwall (Photo: J. Bosch).

Figure 4.5.1.5 Length of a fascine (Photo: J. Bosch).

Live Staking

Description: Inserting live stakes or cuttings of species that can be propagated vegetatively, such as willows, privets, tamarisks or oleanders, in the ground or through riprap interstices.

Use: Method used on gentle slopes, on river and lake banks, in riprap, walls or gabions, or as live stakes when installing natural geotextile matting or netting, fascines or wattling.

Construction: 1-1.5 m long stakes are cut from species that can be propagated vegetatively and are planted in alternate rows in the ground (triangular planting). In riprap, the stakes are inserted into the gaps and must reach through to the earth behind.

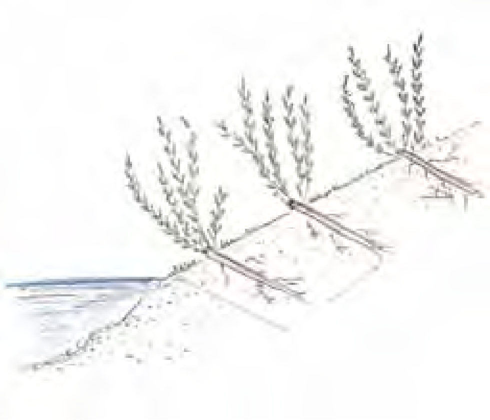

Figure 4.5.2.1 Live staking on a riverbank (Paola Sangalli).

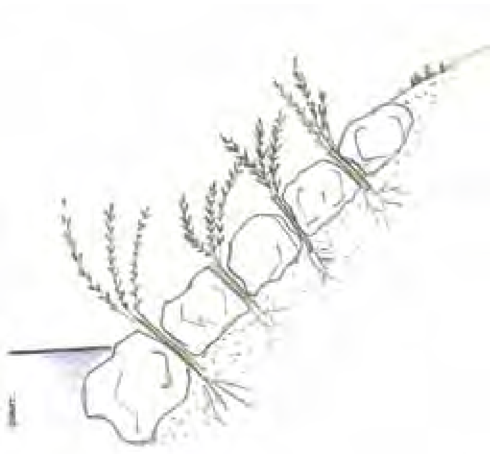

Figure 4.5.2. 2 Riprap with live stakes (Paola Sangalli).

Materials: Cuttings of willow and/or other easy-to-root species, 1 to 1.5 m long

Limitations: Altitude and the weather and soil requirements of the species employed. The various willow species cover a wide range of habitats, from sea level up to 2000 metres, but are not suited to very arid Mediterranean climates, excessively saline soils or too shady alocation, whereas privets, tamarisks or oleanders are suitable for these conditions but cannot be used above 400 m.

Figure 4.5.2.3 Sprouted Oleander cuttings at the toe of a riverbank. Tuéjar River in Valencia, Spain (Photo: Daniel Arizpe).

Figure 4.5.2.4 Vegetated riprap (Photo: Paola Sangalli).

Figure 4.5.2.5 Reinforced slope with live stakes (Photo: P. Barraqueta).

Wattling

Description: Structure made by weaving withies of woody species that can be propagated vegetatively around wooden stakes.

Use: Stabilization and rebuilding of riverbanks subjected to erosion by water courses of medium-low flow volume and speed with little sediment transport.

Construction: The wooden stakes are driven into the ground parallel to the edge of the river or stream, spacing them at intervals of maximum 1 m, with 0.50 m protruding above the ground. Each of the long, flexible withies is braided around the wooden stakes, first burying its end in the ground. The wattle fence is backfilled with soil to stop the gaps.

Figure 4.5.3.1 Wattling: side view (Paola Sangalli).

Figure 4.5.3.2 Wattling: front view (Paola Sangalli).

Materials: Withies (long, flexible branches) of willow and/or other easy-to-root species, diameter 3-4 cm and minimum length 1.5 m. Conifer or chestnut wood stakes, diameter 8-15 cm and length 1-1.5 m Galvanized wire

Limitations: Should not be used in watercourses with high flow volume and speed

Figure 4.5.3.3 Weaving live willow withies around living stakes. Tuéjar River in Valencia, Spain (Photo: Ana Mendes).

Figure 4.5.3.4 Wattle fence reinforced with live stakes. Tuéjar river in Valencia, Spain (Photo: Antoni Bonafont).

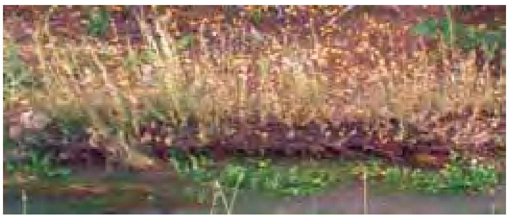

Figure 4.5.3.5 Sprouted wattle fence. Tuéjar river in Valencia, Spain (Photo: J. Garcia Purroy).

Brush mattress

Description: Covering the riverbank with stakes and poles of plant species that can be propagated vegetatively.

Use: An efficient method for protecting riverbank surfaces from erosion caused by flowing water, wave action or rainfall. It creates a continuous, flexible protective covering and improves the moisture balance and thermal balance of the soil, encouraging the growth of both ground level vegetation and the tree canopy.

Construction: After reprofiling the river bank, it is covered with live poles of species that can be propagated vegetatively (*Salix, Tamarix*, etc.). The poles are placed perpendicularly to the direction of the water flow and are held in place by wires stretched between metal pegs or live or dead stakes. The brush is covered with a fine layer of soil.

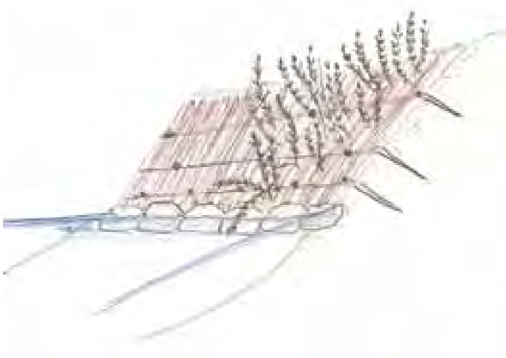

Figure 4.5.4.1 Sketch of a brush mattress on a riverbank (Paola Sangalli).

Figure 4.5.4.2 Side view of a brush mattress on a riverbank (Paola Sangalli).

Materials: Poles of willow and/or other easy-to-root species, Stakes of larch, chestnut or corrugated steel , Rocks, Gravel, Galvanized wire

Limitations: Watercourses with high flow velocities and considerable sediment transport.

Figure 4.5.4. 3 Brush mattress construction with willow poles and a vegetated fibre roll at the base. Ter river in Salt (Girona, Spain) (Photo: J. Bosch).

Figure 4.5.4.4 Brush mattress in an alpine stream (Photo: Florin Florineth).

Figure 4.5.4.5 Brush matress in an urban stretch. Artía stream in Irún (Guipúzcua, Spain) (Photo: Paola Sangalli).

Vegetated log cribwall

Description: Gravity wall formed by a grid of logs with live cuttings

Use: Stabilization and reconstruction of riverbanks subjected to erosion by medium-high water flow volumes and speeds, even with medium sediment transport. Cribwalls can be single-walled or double-walled. The single-walled version is ideal where space or excavation possibilities are limited.

Figure 4.5.5.1 Side view of a vegetated log crib wall (Paola Sangalli)

Construction: An excavation with a slight reverse slope is made. The first row of logs is placed lengthwise, parallel to the river edge. The logs are nailed together with metal nails and filled in. A row of logs is set across the first row and nailed to it. The next row of logs is again placed lengthwise, forming a grid, and cuttings of species that are capable of forming adventitious roots are inserted into the cells of the grid. This pattern is repeated successively, setting each longitudinal row of logs further back than the one below.

Figure 4.5.5. 2 Joining logs together with corrugated steel u-nails (Photo: Antoni Bonafont).

Figure 4.5.5.3 Willow cuttings placed in the crib wall cells and covered with soil (Photo: Antoni Bonafont).

Materials: Cuttings of willow and/or other easy-to-root species, Logs minimum 20 cm in diameter, Metal nails or staples to join the logs, Corrugated steel bars, 12-14 mm in diameter, Rocks, Inert filling material Galvanized wire

Limitations: Water speed and sediment transport greater than the resistance of the log wall. Not advisable when speeds exceed 4 m/s

Figure 4.5.5.4 Construction of a log cribwall in an urban stretch. Artía stream in Irún (Guipúzcua, Spain) (Photo: Paola Sangalli).

Figure 4.5.5.5 View of the rehabilitated Artía stream in Irún (Guipúzcua, Spain) (Photo: Paola Sangalli).

MACHINERY

Gonçalo Leal
António Campeã da Mota
Carlos Freitas

Hand Tools

Cutting tools

For cutting back trees and shrubs, chainsaws and hedge cutters are used for branches hanging in the channel. Occasionally, saws and pruning shears are also used. Herbaceous vegetation (including aquatic) is cut using a cutter, a sickle or a scythe

Chainsaw

A machine equipped with a 2 stroke motor used in cutting back large-diameter vegetation (trees and bushes).

Hedge cutter

The principal function of a hedge cutter is to cut back unwanted branches. It consists of two interlocking saws from 40 to 80cm in length, powered by an electric motor, and can cut branches up to 17mm thick

Strimmer

Used for cutting herbaceous vegetation (including aquatic plants). It is composed of a cutting head powered by an electric or petrol motor which drives a circular saw or rotating nylon threads and can be used at any angle.

Tools for uprooting plants

Trowels and pickaxes can be used for uprooting herbaceous and woody plants that are infesting the riverbank or preventing soil preparation.

Tools for gathering up material

Accumulated material from clearance work can be formed into piles using rakes and pitchforks; the material can subsequently be used for other purposes or destroyed.

Machinery

Cleaning bucket

- The cleaning bucket can be used for removing both vegetation and sediment (figure 4.6.1).

- Heavy machinery such as a mechanical digger is generally used for operating the cleaning bucket, but a hydraulic digger with wheels or treads can also be used, depending on site conditions.

- A mechanical digger can work on the riverbank. The bucket is operated via a hydraulically operated arm; the reach of the arm depends upon its size.

Mowing bucket

- A mowing bucket carries out both the cutting and removal of bank face vegetation from the bankside.

- The machine consists of an open bucket with vertical bars that collects plant material which has been cut with a hydraulic cutting bar mounted on the front of the bucket.

- It can be operated around trees and other obstructions where bankside access is necessary.

Figure 4.6.1 Mowing bucket (Photo: I. Moreira).

Figure 4.6.2 Hydraulic digger with a cleaning bucket in operation on a channel bank (Photo: I. Moreira).

- It can be used in conjunction with other mechanical equipment to remove riverbed sediment.

- Working speed is estimated at 0.2 – 0.5 km/hour.

Harvesters

- Harvesters are machines which both cut and collect plants material and are used in the water (figure 4.6.3).

- The machine is made up of one horizontal and two vertical cutters that surround the central part of the machine, where the materials are collected on a rolling carpet.

Figure 4.6.3 Harvester operating at Alverca da Golegã (Photo: I. Moreira).

- The machines have been adapted for use in relatively small watercourses, since they are relatively mobile.

- A disadvantage of their use is that they can also remove fish, amphibians, birds and other wildlife.

Mowers

The recomended mower types are motor mowers, reciprocating knife mowers with one or two cutter bars, rotary mowers and flail mowers. The latter are the least sensitive to saturation caused by wet substrates.

Reciprocating knife mower

- The cutter bar has one or more blades that move horizontally over a fixed, comb-like guide bar.

- The distance between the teeth can be changed to suit the type of vegetation:

a) Thick or rigid stems: 5" or 40 mm
b) Medium sized stems: 2" or 51 mm
c) Fine stems: 1 1/2" or 38 mm.

- Some reciprocating knife mowers have two cutter bars: these machines are more expensive but give superior performance and are less sensitive to obstacles.

Rotary mower

- Cutting equipment operates by rotation.

- Horizontal cutting blades cut and lacerate grass, depositing it on the ground in a row.

- Vertical cutters, which rapidly cut the stems, may be in the form of discs or drums. The difference is in cutting precision: disc mowers do not cut so

Figure 4.6.4 Bankside clearance using a rotary mower (Photo: I. Moreira).

close to the ground, which can be a disadvantage over low lying level areas but advantageous in more irregular or stony terrain.

Advantages:

1) Better performance

2) Cutting apparatus less prone to blockage, thereby needing less maintenance

3) Allows a working speed of 10-15 km/h, without soil saturation

Disadvantages:

1) Requires more power compared to other methods

2) More expensive

3) Difficulty in operating on stony ground, since blades are rapidly blunted and stones are thrown from the machine; a protective guard should be mounted on the mower

Flail mower

- A flail mower is composed of a series of articulated flails that rotate around a horizontal axis mounted on the front of the machine.

- The flails are curved in the direction of rotation and have a cutting face. The rotor is covered by a front-mounted semi-cylindrical housing with a shear bar on the lower edge.

Tractor operation

- For tractor efficiency and to avoid damage to the mower, a minimum distance of 50cm should be kept between the tractor wheel track and the bank face edge. For precise mowing, the mower should be at a minimum angle of 55º to the ground (figure 4.6.5).

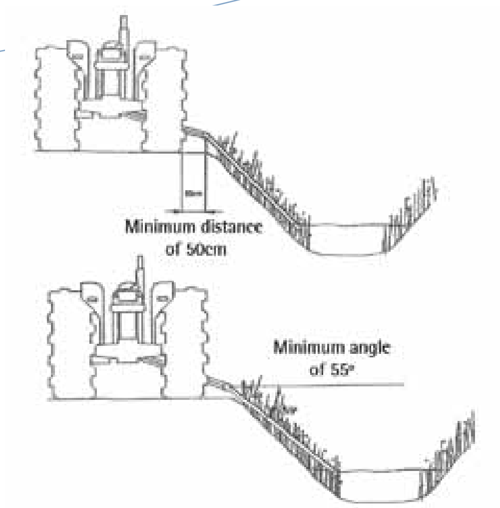

Figure 4.6.5 Tractors operating on the margins (chapter authors).

Chemical control

Jet sprayers

- Mix and spray the product under pressure through spray nozzles using a pump.

Consumption of spray mixture - high:

Herbaceous plants: > 700 litres

Trees and bushes: > 1000 litres

Figure 4.6.6 Exemple of jet spraier application (Photo: I. Moreira).

Mistblowers

- Spray delivered by fan-propelled airstream.

Consumption of spray mixture - medium:
Herbaceous plants: 200 – 700 litres
Trees and bushes: 500 – 1000 litres

Advantages:

1) Less mixture used per hectare, permits a larger area to be treated and allows penetration of small drops via the airstream.

Pneumatic sprayers or atomizers

- Continuous uniform flow of mixture to spray nozzle, pump operated.
- Mixture transported under pressure to nozzle where it is mixed with a jet of air from an air pump, forming extremely fine droplets

Consumption of spray mixture - low:
Herbaceous plants: 50 – 200 litres
Trees and bushes: 200 – 500 litres

Rotary atomizers

- Spray droplets are formed by the centrifugal force of a spinning disc or cup; the grooves carry the mixture to the edge of the disc.
- The larger the disc and the faster it rotates, the smaller the droplets will be

Consumption of spray mixture – very low:
Herbaceous plants: 5 – 50 litres

Advantages:

1) Very fine droplets are formed and the quantity of mixture used is very low
2) Droplet size is homogenous
3) Facilitates the use and preparation of herbicides in areas with little water

Disadvantages:

1) Herbicide may inadvertently be applied on neighbouring vegetation
2) Penetration difficult in reed beds

Granule distributors

- Granule based formulations have the advantage of eliminating inadvertent drift, which tends to occur with spray mixtures.
- Several types of delivery equipment can be found on the market, such as hand- or motor-operated backpacks, small trolleys or trailers attached to tractors.

Figure 4.6.7 Application of herbicides from the river channel (Photo: I. Moreira).

Figure 4.6.8 Application of herbicides using tractor (Photo: I. Moreira).

ESTABLISHING RIPARIAN VEGETATION

Domingo Baeza Sanz
Diego García de Jalón-Lastra
Juan Carlos López Almansa
Miguel Marchamalo, Ana Monteiro
Ilidio Moreira, Pilar Vizcaino Martínez

Introduction

Given the importance of riparian vegetation for ecologically-balanced functioning of river corridors, as discussed in some breadth in this guide, this section focuses on its recuperation, through spontaneous or induced establishment of riparian plant species, with landscape and environmental protection aims.

Recognition of the need to conserve the riparian strip springs from the multiple environmental benefits of keeping the land adjacent to watercourses covered with natural vegetation. However, riparian woods are often damaged or completely replaced by other types of land uses, mainly agricultural, which makes it necessary to take action to repair or restore them.

When restoring these systems, characteristics such as the natural conditions (sediment type, water and hydraulic conditions, climate), the habitat type and plant community composition, the social uses of the recovered space and the width of the riparian strip must be taken into account. The recommended width of this strip is an important factor that varies, among others, with the environmental value of the site and the level of anthropogenic pressure derived from the uses of the adjacent land. It is also important to consider land tenure structure and to encourage cooperation from neighbouring landowners.

The riparian strip should ideally be made up of three distinct areas, considering its efficacy in controlling diffuse pollution, facilitating stormwater infiltration, thus reducing runoff and attenuating the transport of nutrients and sediments. The three areas include a shrub- and bush-covered area, a tree-covered area and an area of herbaceous plants.

Species selection

The selection of the species to be used in the recovery of riparian plant communities is one of the most important aspects that need to be considered in order to guarantee successful establishment of the plants that are introduced and minimize negative impacts on the environment. The following should be taken into account:

- The ecological characteristics of the reach that will be subject to intervention (geographical area, climate, soil, pH, salinity etc.) and the natural distribution of the species.

- The geomorphology and position of the reach along the river's longitudinal profile – for example, in the headwaters, which are subject to higher flow energy and erosion, the species to be used should have a well developed root system.

- The flow regime, including frequency and duration of flooding; species such as Common Alder, which have a great need for water during the entire year, should be planted in rivers with a permanent flow regime whilst Narrow-leaved Ash, which can tolerate drier weather, can be placed in reaches with a temporary flow regime.

- Wetted width of the water body; the use of emergent rhizomes, for example, can be suitable in wide, deep waterbodies but not in narrow, shallow watercourses, since the plants can eventually occupy the whole waterbody.

Species selection must take into account that these woodlands are sometimes structured into strips, with different species occupying different positions on the bank and on the terraces near the river. It is advisable to observe the position of well-preserved groups of natural vegetation, more or less close to the water, identifying the species located in each of the bands. Various models have been used to describe these bands of vegetation (Lara *et al.*, 1996; King *et al.*, 2000; Lynch and Catterall, 1999) and there is currently some controversy over the terminology to employ (Richard et al, 2001). For the sake of simplicity, we shall divide the riverbank area into three zones. From the furthest to the closest to the water these are:

- The top of the bank face or dry strip. This area is subject to the effects of flooding, with 2 year occurrence for lower-lying banks and 20 years for higher banks. This is a transitional area characterized by large trees and bushes with deep root systems and herbaceous vegetation which helps retain the soil. This vegetation band leads into the next in a lower transition zone.

- Middle area or humid strip. This area is regularly wetted by high and medium river flow regimes and is characterised by a mixture of trees, bushes and herbaceous vegetation which slows down the flow when water passes over it.

- Lower area or aquatic strip. This area is in contact with the water and is flooded as soon as the water level rises. The vegetation is adapted to such conditions, with a strong root system (in many cases rhizomes), and flexible branches that allow oxygen to circulate. Plants in this zone are tolerant to periodic flooding (Telfer and Connell, 1998). This is a non-rigid structure of features that may be altered or simplified, taking into account the role of the vegetation structure in the given area and the geomorphology.

This structure is not necessarily fixed and it can be simplified or modified in view of the vegetation structure of other stretches in the area which are in good condition.

It is preferable to choose native plants rather than exotic plants for the following reasons:

- They are adapted to local environmental characteristics such as the climate, soils and river flow regimes

- They present fewer plant health problems such as fungal infections and insect attacks

- Once they are established they do not need watering or maintenance

- The local fauna depends upon them

- They add value to the native genetic heritage

- Generally they do not become invasive, contrary to many exotic species

- They are integral to the riverine landscape.

The most advisable way to go about choosing species depends on the inventory of native species carried out along reaches in a good state of conservation situated close to the intervention area that have similar ecological characteristics.

One of the main limitations on using native vegetation is obtaining plants because they are often not available from nurseries. In every project that includes plantings it is therefore extremely important to set down the procedures concerning the use and production of native species and local ecotypes in the list of tasks to be carried out. The required plants can be produced with prior planning, starting one or two years before planting. Material can be obtained by taking cuttings, seeds or propagules along river reaches in a good state of conservation; the use of nursery stock from other biogeographical areas should be avoided.

Planning and design criteria

Whatever the species selected, the desired final vegetation structure and the implementation method, the restoration design should take the following into account:

1) Plantings should be as diverse as possible in both their horizontal and vertical structure and should always use species and varieties that are native to the area.

2) The vegetation should have functional connection with the channel, allowing a systemic relation between the river and the riparian zone. This does not mean simply planting trees along the river's edge, it means mutual influence between the terrestrial and aquatic ecosystems, allowing the riverine vegetation to provide shade and protection for aquatic species whilst the river provides water for the riparian species.

3) The restored riparian strip should be sufficiently wide to ensure protection of the riverbank. A general rule of thumb is that the riparian strip should be at least as wide as the river and even up to five times its width; it should never be less than 5-6 metres wide (González del Tánago and García de Jalón, 1998).

4) Wherever possible, both sides of the river should be restored, given that protection of river plant communities is considerable diminished if only one side is protected.

5) River restoration should involve considerable longitudinal stretches of the river. A small restoration effort in a small area would barely have any hydrological or ecological effects. In addition, a larger intervention scale favours the corridor effect of the river, which is important for the movement of fauna.

In setting out vegetation recuperation criteria, it is important not to forget the importance of riparian gallery continuity, whether on both margins or alternately along both margins, so that the gallery can continue to act as an ecological corridor for the fauna.

In order to achieve a well structured and diversified riparian gallery, modules composed of trees, shrubs and herbaceous plants should be devised and their position along the riparian strip should be decided. It is important to take into account:

- The water requirements of each species, placing the most demanding ones close to the channel (willow and alder) and the less demanding ones further away (*e.g.* ash and elm)
- Type of channel and channel stability, planting species that tolerate faster flow rates and sandy soils on the outside curve of meanders
- Exposure of the reach to be restored, taking into account the effect of shading of the waterbody (especially along narrow watercourses) and the surrounding area by larger species (trees and bushes). NB: it is beneficial to have alternate areas of shade and sun so that sunlight can reach the waterbody.
- Type of plant community, planting mostly the typical species of the community to be established (*e.g.* in an ash stand, it is obvious that mostly ash saplings should be planted).

Revegetation strategies

Natural revegetation

The natural revegetation method should always be the first to be considered, as it has many advantages. The area to be reforested needs to be protected from grazing animals and the young trees, once established, require protection from damage by wild animals. Herbaceous species must also be kept under control, especially if they are exotic or assisted by human actions and could be considered invasive.

This method presents advantages of several types. From the financial point of view, it is a low cost strategy as it only involves protecting the area and keeping the weeds under control. From the point of view of ecological quality, it achieves a community with a diverse composition and structure and the species are normally better adapted for survival in the area in question.

Figure 4.7.1 Natural regeneration of *Populus nigra* on a gravel bed intermitent stream (Photo: Olga Mayoral and Miguel Ángel Gómez).

The problem with this type of revegetation is that it requires a sufficient number of propagules, which have to come from nearby areas, normally upstream or from the soil seed bank. This means that neighbouring stretches need to have goodly lengths of native riparian woods in good state of conservation and, also, that the external factors which can influence the successful regeneration of the vegetation need to be favourable, including suitable temperatures and a sufficient and seasonally appropriate supply of water.

Management and Planting

On occasion, human intervention in the revegetation process may be more appropriate. This can be the case when species that do not easily germinate from seed are used, when the space available for restoration is limited and natural processes are unlikely to be successful, or if sufficient plant material (propagules) does not reach the site to be restored. If it is decided that intervening to assist the spread of the riparian vegetation would be more advantageous, the restoration should be carried out in the following stages:

1) **Terreain Preparation.** Readying the ground for planting, to make it easier for the seeds to germinate or the seedlings to take root. The ground should be prepared in a way that imitates the effects of freshets, which are the main factor that favours the regeneration of riparian vegetation. Consequently, this preparation should fulfil the following objectives:

   a) **Clear the banks**, removing waste that does not belong to the riverine environment.

   b) **Selective removal of trees** if they have proliferated excessively owing to human activities. This will open up clearings in the canopy to increase the amount of sunlight reaching the ground, which will encourage the growth of the early stages of colonizing species such as poplars, willows and elms. These clearings mush be made immediately before planting, as clearing too far in advance only manages to encourage the development of a herbaceous layer that then becomes a considerable hindrance to introducing the woody vegetation.

   c) **Selective clearing of bushes** such as brambles that could prevent regeneration of the desired species and removal of scrub, dead leaves and ground-covering species that could impede the establishment of the seedlings or sets. It can be local, at the particular spots where the species are to be introduced, or area-wide, clearing down to the mineral soil. The latter method has the advantage that if it is combined with watering the ground and even artificially introducing fines, which can be done by hydroseeding techniques, a perfect imitation of the natural regeneration mechanisms of riparian species can be achieved, though the cost is higher.

2) **Introducing the vegetatio**n, which can be done by various methods:

   a) **Seeding.** This is the most suitable method for herbaceous species. It can be done manually, by broadcast sowing, or by hydroseeding with machines. The advantage of the latter is that since water and fertilizers are supplied at the same time, the seeds germinate more rapidly and develop better roots.

Woody species can also be introduced by direct sowing, although this method is not often applied in practice because the risk of failure is greater, as it depends on the weather to a far greater extent than other techniques. Also, the differences in fruiting dates of the different riparian species, together with the short survival period of the seed in the case of Salicaceae, would make several sowing campaigns necessary to achieve a varied cover of vegetation and would not be very viable, as the ground cover would have grown between one and the next, hindering the germination and rooting of the woody species enormously and increasing the costs.

Annual and fast growing species should be sown after all other planting has taken place to avoid trampling and give a better finish to the work. If the soil is very compacted, the surface should be lightly tilled. Sowing can be carried out manually or by machine. Sowing density depends upon the species, but a recommended minimum of 30 g/m2 is often given. Seeds can be broadcast and buried, which can be done by tilling and rolling the surface of the soil, or mats or other types of covering can be used to avoid birds and other seed-eating animals taking the newly sown seed. Like trees and shrubs, herbaceous plants also need watering-in, which should be done after covering the seeds.

Where the bank face is steep or soil humidity conditions are bad, hydro seeding is used. This technique projects a mixture of water, seeds, fertilizer, mulch and binder onto the soil surface, which has been previously protected with a biodegradable geotextile, allowing plant development.

b) **Planting cuttings.** This is the technique most often used for Salicaceae, as their branches easily grow roots. Species from other families such as tamarisks and some elms can also be planted in this way (see chapter 4.6.2). For fast-growing herbaceous plants, plugs or cuttings can also be planted, although the demands of each species should be taken into account, especially as regards planting depth and watering requirements. When the soil is very dry, especially during hot weather, it is advisable to water the soil prior to plantings and wait until the soil is in a suitable condition before proceeding.

c) **Ball Planting.** This is the technique most usually employed for elms, ashes, alders and other tree species as although it increases the transport and planting costs, it is a far safermethod in unstable climates such as the Mediterranean.

Once the areas where the trees and shrubs will be planted have been marked, it may be necessary to dig holes, whether manually or using machinery; the holes should be roughly cylindrical, 1 m deep and 1 m wide for trees and 0.6 m by 0.6 m for bushes. The base and sides of the hole should be lightly roughened to promote better adherence of the soil used to fill the hole.

Where the soil in the base of the hole is of bad quality it should be removed and disposed of and replaced by healthy surface soil. The quantities of manure or organic compost employed will depend on the needs of the species and on the fertility of the soil; in extreme cases, 0.1 m3 of manure or 25 kg of organic compost in the hole may be required for trees, with the addition of 0.2 kg of compound fertilizer in both cases, and 0.05 m3 of manure or 10 kg of organic compost with 0.1 kg of compound fertilizer for large shrubs.

The fertilized earth is compacted and small planting holes are dug in it, of a suitable size for the soil plugs or root balls or for the root systems of bare-rooted plants if these are being used. While planting, the root ball or bare roots should be covered and kept damp to avoid damage and drying out. Plants should be watered-in immediately to improve soil adherence to the roots; small channels can be made to aid this process. Where necessary for plant development, stakes can be used to support the plants, taking care to protect the tie area with paper, webbing or some other suitable material to avoid wounding the tree.

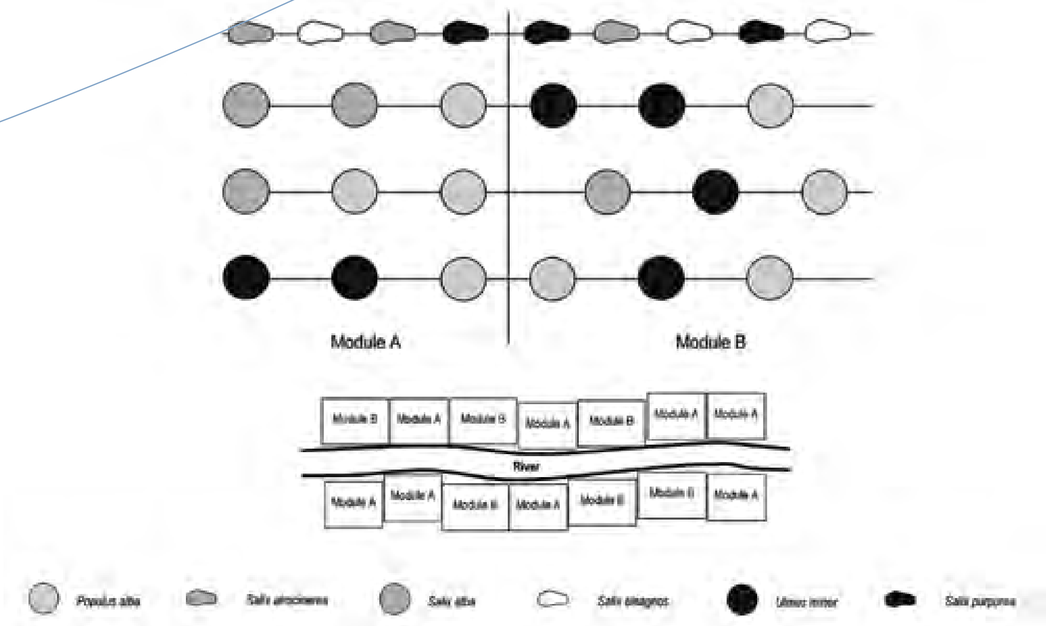

Figure 4.7.2 Example of modular planting pattern for riparian restoration.

d) **Rhizome Planting.** This technique is used mainly for aquatic plants such as Fat Hen (*Chenopodium album*), Bullrushes (*Typha* spp.), reeds (*Phragmites* spp.) and irises (*Iris* spp.), among others.

Normally, planting patterns are designed on a modular basis, as this is the easiest way to achieve floristically and structurally varied vegetation. Each pattern includes one or two tree species and some shrubs in specific positions and the different patterns are allocated at random over the area to be restored, so the final structure will lack any immediately visible order (figure 4.7.2). When replanting, it is not advisable for the layout to be followed too precisely, as a certain margin of variation between the initial plans for the project and the final result helps to increase the natural appearance of the new planting, as well as simplifying the work.

The main objective of planting is to provide sufficient protection for the fluvial corridor and facilitate the progressive enrichment of the species that will spontaneously recolonise the riverbank. In time, nature will shape the riparian strip, so it is not necessary to plant modules too densely (figure 4.7.2). This example is purely for illustration; factors such as climate, river dynamics and riparian strip width must be taken into consideration.

The planned modules are repeated randomly along the watercourse and adjusted according to the channel width. The recommended spacing between modules is 2-3 metres, facilitating planting, maintenance and access to the river. The spaces will hopefully be filled in by natural plant regeneration processes.

In many cases, reconstituting the tree and shrub understory aids the natural recuperation of herbaceous vegetation. However, woody vegetation takes some time to grow and the long term benefits such as amelioration of the effects of erosion are not immediately noticeable. In order to reduce soil losses, it is important to minimise soil movements as much as possible during site preparation. Seeding the area with fast growing herbaceous plants (whether or not simultaneously with planting trees and shrubs) should be considered in order to protect the bank face during the first few months. The most suitable herbaceous plants in this type of situation need to include a mixture of plants that develop large root systems but have a small aerial structure. The species chosen should be typical of the local area, using seeds collected in the area or in an area with similar ecological conditions.

All the nursery stock should comply with current plant standards: the material should be young, healthy, well formed specimens with vigorous straight stems, a terminal bud and a root ball that is well developed and well spread, not curled up.

The best time for planting is when plants are vegetatively dormant and the weather conditions are favourable: enough soil humidity and absence of severe frosts. These conditions are normally met in spring as the soil beginns to warm up. In locations with typical Mediterranean conditions, mild humid winters and dry summers, it is advisable to plant in late-autumn.

Despite their proximity to the waterbody the plants and seedlings should be watered regularly during dry periods, as modification of the soil structure following earth-moving operations and their limited root development can make it difficult for the young plants to obtain their water requirements.

And finally, it is important to protect the introduced plants over their initial development period from being damaged by strong winds, humans or domestic and wild animals. This can be done by either fencing the entire area and completely restricitng acces to it, or by using individual protecting structures like stakes, wire or plastic tree guards, plastic tube shelters or root barriers against rodents. The relative vulnerability of the different species to being browsed has to be taken into account when choosing the protection system in order to reduce costs (Hodge and Pepper, 1998). Ashes, willows and Black Poplars are very sensitive (DCS, 2008) for example, while Elders, White Poplars or Tamarisks (Zouhar, 2003) seem to be less appetizing to ruminants. During the first years grazing and access of cattle to the water body should be prevented; where necessary, designated areas can be set out. More information about the management of grazing areas in riparian zones can be found in the following chapter.

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André Fabião
António Fabião

SUSTAINABLE RIVER VALLEYS: ECONOMIC VALUE AND GOOD FOREST PRACTICES

Threats

The dynamic character of riparian galleries makes them particularly vulnerable to change caused by human activity (Brinson and Verhoeven, 1999). Negative effects of anthropogenic impacts on riparian plant communities, namely hydrological disturbance caused by lowering of the water table, have been cited by several authors (*e. g.* Cortes and Ferreira; 1998; Mitsch and Gosselink, 2000). At the same time, the expansion of both urban and agricultural areas has resulted in the degradation and disappearance of riparian galleries, which have been replaced by other types of land use, since availability and access to water provide strong incentives for economic development (Larsen, 1996; Duarte *et al.*, 2002; Angradi *et al.*, 2004).

Uncontrolled grazing and the indiscriminate clearing of trees for various reasons have been pointed out as some of the main factors in riparian degradation. Livestock access to water via paths which follow the steepest part of the riverbank results in erosion of the bank face and a gradual expansion of the degraded area. Cutting down trees, whether to improve access or for commercial reasons, accelerates and worsens the degradation process. Later, these degraded reaches become sought after for the removal of substrates – mainly sand for the construction industry – and/or for the access they provide. This type of activity affects not only the already degraded margins but also the stability of the river channel; for this reason, areas earmarked for this type of activity must be carefully selected according to specific criteria rather than using sites that have previously been damaged through unsuitable riverbank and bankside vegetation management.

The economic value of riparian galleries

Some of the environmental services provided by riparian galleries – improved water quality and better habitats for fish and other forms of wildlife, as well as local and regional flow regime stability – are well documented (Hunter, 1990; Jeffries and Mills, 1991; Smith *et al.*, 1997; Cortes and Ferreira, 1998; Moreira *et al.*, 1999; Mitsch and Gosselink, 2000; Friedman and Lee, 2002; Moreira and Duarte; 2002). Nonetheless, the economic value of the environmental services delivered by a riparian gallery remains outside the scope of classic economic market evaluations. Placing a monetary value on this kind of service is mainly a political and social process that largely depends upon the subjective value attributed to them by society. However, many of these services only become apparent years or even decades later, which makes the advantages of the presence of riverine vegetation less evident, due to the time lag (Lynch and Tjadem, 2000; Brismar, 2002).

As well as the environmental value of the riverine woody species, exploiting riverine and associated areas in a more direct way can generate economic benefits if it is carried out with conservation precautions in mind. For example, in Europe, timber from riparian galleries has been exploited for different uses, depending on the type of vegetation of which they are composed (Oszlányi, 2001). Forest exploitation of riparian woodlands can be highly remunerative, as timber of the species that can be cultivated in these areas (*e.g. Juglans* spp.) fetches a higher price than some conventional timber species (*e.g.* pine). An analysis of the average cost per cubic metre of timber paid to the producer can be seen in table 4.8.1. Quality timber production can be seen as an opportunity to maintain riparian environmental benefits while also generating wealth in rural areas. However, such timber production must not compromise the protection of the riparian gallery and of river integrity, which should always be maintained.

Table 4.8.1 Prices of timber from trees suited to river habitats, paid to private producers in France and Portugal. The values given are merely indicative and can vary between regions within each country. This table does not take into account annual price variations related to the quality of the timber (*e.g.* dimensions, presence or not of defects) and prudence in the interpretation of these values is recommended. Pinus pinaster is included for the purpose of comparison with a non riverine species that is widely cultivated in both countries (Source: Anonymous, 2004; Anonymous, 2005; DSPE, 2006; Anonymous, 2007).

Species	Average price (Euros/m3)					
	France			Portugal		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Quercus spp.	5 - 8	400	118	13	107	38
Fraxinus excelsior	20	200	78	n/a	n/a	n/a
Fagus sylvatica	5 - 8	190	56	n/a	n/a	n/a
Betula spp.	15	60	38	20	31	27
Tilia spp.	30	90	60	n/a	n/a	n/a
Prunus avium	40	400	185	n/a	n/a	n/a
Juglans spp.	100	3000	1015	n/a	n/a	n/a
Castanea sativa	15	200	86	17	188	57
Acer pseudoplatanus	100	230	165	n/a	n/a	n/a
Populus spp.	5	65	26	20	82	45
Pinus pinaster	8 - 17	25 - 40	22	3	86	35

The technical characteristics of timber from riparian galleries and the area immediately around can vary widely within each tree species, which partly justifies the variation in prices shown in table 4.8.1. Table 4.8.2 gives the different properties and technical characteristics of the timber of some riparian species.

Other economic activities can benefit from the presence of well structured riparian galleries, such as leisure activities and tourism, partially or totally based upon the use of the riparian zone (angling, training circuits, picnic areas, fluvial beaches etc), as long as these activities are developed in such a way as to prevent environmental impacts. The river habitat attracts many types of vertebrates including game species. Game hunting areas situated next to well structured and conserved riparian galleries will benefit in species abundance and diversity as a result of their proximity.

Table 4.8.2 Properties, characteristics and main uses of timber from riverine trees or trees that frequently occur in riparian galleries (Source: Anonymous, n.d.; Oliveira, n.d.; Carvalho, 1997; López González, 2004).

Species	Colour	Applications	Observations
Alnus glutinosa	Pinky yellow	Furniture (indoor); hydraulic structures, decorative laminates, packaging, tools, various types of small objects	Timber with improved durability when submerged in waters
Alnus cordata	Orangey red, slowly darkens	Packaging, hydraulic structures, various types of small objects	Timber with improved durability when submerged in waters
Betula pubescens	Pale white or pink-white	Particleboard, paper pulp, charcoal, sometimes used in construction (including aeronautical)	
Fraxinus angustifolia	Pinky yellow	Heavy furniture; particleboard and laminates, interior carpentry and tools	
Fraxinus excelsior	Yellowy brown	Sports equipment, furniture, tools, floorboards	
Frangula alnus		Charcoal for gunpowder	
Populus nigra	Red-grey	Construction (structures), interior furniture, bases and backing and panels, particleboard and laminates, fine carpen try and toys; matches and toothpicks, leaf, paper pulp and chipboard	
Populus alba	Pink-hued	Construction (structures), interior furniture, bases and backing and panels, particleboard and laminates, fine carpen try and toys; matches and toothpicks, leaf, paper pulp	
Castanea sativa	Brown (heartwood); White/yellow hues (sapwood)	Interior and exterior structures and carpentry; laminates; lathed furniture, naval construction, baskets, tool handles, barrel making, glued and moulded goods, posts, firewood	
Prunus avium	Brown; brown with red hues	Furniture, musical instruments, tools, barrel making, covering, laminates	
Quercus pyrenaica	Brown with yellow hues (heartwood); white with yellow hues (sapwood)	Flooring (parquet);wood panelling, utensils and construction, stakes, barrel making	
Quercus faginea	Brown with yellow hues (heartwood); white with yellow hues (sapwood)	Construction (structures and carpentry), wood panelling and floors, furniture making (structures and heavy furniture), trays	Difficult to mill due to hardness and the form of the trunks

Riparian gallery management

Scope and challenges

A riparian gallery must be well structured and made up of healthy specimens to ensure that its presence will have maximum positive impact on water quality, wildlife, timber production and the inhabitants of the region (Goard, 2006a). Effective conservation and rehabilitation of river spaces needs adequate legal regulation that stimulates landowners to make areas available to increase the conservation value of the riparian galleries and corresponding river corridor. As well as this, the management of these areas must be river-basin specific, since each river has unique characteristics. Management cannot be limited to isolated components of the river but must be as ecologically far-reaching as possible and carried out at several scales – that is to say that management at the river reach scale must fit into plans for the catchment area to which the reach belongs and also into wider reaching catchment management plans (Hughes *et al*., 2001).

One of the main challenges for the management of these areas, especially in basins with high levels of human activity, is reconciling the maintenance of land-water interaction integrity with the multiple types of land use. Riverbanks present many important benefits to society and their conservation provides important environmental services; in many countries and regions they are legally considered public property, together with the river channel and the water itself. However, adjacent landowners, who may be private owners, have privileged access to water and associated resources, making it necessary to regulate rights and obligations and oversee compliance.

One of the most sensitive areas concerns the creation of access to water (for both people and livestock), which can compromise riverbank and plant community integrity, as can indiscriminate tree felling for timber, removal of substrates for aggregate without adequate supervision and excessive unauthorized water diversion for irrigation and other uses. Indeed, any activity concerned with the use and management of forest resources near or within the riparian gallery can potentially have a negative effect upon water quality, the aquatic and terrestrial habitat and other values and functions of the riparian zone (table 4.8.3).

Table 4.8.3 Potential impacts of forest use activities on river galleries (adapted from Phillips *et al*., 2000).

Forest management activity	Increased sedimentation and erosion	Chemical water pollution	Residues from felling	Temperature rises	Soil compacting	Type of habitat, structure and quantity		Cultural resources	Forest soil productivity
						Terrestrial	Aquatic		
Productive intervention	X	X	X	X	X	X	X	X	X
Timber extraction	X	X	X	X	X	X	X	X	X
Site preparation		X		X		X	X		X
Use of pesticides	X	X		X		X	X	X	X
Prescribed burning	X	X		X		X	X	X	X
Construction of fire breaks	X	X	X		X		X	X	X
Roads	X	X	X	X	X	X	X	X	X
Recreational use	X	X	X	X	X	X	X	X	X

If one of the management objectives in these areas is timber production, the recommended form of utilization generally consists of leaving a buffer zone, namely a strip adjacent to the watercourse that is not used for commercial activities (Hunter, 1990) – which does not preclude necessary management such as felling for health and safety reasons – although there may be less sensitive zones where selective felling or group selection (felling of small stands) can be carried out. This leads to the development of irregularly structured wooded strips (*i.e.* stands with a diversity of age classes, species composition and dimensions), resulting in a forest showing high habitat diversity, which is positive from an environmental point of view. From a purely economic point of view, this type of forestry is only viable if the price of the extracted timber is high, which points to the extraction of valuable timbers such as oak, chestnut, wild cherry and ash, amongst others. Most of these species have a preference for humid soils and are often found on the outside edge of riparian galleries.

Prior to initiating any type of forest utilization activity in the riparian zone, the objectives of this activity should be set out clearly; only after this can the planning of best management practices be carried out (Phillips *et al.*, 2000). Timely planning is essential to identify th e risks and costs associated with riparian zone management. This is also the most appropriate time to identify the specific needs of each stretch, define forestry operation areas and the intensity of these activities, draw up and implement landscape quality safeguards, diagnose potential problems and conflicts and define impact mitigation actions that will contribute to improvements compared to the pre-existing situation (Phillips *et al.*, 2000).

The buffer zone

The buffer zone is an area of variable width adjacent to the watercourse which is not subject to any form of intervention, except when necessary for technical reasons. Determining the most suitable width is a complex process which is reached via one of two ways (Phillips *et al.*, 2000): (1) define a fixed width that can vary with the slope or the river type, or (2) define a variable width based upon the specific conditions of each site (composition, age and condition of vegetation, site geomorphology, adjacent land use or other recommended local features). Maintenance of suitable buffer zones is particularly important on unstable or steep bankfaces, which are particularly vulnerable to erosion (Brinson and Verhoeven, 1999). Several studies carried out worldwide on riparian galleries and the function of their respective buffer zones make it possible to synthesise some general principles to take into account when deciding upon the width of these strips (Brinson and Verhoeven, 1999):

a) Although socio-economic objectives exclude the designation of exceptionally wide buffer zones, the wider the buffer zone the better the conditions for maintaining biodiversity, on the whole.

b) In order to obtain similar levels of protection, the greater the level of adjacent economic activity, the wider the buffer strip.

c) All aquatic environments need riparian buffer zones, whether they are located in alluvial plains or in steep headwater sites.

d) Headwaters are essential to maintaining water quality and for flood control; however they are also the area most vulnerable to change.

For each separate situation, the study of different factors such as the local or basin level features, intensity of land use or intended function of the buffer zone (amongst others) will point towards scientifically-based solutions.

However, in order to make a final decision about the width of the buffer zone, scientific answers often need to be brought into conjunction with restrictions and with the objectives of the general population or the local managers (figure 4.8.1) (Palone and Todd, 1998; Phillips *et al.*, 2000).

Based upon Palone and Todd (1998) and Phillips *et al.* (2000), the minimum recommended width of a buffer area in the USA varies from between 10-15 and 30-35 metres (for each river bank), depending on the site and the desired objectives.

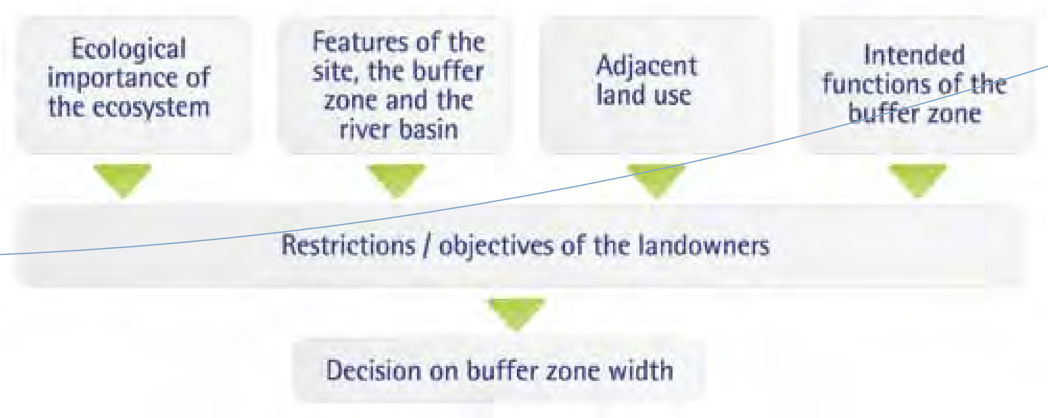

Figure 4.8.1 Criteria for determining the width of a river buffer zone (adapted from Palone and Todd, 1998).

Best Management Practice

Best Management Practice measures for riparian forests aim to prevent adverse impacts in the lotic ecosystem that can result in altered habitats, caused by accumulation of fine sediments, variation in temperature and flow and the introduction of chemical products and organic and solid residues (Phillips *et al.*, 2000).

Generally, the landowners or the managers should be aware of the following recommendations concerning intervention in the riparian zone (Palone and Todd, 1988; Phillips *et al.*, 2000; Goard, 2006a):

1) Identify objectives and plan activities to be carried out.

2) Define and implement buffer zone features.

3) Minimize impacts on forest soil, keeping the organic layer intact.

4) Prohibit the entry of heavy machinery into the river channel. If crossing is unavoidable it should be carried out at designated areas that have been prepared for this function.

5) Remove of large trees and branches which might fall into the watercourse after felling.

6) Treat residues resulting from felling appropriately (remove chippings and cuttings).

Table 4.8.4 provides more specific recommendations for different structures/operations to build/carry out during logging operations in riparian zones.

Table 4.8.4 Recommendations for best forestry management practice in riparian galleries (adapted from Goard, 2006b).

Access	Crossings	Felling and yarding	Post-felling
▪ Access ways and log ladings must be at least 8m away from streams	▪ Minimize the number of crossing places and soil disturbance	▪ Work when the soil is dry	▪ Stabilize bare soils in disturbed areas in order to avoid erosion
▪ Designed so as to minimize erosion (at an angle to the channel and bank)	▪ Always cross streams at a 90º angle and only in areas where the stream-bed and banks are composed of cohesive materials	▪ Do not fell more than 25% of trees	▪ Re-seed and plant felled areas with native species
▪ Whenever possible use existing roads or tracks		▪ Do not deposit logging residues in streams	
▪ As narrow as possible (but functional)		▪ Do not yard or skid logs and trees across streams	
		▪ Ensure that the forestry contractor knows which trees to fell and the structure of the access ways	

Concerning livestock access to the riparian gallery and the water, it is sometimes advisable to limit it by using fencing; uncontrolled grazing in the riparian zone can damage the vegetation cover, compact the soil and lead to erosion of the bank face (Goard, 2006c). Thus, fencing should be placed approximately 20m away from the watercourse (to avoid damage during sudden rises in water level). Nevertheless, whenever it is necessary to guarantee livestock access to the water's edge (to drink or cross), some fencing could be placed inside the water channel (Goard, 2006c):

a) In suitable areas, built in order to minimize river channel disturbance.

b) The channel and the bank face of selected areas should be stable, preferably of exposed rock or large stones which are not easily moved by higher rates of flow.

c) The slope of the crossing area should be constant.

d) The crossing areas should not interfere with water movement or aquatic life.

e) Fencing erected in these areas should be robust enough to withstand the movement of debris and flood flow regimes.

However, there are situations where the controlled presence of livestock in riparian woodlands can bring more ecological benefits than problems to the system. One example is in regulated rivers, where the absence of yearly floods can cause extreme proliferation of vegetation on typical riverine open spaces like gravel banks and sand bars, which are very important habitats for many breeding birds, arthropods and insects. Grazing can also be a cheap management practice for controlling problems with non-native invasive species like the Giant Reed (*Arundo donax*). It is not unusual for some restoration projects to include the controlled introduction of livestock as a fundamental piece in ecosystem equilibrium (see http://www.newforestlife.org.uk/). The effects of grazing in riparian areas must be studied for each particular case and no generalizations can be made. More research is needed to understand the ecologically very important plant/animal interactions that influence riparian areas in silvopastoral systems.

Conclusions

The increasing awareness of the environmental importance of riparian corridors has led to growing interest in their conservation, in accordance with rural and natural area good practice guidelines. However, good management practices for riparian corridors have seldom been applied in spite of the economic value of some of the tree species involved and the important role of riparian vegetation in conserving biodiversity, in mitigating floods and delaying peak flood runoff and in stabilizing banksides.

Therefore, it is indispensible to increase public awareness of the environmental and economic importance of these vital and unique ecosystems. There is also a strong need for practical intervention through specific management actions, based on knowledge already obtained through scientific investigation and experimentation, in order to preserve this important biological resource in a sustainable manner. Rehabilitation and sustainable management of woody riparian corridors are essential for protecting t he biodiversity and sustainability of aquatic ecosystems, as well as their ecological integrity.

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5 Case Studies

A SINGLE LANDOWNER IN A RURAL AREA: PAUL DA GOUCHA MITIGATION PROJECT

Ana Mendes, Carla Faria, André Fabião, Artur Ribeiro
Rui Peixoto, Rosário Fernandes, Maria Teresa Ferreira
António Fabião, Maria Helena Almeida, Dalila Espírito-Santo
Rita Hipólito, José Carlos Ferreirinha, Vanda Nunes
Joaquim Rosa do Céu

Introduction

The Paul da Goucha environmental restoration project started in January 2005 and comprised one of the several restoration initiatives developed through the Ripidurable project. Paul da Goucha is situated in an alluvial depression in the south of the Alpiarça municipality. It is an area that has been heavily influenced by human activity, such as agriculture, livestock and quarrying of aggregates. The latter activity has significantly affected vegetation cover and in some areas has created small artificial lakes, which have been used subsequently for dumping litter and building waste. Paul da Goucha is a unique natural heritage site in the national context and its degradation threatens its preservation. In fact Paul da Goucha possesses some unique characteristics:

- It is a priority habitat, according to the Directive 43/92/CEE, namely willow and alder wet woodlands (91E0pt3)

- This area contains the largest wet willow woodland in Portugal and one of the rare wetland woods of significant size still found in the South of the Iberian Peninsula

- Within the wetland wood there is an eleven thousand year old mire.

- The area contains several threatened vertebrate species

- The area suffers from signs of degradation and human pressures, which can compromise its viability as a natural system.

In this context, the Alpiarça Municipal Council (AMC) aimed to mitigate the effects of aggregate quarrying activities on the ecosystem and natural landscape values. Since this is a task that will almost certainly take many years to conclude, the Ripidurable Project allowed the AMC to come into contact with other European realities and their "know-how" in the implementation of river and riparian habitats restoration techniques. The Paul da Goucha restoration project comprised two areas: mitigation of habitat degradation and Nature interpretation. In this chapter we refer to task development, from conception to implementation "on the ground".

Objectives

It is important to make clear that the aggregate quarrying activities had caused significant impacts on the ecosystem and that it was not possible to restore it to its initial state. The intervention can not be considered as a formal habitat restoration initiative, since it was not possible to return to the pristine natural conditions; this is a habitat mitigation initiative, therefore the techniques implemented were conceived to lead to the development of a new ecological state. The project aimed to recreate the conditions that would facilitate the establishment of natural riverine vegetation in the Paul da Goucha.

Within the Paul da Goucha Environmental Requalification Project, the AMC aimed to achieve the following additional objectives:

- Develop feeding, breeding and refuge habitats for aquatic birds;

- Plant native species that could lead to colonization of the area;

- Develop an environmental interpretation centre to promote the importance of river habitat restoration and the role of these habitats as ecological corridors.

Planning, execution and results

General characterization of the area

In order to become acquainted with necessary elements and the most appropriate management measures, a survey of the situation “on the ground” was carried out beforehand (table 5.1.1).

Data were collected during 2005 and brought together during 2006; monitoring of intervention measures was undertaken during the entire period of the project (until June 2008) and after the projects conclusion.

The systematic collection of these elements allowed characterization of the area in detail sufficient enough to allow the development of intervention plans. Here, we summarise the most relevant aspects taken into account for the development of tasks.

The area to undergo restoration, identified by a red polygon in figure 5.1.1, has a total area of 29.5 hectares and is partially included in the wetland area known as Paul da Goucha. It is part of an alluvial zone that is crossed by the Vale de Atela River, a permanent watercourse with a catchment area of 92km^2 (figure 5.1.2).

As a humid area, Paul da Goucha is not under any form of legal protection, although the aim is to have the site classified in the future, in order to prevent this situation. In the Municipal Development Plan (MDP), which was approved in 1994 there is no conservation, management or monitoring plan (Resolution of the Council of Ministers 14/94, 15th of March, ratification Resolution of the Council of Ministers 90/2001).

However, this is a Habitat Directive 43/92/CEE priority habitat with 91E0 Alluvial forests with Alnus glutinosa, 92B0 (Riparian formations on intermittent Mediterranean water) and also 7140 (Transition mires and quaking bogs). Furthermore this is the largest willow wet woodland in Portugal, with the oldest trees between 35-40 years old (Rodriguez, personal communication 2006, information taken from core samples).

The AMC is the sole owner of the land where the intervention tasks took place; the surrounding area and the area of greatest ecological value are privately owned.

Geologically, the area comprises Pleisto-Holocene alluvial deposits; there are also transition mires at the end of the catchment, with deposits that are over 8 metres thick (CONSMAGA, 2002).

Tabe 5.1.1 Aspects considered for a survey of the situation “on the ground”.

- **1 Situation**
  - Geographic location
  - Legal situation
  - Management and planning issues
- **2 Physical Characterization**
  - Geology
  - Pedology
  - Hydrology
  - Climate
- **3 Biological Characterization**
  - Flora
  - Vegetation
  - Fauna
  - Biotypes
- **4 Landscape units**
- **5 Natural Heritage Characterization**
  - Architectonic Heritage
  - Archaeological Heritage
  - Ethnographical Heritage
- **6 Socio-Economics**
  - Population
  - Human Activities
  - Tributaries
  - Pollution

Figure 5.1.1 Cartographic map with geographical location of the requalification area (Military Map number 353 - 1:25 000).

Figure 5.1.2 View of the Goucha valley where the Paul and associated landscapes are situated (Photo: Ana Mendes)

Previously the Paul da Goucha area would have been a permanent freshwater body with partially immersed emergent vegetation during the growing season. The vegetation would probably have been dominated by mixed stands of *Salix* spp. However, in the past a change of land use to agriculture has been documented.

The water level would have been kept low by river regulation in order to allow the culture and irrigation of traditional crops such as maize and rice. As a result of this regulation, the area silted up due to natural factors (sediment transport during periods of rainfall and periodic flooding) and human impacts (removal of aggregate, north of the river). The sedimentation, the confined space and successive flooding resulted in the abandonment of agricultural activities in the recent past (20 years according to CONSMAGA, 2002); as a result, this area, rapidly underwent a transition/ succession to a wetland area, as it was in the past.

In its present state, the drainage basin of this small river has undergone considerable sedimentation, which impedes water flow. Based upon data on the relative age of the oldest trees in the area, agricultural activities were abandoned at the beginning of the 1970's.

Intensive quarrying of aggregates began in 1980 and by 1993 major changes in the vegetation cover of the Paul and the surroundings become evident. Quarrying activities ceased in 2000 via an agreement with the AMC and also as a result of the interest of preserving a Natural Heritage area. Meanwhile, as the excavations left by the quarrying were abandoned, they were filled with rubble from varied origins and also difficult to characterize. It is important to note that a confined area was used as a landfill site for domestic waste; the site was sealed following cessation of use. These alterations, deposits and excavations can be compared using aerial photographs taken in 1993 and 2007 (figure 5.1.3).

A major concern since the beginning of the project was possible water contamination of the lakes and the Paul adjacent to the sealed landfill site. The study developed for the "Sealing and Environmental Recovery of landfill sites of the Tagus Lezíria region – Left Margin of the Tagus" mentions that the clay layer that surrounds the landfill site acts to isolate contaminants. This fact is confirmed by results of water and sediment analyses from samples taken form the lakes next to the sealed landfill site. The analyses were carried out by independent certified laboratories; the results allow us to conclude that the water and sediments did not contain levels of pollutants above the legal values (table 5.1.2).

Figure 5.1.3 Aerial photographs of the work site in 1993 (a) and 2007 (b).

Table 5.1.2 Results of water and sediment analyses carried out by the Environmental Institute.

Sample type – Surface Water
Sampling point – Pedreira do Hilário Lake
Sampling date – 27/06/2006

	Recommended Maximum Acceptable Value (MAV) Water for human consumption	Recommended (MAV) Irrigation water	Recommended (MAV) Surface Waters (minimum quality)	Result
Amonia nitrogen			5 mg/L	< 0.08 mg/L
Kjeldahl nitrogen			3 mg/L	< 0.50 mg/L
BOD5			10 mg/L	< 3 mg/L
Conductivity	1000 µS/cm			629 µS/cm
COD	30 mg/L			23 mg/L
Phosphates	0.4 - 0.7 mg/L			< 0.1mg/L
Total Phosphorous			1 mg/L	0.12 mg/L
Nitrates	25 mg/L	30 mg/L		< 1.0 mg/L
Nitrites	25 mg/L	30 mg/L		< 0.05 mg/L
Total solids in suspension	25 mg/L			29 mg/L
pH (laboratory)			9	8.3
Temperature (pH)	22 °C		30 °C	22 °C
Arsenic	0.01 mg/L		0.1 mg/L	3.3 µg/L
Cadmium	0.001 mg/L		0.05 mg/L	< 0.5 µg/L
Lead			0.05 mg/L	< 5 µg/L
Copper	0.02 mg/L		0.5 mg/L	< 0.04 mg/L
Crhrome			0.05 mg/L	< 2 µg/L
Mercury	0.0001 mg/L		0.001 mg/L	< 0.10 µg/L
Zinc	0.5 mg/L		1 mg/L	< 0.05 mg/L
Nickel			0.05 mg/L	< 5 µg/L
Calcium				44 mg/L
Magnesium				21 mg/L
Total hardness				0.20 g/L

Sample type - Sediment
Sampling point – Pedreira do Hilário Lake
Sampling date – 27/06/2006

	Reference value*a mg/kg	Result mg/kg
Cadmium	20	2
Copper	1000	24
Lead	750	31
Zinc	2500	59
	g/kg	g/kg
Kjeldahl nitrogen	-*b	1.7
Total nitrogen	-*b	1.9
Total phosphorous	-*b	69
Polycyclic aromatic hydrocarbons (PAH)		**Result µg/kg**
Aenafthene	6	<4.8
Acenaftylene	6	<4.6
Anthracene	6	<4.4
Benzo(a)anthracene	6	26.5
Benzo(a)pyrene	6	<3.6
Benzo(b)fluoranthene	6	27.1
Benzo(g,h,i) perylene	6	<14.2
Benzo(k) fluoranthene	6	<2.4
Crisene	6	<3.6
Dibenzo(a,h)antrachene	6	<11.3
Fenanthen	6	<5.3
Fluoranthene	6	35.2
Fluorene	6	5.4
Indeno(1,2,3-c,d)pyrene	6	<11
Napthalene	6	37.6
Pyrene	6	35.3

* Concentration Limit value for organic compounds in muds destined for agriculture, in accordance with Decreto-Lei 446/91, Portaria 176/96 (2ª series) 3rd of October.
*a Concentration Limit value for heavy metals in muds destined for agriculture, in accordance with Decreto-Lei 446/91, Portaria 176/96 (2ª series) 3rd of October.
*b not defined

The present vegetation cover in Paul da Goucha comprises different types of vegetation related to specific habitat types. Generally speaking, the most abundant species is the Large Grey Willow (*Salix atrocinera*); the invasive exotic Parrot Feather Water Milfoil (*Myriophyllum aquaticum*) is also highly abundant.

Concerning the fauna there are 11 recorded fish species, 13 species of amphibians, 17 species of reptiles, 167 bird species and 27 mammal species. Twenty five of the recorded bird species are listed in figure 1 of the Habitats Directive, 8 of which are protected since they are listed as "endangered" by the Vertebrate Red Data Book for Portugal (Cabral *et al*., 2006); 82 species are know to nest in the area. One of the 27 mammal species is classified as critically endangered and another as "vulnerable" (Cabral *et al*., 2006).

Intervention project

The requalification project was drawn up over several discussions and meetings with a range of experts in order to meet the proposed objective. During the early phase of the project, the environmental consultancy service of the Wetlands and Wildfowl Trust were contracted to draw up the project concept. The function of the project concept was to analyse the following areas: target groups, access, interpretive and educational principles, material for publicity, opportunities and limitations, phasing of operations. At this phase the requalification project was divided into 4 areas, with each comprising distinct periods of intervention. Area A comprised the space between the sand quarry ravines and the sealed landfill site; area B represents the area of the sealed landfill site and the larger lake. Areas A and B were defined as priority habitat recovery areas. Area C comprised the area where "montado" was present where the interpretive walkways would be placed. Area D comprises the entire wetland area around the Paul, which is private property and also has the greatest ecological value.

The initial concept plan took into consideration that the implementation of an economically sustainable interpretation centre would require a sufficient number of visitors. Thus, intervention phases were defined that followed one another over time (figure 5.1.4); at the same time, a study of the necessary human resources was carried out.

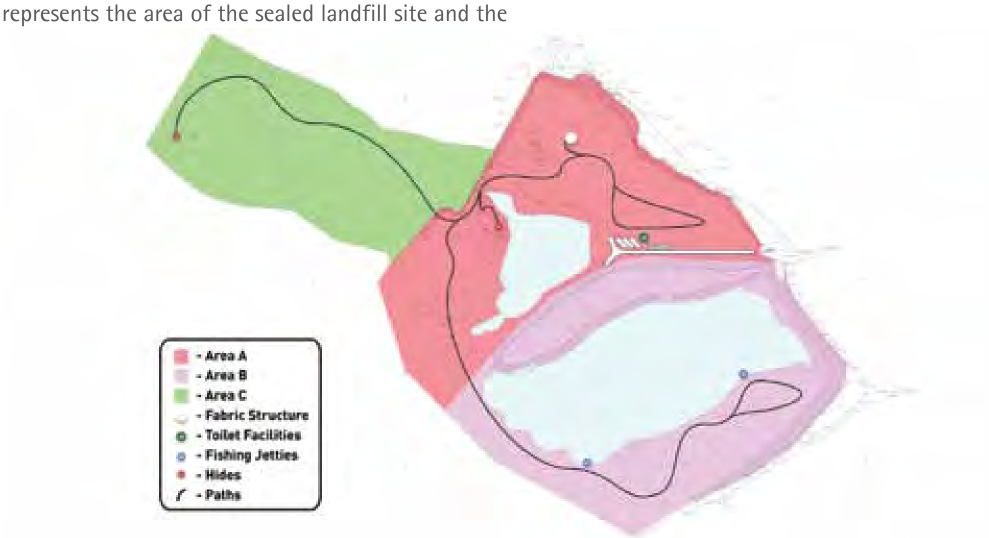

Figure 5.1.4 Map of the intervention areas from the concept plan.

Phase 1 interventions concentrate on areas A and B, in particular the following activities:

- Land clearance in area A and the incorporation of soil suitable for plant growth.
- Retention of the Sand Martin (*Riparia riparia*) nesting ravines and the placement of trails at a suitable distance so as not to disturb nesting;
- Landscaping of the lake margins, so that the margin height permit the development of plants and provides suitable feeding, nesting and sheltered habitats for birds;
- Landscaping of the island in the middle of the lake in order to make it more suitable for aquatic birds;
- Development of interpretive nature trails around the lake.

Necessary personnel: 1 educator that can travel to the site when visits are being made.

Phase 2 anticipated habit creation measures and improved conditions for visitors:

- Creation of several small lakes in area A, to provide habitats for amphibians, dragonflies and other invertebrates;
- Creation of a reedbed, wetland wood and areas of open water (removal of exotic species);
- Creation of an artificial lake for environmental education activities such as the identification of macroinvertebrates;
- Landscaping and planting in area B, as well as the placement of walkways;
- Placement of observatories.

Necessary personnel: 2 or more educators, according to the number of organized visits that can travel to the site when visits are being made.

Phase 3 should attract the adjacent landowners (area D) to join the project hereby allowing the management of marginal habitats in such a way that would favour and maintain the ecosystems and natural values.

Necessary personnel: 3 or more educators, according to the number of organized visits that can travel to the site when visits are being made.

Phase 4 should assess whether the area attracts a sufficient number of visitors to justify the implementation of the interpretive centre. If this is the case, the following infrastructures will be necessary: a car park, public toilets, a bar, improvements to the interpretive trails and an activity area.

Figure 5.1.5 General plan and drawings of the works presentation project.

Necessary personnel: centre manager, 2 permanent staff members, 3 or more educators and 2 or more filed workers, according to volunteer and local community response.

Following conclusion of the project concept, a team of biophysical engineers was contracted to draw up a detailed work plan (figure 5.1.5 and table 5.1.3). Details were given on the characterisation of the site and the concept plan. Several meetings were held with the aim of making clear what would take place at the site in order to meet the project objectives.

Following the presentation of the preliminary project, a series of meetings were held with specialists from different areas (biologists, forestry engineers, ornithologists) in order to assess the components of the preliminary project.

The choice of trees, shrubs and herbaceous plants, as well as the location of observatories and interpretive trails, was subject to rigorous analyses. Concerning the choice of plants, only species that already existed in the catchment area of the region were considered (left margin of the Tagus), based upon floristic surveys carried out by the Instituto Superior de Agronomia as

Table 5.1.3 Elements of the detailed work plan.

Description		Content
Written elements	Technical memorandum	Characterization: evaluation of the area (strong and weak points, opportunities, threats), intervention objectives, proposal of intervention estimate of costs.
	Dossier of specifications	For each of the following elements the criteria for measurement, description of the article and technical conditions are given: ▪ preparatory work (demolition and clearance) ▪ heavy landscaping (digging, landfill, land lending) ▪ Pavements, covering, kerbs and guttering (crushed material base, tout-venant, sand/clay pavement, concrete and wooden kerbs, gutters) ▪ Planting (general preparation of the land, planting of trees, shrubs and herbaceous plants, seed bearing plants). ▪ Furniture, equipment, fencing and gates (bench and tables, information boards, support structure for environmental education) ▪ Other tasks (construction and dismantling of work depot, final covers) ▪ Responsibilities and guarantees
	Measurements and quotes	Quantification of costs for quantities and unit price for each item mentioned in the dossier of specifications.
Designed Elements	General plan	General aspect of the entire work plan with introduction to most of the elements.
	Altimetry	Topographic survey of the work area
	Planimetry	Planimetric modelling to be achieved during project execution
	Tree planting plan	Specification of the areas where each species of tree will be planted
	Shrub planting plan	Specification of the areas where each species of shrub will be planted
	Seed and herbaceous planting plan	Specification of the areas where each herbaceous and seed producing plants of tree will be planted
	Paving, equipment and drainage plan	Plans of locale of pavements, equipment and drainage to implement
	Detailed work plan	Details of implementation of pavements, equipment and drainage

part of the Ripidurable Project. Plants that were not native to the region were excluded.

The location of observatories and interpretive trails were based on the recommendations of Andrews and Kinsman (1990) concerning measures that favour nesting activity and minimize disturbance. Special care was taken concerning the nesting of the Sand Martin (*Riparia riparia*). The discussed aspects were later included in the final project.

Execution

Preparatory work (demolition and clearance)

Requalification work began in 2005, despite the fact that the project had not been approved at this time and that the site was still under characterization in order to draw up the intervention project. An initial evaluation indicated the urgent removal of all litter and building debris in the area in order to free the avaialbe area for work (figure 5.1.6).

During this phase it was also possible to obtain more information on the type of waste that was used in the past to fill the excavations resulting from quarrying aggregates. There were essentially 3 types of waste: waste originating from aggregate quarrying (itself deposits not suitable for aggregate); building waste (bricks, concrete, asphalt and sand deposits mixed with debris) and waste containing pollutants such as car batteries, refrigerators and leftover pesticides. This last group was present only in residual amounts.

Figure 5.1.6 General aspect of the work area before (1) and after the clearing operations (2) (Photo: Ana Mendes).

Landscaping

This task was characterised by the following conditions:

a) Landscaping of excavations and bankfaces were carried out to give regular surfaces;

b) Existing trees were not cut down unless express permission was given by the site supervisor; some cutting back was carried out only when absolutely necessary.

c) Material resulting from excavations was transported offsite to deposit sites; excess was sent to tips;

d) Measures were taken to reduce local scale erosion following excavations;

e) Removal of giant reed (*Arundo donax*) included removal of the whole plant and rhizomes, in order to reduce it spreading across the area.

f) Work was overseen by AMC and ISA on a daily basis, facilitating on the spot alterations to the original plan whenever necessary. AMC and ISA's constant presence became essential for putting the project plans into effect at the work site;

g) Material used in the pits consisted of soils and other materials obtained during on site excavations that met the requisite technical conditions;

h) Wherever possible, the introduced soil did not contain plant remains, litter or other types of organic or inorganic debris;

i) Compacting of the topsoil was avoided in the areas destined for planting;

j) During construction of the pit, care was taken to place the poorest soils at the pit base and reserve the better quality soils for the bankface surface.

Figure 5.1.7 General aspect before landscaping (1 and 2) and during the final phase of landscaping (3) (Photo: Ana Mendes).

Paving, coverings, kerbs and guttering

Implementation of technical specifications given in the dossier of specifications was carried out after planting had taken place. Ideally, this should be carried out after the placement of paving, coverings, kerbs and guttering. However this was not possible due to a number of delays; therefore planting went ahead before the placement of these structures. In figure 5.1.8, we can see the general aspect of the kerbs for the interpretation trails.

Figure 5.1.8 General aspect of the kerbs used for the interpretation trails (Photo: Ana Mendes).

Planting

Following clearance of litter and waste and landscaping, clean topsoil was spread in a 15cm layer over the site (figure 5.1.9) using a bulldozer. Although fertilization with organic manure is recommended, this was not carried out, since it was considered that the plant species would tolerate well the conditions offered on site.

The planting schemes involved the planting of 28 different tree and shrub species, approximately 575 trees and 942 shrubs, most of which were containerized. It was necessary to colour code (the pot and trunk) each species in order to facilitate identification by the team in charge of plantings.

Prior to planting, the area was staked out using colour coded stakes corresponding to each of the species to be planted, in accordance with the plan that had been drawn up. Planting was carried out by digging using an automatic excavator (figures 5.1.10, 5.1.11 and 5.1.12).

Figure 5.1.9 General aspect of the topsoil (1) and spreading over the site (2) (Photo: Ana Mendes).

Figure 5.1.10 Detail of colour coded stakes to aid recognition of the species to plant (1) and the holes used to plant trees and shrubs (2) (Photo: Ana Mendes).

Figure 5.1.11 General planting sequence (Photo: Ana Mendes).

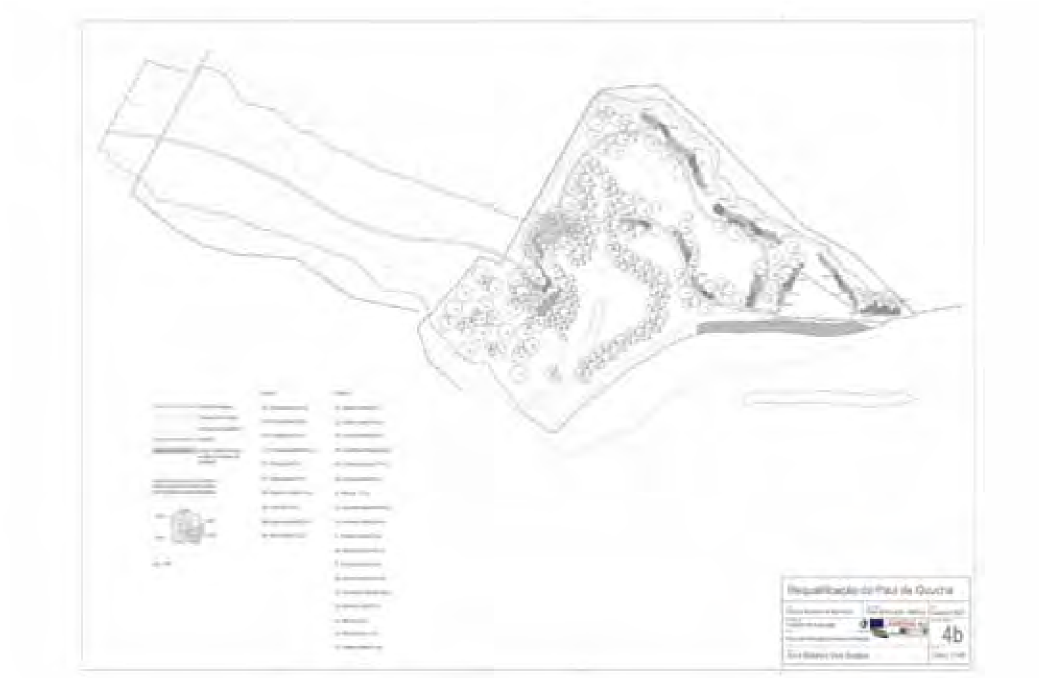

Figure 5.1.12 Planting plan for trees and shrubs in the works project.

Trails and observatories conceptualization

Trails and localization of observatories were defined together with the pedagogic stories and natural values that the project aimed to divulge and promote. General objectives were laid down in a primary phase, such as the type of public conduct we wished to promote as a result of the proposed activities:

a) Inspire and challenge people by taking positive actions and measures with the Paul da Goucha and the natural environment in general to:

- No longer use the Paul for dumping waste;
- Stop illegal hunting;
- Regulate fishing;
- Inform anglers about the fish species with greater environmental impact;
- Stop using the watercourses that flow into the Paul as wastewater channels;
- Explain the negative impact of the excessive use of fertilizers and pesticides to the population;
- Explain how water for human consumption becomes contaminated;
- Respect nature (no egg stealing from bird nests; explain what is passive stealing; not to kill snakes, lizards and frogs).

b) Keep visitors/people informed of how the Paul da Goucha is managed to:

- Divulge the importance of the Paul da Goucha in a European context;
- Divulge the existing species of flora and fauna.

c) Promote and develop the involvement of the local population surrounding the Paul.

d) Promote and develop interaction between people and wildlife for the benefit of both parties and sustainable development.

e) Invite visitors to contribute to future informative placards (*e.g.* via thematic exhibitions and debates).

f) Develop environmental initiatives promoted by the private sector and NGO's.

Some of the proposed objectives were put into practise using various trails along the intervention area. Each trail was given the name of a bird and had an associated message with an environmental theme. The following trails were defined:

- Martin/Pipit trail, which aims to illustrate bird migration and the importance of habitat protection. The species found along this trail vary over along the year, *i.e.* Martins occur during the spring and summer, while pipits occur during the autumn and winter;
- The Kingfisher trail aims to illustrate the whole restoration project carried out in the Paul da Goucha and the species that can be found there;
- The Grey Heron Trail, that illustrates the importance of water and its effects on vegetation and animals.

The language used was chosen in accordance with the previously defined target public - the students - since they potentially can help to convey a greater short, medium and long term impact concerning the level of preservation of the Paul da Goucha. By contracting a design company, the most suitable aids to be used in the Paul da Goucha were defined in order to catch visitor's attention (figure 5.1.13).

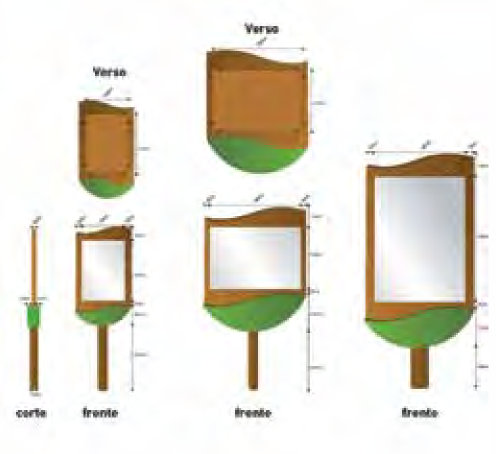

Figure 5.1.13 Technical designs of the informative placards created for the Paul da Goucha.

The observatories were placed in areas that allowed a good view of the whole area but did not disturb the birds. The observatories were equipped to allow wheelchair access. Figure 5.1.14 shows the interpretation plan.

Figure 5.1.14 General scheme of the implemented interpretive plan.

Environmental Education visits

A range of activities for visitors throughout the year was developed in such a way that they would not be exhausted in just one visit. Care was taken to make sure that the content of the activity programme covered several disciplines of the National Curriculum.
The following educational activities were created:

- Water gymkhana
- Let's get to know the birds of Paul da Goucha
- Educational theatre "The kingfisher"
- Let's discover the Paul lake
- I have a little house just like that
- Interpretive trails (with or without guide)
- Predator and prey
- Let's protect birds
- Sing with "Ripi"

For each of the listed activities, associated activities were designed to be carried out by visitors once they have left the area, with the aim of motivating the public to return and discover more about the natural space they have visited. Figures 5.1.15 to 5.1.17 show some of the educational material created for on site and offsite activities.

In order to draw public attention to the activities being developed at Paul da Goucha and attract them to the site, a stand was created divulging some of the messages integral to the Ripidurable project (figure 5.1.19). Hopefully, the project will start a process of attracting the public to the site thereby increasing awareness to the importance of the sustained equilibrium of Nature and its role in Man's well being. A specific aim of the project is to increase awareness on the important role of riverine vegetation in improving water quality, in flood prevention and as a filter of pollutants.

Figure 5.1.15 (1) Educational package for activities “Let’s get to know the birds of Paul da Goucha”; “Let’s discover the lakes of the Paul”; “Let’s protect the trees”, amongst others (2) Case for keeping work carried out during the visit. (3) Worksheets created specifically for the “Let’s discover the lakes of the Paul” activity.

Figure 5.1.16 Didactic game for children over 7 years old.

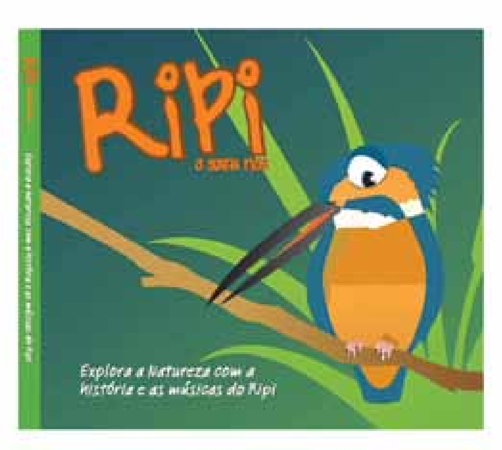

Figure 5.1.17 Accompanying activities CD for singing and exploring the sounds of nature; it includes the songs from the didactic play and other sounds.

Figure 5.1.18 Educational play “The kingfisher” (Photo: Ana Mendes).

Figure 5.1.19 Triptych stand for use in education, farming and natural space management fairs.

Results

Habitat recovery

It was only possible to obtain a submerged slope of 14% (1.7m depth in an area of approximately 5m) and not 7% below the water surface (1m depth in an area of approx. 15m), as was previously planned in accordance with Andrews and Kinsman (1990). This objective was restricted by the machinery used and the steep underwater vertical slopes (5 metres vertical depth), which was plainly unsafe for the bulldozer operator, illustrated in figure 5.1.20).

The softening of the terrestrial slopes was easier to carry out, respecting the original plan wherever possible. Other areas within the work area were also used to control surface drainage of rainwater and subsequent erosion.

As work was underway, improvements were constantly made that further improved the habitat recovery process. Main project alterations were:

1) Creation of an artificial lake for (a) environmental education activities such as the identification of macroinvertebrates and (b) to provide habitats for amphibians, dragonflies and other invertebrates;

2) Landscaping of the island, which although not present in the plan, was carried out during the works;

3) Landscaping of the southwest margin of the lake using natural engineering techniques;

4) Partial landscaping of the lake by the east bank (found to be used by freshwater turtles as a sunbathing area).

The artificial lake for educational activities was introduced in order to make use of the spring that was found when landscaping work first got underway. Although previous indications pointed towards a high water table in the area, it was found that the artificial lake could be created with only a shallow excavation (figure 5.1.21).

The island in the lake was very steep, a factor that had to be corrected, since it prevented the development of vegetation typically occurring in the region. This correction was not included in the initial plan due to budget restrictions. However, once heavy landscaping (earth movements) was underway, it was found that the excavated spoil could be used to reach the island and correct its steep slopes. The operation greatly improved bird habitats since it created a place where they could shelter (figure 5.1.22).

A less positive aspect of this type of task is the difficulty in carrying it out at a time that causes the least disturbance to birds (August-September). Due to delays in contracting a company to carry out this work, the task was carried out during the most sensitive part of the nesting period (April-May). However, since the site had been covered in debris and subject to the constant movement of Lorries

Figure 5.1.20 Final phase of work (1 e 2) and problems with submergence of heavy machinery due to the extreme underwater slopes (3) (Photo: Ana Mendes).

and other vehicles for several years, the impact was considered to be minimal in this first year. However it is important to emphasise that the season that causes the least impact on bird and animal reproduction should be chosen.

Landscaping of the southeast margin came about following a course on Natural engineering that took place in Tuéjar, organized by the Valencian partner CIEF. The idea was discussed with the course organizers, after the stage at which the Paul da Goucha requalification works were at was assessed. This initiative resulted in the creation of a more open area of water through application of two techniques. Available soil was used to reduce the depth around the margins. Also, deeper excavations were made next to the margin in order to reduce the submerged slope (figure 5.1.23).

Figure 5.1.21 Creation of the artificial lake with habitats for amphibians, insects and macroinvertebrates (Photo: Ana Mendes)

Figure 5.1.22 Sequence of work on the lakes island: initial aspect (1); beginning of works (2); final phase (3) e after 6 months (4) (Photo: Ana Mendes).

Figure 5.1.23 Initial aspect of the east margin following intervention (1) and after 6 months (2) (_____ initial location of margin) (Photo: Ana Mendes).

The introduction of other natural engineering techniques in the Paul da Goucha was suggested for improving the habitat and landscape. A natural engineering practical course was held in conjunction with the need to introduce a number of techniques at the site and the need to pass the knowledge to personnel working in the environmental area.

During the course, the following techniques were used (figures 5.1.24 and 5.1.25).

- Cribwall;
- Woven fences;
- Fascines;
- Brush mattress;
- Bio-rolls.

Figure 5.1.24 Construction of the cribwall to prevent erosion (1) general aspect (2) detail following budding (3) (Photos: Regina Carriço, 1 and André Fabião, 2 and 3).

Figure 5.1.25 Woven fences (1); fascines (2); brush mattress (3) and bio roll (4) (Photos: Regina Carriço, 1 and 2, and André Fabião, 2 and 3).

Reduction of the slopes led to the rapid proliferation of the exotic invasive Parrot Feather Watermilfoil (*Miriophyllum aquaticum*). This species must be controlled by mechanical clearance in order to allow native species to colonize the site (figure 5.1.26).

At the same time, there was rapid colonisation by Grey Heron (*Ardea cinerea*), Mallard Ducks (*Anas platyrhynchos*), Common Moorhen (*Gallinula chloropus*) and Little Ringed Plover (*Charadius dubius*) on the east margin. These first species are extremely common and tolerant of human presence, thus their colonisation of the site is no surprise since the ecological conditions at the site allowed the development of feeding areas (used by the offspring of these species). The Little Ringed Plover is a pioneer species that tends to disappear from the area as aquatic vegetation develops.

Figure 5.1.26 Proliferation of vegetation at the beginning (1), after 6 months (2), after 1 year and (3) after 2 years (4) (Photo: Ana Mendes)

Improving colonization potential of the space by planting with native species

After the first Spring, the survival rate of the planted tree specimens was determined (see table 5.1.4). That evaluation showed a survival rate of 68%, and a mortality rate of 14%. One situation that was not forecasted at the beginning of the project was the theft of plated trees, wich ocurred 7% of the cases (figure 5.1.27); there was a notable preference for the Black Poplar (*Populus nigra*) and the Strawberry Tree (*Arbutus unedo*).

Table 5.1.4 Percentage survival resulting from the planting operations carried out in the Paul da Goucha (per species).

	Percentages per species				
	Nº planted	Alive	Dead	Stolen	Not found
Alnus glutinosa	51	56,86	31,37	7,84	3,92
Arbutus unedo	36	52,78	19,44	16,67	11,11
Celtis australis	43	95,35	2,33	0,00	2,33
Frangula alnus	23	60,87	13,04	0,00	26,09
Fraxinus angustifolia	71	70,42	5,63	1,41	22,54
Pinus pinea	37	75,68	18,92	0,00	5,41
Populus nigra	80	53,75	18,75	22,50	5,00
Quercus suber	22	81,82	18,18	0,00	0,00
Salix alba	72	63,89	19,44	8,33	8,33
Salix atrocinerea	64	59,38	4,69	4,69	31,25
Salix salvifolia	51	76,47	9,80	0,00	13,73
Tamarix africana	25	100,00	0,00	0,00	0,00
Total	575	390	79	38	68
Total in %	100,00	67,83	13,74	6,61	11,83

Figure 5.1.27 Dead *Salix alba* (1), live specimen of *Arbutus unedo* (2) and signs of vandalism (3) (Photo: Ana Mendes).

Stealing occurred mostly in the more visible/ accessible areas, facilitated by the presence of stakes used during the planting process. Concerning species counted as “not found”, landscaping of the area led to the rapid development of pioneer river vegetation that complicated the elaboration of inventories and compromised the chance of plant survival (figure 5.1.28). This latter category includes dead and stolen specimens, those hidden by vegetation, buried by heavy landscaping etc.

As previously mentioned, earth movement improved the potential natural recolonization of the area, made evident by the fact that 64 inventoried tree specimens (*Populus* spp. and *Salix* spp.) regenerated naturally, a very good indicator of reaching project objectives.

Although invasive Giant Reed plants were removed 2 years ago, they reappeared, indicating that new work will have to be undertaken to control this invasive species.

Figure 5.1.28 Illustration of the difficulty in carrying out inventories of surviving plant in some locales (1); growth of some planted trees (2); reappearance of the invasive *Arundo donax* (3) (Photo: Ana Mendes).

Implementation of the Paul da Goucha interpretation complex

Over the entire period of the project, several environmental education visits with schools from the municipality took place (figure 5.1.29). A total of 6 visits by 159 students were made in order to assess the public interaction methods and establish objectives for the end of each visit.

It is important to take into account that, in order to guarantee the quality of the visits, there should be one educator per group of 25 children and 1 assistant per group of 5 children, ensuring that the children can meet the educational objectives of the activities. Preferentially, meetings should be held with teachers that will accompany the students prior to the visit, so that they become involved in the activities that will take place.

Figure 5.1.29 Examples of some environmental education activities: water gymkhana (1); Let's get to know the birds of the Paul" (2); "Let's get to know the pools of the Paul" (3); "Freshwater turtles" (4) (Photos: Ana Mendes, 1 to 4 and Regina Carriço, 5 and 6).

Final considerations

The Ripidurable project aimed to develop a pilot recovery project of part of the Paul da Goucha in Alpiarça, where negative impacts resulting from the quarrying of aggregates had led to an increase in local levels of pollution.

Some delays and financial restrictions, due to the pioneering nature of the project, compromised the initial plan of work. However, it is important to emphasise that a project of this nature demands constant adaptation to the conditions that materialize on site.

Despite the fact that some plantings and interpretive trails have not been completed, the site will serve to provide environmental information to the population in order to bring about changes in conduct and to promote understanding of the importance of the 'rivers and vegetations' role in the natural water cycle.

The local council intends to go ahead with classifying the Paul da Goucha as a "Regionally Protected Landscape", as a result of its natural values and to continue the environmental requalification process, which will take some years to achieve.

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Acnowledgements

António Albuquerque, João Oliveira, Jorge Gonçalves, José Maria Santos, Patrícia Rodriguez-Gonzalez, Paulo Barreiros e Sérgio Marques

SEVERAL LANDOWNERS IN A RURAL AREA: REHABILITATION OF THE GANDUM AND THE ALMANSOR

Filipa Pais

Introduction

The increasing recognition of riparian habitats as areas of high biological diversity and of their important role as suppliers of multiple environmental services is the main cause of the growing interest in conserving and recovering this type of nature systems. However, in spite of being more and more conscious of the limits of natural resource sustainability, we humans continue to carrying out actions that alter the environment negatively and rebound on ourselves. Excessive water extraction and diversion, replacement of the riparian buffer strip by crops and pastures or the contamination of water with nutrients from agriculture and cattle are some of the impacts that alter the physical structure of fluvial ecosystems and facilitate the proliferation of invading species at the expense of native vegetation, resulting in a loss of the river's natural values

With these concerns in mind the Montemor-o-Novo Municipal Council (CMMN), through partnership in the RIPIDURABLE (INTERREG IIIC) project, has undertaken a series of actions since 2005 to restore and upgrade two river reaches; the first is situated on the Gandum stream and the second on a principal watercourse, the Almansor river.

The complexity and dynamics of the intervention area were of a very particular nature, falling far short of the environmental quality that could be expected of this type of waterbody: the sites were very degraded, lacked structure and exhibited flow problems.

Being aware that the water courses were extremely degraded and their functions (biophysical, landscape, socio economic and hydraulic) were affected, resulting in loss and degradation of habitats (as well as other natural values), the CMMN proposed to restore and upgrade them in an ecological restoration project. This aimed to recover stream functionality and to provide the means to increase the associated biodiversity by rehabilitating the riparian gallery, with the intention of creating sustainable conditions that fulfil both social and ecological demands and link them together.

Objectives of the intervention measures

With the aim of reinstating some of the wellbeing that was formerly known to exist on the Gandum stream and the Almansor river, the principal objective of the CMMN was to bring these sites back into their natural equilibrium.

Clearing the banksides and channel followed by planting with riparian species typical of the existing habitat were some of the initiatives in this difficult task carried out by the CMMN as part of the RIPIDURABLE project. The objectives of the CMMN were to:

- Promote the upgrading and sustainable use of the degraded riparian gallery, resulting in diversification of its use and in environmental conservation.
- Improve the knowledge of the natural characteristics of the local riparian galleries, including their use as ecological corridors and interaction with other elements of the local flora and fauna.
- Identify technical solutions and methods for the restoration and promotion of local riparian galleries, and divulge the findings to other interested parties.
- Return to ancestral uses of the riparian gallery, including the promotion of sustainable forms of tourism and of education-based activities, thereby promoting rural development
- Increase landowner awareness concerning the maintenance and conservation of these areas
- Support other future initiatives.

General characterization of the reaches to be rehabilitated

Situated SW of the city of Montemor-o-Novo, in the area of Monfurado, the Gandum stream is approximately 5km long, has a basin area of approximately 536 hectares and is a major tributary of the Almansor river. The source of the stream is in an area of *montado* with an altitude of 190m – 362 m. The hydrological study of the stream reveals annual rainfall and runoff values of 700 mm and 220 mm respectively with a daily average flow rate of 0,037 cumecs (m^3/s). (Flebbe, 2002).

The reach for restoration, starting at the confluence with the Almansor River and ending next to the tracks that pass by the Reguengo and "Courela de João Pais" farmsteads, is approximately 2,800 metres long. It passes through 17 properties, 14 of which belong to private landowners, which made the management of this whole process very difficult. In previous studies by the Regional Directorate for the Environment and Territory the watercourse was classified as extremely degraded as regards the natural structure and function of different individual features.

Despite the extremely run-down state of the watercourse, mostly resulting from pig slurry discharges into the channel, in stretches with permanent flow it was still possible to find some small ponds of high ecological value .

It was also observed that the accompanying riparian vegetation showed drastic floristic impoverishment, exemplified by the absence of a continuous tree layer and a poor herbaceous plant community. However, some individual adult tree specimens of the two habitat types that tend to occur alternately along these kind of streams, *i.e.* Natura 2000 priority habitats 91E0, Common Alder woods, and 91B0, Narrow-leaved Ash woods (ICN, 2006a and 2006b), could be found in the area and gave a very valuable indication of how the river should be restored (for a closer description of the vegetation types see chapters 2.1.2 and 2.1.3).

During summer 2005 fieldwork, large, dense stands of Giant Reed and brambles were found all along the river. The proliferation of these species is often associated with habitat degradation and high nitrogen availability.. The Giant Reed stands were more extensive, reaching a total length of 1700 metres.

Figure 5.2.1 The Gandum river basin.

Figure 5.2.2 Predominance of infestant plants in the Gandum Stream (Photo: F. Pais).

General characterization of the intervention measures

Restoration actions comprising 3 phases began in 2004 in conjunction with the start of the project. The aim of Phase one was in situ characterization and understanding of the stream and preparing maps to support restoration measures. Phase one took place over the summer of 2004, when fieldwork was carried out along the whole stretch of the river. At the same time, given that it would be necessary to obtain the landowners' consent to carry out work along the Gandum, a series of contacts was made with landowners and land tenants in order to obtain authorization, which in most cases turned out to be a difficult and drawn-out process since the CMMN's proposed intervention was looked upon by many with suspicion and reluctance. Door to door contact was made with the landowners and public awareness sessions were organised. Only 11 of the 14 landowners gave authorization for restoration actions to take place; the remaining 3 landowners stated that they would carry out their own operations. With the aim of meeting the proposed objectives, the CMMN decided to restore a reach of approximately 800 metres of the Almansor River situated between the confluence of the stream and the river and the Ananil Mill. The CMMN did not need authorisation to carry out restoration measures here, since it is situated in an urban area

With all of the maps and authorizations in place, the CMMN requested a license to carry out works from the Alentejo Regional Coordination and Development Commission in accordance with Law 46/94 of 22nd February 1994.

The second phase began the restoration work. All of the legal requirements concerning preparing and implementing a call for public tender to execute the restoration work were concluded and work got underway during the first half of 2006. The restoration work comprised three steps, namely cleaning and clearing, planting the reaches and installing urban infrastructure.

Clearing of the Gandum and Almansor rivers was carried out manually using suitable tools such as mowers, chainsaws, strimmers and other such equipment. The contract work comprised:

- Cutting and removal of plant material: carried out up to a maximum of 10 metres for each bank; the work comprised close cutting of vegetation (herbaceous and shrubs) in order to maintain the root systems intact, thereby ensuring bankface stability, which was degraded through pig slurry discharge. Where necessary, dry and dead branches or branches that impeded water flow were removed

- Clearing of the river channel: this work involved removing living or dead plant material that impeded or affected the flow. Domestic trash, tyres and some large substrate materials were also removed

- Herbicide application: the CMMN applied herbicides in selected areas in order to control the growth of Giant Reed (*Arundo donax*) and brambles (*Rubus* spp.).

  This option was carefully researched, based on studies by Leal *et al.* (in Morgado, 2001) which demonstrate that chemical control of these infestants gives very satisfactory results compared to mechanical control methods. Visits made by specialists in this area under the auspices of the Project also confirmed chemical control as the most viable option to adopt.

Once the clearance operations were concluded, planting could begin. The planting operations comprised the second step of the second phase of the project and were carried out by the CMMN. Firstly, the areas to be planted were staked out using a pre-established colour coded system. The CMMN gardening team then planted the respective tree species, taking care to protect them – particularly from livestock, which was present on most of the adjoining properties. Protection was carried out using three methods: fencing the entire area, placing individual tubes and installing welded mesh tree guards. This work was carried out within another project underway in the municipality, the GAPS project – Active and Shared Management in Monfurado (Gestão Activa e Participada do Sítio de Monfurado) – co-financed by the European Commission (LIFE programme).

The plants reintroduced in the Gandum stream and the Almansor river came from the CMMN nursery and were produced from seeds and cuttings taken from the local stands. The species planted were *Alnus glutinosa*, *Fraxinus angustifolia, Populus alba* and *Salix salvifolia*.

Plant waste and residues were temporarily deposited of on adjacent land, then shredded and taken by the CMMN to the municipal plant nursery where they were processed in the municipal composting centre.

The third and final step of the second phase, the installation of urban infrastructure along the riverbanks, underwent some alterations. The planned

Figure 5.2.3 Examples of contracted restoration work carried out along the two reaches (Gandum Stream and Almansor River) (Photo: F. Pais).

Figure 5.2.4 Planting work carried out during the project (Photo: F. Pais).

installation of benches and information panels along the Gandum stream was not possible due to refusal of authorization by landowners who claimed that the presence of livestock (principally sheep) was incompatible with the intended presence of walkers using the area. Once again the project's attention turned to the Almansor site, to create a pathway and a picnic area. The outdoor furniture placed there was installed by the River Almansor authority.

The third phase was the finalisation of operations. It was somewhat similar to the preceding phase in that cleaning and herbicide applications were carried out, although the preceding phase had involved large-scale clearance of the whole reach. The final phase concentrated on clearing Giant Reeds and bramble patches by applying herbicides. Although herbicide application is most effective immediately following the cutting of reeds and bramble patches, it did not take place at that point because unweaned lambs were in adjoining land at the time of the cutting operations. Despite the non-residual systemic nature of the herbicide to be used at the time, the CMMN preferred to wait until the lambs were weaned to avoid any risk of contamination.

Figure 5.2. 5 Outdoor furniture along the Almansor River (Photo: F. Pais).

Other promotion activities

Together with the work carried out on the Gandum and Almansor sites, ever since the beginning of the project the CMMN has been particularly concerned with increasing public awareness of the operations being carried out and informing not only the landowners directly involved in the process but also the public in general concerning their duties and obligations in the management of these aquatic areas. As a result, the CMMN has organized walks and public information sessions. Additionally, taking a cue from the central theme of the 2006 "*Feira da Luz*", a key event for publicizing and promoting economic, cultural and leisure activities related with the environment and the activities of the Environmental and Urban Services division, which is responsible for the day to day management of the project, the 4500 participants in this event were given the opportunity to take a virtual bike tour of the Gandum river, taking in the best and most beautiful aspects of its flora and fauna.

Figure 5.2.6 Real and virtual trips publicize the work carried out under the auspices of the RIPIDURABLE Project (Photo: F. Pais).

Final considerations

Despite the original plan to restore the entire length of the Gandum stream (approximately 5km in total), given the budget approved and the council's wish to carry out a quality demonstration project it rapidly became obvious that the area earmarked for intervention would have to be reduced. With these limitations in mind, it was decided to restore the downstream section of the stream, an approximately 2,800 m long stretch close to the town of Montemor-o-Novo and the confluence with the Almansor river

Through fieldwork and contact with landowners, a difficult and slow process that sometimes affected the project's work schedule, the CMMN managed to carry out restoration operations not only on the Gandum stream but also the Almansor river, owing to some landowners' refusing permission on the Gandum. However, there is a positive outcome in that some of the landowners that initially resisted the restoration operations later made enquiries to the council concerning participation in future initiatives of this nature.

Although the outdoor furniture is already installed along the banks of the Almansor river (not the Gandum stream, for the reasons mentioned above), an area intended for public use, the footpath, will need to be reinforced.

In the near future the council intends to continue the work already carried out. The restoration and upgrading of the Almansor river will be carried out in the short term, not just because it is situated in an urban area, which makes the whole process much easier (the CMMN does not need seek landowners' permission to carry out work), but also because the CMMN wishes to restore the dignity and respect that a river of this nature had in the past.

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Stamatis Zogaris
Vassilis Hatzirvassanis
Irini Loi
Alexios Vlamis-Gardikas

SEVERAL LANDOWNERS IN A PROTECTED AREA: RIPARIAN WOODLAND AT AMVRAKIKOS

Introduction

The Amvrakikos, a proposed National Park on the west coast of Greece, has a turbulent history of nature conservation challenges and problems. This case-study describes small-scale restoration initiatives at the western edge of the proposed Park, in the lower section of the Louros river corridor in Preveza Prefecture. Recent history, strategic planning approaches and current problems are reviewed, especially with regard to initiating riparian woodland restoration at and around an important patch of relic riparian woodland, the Agios Varnavas Wood. The project does not focus solely on the Agios Varnavas site but also on the wider landscape of the low-lying land on the west bank of the river, the 'Western Louros Floodplain' (in Greek: *Ditiki Pediada Plimiron Lourou*). The small-scale restoration actions at Agios Varnavas and in its surroundings represent an initial step in a restoration and demonstration effort aimed at promoting a landscape-scale 're-greening' effort in order to enhance both the wildlife habitat and the recreation and education opportunities for the local communities of this area.

The Amvrakikos is a Ramsar wetland (covering 236 km2) and a proposed National Park (c. 450 km^2), but it is also a highly threatened conservation area, plagued by serious anthropogenic pressures related to agricultural land intensification, water overexploitation, water pollution, aquaculture developments, habitat alterations and widespread illegal hunting and poaching. Since 1990, the Amvrakikos has been included in the Ramsar Convention's Montreux Record as a site where an "adverse change in ecological character" is occurring, and is therefore "in need of priority conservation attention" (Gerakis *et al.*, 1999).

A central problem in protecting nature in the Amvrakikos concerns the lack of coordination in addressing a multitude of anthropogenic pressures over a large and diverse wetland/upland area. Although the management body of the National Park was officially set up in 2003, there has been very little effort to coordinate and promote conservation actions by the Greek state since the organization's inception. As a result of this state of neglect, serious pressures still impact on certain parts of the protected area and especially on certain habitat types, particularly the freshwater wetlands on the agricultural/semi-aquatic fringe and the remnant riparian woodlands (Zogaris *et al.*, 2003).

Figure 5.3.1 Amvrakikos Gulf Orientation Map.

A short history of riparian woodlands at Amvrakikos

Two major river basins, the Louros and Arachthos, dominate the structure and functioning of the Amvrakikos wetland system. Until the late 1940s, extensive areas of riparian woods clothed the riverbanks and humid alluvial delta plains on the northern side of the gulf. Part of the reason for the survival of extensive natural areas was due to the position of these wetlands on the former frontier between Greece and the Ottoman Empire (until 1912). The Arachthos river was the international border between these two states for decades. After the 1920s, resettlement of refugees from the Greco-Turkish war in Asia Minor necessitated agricultural land development and the Greek state began to convert the delta's lowlands to agricultural land. Despite their complex geography and dynamic hydrology, the different lowland wetlands and woodlands slowly retreated, particularly after the Second World War. Through the 1950s and early 1960s, embankments and pump-houses were built and former wetland areas were appropriated to local residents (Arapis *et al.*, 2002).

In the early 1960s, the largest riparian forests of the Louros were logged. Military aerial photos from 1945 and 1960 show that up to then, two large woods existed east of the village of Louros, on either side of the Louros river. The Roubas Forest (in an area between Petra Bridge and Rogi Castle) covered over 200 hectares and was perhaps one of the country's largest continuous riparian woods at the time (Kazoglou and Zogaris, 2003). The Fraxias Forest, which included today's relic Agios Varnavas Wood and the Skala Springs, was more open and fragmented but covered at least 150 ha, including linear stands on the banks of the Louros river. Other continuous areas of high forest existed at several locations in the Amvrakikos, such as within the Rodia swamp beside the Louros; along the lower Arachthos river; by Voulkaria lake and in various areas in the Arta's deltaic plain. The woods were gradually transformed into small isolated stands or hedgerow-like thickets, with most vanishing by the 1970s. Since much of the Arta plain still maintains an extensive network of hedgerows, scattered hydrophilous trees and a few small stands still survive (on the lower Arachthos, near the villages of Aneza and Glykoriza, and even near the original Roubas forest site, near Agios Spiridon village). Most woodland relics are fragmented and degraded by uncontrolled tree-felling, localized overgrazing by livestock and the expansion of agriculture, especially citrus orchards. Around 1980, riparian forests were estimated at about 250 ha in the northern part of the Amvrakikos Gulf (Severin and Lösing, 1981). Today, this figure may be smaller but no specific inventory has ever been completed.

The most prominent change in the northern Amvrakikos wetlands after the construction of the Louros river embankments (late 1960s) was the salinization of the Rodia Swamp and other coastal wetlands in the '70s and '80s. The Rodia swamp covered more than 30 km2 and maintained old river channels and riverine deltaic distributaries with wooded portions, including extensive willow woods. The construction of the Louros river embankments cut off the freshwater supply and natural circulation in this riverine swamp, causing an immediate increase in salinity from the adjacent lagoons that eradicated the flooded woodlands. This eventually led to degradation of its reed-beds and freshwater lentic habitats (Lawrie, 2002). There are still place names in the middle of this reed swamp which refer to willows and planes or to vast water-lily beds (Kazoglou and Zogaris, 2003). The degradation was followed by a similar change in the adjacent Arachthos. In the early 1980s a high hydroelectric dam was built just north of Arta, damming the Arachthos and altering the natural flow regime of the river. A massive die-back of tamarisk scrubland along the coastal wetlands has been attributed to increased soil salinization due to the hydrologic changes. These recent landscape-scale transformations brought about remarkable ecological changes that are vividly remembered by many of the older local inhabitants.

The anthropogenic habitat changes in the Amvrakikos were responsible for considerable declines in biodiversity, even if the relic wetlands are extensive. These effects are poorly documented, but we do know that the breeding populations of several birds associated with riparian woods and wetlands have been totally extirpated from Amvrakikos during the last 80 years (Handrinos and Akriotis, 1997; Zogaris, 2001). Species which are presumed to have once bred in the area include: *Aquila heliaca, Phalacrocorax pymaeus, Ciconia nigra, Oxyoura leucocephala*, and *Phasianus colchicus* (Powys, 1860; Reiser 1905). Marmaronetta angustirostris was also extirpated from the area, although there is little evidence that it bred there (Handrinos and Akriotis, 1997). At least two species of birds of prey are known to have recently stopped breeding in the delta lowlands: *Aquila pomarina* ceased nesting in the delta in the 1980s, although one pair survived in the wooded hills of adjacent Mount Zaloggo in 2002 (Zogaris *et al.*, 2003), and *Haliaetus albicilla* ceased breeding in the area in the late 1980s; this was the last pair in western Greece (Pergantis, 1989). Of course, the scant information on breeding birds represents only a tiny fraction of the changes in biodiversity that have taken place, as important declines in fish, wetland plants and habitat types have also been attributed to the drastic hydrological changes (Lawrie, 2002; Zogaris *et al.*, 2002; Theocharis *et al.*, 2004; Economou *et al.*, 2004). Some of these species certainly felt the impact of riparian woodland degradation, but human persecution (especially of large-bodied birds) probably acted in synergy with habitat loss to bring about biodiversity decline.

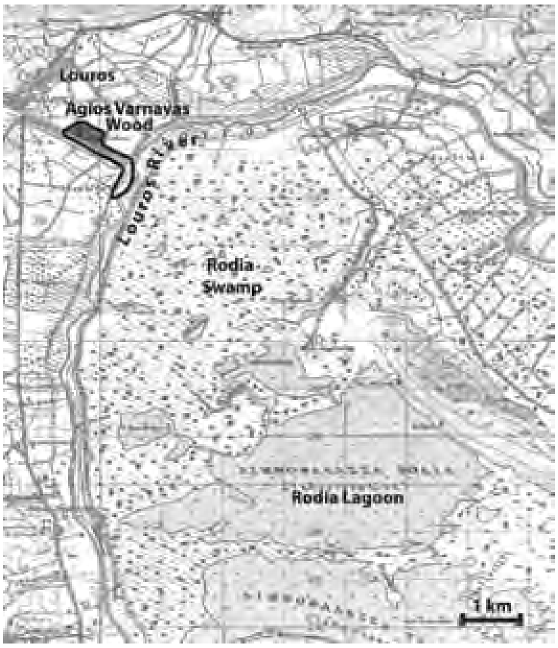

Figure 5.3.2 Map of the northwest section of the Amvrakikos and the Western Louros Floodplain. The area where restoration efforts focused in 2006/07 is outlined.

Restoration planning in the case-study area: Agios Varnavas Wood and "The Western Louros Floodplain"

The restoration initiatives described here concern the Agios Varvavas Wood and its surrounding area. This area is located in a low-lying floodplain, approximately 10 km from the river's outlet to the Amvrakikos Gulf. This area is of special conservation interest because it holds unique woodland relics, spring-fed wetlands and the extensive flood-zone of the Louros; it is arbitrarily named the Western Louros Floodplain due to its location on the west bank of the river, next to the village of Louros. In the past, this area was a target for large-scale drainage projects and was loosely referred to as Lamari, and part of the site is also called Fraxias. Agios Varnavas Wood is a small relic riparian woodland covering approximately 14 hectares of hygrophilous high forest near the center of this area. The Agios Varnavas Wood and its surroundings have long been known as an important site for biodiversity within the Amvrakikos wetlands (Szijj, 1981). Hence, an important issue here is strategic planning to enhance the site and its surrounding landscape for the benefit of its wildlife values rather than just for human recreation or other anthropocentric developments.

Biodiversity information on the Agios Varnavas Wood and Western Louros Floodplain

As is common in Greece, very little specific information exists on the natural history of the Western Louros Floodplain. A lack of baseline natural history knowledge has certainly been an impediment to the area's conservation. In fact, it is notable that an important population of a globally endangered fish and unique wetland habitats were discovered at Skala Springs in 2005 just a few hundred meters beyond the proposed boundaries of the National Park (Kalogianni *et al.*, 2006). A large part of the Western Louros Floodplain Area is not within the strictly protected zones of the Park. The ecological requirements of protected and rare species are very important in management planning. Table 5.3.1 refers to the most important documented evidence of the area's biodiversity interest, primarily based on the author's personal observations. A summary of the area's five riparian woodland habitats with reference to their status within the Amvrakikos Naional Park is provided in Appendix I at the end of this chapter.

Table 5.3.1 Principal biodiversity values of the Agios Varnavas Wood and the Western Louros Floodplain.

Biodiversity Category	Approximate Number of Species	Comments
Mammals	14	Several protected species such as bats use the Wood (Epsilon and Pergantis, 1994). *Lutra lutra* and *Felix sylvestris* are permanent residents (Hatzirvassanis *et al.*, 2006).
Birds	100+	82 species were recorded in the Agios Varnavas Wood (Epsilon and Pergantis, 1994); 30 protected species recorded recently (Hatzirvassanis *et al.*, 2006); These include *Accipiter brevipes*, *Aquila pomarina*, *Aquila clanga,* and *Dendrocopus* spp.
Reptiles and Amphibians	19	Including at least 7 species of snakes (Epsilon and Pergantis, 1994). Several protected species have been recorded, *e.g. Elaphe quatuorlineata.*
Fish	6	5 species were observed in Xeropotamos stream, including fish endemic to western Greece (Economou *et al.*, 2004); an interna tionally important population of *Valencia letourneuxi* is present in the nearby Skala Springs (Kalogianni *et al.*, 2006)
Invertebrates	N/A	Important for a large diversity of spiders (Szijj,1981) and lepido-ptera (including *Danaus chryssippus*).The presence of varied micro-habitats, humid localities, and the *Xeropotmos stream* augments species-richness. The protected beetle Morimus funereus was recorded as fairly common in Agios Varnavas Wood in 2007.
Flora	100+	c. 45 species mentioned as inhabiting the Western Louros Flood plain (Severin and Lösing, 1981); 39 spp. mentioned in a small part of this area, the Fraxias site (Hatzirvassanis, 2001). These lists are fragmentary and incomplete.
Habitat Types	c.9	5 riparian woodland habitat types are present in the area. See Appendix I for a brief description.

The Agios Varnavas Wood and the Western Louros Floodplain

As mentioned above, up until the late 1950s the lower Louros river east of Louros village sustained a remarkable riparian forest. This particular area was difficult to drain completely due to extensive karstic springs and the frequent flooding of the Louros. Military aerial photos from 1960 show an open woodland/pasture area at the Fraxias site, stretching from Skala Springs to the Louros and to Agios Varnavas. Local inhabitants say the area was dominated by *Fraxinus angustifolia* but also had many other hygdrophilous species. Due to the dynamic wetland/riparian conditions, the area was drained only after the combined construction in the early 1970s of the embankments on the Louros and the modern pump-house and drainage canals on the Lamari (Theocharis, pers. com.). Since the late 1950s, because of extensive logging, only isolated 'islets' of forest now remain in the transformed agricultural landscape. The most important pocket of relic woodland survives around the church of Agios Varnavas. The wood is on public land that belonged to the Ministry of Agriculture but was transferred to the Municipality of Louros in 1955 (Douros, 1986). This woodland plot has been called the Agios Varnavas Wood since the early 1980s (Douros, 1986; YPECHODE, 1986).

Agios Varnavas Wood has also been protected effectively by its religious associations, being connected with the church dedicated to Saint Barnabas. This historic monument in the middle of the Wood was built on the foundations of a Byzantine church dating from 1148-1149 (Mamalukos, 2002). Even during difficult times of war, certain trees in this sacred grove next to the church were protected and left uncut (Father Agathangelos, pers com.). Despite this unique ecclesiastical connection, the history of modern conservation attempts at Agios Varnavas is very recent. In 1979 the small relic riparian woods east of Louros village were 'discovered' by an ecological research team headed by the University of Essen, which drafted the first base-line ecological study of the Amvrakikos (Szijj, 1981). At this time there was no mention of the name Agios Varnavas; instead, there was a reference to several small woodland stands, most suffering from overgrazing and wood-cutting. After this initial description, the woods were frequently referred to in all major environmental studies concerning the Amvrakikos wetlands (YPECHODE, 1986). In the mid-80s, a fence was erected around the Agios Varnavas Wood after an initial forest recreation study (Douros, 1986). This initiative by the Forest Service of Preveza finally stopped the overgrazing by livestock, but the protection of the forest was clearly focused on recreation and public enjoyment, not on preserving its unique biodiversity. In later years, local development agencies and the Municipality of Louros took steps to develop this recreational aspect of the Wood: benches, wooden kiosks, and a small playground were built, road access was ameliorated and trails were cleared. In the mid 1990s three small buildings were built in the area and its immediate surroundings; these included two toilets and a small cantina with a decorative water fountain at the entrance to the Wood. Today these small buildings are in a near-derelict condition. Some of these works certainly made the area more accessible for visitors; however, a controversy began on whether to protect and enhance the 'natural state' of the wood, or to develop it further as a recreational green space.

Sadly, management actions by the local authorities have been inconsistent with particular demands for its protection. One of these poor decisions was the extensive clearing of dead and rotting trees, dead wood and bramble scrub from the forest floor. This activity coincided with a Forest Service project to fell and remove hybrid poplars and diseased elms from the Wood. This act promoted the idea of 'cleaning up the forest floor' for aesthetic and recreational reasons. Although this clearing has not always been directly damaging, the issue of biodiversity-sensitive management was accentuated. What is the desired future state of the Agios Varnavas Wood and how should it be decided? Furthermore, it is important to define exactly what area needs to be managed or restored; is the Agios Varnavas Wood (14 ha) large enough to accommodate both a biodiversity refuge and a multitude of recreational activities? It has been made obvious that promoting local awareness of biodiversity values is critical in addressing such a management problem.

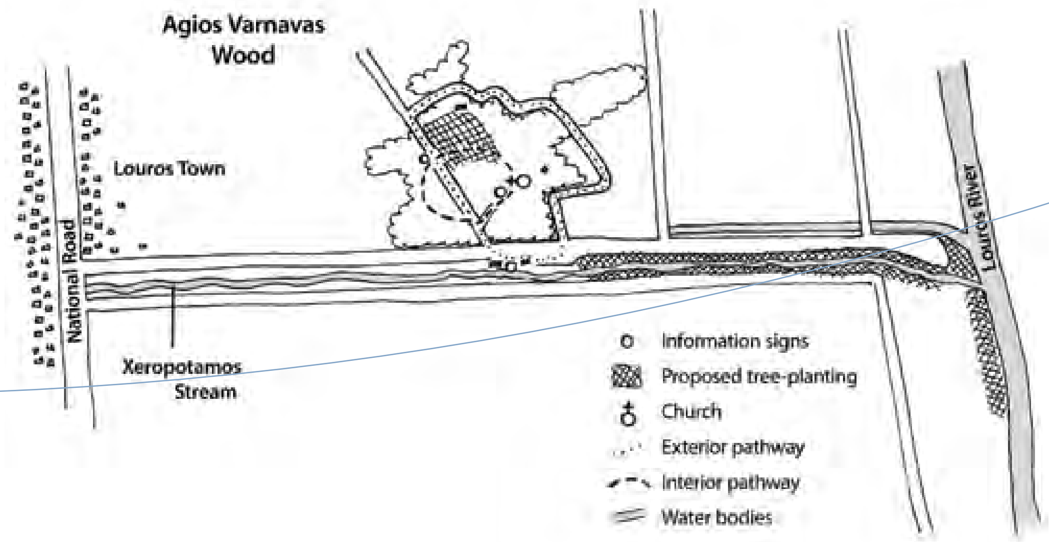

Figure 5.3.3 Agios Varnavas Woodland Site and its vacinity. Tree-planting areas and other restoration/demonstration actions are shown.

At the turn of the century, scientists began focusing on the wider landscape around Agios Varnavas as an area of restoration potential. The importance of the wider Louros river lowlands was identified in a Life-Nature project proposal (ETANAM S.A., 1999). In 2002, during progress on the Life-Nature project, specific small-scale tree plantings took place along the west bank of the Louros and on the floodplain embankments near Agios Varnavas. Although there were objections from shepherds and adjacent landowners, the Municipality of Louros officially supported these restorative tree-planting measures – the first ever at Amvrakikos (Hatzirvassanis, 2001). Although several hundred trees were planted (mostly Narrow-leaved Ash and White Poplar), in several cases the fencing was damaged by the shepherds. Dozens of trees were destroyed by browsing goats and a flood-event in 2005 downed some of the riverside fences. It goes without saying that an investment such as tree-planting needs many years of after-care to be truly successful. Nonetheless, many dozens of planted trees grew to over three meters and now flourish. Furthermore, this first act of 'restoration' was an important lesson that increased local interest in the protection and restoration of the surrounding area. Perhaps the most important step in this direction was the closing of the unofficial rubbish dump of Louros village, located immediately next to the riverside tree-plantings and only a few hundred meters from the Agios Varnavas Wood

An important aspect of the chronicle of conservation in this area is the gradual change in attitudes and perceptions concerning riparian habitat protection and restoration. After 2005, more work in the area focused on the protection of the wider landscape of the Western Louros Floodplain, not just Agios Varnavas. The RIPIDURABLE restoration/demonstration project was fortunate to act in this area at this time in its history.

Planning for restoration: strategic conservation planning

Strategy is important for effective conservation actions. Strategic planning is a disciplined effort to generate fundamental decisions for actions concerning a particular project. This kind of planning results from the analysis of the strengths and weaknesses of various options and may thus determine what the particular situation has to offer (the opportunities and threats) so that the desired objectives can materialize. In planning this restoration, we used the SWOT analysis approach, of ten employed in business management and ecently in conservation (Moughtin, 1999). SWOT stands for "strengths-weaknesses-opportunities-threats" and is a planning tool that addresses the question of devising a strategy from a two-fold perspective: external appraisal (threats and opportunities in the environment) and internal appraisal (strengths and weaknesses of the organization). This analysis, used in a matrix form (Appendix II), is a powerful yet simple tool for dissecting the properties and potential of restoration options.

Type of restoration project

The type of project promoted here can be referred to as a 'repair and enhancement of a damaged ecosystem project' (Clewell, 2000). Restoration actions are primarily undertaken to enhance the naturalness of the remaining vegetation formations, to provide a habitat for threatened species, and to initiate the creation of wildlife corridors to reconnect woodland stands. This approach attempts to regain some attributes of the historic or pre-existing condition of a particular landscape. Such enhancement restoration may be termed in-kind (the historic type of ecosystem is restored) and on-site (restoration occurs at the same location where the historic ecosystem was damaged) (Clewell, 2000). The area's desired future state is obviously one which is shared by agro-pastoral activities and various forms of recreation and wildlife conservation interests. In the future, the restoration effort may expand and may introduce other qualitative aspects, such hydrological engineering to provide re-wetting or restoration of water flow regimes.

Type of ecosystem to be restored by the project

The area being restored is part of a floodplain and alluvial lowland system with a mixture of very different plant communities. Little is known of the particular structure and dynamics of the original natural vegetation; most of our understanding of its structure is from interviews with local residents and the careful interpretation of older aerial photos from the Greek Army Geographical Sevice (years 1945, 1960) (Kazoglou and Zogaris, 2003). The available evidence supports the conclusion that extensive parts of the drier upland riparian area were dominated by Narrow-leaved Ash, Common Elm, and perhaps Pedunculate Oak (specifically in the Agios Varnavas Wood and much of the Fraxias area). Locally, stands of Common Alder with willows and other small trees and shrubs existed in swamp-like conditions in spring-fed wetlands, particularly in the Skala Springs. Stands of Oriental Plane and White Poplar dominated areas on the Xeropotamos alluvial fan (now the channalized Xeropotamos stream) and other sites disturbed by torrential alluvial processes. Willow-poplar-ash and tamarisk scrub clothed extensive open areas of frequently-flooded Louros riverbanks. Water meadows and emergent reed-swamp formations developed along the Louros riverine wetlands (See Appendix I at the end of this chapter).

Logging and cattle grazing were prevalent in the area for a long time and it should be mentioned that the Louros river was navigable up to the village of Agios Spiridon, so trees could be removed and exported rather easily. Of the above mentioned trees, Pedunculate Oak was definitely selectively felled for fire-wood and construction timber, and subsequently became extremely rare; today it is nearly at the point of extirpation from this area. The Western Louros Floodplain is nowadays part of a cultural landscape dominated by agricultural and agro-pastoral activities, with a patchwork of fragmented semi-natural woodlands on the fringes of the agricultural land and riverine wetlands. Fortunately, extensive marshlands and regenerating woody scrub survive along the Louros flood-zone; so this belt of semi-natural wetland creates an important semi-natural corridor. Bringing back the extensive forests of the past is not feasible in this cultural landscape, since the upland portions of the floodplain that once held high forest stands were the first to be effectively drained and given over to private ownership.

Specific restoration aims

The specific aims are small-scale but will affect the entire landscape and its biodiversity if they are carefully managed. In outline, they are:

a) An 'initiating-act' to demonstrate the importance of native woodland restoration. This restoration/demonstration project must create positive community involvement and widespread awareness, effectively combining multiple-use recreational and biodiversity conservation benefits. The result will be a long-term example of on-going habitat enhancement that will promote restoration of other riparian woodland relics at the landscape-scale.

b) The effective expansion of riparian woodland corridors beyond the Agios Varnavas Wood aims to create corridor-like greenways among the area's three most important biodiversity nodes: the Louros river flood-zone, the Skala Springs and the wider vicinity of the Agios Varnavas Woodland. The promotion of wooded corridors is a viable and extremely important aim in this area (Bennett, 1999).

c) Biodiversity protection must be given priority in the relict woodlands and corridors and even within the Agios Varnavas Wood, which has seen much degradation in the name of so-called 'ecotourism development'.

d) The enhancement and re-establishment of native woodland stands must be similar to pre-existing native woodlands. The functioning ecosystem will contain enough biodiversity to regenerate itself and mature by natural processes, and to evolve in response to changing environmental conditions.

e) An outstanding aspect of restoration is the creation of cover and shelter for locally threatened and protected wildlife such as raptors, forest birds, and large wading birds; certain mammals (bats, wildcat and otter), reptiles and amphibians, woodland and wetland invertebrates, and the native wetland and woodland flora (Efthimiou *et al.*, 2006). High tree stands have been proven to be important as resting and roosting sites of large birds of prey such as *Aquila clanga* at Amvrakikos (Alivizatos *et al.*, 2004), so recreational disturbance may create conflicts.

f) Woodland restoration actions must not degrade existing water meadows and other open marshland or wet grassland habitats in the flood-zone area of the Louros floodplain.

Duration of restoration work

The project initiated actions that will help limited areas with tree stands to be established in the wider area within the next 20 years. This time-frame is critical because forests in the surrounding area have been deteriorating (wildfires, logging, roads, quarries and other human disturbances) and other lowland riparian or alluvial forest strongholds have also vanished very recently. It is therefore important to consider the project as an initial investment supporting woodland biodiversity within a threatened protected area. Aftercare, wardening and supplementary work must continue for at least two decades in these restored areas. If riparian forests are left to develop freely, they usually reach a natural appearance at 60-80 years (Angelstam, 1996). The project should have a dynamic nature, organized according to an 'adaptive management' paradigm. Local authorities such as the National Park Management Body, the Municipality of Louros and other organizations must work together to secure funds for the long-term continuation of this project.

Specific restoration actions and results of the RIPIDURABLE project

Hatzirvassanis and others (2006) proposed several small-scale restoration actions within the RIPIDURABLE restoration/demonstration project, most of which were undertaken by the Amvrakikos Development Agency ETANAM S.A. with the approval of the Forest Service of Preveza. Of course, the funding available for such a short-term project cannot cover all that is necessary in full-scale ecological restoration, and many important tasks were not completed (*i.e.* hydrological engineering at the site, native tree nursery creation, horticultural aftercare, scientific monitoring, etc). The RIPIDURABLE actions were meant to demonstrate and help initiate restoration approaches. The following proposals/actions and results took place during the 2006/07 period:

1) Complete removal of garbage and builder's waste at the former rubbish dump of Louros; cleaning-up work at the Xeropotamos stream and along the road leading from the Agios Varnavas wood to the Louros river. RESULTS: Successfully undertaken, this initiative represents the 'last act' in the successful removal of the formerly notorious Louros rubbish dump.

2) Construction of carefully-crafted interpretive signs, promoting biodiversity conservation. RESULTS: Three signs were installed within the Agios Varnavas wood in 2007 (figure 5.3.4).

3) Planting of native hygrophilous species of trees. RESULTS: 650 specimens were planted, mostly *Fraxinus angustifolia, Platanus orientalis* and *Populus alba.* These plantings were undertaken in late 2006 and early 2007. Additionally, dozens of *Fraxinus angustifolia* were transplanted as 'rescued' specimens from the surrounding area (especially from hedgerows close to Louros town). Planting took place: a) within the large clearing in the Agios Varnavas wood; b) along the embankment of the Xeropotamos Stream; and, c) in a fenced area (the former rubbish dump of Louros village) near the confluence of the Xeropotamos with the river Louros, on the west bank of the latter (figure 5.3.5.)

4) Aftercare and wardening. RESULTS: The trees were all watered during the very dry summer of 2007. The Municipality of Louros helped provide an unofficial volunteer site-caretaker who supported aftercare activities such as wardening, transplanting and tree-planting.

5) Removal and/or alteration of the small buildings and toilet facilities that were constructed in the mid 1990's at Agios Varnavas Wood. The study asserts that these buildings (cantina, toilets etc.) are incompatible with the promotion of the area for biodiversity protection and environmental education. RESULTS: No action taken.

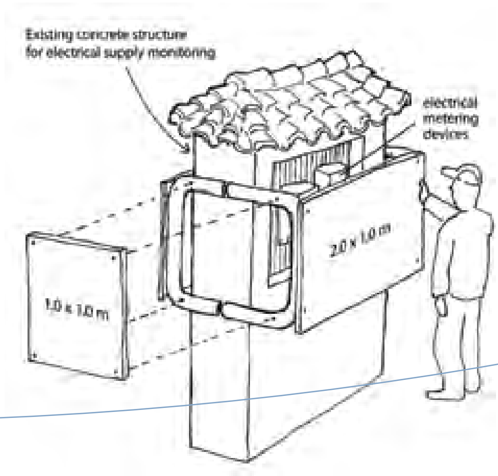

Figure 5.3.4 Sketch of interpretive signs created as an aesthetic way to cover an electricity meter next to Agios Varnavas Church.

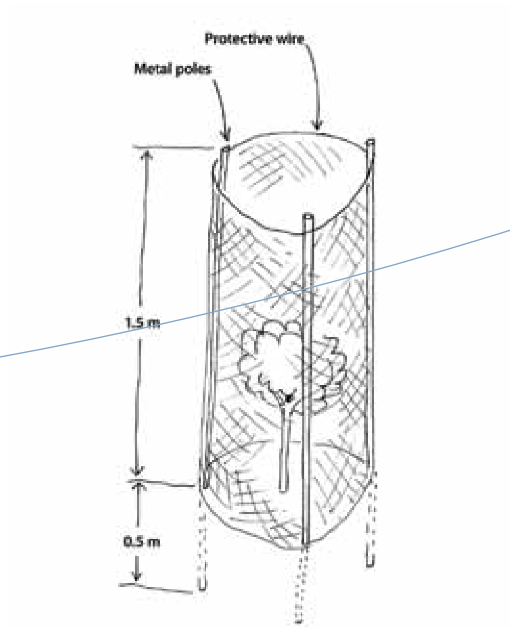

Figure 5.3.5 Sketch of a sapling planted with protection against goat browsing.

Present problems and unmet needs

As mentioned above, there are potential conflicts between biodiversity conservation and many anthropogenic activities such as agriculture and tourism/recreation in Agios Varnavas wood and its surrounding landscape.

The possibility of conflicts is intensified by unclear land tenure along the flood-zone of the Louros river, the fact that remnants of natural riparian woodlands areas exist on private land and beside drainage canals, ditches and unprotected riparian zones, and the undefined protected-area legislation (proposed National Park).

Important considerations:

a) Indiscriminate/uncontrolled tree cutting. Tree stands do not easily regenerate in the area because of persistent widespread tree-cutting. Clearing of vegetation and dredging of drainage ditches and canals is regularly practiced by the local authorities of the Prefecture of Preveza with blatant disregard for trees on banks, local residents also regularly cut saplings and young trees for animal fodder and for farming needs, and there is no special protection of the rare hygrophilous species such as ashes or oaks.

b) Protecting existing habitat resources in the Western Louros Floodplain. The area is threatened by several private interests and some of it is outside the proposed national park boundaries. No management plan exists. Some kind of wardening must be set in place as soon as possible during an interim period before legal protection is enacted. This includes the care of existing tree-stands, riparian zones and fenced-in restoration plots. Volunteer wardening approved by the Municipality of Louros and the Forest Department of Preveza is perhaps viable for the short-term.

c) Nursery creation and tree-planting. A nursery should be set up to propagate local Narrow-leaved Ashes, Pedunculate Oaks and White Poplars. Since specimens of known provenance cannot be reliably obtained, wild stock from seed or transplanted saplings should be grown at a nursery. Ash seeds (keys) should be collected in early winter and planted in shallow sand-compost. Poplars should also be collected and grown. Elms may be collected from suckers. Oaks can be planted from acorns or grown from collections of young saplings. Tree planting must continue within the designated plots to maintain the green corridors. It goes without saying that only local stock should be used in tree-plantings. The nearby monastery of Profitis Ilias of Preveza has shown an interest in maintaining a nursery, a rather simple undertaking if a committed organization is sincerely interested. Volunteer support for this may be needed in the short-term.

d) Agios Varnavas wood as a 'natural monument'. Agios Varnavas wood is currently treated as multiple-use 'recreational forest' (as proposed by Douros, 1986). We recommend a new paradigm: the wood as a 'protected natural monument' where passive recreation and protection are promoted but priority is given to protecting its biodiversity. If this small woodland is treated as a 'natural and cultural sanctuary', some details of its management will need special care. The use of the derelict buildings at Agios Varnavas is unresolved and they detract from its aesthetic naturalness. We recommend the removal of nearly all buildings (cantina, decorative fountain, two toilet structures within and at the entrance to the wood). The former cantina site could become a small interpretive spot (*i.e.* one of the building's walls should be retained and altered to a kiosk-like structure with interpretive signs). Removable chemical toilets will be in use during the Agios Varnavas festival (June 11) since it is costly and difficult to maintain clean, functioning toilet facilities on-site. The Municipality of Louros should review the implications of the unofficial designation of Agios Varnavas wood as a 'natural monument' and carefully consider its particular management.

e) Research and Monitoring. A careful study of the Western Louros Floodplain is needed to help define biodiversity protection and opportunities for restoration at other important biodiversity nodes – particularly at the Skala Springs site. Besides this, monitoring should include a systematic series of surveys to evaluate the changes and the effectiveness of the restoration actions. A very important part of this work is exact documentation so that the project may act as an example of riparian forest restoration for any area that may have neglected the protection and enhancement of riparian woodlands. To avoid only baseline information being gathered, monitoring must be programmed within a management framework (Clewell and Rieger, 1997).

Management Implications

Examples of scientifically-guided riparian forest enhancement or restoration in Greece are isolated and very recent (Efthimiou *et al.*, 2006). The demise and degradation of riparian forests in this country has been remarkable, as these woodlands have followed the fate of the country's lowland wetlands (Antipas, 1985; Jerrentrup und Lösing, 1991). The Amvrakikos is an area that holds diverse but very small relic riparian woodlands. Planning their protection and promoting restoration to protect biodiversity values should be a priority within the proposed National Park's management plans. A specific restoration plan for the Western Louros Floodplain must be incorporated into the official management plans so that the restoration-demonstration project outlined here can continue.

Important aspects for restoration of riparian areas at Amvrakikos include the following:

- Building a vision of the desired future state of the Western Louros Floodplain. Strategic planning must guide specific management options. In this case-study a SWOT analysis helped produce particular directions for the desired future state of Agios Varnavas Wood. Through this analysis, it is obvious that biodiversity enhancement and conservation actions in the Agios Varnavas Wood far outweigh the benefits from other more anthropocentric development proposals (*i.e.* solely urban-style tourism/recreation use). Part of our proposal involves changing the management paradigm of Agios Varnavas Wood from a 'recreational forest park' to a 'protected natural monument'. Our vision for restoration is not confined to Agios Varnavas, but based on a long-term re-greening effort at the landscape scale. Existing pockets of riparian stands and wetlands should be interconnected with greenway corridors. Agro-pastoral land use and various recreational activities can co-exist with nature conservation and a rich biodiversity if strategic planning, strict protective measures and monitoring are in place.

- Basic biodiversity information about this area is still far from complete. Baseline biodiversity knowledge and monitoring is fundamental for continued restoration actions, completion of protected-area zoning and conservation management.

- The legal protection status of the area within the Western Louros Floodplain is still incomplete. More specifically, part of the study area is actually outside the proposed national park boundaries and this part includes the important Skala Springs site, an area with international biodiversity interest (*i.e.* stronghold for the critically endangered fish *Valencia latourneuxi*). Protecting patches of wildlife habitat within the agro-pastoral landscape is critical. This may involve setting up micro-reserves or extending the park boundaries to encompass them; this will have no societal or financial cost since these linear riparian or wetland areas are primarily on public land. The Municipality of Louros must play an active part in this landscape conservation initiative since it involves careful peri-urban and agricultural land planning.

- It is extremely important to have regular community participation in protection, management and decision-making. Popularization through the media often helps gain rapid and widespread community support. Important initiatives for this may be the instigation of a natural history theme during the popular saints-day festival of Agios Varnavas (June 11). The development of other kinds of nature-celebration events and publications at regular intervals is important. Other initiatives may involve NGOs, study-tours, seminars, and media-attractive competitions such as bird races (Zogaris, 2005). Another successful practice is the creation of a network of caretakers who monitor and protect special wildlife habitat areas. Whatever the case, organized volunteer involvement has definitely paved the way towards conservation practice at Amvrakikos, and should continue.

This work reiterates that 'no park is an island'. The Agios Varnavas Wood, at a mere 14 ha in size, cannot support the biodiversity that distinguishes the landscape of the wider area. Efforts at restoration must have a landscape-scale perspective, encompassing the entire Western Louros Floodplain. For adequate promotion of protection that will enjoy long-term sustainability, a kind of biodiversity-centered development is called for. Biodiversity-centered development consists of three basic, overlapping steps expressed by a simple slogan: "save it, know it, use it" (Janzen and Gamez, 1997). The Western Louros Floodplain is an example of an area of special biodiversity interest where a variety of economic and development activities could be developed in tandem with measures to protect and restore natural heritage values.

Acknowledgements

This work was guided by personnel at the Institute of Inland Waters, Hellenic Center for Marine Research, working in close cooperation with ETANAM S.A. and the Municipality of Louros. At the Municipality of Louros we are particularly indebted to the Mayor, Mr Ch. Bailis, and to Mr. N. Giousas for assistance and information-gathering. The following persons provided important information and support: Father Agathangelos of The Holy Monastery of Profitis Ilias, P. Pergantis, Y. Roussopoulos, N. Kardakari, M. Theocharis, D. Borelos, V. Vlami, and particularly the Forest Service of Preveza, especially V. Dallaros. Special thanks go to P. Dimopoulos, who provided data on the area's habitat types, and to Oikos-Nature Management LTD for access to important documents that supported our research.

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Appendix I - Riparian Woodland Habitat Descriptions

The riparian woodland flora of the Amvrakikos wetlands is of interest because it is isolated from other woodland habitats and represents a rare example of lowland semi-terrestrial forest formations. Very little is actually known or has ever been published on the riparian or upland flora, despite the wider area's exceptional richness in wetland species (Sarika *et al.*, 2005). The Western Louros Floodplain holds examples of all five riparian woodland habitat types found in the Amvrakikos. These are briefly summarized below.

- *Platanus orientalis* woods (Natura 2000 Code 92C0). These form linear strips of high, closed forest primarily along the middle parts of the rivers Louros and Arachthos and their tributaries. Scattered examples exist in many areas inside the delta plain, particularly along reaches with coarse gravel river beds (*e.g.* especially along the Arachthos, south of the city of Arta). The Oriental Plane usually dominates on semi-natural embanked stream banks such as the lower course of the Xeropotamos stream, at Agios Varnavas; but in many other cases it is found in mixed formations with Common aAlder, White Poplar, and willows (*e.g.* lower Aracthos). In the past the Xeropotamos created an alluvial fan in the area, with coarse soils which were deposited in this part of the low-lying plain. A few centuries-old trees also exist in the Agios Varnavas Wood itself; two of these trees can be considered ancient trees in need of specific protection.

- Alluvial forests with *Alnus glutinosa* (Natura 2000 Code: 91E0). This habitat is very localized in the Amvrakikos. The largest stands exist in former river channels (within the drying meander ox-bows) of the Arachthos floodplain, north of Neochori village. Small stands also exist at certain locations along the Louros. In our study area, there is a very small Common Alder stand near the karstic Skala spring, where a 'flooded forest' of alders also includes isolated specimens of wild *Laurus nobilis*, along with a unique and rare plant community with *Frangula alnus, Salix* spp. and various emergents.

- Riparian mixed forests of *Quercus robur, Ulmus minor,* and *Fraxinus angustifolia (Ulmenion minoris)* (Natura 2000 Code: 91F0). This habitat is probably the most threatened in the Amvrakikos. Several nearly pure stands of *Fraxinus angustifolia* still exist (*e.g.* near Glykoriza village, Mazoma Lagoon, Voulkaria lake). One particular nearly-pure stand of Narrow-leaved Ash, *Fraxinus angustifolia,* is part of the Agios Varnavas wood. Surprisingly, most trees in the wood are rather young (estimated at 70-90 years old). They were presumably logged actively in the past due to the very close proximity to the town of Louros. Common Elm, *Ulmus minor,* was common in the Agios Varnavas wood and still regenerates; however, almost all the larger trees have succumbed to elm disease. Particularly rare are older stands of the hygrophilous Pedunculate Oak *Quercus robur subsp. pedunculiflora.* In the Agios Varnavas wood, only 3 specimens of this species were found. This is probably related to selective logging of this important hardwood in the past. Oak stands also exist in alluvial soils near the village of Aneza, so lowland hardwoods were probably more widespread in the recent past.

- White Willow *Salix alba* and White Poplar *Populus alba* galleries (Natura 2000 Code: 92A0). This is the most widespread type of riparian woodland in the lower reaches of the rivers and along drainage canals in the delta plain, but the conservation status of many of these is severely degraded. However, this particular type of woodland has the greatest potential for regeneration and restoration, since many sites with its preferred hydrology and soils still survive and scattered willows are present. In the northern Amvrakikos wetlands, thin strips and linear thicket-like areas of this habitat are found along the Arachthos and locally on the Louros. Relict high-forest conditions with white poplar only exist along the Arachthos (along the river banks, and in the large meanders north and southwest of Neochori). It is remarkable that only isolated white poplars survive along the Louros, and the only really large stand of white poplars comprises part of Agios Varnavas Wood. Nearly half of the Wood consists of a remarkably high grove of these softwoods. These trees are probably of native provenance, although this has never been investigated.

- Thermo-Mediterranean riparian galleries with tamarisk (Nerio-Tamaricetea) (Natura 2000 Code: 92D0). These mainly include tamarisk thickets (*Tamarix* spp.), sometimes associated with Chaste Tree thickets (*Vitex agnus castus*). These formations are widespread and varied in the Amvrakikos wetlands and include extensive areas around lagoons and estuaries, most prominently near the Arachthos and Louros river mouths. In some locations near the coast and on the lagoons, many of even the most salt-tolerant formations have died back, probably due to increased salinization of the lagoons and the fringing marshes. Many hectares of dead tamarisk trees were located in an overflight of the Arachthos delta in 2001; this may be related to hydrological changes brought about by the construction of the Pournari Hydroelectric Dam in the early 1980s. On the Western Louros Floodplain, tamarisk and Chaste Tree are widespread as low and medium high thickets in low-lying areas, especially in the Louros flood zone. Most stands probably represent secondary regeneration after the high forest of willow/poplar has been felled or disturbed.

Appendix II -Swot analysis

Two options are analyzed and compared analytically in order to assist decision making.

Option 1

Agios Varnavas is converted into a recreational park for residents and visitors. The site will be managed to receive large numbers of people and will regularly be kept 'clean' and organized by clearing nearly all bramble, low shrubs, dead trees and coarse woody litter. The entire site will be accessible with a multitude of small and larger footpaths.

SWOT Analysis

Strengths

- Low-cost, low-maintenance option.
- Some residents may say they want to protect the Wood, but in fact may prefer to 'protect and develop', as would be the case if the Wood was converted into a recreational park.
- Socio-political benefits may exist if the site is 'developed' into peri-urban green-space; many residents may not recognize the value of the site as a 'natural monument' or the interest in keeping parts of it in a 'wild state'.

Opportunities

- May provide time to consider longer-term plans for the wider area or to focus conservation efforts elsewhere in the proposed Amvrakikos National Park.

Weaknessess

- Formerly officially recognized 'forest relic' not restored as suggested in several studies and government proposals; therefore an infringement of consistency in protected natural area management.
- Documented failure in terms of national park management.
- Suburban or peri-urban housing may extend from nearby Louros town towards the woodland, engulfing the new 'green space'.

Threats

- Many natural characteristics of the forest will be lost; particularly the natural forest-wood litter cycle; natural succession and regeneration.
- Opportunity for nature/society interface and environmental education lost.
- Biodiveristy loss: many animal and plant species prefer wild natural conditions and management of the Wood as a 'green space park' would mean loss and displace ment. Some bird species may be displaced (*Accipiter brevipes*, *Oriolus oriolus*, *Dendrocopus* spp., *Aquilla pomarina*). The site will not be used by large-bodied birds such as raptors that are easily disturbed by large numbers of visitors.

Option 2

Agios Varnavas Wood is rehabilitated and managed with a primary focus on biodiversity restoration and natural history education. Only passive recreation will be encouraged and parts of the site will remain inaccessible and in a 'wild state' (exceptions include the area immediately around the Church of Agios Varnavas). Nearly all woody litter and old rotting trees will be left in place. Efforts will be made to create green corridors to connect the Wood with remnant riparian areas in the Western Louros Floodplain.

SWOT Analysis

Strengths

- The site is strategically located to showcase and demonstrate restoration possibilities and results.
- The site assures success as a 'honey-pot' or hotspot for ecotourism and passive recreation.
- The site's unofficial distinction as a 'natural monument' is confirmed and advertised to other local communities and visitors.
- Socio-political profit and pride will be gained; especially for the Municipality of Louros.

Weaknessess

- Maintenance of site will incur increased costs and surveillance/guarding; in which the Municipality of Louros must play an active part.
- This option represents an additional responsibility for the National Park Management Body and other authorities responsible for management of the proposed Park.

Opportunities

- The location of Agios Varnavas wood provides an important economic and social foundation for the future conservation of the wider landscape.
- Agios Varnavas is only one landscape feature of outstanding biodiversity and education interest in the Western Louros Floodplain; the protection and management of this wood may help save the other areas too.
- Unresolved management issues such as the derelict buildings (Cantina etc.) will be addressed if a management plan for the site is developed.
- Coordination between the Municipality of Louros, the Forest Department of Preveza, the National Park Management Body and other stakeholders will assist in building relationships centered on conservation in practice.
- Volunteer efforts by scientists, educators, environmentalists and ecotourism operators may help promote the protection and management of the site.

Threats

- Maintaining the quality of the site requires investment and enforcement against illegal pressures. (Illegal logging may continue to destroy dozens of trees a year).
- Visitor management is critically important: a special management plan will be needed; this must help retain large parts of the site in a 'wild state'.
- The Municipality of Louros may change its opinion in future and may want to 'hybridize' restoration with other development interests.
- Development and management proposals may create incremental changes that may degrade the naturalness and attractiveness of the site as a natural monument.

A PUBLIC LANDOWNER IN A RURAL AREA: REFORESTATION AROUND THE PEDRÓGÃO

David Catita
Ana Ilhéu

Introduction

The Pedrógão reservoir is situated along the Guadiana and Ardila rivers, immediately downstream of the Alqueva dam, occupying an area of approximately 1000 hectares. The reservoir is part of the infrastructure comprising the Alqueva Multiple Final Uses Project (EFMA). It was created to act as a return reservoir, allowing the waters released by this dam to be pumped back up to the Alqueva reservoir. The Pedrógão reservoir is equipped with a hydroelectric station and there are plans to install two surface water outlets for irrigation as part of the EFMA irrigation system.

Given the multifunctional use of the Pedrógão reservoir, there is strong bankface and water level oscillation. Additionally, the Pedrógão reservoir forms a barrier to the natural movement of species. Therefore, it was considered essential to plant trees along the margin to allow the fauna to move around the reservoir's edge and to connect with tributaries of the Guadiana that are not dammed.

Figure 5.4.1 White Poplar in the spring after planting (Photo: David Catita).

Objectives

In keeping with the objectives laid down in the EFMA Environmental Management Programme (2005 version), the reforestation of the Pedrógão reservoir margin was defined as a priority, since the banks do not have any trees or shrubs and they also coincide with areas of intensive agriculture. One of the aims was to create a continuous forested belt around the entire reservoir, like a riparian gallery. Another aim was to prevent encroachment on this space by adjacent landowners and prevent inappropriate uses, such as the presence of cattle, which would cause a negative effect on reservoir water quality.

Although riparian planting along the margins of a reservoir appears to be an easy and natural process, it is not. The existence of water halfway down a slope does not constitute in it self a riparian bankface, since the constant changes in water level, together with the thin, relatively unfertile soil conditions, compromise the establishment and survival of plants.

Figure 5.4.2 Young tree protected by a wire mesh tree guard, allowing good sapling aeration (Photo: David Catita).

Planning, implementation and results

The Pedregão reservoir plant cover improvement initiatives took place over a three year period, starting in 2005. All the planting operations were carried out along contour lines parallel to the Retention Water Level (RWL). The planting area corresponds to the inundation area between the RWL and the public property boundary (flood surcharge buffer area) associated with a flow of 5000 m^3/s and an 8 year return period. Since temporary submersion is expected in this area, the selected species must be naturally adapted to such conditions.

Year I - 2005

Planting in the first year (2005) was carried out in groups of 3 parallel lines, 2 metres apart, with 10 metres between groups (see figure 5.4.6). The objective was to create small woods that would serve as shelter for wildlife and favour growing conditions for tall trees with long, straight trunks.

Six species were selected for planting in the first year. Four of them possess typically riparian characteristics White Willow (*Salix alba* L.), Common Alder (*Alnus glutinosa* L.), White Poplar (*Populus alba* L.), Narrow-leaved Ash (*Fraxinus angustifolia* Vahl.) while the other two species, Common Elm (*Ulmus minor* Mill.) and the European Hackberry (*Celtis australis* L.), occur naturally on the edges of the reservoir.

It was necessary to protect the saplings individually using plastic and wire mesh tree guards because fencing the entire area was not possible. Fences were only installed at the external edge of the plantation, since their presence below the RWL would present a hazard for boats.

The four more typically riparian species were planted in the strips closer to the reservoir. In fact, this made little difference, since the waterbody did not have a significant influence on either the soil moisture levels or the atmospheric humidity. 2005 was an extraordinarily dry year and despite regular watering it was difficult to maintain soil humidity. As a result, species that were more sensitive to drought had low success rates (approximately 15%).

Figure 5.4.3 General view of new plantings, showing two kinds of tree guards: plastic and wire mesh (Photo: David Catita).

Table 5.4.1 Details of plant cover improvement work carried out in 2005

Species	Number of plants	% of total plants	Success rate
White Willow	2,953	10%	15%
Common Alder	4,576	15%	15%
Narrow-leaved Ash	16.065	52%	60%
White Poplar	4,618	15%	60%
Common Elm	400	1%	20%
European Hackberry	2,006	7%	100%
Total	30,618	100%	33%

The method of planting three lines close together resulted in good vertical growth rates, as expected. However, maintenance work such as watering and weed clearing were very difficult and time-consuming, since mechanical methods were not suitable and the work had to be carried out manually.

The protective tubes placed on the saplings (1.2 m high) with the aim of producing a taller trunk caused overheating in the slower growing species, which may have been a contributing factor to the reduced success rate.

Figure 5.4.4 Narrow-leaved Ash two years after planting (Photo: David Catita).

Year 2 - 2006

Based on the above observations, some modifications were made during the second year of planting (2006).

Only the species with a success rate greater than 50 % were planted, namely Narrow-leaved Ash, White Poplar and European Hackberry and no protective tubes were placed around the saplings.

In order to facilitate maintenance, the trees were planted in groups along only two parallel lines, 2 metres apart, with 8 metres between the groups.

Table 5.4.2 Details of plant cover improvement work carried out in 2006.

Species	Number of plants	% of total plants	Success rate
Narrow-leaved Ash	10,000	67%	80%
White Poplar	2,000	13%	80%
European Hackberry	3,000	20%	100%
Total	15,000	100%	84%

The two-row planting method greatly improved the planting operations, especially watering, which was carried out by a single person with a hose walking between the rows. However, weeding between rows was still labour intensive and difficult since there was no space for conventional farm machinery

Figure 5.4.5 General view of the planting carried out in 2006, showing European Hackberry after one (left) and two years (right) (Photo: David Catita).

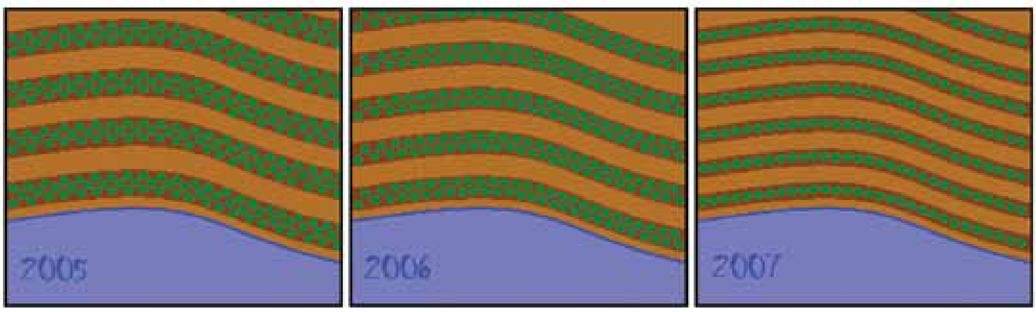

Figure 5.4.6 Various types of planting schemes implemented.

Year 3 – 2007

During the third year of the project (2007) the same combination of plants was used as the previous year, but without protective tubes and planted in a single row with a distance of approximately 6m between the groups.

The 2007 planting has given good results and, especially, has made it easier to use mechanized maintenance methods.

Dead specimens were replaced with living saplings in all stands, mostly using Narrow-leaved Ash and White Poplar.

Table 5.4.3 Details of plant cover improvement work carried out in 2007 (estimated)

Species	Number of plants	% of total plants	Success rate
Narrow-leaved Ash	7,666	40%	90%
White Poplar	7,666	40%	90%
European Hackberry	3,835	20%	80%
Total	19,167	100%	84%

Figure 5.4.7 General view of planting carried out in 2007 (Photo: David Catita).

Final considerations

The operations carried out until now have aimed to create a continuous wooded area around the margin of the Pedrógão reservoir. It is hoped that this area will take on a more productive character over the long term, producing prime timbers such as Narrow-leaved Ash.

However, since the area subject to improvements is relatively arid and highly exposed to sunlight it has proved necessary to eliminate weeds, which grew intensively over the planting period since the saplings provided little shade, and to water the saplings during the hottest months of the year.

The creation of small wooded areas (with approximately 3 lines of trees) gave rise to evident operational difficulties. The planting plan carried out in the second year facilitated the watering operations, which were mechanized, but still presented weed clearance difficulties. The third-year planting methods made the execution of both maintenance operations much easier; however, these trees will probably develop smaller, less vertical trunks compared to the trees planted in the preceding years.

Additionally, the reduction in the number of rows planted may reduce the natural look that is intended for these improved areas, although the dimensions of the improved area –over 200 hectares – may attenuate this effect.

Figure 5.4.8 Three year old Populus alba trees at the edge of the reservoir (Photo: David Catita).

SEVERAL LANDOWNERS IN A PROTECTED AREA: REVITALISATION OF THE TYROLEAN RIVER LECH

Johannes Konstanzer
Christian Moritz

The 'LIFE 00NAT/A/7053: Wildflusslandschaft Tiroler Lech' project (www.tiroler-lech.at) started in April 2001 and lasted, with a year's extension, till March 2007. It implemented a broader concept than usual of river protection and restoration. This case study summarizes the most important facts.

Figure 5.5.1 Where we are.

The geographical framework is the 4,138 hectares of the Natura 2000 region in the Tyrolean Lech valley (political district Reutte, county Tyrol, country Austria).

The Lech River has influenced the phenotype of the Tyrolean Lech valley right up to the present time. Wide areas of alluvial forest with softwood water meadows (Salici-Myricarietum, Salicion eleagno-daphnoidis), alder and ash water meadows (Alnenion glutinoso-incanae) and dry pine water meadows (Dorycnio-Pinetum) edge the wild river. Large, dynamically changing branches of water are still possible in the parts where the river bed is very wide.

The following details from an old military map (figure 5.5.2) show the highly heterogeneous morphology of the pristine river valley. In the upper reach, with a relatively steep gradient, the Lech is of an elongated type, whereas with diminishing gradient and higher gravel input the Lech changes more and more to the well-known, characteristic type of a braided river.

The current state is best characterized by an aerial photo (figure 5.3.3) which depicts the whole spectrum of the present-day river morphology. A major part of the Lech is as heavily regulated as most parts of alpine rivers in general (red arrow). In other areas, elements of a near-natural river structure are still left, even if human impact has left very characteristic footprints (here in the form of a 'string of pearls' pattern, which makes this region easy to spot even in pictures taken by space-cams; green arrow). Then there are the most famous areas where the river is still wide enough to allow the formation of a braided river type (blue arrow), although regulation has taken place and is recognizable in the form of a linear river bank on one side. Up to now the river is still the Lech valley's 'most important landowner'.

Figure 5.5.2 The Lech River showing various channel planform types according to an old military map (Franziszeische Landesaufnahme 1816-1821; source: Österr. Staatsarchiv).

Figure 5.5.3 Aerial photo with characteristic types of the present-day river morphology.

Basic project information, partners, time frame

A total of 7.82 million Euros were available for the project. The precondition for 49.5% EU funding was declaration of the target region as a Natura 2000 area. The remaining 50.5% of the costs is shared between the following national project partners:

- Amt der Tiroler Landesregierung, Abteilung Umweltschutz und Abteilung Wasserwirtschaft (Office of the Regional Government of Tyrol, Nature Conservation and Water Management Depts.)
- Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft: Sektion Ländlicher Raum und Sektion Wasserwirtschaft (Federal Ministry of Agriculture, Forestry, Environment and Water Management; http://www.lebensministerium.at/)
- Forsttechnischer Dienst für Wildbach und Lawinenverbauung, Sektion Tirol (Technical Service for Flood and Avalanche Protection; http://www.die-wildbach.at/)
- WWF Österreich (WWF Austria)

A delightful aspect of the LIFE-Project is the cooperation of various departments/organisations with rather divergent interests to achieve a common goal.

The project lasted 6 years (2001 – 2007). Originally 5 years were scheduled, but a 1 year extension became necessary for 2 reasons:

- In August 2005 an extreme flood took place. This unpredictable event with a 5000-year probability (according to the reports of the Tyrolean government's hydrographic department) naturally led to restrictions in the capacity to carry out the work, and resources are still partly tied up with repair and flood protection works
- One of the larger river restoration measures (widening of the Lech at Martinau) became much more expensive in the detailed planning process than originally estimated, so work could only start after additional funding from national resources had been secured.

Problems involved

Following flood catastrophes at the beginning of the 20th century and the increasing pressure to exploit the valley (only about 7% of the district is productive!), structural measures such as river regulation or bedload protection in the side valleys became a necessity, but they are partly to blame for today's problematic situation.

Apart from losing areas of natural habitats and thus affecting many species covered by the Habitats Directive, the sinking riverbed is another major problem. It has been caused by a combination of river channelization, sediment-retaining dams built on the major tributaries and increasing aggregate winning. The lowering of the bed level has not only led to further negative impacts on the fluvial system such as disconnection between the river and its adjacent floodplain, a fall in the groundwater level and further drying out of fluvial wetlands, but has also caused problems for protective structures (washout of riverbank protections, etc.). Thus, not only are the rare plant and animal species endangered but also, to a certain extent, the settlement areas.

Other problems include insufficient control of visitors, endangering sensitive habitats and typical flora, or the scepticism on socio-economic grounds of some sections of the population and interest groups about the Natura 2000 area.

Aims of the LIFE-project

Reacting to the above-mentioned problems, the LIFE-Project aims at following goals:

1) Conserving and restoring the fairly natural, dynamic fluvial habitats.

2) Stopping the sinking of the riverbed and fall of groundwater level.

3) Improving flood protection in accordance with environmental protection regulations

4) Preserving animals and plants that are listed by the EU as important, vulnerable or endangered

5) Improving the ecological awareness of the local people

6) Carrying out a joint project with organisations from different fields of interest

Measures, special projects

The LIFE project included a total of 53 individual projects. The most important measures and projects employed to achieve the set goals are as follows:

- River widening, by removing several constructions: river Lech at the Johannesbrücke bridge and Martinau hamlet; river Vils.
- Step-by-step removal of sediment-retaining dams on the river tributaries to ensure unobstructed bedload transport: Hornbach and Schwarzwasserbach brooks.
- Revitalization of the riverside waters and linking them up to their parent river: *e.g.* well water at Häselgehr
- Preservation and resettlement of target species: *e.g.* Little Ringed Plover, Common Sandpiper, German Tamarisk, Lady's Slipper, Bilek's Azure Damselfly and amphibians
- PR work

The most important river restoration and engineering measures are briefly introduced here below to give an overall impression of the most obvious improvements in the riverine landscape.

River restoration and engineering were the main measures employed to cope with the above-mentioned problems of the loss of river habitats and riverbed sinking. The main mechanisms used were river morphology and bedload budget. To simplify these rather complex matters, the Lech can roughly be divided into 3 parts (see figure 4), as follows:

- Upper Reach (Steeg – Elmen): Straight course; stable river bottom
- Middle Reach (Stanzach – Weißenbach): Braided river; erosion processes
- Lower Reach (Höfen–Reutte–Weißhaus): Unfavourable bedload deposition in the main settlement area; reduction of the sediment transport capacity, effective cross section and freeboard; multiple, ecologically disputed dredging operations

A delicate bedload management balance has to be attained, as gravel is needed in the upper and middle reaches to maintain the highly dynamic, braided river type; whereas in the lower reach a bedload surplus would be a severe problem. So a whole set of well-coordinated measures was needed to fulfil all these requirements (figure 5.5.4):

- Broad river widening measures for simultaneous flood protection and river revitalization (examples below)

- Removal of some large sediment-retaining dams in big tributaries to improve the gravel balance (*i.e.* fight the present gravel deficit) in the main river (example below)

- A big bedload trap in the lower reach, which at the same time improves the ecological situation, as an innovative project to protect the main town in the district from the possible bedload surplus (which is in part also consciously caused by our measures in the upstream reaches).

Figure 5.5.4 Location of the largest river engineering/revitalisation measures.

River revitalisation and flood protection Vils

In the 1930's the Vils was forced into a very tight corset, resulting in the river bed sinking by approx. 1.5-2 m. By widening and raising the riverbed and rebuilding smooth banks, a 2.3 km revitalized river stretch, approx. 10 ha of additional alpine river habitat and approx. 5 ha of adjacent areas with alluvial forest and reactivated backwater-systems have been regained. At the same time, this project is also an important flood-protection measure for the town of Vils.

Special attention was paid to measures for enhancing people's environmental awareness and acceptance of the project. These measures clearly increased the project's acceptance and, last but not least, resulted in approving comments in local newspapers.

- Webcam at a high viewing-point ("Falkenstein") – www.zeitfluss.at

- School-projects

- Support for a local initiative to install a "woodhenge" (Celtic tree-circle)

Figure 5.5.5 River revitalisation, Vils.

River revitalisation at Johannesbrücke

Because of the restriction caused by the Johannesbrücke, a bridge built in 1936/37, the river bed of the Lech had sunk by more than 3 m. Adjacent areas were cut off from inundation and the pristine softwood water meadows with willows and German Tamarisk were displaced by dry pine forests on high terraces. Flood protection dams and the Johannesbrücke itself were endangered.

By lengthening the bridge, widening the river bed (to approx. 180 m) and relocating protection dams upstream, on a length of almost 3 km, more than 20 ha of alpine river habitats have been resurrected.

Figure 5.5.6 River revitalisation at Johannesbrücke.

Removal of retention dams at Hornbach and Schwarzwasserbach

Large sediment-retaining dams built in the 1950/60s were removed from two of the major tributaries, the Hornbach and Schwarzwasserbach, freeing roughly 1.2 million m^3 of accumulated sediments for bedload transport over the coming years.

Figure 5.5.7 Removal of sediment-retaining dams, taking the Hornbach as an example.

Public-Relations as a key for acceptance in nature conservation

Public relations have become a key factor in today's nature-conservation work. In recent decades only NGOs (such as WWF or Greenpeace) have tried to convince the public through spectacular events. Nonetheless, Public Relations have become an important part of the project nowadays, raising public awareness of conservation targets.

A considerable part of the Wildflusslandschaft Tiroler Lech Life Project aimed to communicate the particularities of the protected area to a public that had been alienated by years of National Park discussion, nomination as a Natura 2000 area and plans for a hydroelectric plant. The Life project made it possible to communicate in a new way with local stakeholders and opinion leaders.

One of the top goals, besides the river restoration, was to establish a new way for groups with different goals such as the official nature conservation department, the department for regulating torrents and avalanches, the department for river management and the WWF to communicate with each other.

A total of 33 public relations projects were carried out, *e.g.* visitor platforms, themed trails, visitor management and nature guide training.

Figure 5.5.8 Public participation.

Appendices

List of relevant European directives, conventions and communications

River Managament

Flood management and evaluation: Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

Helsinki Convention: trans-boundary watercourses and international lakes: Council Decision 95/308/EC of 24 July 1995 on the conclusion, on behalf of the Community, of the Convention on the protection and use of trans-boundary watercourses and international lakes.

Inland waterways: River information services: Directive 2005/44/EC of the European Parliament and of the Council of 7 September 2005 on harmonised river information services (RIS) on inland waterways in the Community.

Pricing and long-term management of water: Communication from the Commission to the Council, European Parliament and Economic and Social Committee: Pricing and sustainable management of water resources [COM(2000) 477.

Sustainable Aquaculture: Communication from the Commission to the Council and European Parliament of 19 September 2002. A strategy for the sustainable development of European aquaculture [COM(2002) 511 final.

Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000.

Water scarcity and droughts in the European Union: Commission Communication of 18 July 2007: "Addressing the challenge of water scarcity and droughts in the European Union" [COM(2007) 414 final.

Water Quality

Bathing water: Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC.

Discharge of dangerous substances: protection of the aquatic environment: Directive 2006/11/EC of the European Parliament and of the Council of 15 February 2006 on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community.

Quality of drinking water: Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

Quality of shellfish waters: Directive 2006/113/EC of the European Parliament and of the Council of 12 December 2006 on the quality required of shellfish waters.

Urban waste water treatment: Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment.

Water suitable for fish-breeding: Council Directive 2006/44/EC of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life.

Groundwater

Protection of groundwater against pollution: Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration; and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

Protection of waters against pollution caused by nitrates from agricultural sources: Council Directive 91/676/EEC of 12 December 1991.
SOIL

Integrated pollution prevention and control: IPPC Directive: Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control.

Management of waste from extractive industries: Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries.

Thematic strategy for soil protection: Commission Communication of 22 September 2006 entitled "Thematic strategy for soil protection" [COM(2006) 231 final.

Biodiversity

Action Plan for biodiversity: Commission Communication of 22 May 2006 "Halting the loss of biodiversity by 2010 - and beyond - Sustaining ecosystem services for human well-being" [COM(2006) 216 final.

Aquaculture: use of alien and locally absent species: Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture.

Biodiversity Action Plan for Agriculture: Commission Communication of 27 March 2001 to the Council and the European Parliament: Biodiversity Action Plan for Agriculture (Volume III) [COM(2001) 162 final.

Biodiversity Action Plan for Fisheries: Commission Communication of 27 March 2001 to the Council and the European Parliament: Biodiversity Action Plan for Fisheries (Volume IV).

Biodiversity Action Plan for the Conservation of Natural Resources: Commission Communication of 27 March 2001 to the Council and the European Parliament: Biodiversity Action Plan for the Conservation of Natural Resources (Volume II) [COM(2001) 162 final.

Conservation of migratory species - Bonn Convention: Council Decision 82/461/EEC of 24 June 1982 on the conclusion of the Convention on the conservation of migratory species of wild animals (Bonn Convention).

Conservation of wild birds: Birds Directive: Council Directive 79/409/EEC on the conservation of wild birds.

Endangered species of wild fauna and flora (in accordance with the CITES): Council Regulation (EC) No 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein; and Commission Regulation (EC) No 318/2008 of 31 March 2008.

Natural habitats (Natura 2000): The Habitats Directive: Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

Forestry

European Union forest action plan: Communication from the Commission to the Council and the European Parliament of 15 June 2006 on an EU Forest Action Plan [COM(2006) 302 final.

Forest reproductive material: Council Directive 1999/105/EC of 22 December 1999 on the marketing of forest reproductive material.

Forests and development: the EC approach: Communication from the Commission to the Council and the European Parliament of 4 November 1999 on forests and development: the EC approach [COM(1999) 554 final.

The EU forestry strategy: Communication of 10 March 2005 from the Commission to the Council and the European Parliament - Reporting on the implementation of the EU forestry strategy [COM(2005) 84 final.

Landscape Management

European Landscape Convention: Council of Europe Treaty Series no. 176 (CETS No.: 176) Florence, Italy. 20 October 2000.

Guidelines for the implementation of the European Landscape Convention: Recommendation CM/Rec(2008)3 of the Committee of Ministers to member states. Adopted by the Committee of Ministers on 6 February 2008.

Pan-European Biological and Landscape Diversity Strategy: Council of Europe and European Centre for Nature Conservation. Ministerial Conference "Environment for Europe" (Sofia, Bulgaria, 23-25 October 1995). Nature and Environment, No. 74 Council of Europe Press, 1996.

Regional planning and the protection of water resources: Resolution 238 (1992) of the Standing Conference of Local and Regional Authorities of Europe.

Environmental Protection And Sustainable Development

Approaches to sustainable agriculture: Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions of 27 January 1999: Approaches to sustainable agriculture [COM(1999) 22 final.

Common Agricultural Policy (CAP)- Single Farm Payment (SFP): Council Regulation (EC) No 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy.

Community strategic guidelines for rural development; European Agricultural Fund for Rural Development (EAFRD): Council Decision of 20 February 2006 on Community strategic guidelines for rural development (programming period 2007 to 2013). Council Decision 2006/144/EC.

Environmental indicators: Report from the Commission to the Council of 20 September 2002, Analysis of the "open list" of environment-related headline indicators [COM(2002) 524 final.

Evironmental damage: Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage.

Global Monitoring for Environment and Security (GMES): Communication from the Commission, of 10 November 2005, entitled: "Global Monitoring for Environment and Security (GMES): from concept to reality." [COM(2005) 565 final.

LIFE+: a financial instrument for the environment: Regulation (EC) No 614/2007 of the European Parliament and of the Council of 23 May 2007 concerning the Financial Instrument for the Environment (LIFE+).

Sixth Environment Action Programme: "Environment 2010: Our future, Our choice" [COM (2001) 31 ; and Mid-term review of the Sixth Community Environment Action Programme [COM(2007) 225 final.

Strategy for sustainable development. [COM(2001) 264 final ; (COM(2005) 658; [COM(2007) 642 final.

Strategy on the sustainable use of natural resources: Communication from the Commission of 21 December 2005 - Thematic Strategy on the sustainable use of natural resources [COM(2005) 670.

The precautionary principle: Communication from the Commission of 2 February 2000 on the precautionary principle [COM(2000) 1 final.

The Strategic Environmental Assessment (SEA) Directive: Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.

White Paper of 9 February 2000 on environmental liability [COM(2000) 66.

Climate Change

European Climate Change Programme (ECCP): Communication from the Commission of 8 March 2000 on EU policies and measures to reduce greenhouse gas emissions: towards a European Climate Change Programme (ECCP) [COM(2000) 88 final.

Strategy on climate change: the way ahead for 2020 and beyond: Communication from the Commission, of 10 January 2007, entitled: "Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond" [COM(2007) 2 final.

Partners of the RIPIDURABLE-project

Alpiarça Municipal Council (lead partner)
Câmara Municipal de Alpiarça
R. José Relvas nº374
2090-100 Alpiarça
Portugal
www.cm-alpiarca.pt

Montemor-o-Novo Municipal Council
Câmara Municipal de Montemor-o-Novo
Largo dos Paços do Concelho
7050-127 Montemor-o-Novo
Portugal
www.cm-montemornovo.pt

Higher Institute of Agronomy
Technical University of Lisbon, Forestry Department,
Instituto Superior de Agronomia (ISA)
Universidade Técnica de Lisboa, Departamento de Engenharia Florestal
Tapada da Ajuda
1349-017 Lisboa
Portugal
www.isa.utl.pt

University of Évora,
LabOr - Laboratory of Ornithology,
Department of Biology
Universidade de Évora
LabOr - Laboratório de Ornitologia
Unidade de Biologia da Conservação, Departamento de Biologia
7002-554 Évora
Portugal
www.labor.uevora.pt

National Centre of Scientific Research
CNRS-CEFE
Centre national de la recherche scientifique
Centre d'Ecologie Fonctionnelle et Evolutive
1919 Route de Mende
34293 Montpellier cedex 5
France
www.cefe.cnrs.fr

University of Burgundy
Université de Bourgogne
UMR CNRS BioGéoSciences
Ecologie Evolutive
6 Bd Gabriel
21000 Dijon
France
www.u-bourgogne.fr

Hellenic Center for Marine Research, Institute of Inland Waters (HCMR)
46,7 km Athens-Sounio, Mavro Lithari
GR-19013 Anavissos, Attiki
Greece
www.hcmr.gr

University of Ioannina
Faculty of Environmental and Natural Resources Management
Lab. of Ecology and Biodiversity Conservation
Seferi 2
30100 Agrinio
Greece
www.env.uoi.gr/

ETANAM S.A.
Development Agency for South Epirus and Amvrakikos
Lascaratou, Periochi Ydatopyrgos
48100 Preveza
Greece
www.etanam.gr

Forest Center for Applied Research (CIEF)
Office for Environment Protection, Water, Urbanism and Housing of the Valencian Regional Government
Centre per a la Investigació i l'Experimentació Forestal (CIEF); Conselleria de Medi Ambient, Aigua, Urbanisme i Habitatge, Generalitat Valenciana
Comarques del Pais Valencià 114-6,
46930 Quart de Poblet,
Spain
http://www.cth.gva.es/

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RIPIDURABLE

Sustainable Management of Riparian Woods

Lead partner/Chef de file
Alpiarça Municipal Council
Câmara Municipal de Alpiarça
R. José Relvas nº374
2090-106 Alpiarça
Portugal

T +351 243 559 100
F +351 243 559 105

info@ripidurable.eu
www.ripidurable.eu

Partners

Alpiarça MUNICÍPIO

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DEVELOPMENT AGENCY FOR SOUTH EPIRUS-AMVRAKIKOS S.A.

CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

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CONSELLERIA DE MEDI AMBIENT AIGUA, URBANISME I HABITATGE

Project co-financed by

Nord Est SUD Ouest INTERREG IIIC