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河流生态修复

River Restoration



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◎ 董哲仁 等 著



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内 容 提 要

河流生态修复是指在充分发挥生态系统自修复功能的基础上,采取工程和非工程措施,促使河流生态系统恢复到较为自然的状态,改善其生态完整性和可持续性的一种生态保护行动。本书在深入论述河流生态系统过程与功能的基础上,系统地阐述了河流生态修复的规划方法、技术措施和监测评估方法。

本书共5章,阐述了河流生态系统的过程与功能,深入分析了各类经济建设活动对河流生态系统的影响;阐述了河流调查与分析,涉及地貌过程、景观格局、水文过程、物理化学过程和环境压力—生物响应分析;重点阐述了河流生态修复规划,包括规划的时空尺度,河流生态状况分级系统,修复目标与任务,修复规划原则、规划内容和编制流程以及修复措施工具箱;详细介绍了各类河流生态修复技术,包括河道内栖息地修复与加强,岸坡防护技术、洄游鱼类保护、水库分层取水设施、环境水流评价方法、兼顾生态保护的水库调度方法、污染源治理以及河湖水系连通性恢复等,同时链接了若干国内外工程案例;介绍了河流生态监测与评估,提出了全指标河流健康评估体系和基于负反馈分析的河流生态修复适应性管理决策支持系统技术。

本书融入了作者多年的研究成果,借鉴和应用了国际上生态修复领域的最新理论和方法,既具理论系统性,又具技术实用性,可供水利、水电、生态、环境、城市景观、园林、地理和国土规划等领域的工程技术人员、科研人员和管理人员参考,也可作为高等院校相关专业的教学参考。

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An aerial photograph of a vast, lush green landscape. A winding river flows through the scene, surrounded by dense forests and rolling hills. The water is a deep blue, contrasting with the vibrant green of the vegetation. The overall scene is peaceful and natural.

上善若水。水善利万物而不争，处众人之所恶，故几于道。

——老子《道德经》



Abstract: River restoration can be defined as an ecological conservation action in order to restore the river ecosystem back to natural conditions and improve ecological integrity and sustainability by taking structural and non-structural measures on the basis of giving full play to the role of ecosystem self-restoration. On the basis of giving an in-depth discussion on the process and function of river ecosystem, the author systematically expounds the planning method, technical measures, monitoring and evaluation methods of river restoration.

This book consists of 5 chapters, the author firstly expounds the structure, function and process features of river ecosystem and analyzes the impact and disturbances of various economic activities on the river ecosystem. Based on that, the author discusses river investigation and analysis methods related to river geomorphology processes, landscape patterns and hydrological processes, physical and chemical processes and environmental pressure versus biotic impact. In this book, emphasis is placed on the river eco-restoration planning methods, including the spatial and temporal scales, the rating systems of river ecological conditions, targets and tasks of restoration, principles of planning formulation, technical procedures and the tool box. A detailed introduction is also given to various technologies of river restoration, including the restoration and reinforcement of habitats in river courses, slope protection, protection of migratory fishes, evaluation of environmental flows, reservoir operation considering ecological conservation, treatment of pollution sources and water connectivity. Many domestic and international project cases are attached to this book. Finally, the author introduces monitoring and evaluation technologies of river restoration, proposes full-indicator river health assessment system and methods of decision-making and supporting system of adaptive management strategies for river restoration on the basis of negative feedback analysis.

This book incorporates the author's research outcome accumulated during past years by building upon and applying international cutting-edge theories and methods. It is both of theoretical and systematical significance, and of technical and practical importance. It can be a good reference book for technical, research and managerial personnel engaged in water conservancy, hydropower ecology, environment, urban landscape, gardens, geography and territory planning. In addition, it can also be taken as a teaching reference for institutions of higher learning.


前言

河流是生命的源泉。

河流生态系统为人类提供淡水、食品、药品等资源；涵养水分、调节气候、调蓄洪水、保持水体自净；维系水文循环、营养物质循环和初级生产；提供休憩、旅游空间以及教育和美学价值。河流生态系统服务功能不但支撑维系了地球的生命支持系统，而且更与人类福祉息息相关，是人类生存与现代文明的基础。

近百年来，全球范围的经济生产活动以空前规模和迅猛速度发展，一方面给人类社会带来了巨大繁荣；另一方面也对自然环境形成了巨大压力，对河流生态系统造成了重大干扰。在工业化过程中，人们从工厂运走了各类产品，却将废水污水倾倒在江河中。在城市化进程中，大范围改变了土地利用方式，还使自然水文循环方式发生改变。森林无度砍伐、河湖围垦、过度捕鱼和养殖等生产活动，引起水土流失、植被破坏、河湖萎缩及物种多样性下降。大规模的基础设施建设，诸如公路、铁路、矿山建设改变了景观格局，造成水土流失、土地塌陷和生物多样性下降。特别是水利水电工程建设，一方面在保障供水，发展农业灌溉和水力发电，保障防洪安全等方面发挥了巨大作用，为社会经济发展做出了巨大贡献；另一方面也使江河湖泊的面貌发生了巨变。在河流上建设的水坝和各类建筑物大幅度改变了河流地貌景观和水文情势；过度的水资源开发利用，造成河流干涸、断流，对河流生态系统产生了重大影响。人类这些大规模经济生产活动对于河流生态系统的干扰所造成的影响往往是巨大而深远的。河流生态系统的退化以及生物多样性的降低，不可避免地危及当代人类福祉，也危及子孙后代的可持续发展。

保护地球家园，维系自然生态，坚持可持续发展，已经成为当代国际社会的共识。我国政府已经把生态文明建设作为国家发展的大政方针，提倡尊重自然、顺应自然、保护自然的生态文明理念，不断加大生态保护力度，颁布了水生态系统保护与修复方

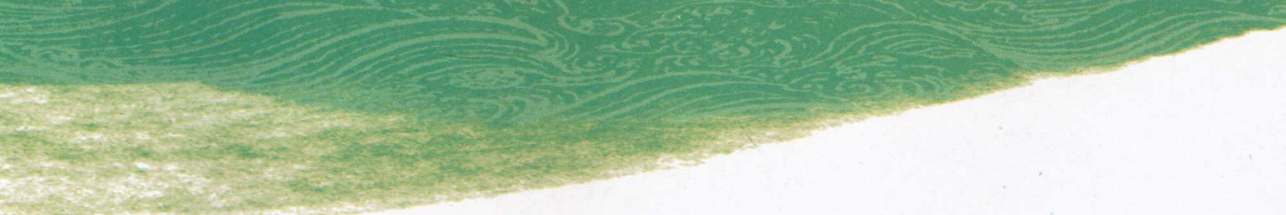


针政策，要求正确处理开发与保护的关系，在保护生态的基础上积极开发水能资源，大力推进生态脆弱地区的生态修复工程。

国内河流生态保护形势发展之快令人鼓舞，同时也迫切需要理论指导和技术支撑。时下国内对河流生态修复有不同的理解和做法，所以需要“河流生态修复”作一个科学的界定。我们在这里所说的河流生态修复，不是创造一个新的河流生态系统，也不可能是自然河流生态系统的完全复原，更不是园林景观建设，而是在调查、监测与评估的基础上，遵循自然规律，制定合理的规划，通过人们的适度干预，来改善水文条件、地貌条件、水质条件，以维持生物多样性，改善河流生态系统的结构与功能。河流生态修复是指在充分发挥生态系统自修复功能的基础上，采取工程和非工程措施，促使河流生态系统恢复到较为自然的状态，从而改善其生态完整性和可持续性的一种生态保护行动。

本书编写的目的是为河流生态修复规划、设计以及生态管理提供理论基础和技术方法。本书第1章阐述了河流生态系统的过程与功能。因为自然河流是河流生态修复的理想状态，所以，掌握大规模人工干扰前的自然河流特征，是确定河流生态修复规划目标的必要理论准备。第2章讨论了河流调查与分析。河流调查和分析是进行河流生态修复规划设计的基础工作。本章首先讨论了生态区划和河流分类原则与方法，进而详细讨论了地貌过程、景观格局和水文过程分析方法，介绍了物理化学评价方法和生物监测方法，阐述了环境压力—生物响应分析模型。第3章阐述了河流生态修复规划，包括确定规划的时空尺度，构建河流生态状况分级系统，确定修复目标与任务，详细阐述了规划编制的原则，给出了技术流程以及工具箱；还介绍了国内外生态修复工程项目规划的典型案例。第4章介绍了河流生态修复技术，为河流生态修复项目设计提供技术支撑。内容包括河道内栖息地修复与加强、岸坡防护技术、洄游鱼类保护、环境水流评价方法、兼顾生态保护的水库调度方法、污染源治理以及水系连通性恢复等。第5章讨论了生态监测与评估，内容包括生态监测体系的构建，河流健康评估方法和指标体系。本章还讨论了河流生态修复的不确定性问题 and 适应性管理策略，提出了基于负反馈分析的河流生态修复适应性管理决策支持系统。在相关章节中链接介绍了若干案例和延伸内容。本书图文并茂，插入了大量图表和精美照片，有助于读者理解和提高阅读兴趣。

本书吸收融入了作者近年来的科研成果，其中不乏创新内容，这些成果得益于水利部公益项目的支持。值得一提的是，作者有幸参与了水利部在全国率先开展的水生态保护与修复全部13个试点项目的技术咨询工作，这些试点项目的实施为今后全



面开展河湖生态修复提供了丰富的实践经验。本书还吸收借鉴了发达国家在河流生态修复中的理论成果和技术经验，特别是作者在担任中国—欧盟合作流域管理项目高级顾问组主席的5年期间，参阅了欧盟大量的科学论文和技术报告，与欧盟专家马丁·格里菲斯、西蒙·思邦纳等诸先生进行了深入的交流和讨论，使作者对欧盟近十年在水资源保护与水生态修复方面的政策与技术新进展有了深度的理解，受到不少启发。可以说，在理论探索、实践经验总结以及国际交流合作三方面的努力，为本书奠定了基础。

本书力求在以下五个方面有所创新：一是引进、融入了生态学相关领域国际最新理念和成果，包括联合国千年生态系统评估报告（MA）、政府间气候变化专门委员会报告（IPCC）、欧盟水框架指令（WFD）等，同时，密切结合我国的国情、水情和河流特点，提出了较为完整的河流生态修复理论和技术方法。二是推动学科的交叉与融合。河流生态修复是一个全新的科技领域，涉及生态系统生态学、生物学、生态水文学、生态水力学、河流地貌学、景观生态学、环境保护科学和水利工程学等，具有明显的跨学科特点，本书在综合应用这些学科知识方面做了大胆尝试。三是力求理论量化。恢复生态学是一门新兴学科，其理论、规律、范式和模型多为定性阐述，本书尝试在生态要素状况评价、预测分析、景观格局分析以及水库生态调度等方面更多引进定量的解析方法和计算机模型。四是强化信息技术应用。作者试图在河流生态修复中更多地应用信息技术包括遥感技术（RS）、地理信息系统（GIS）、全球定位系统（GPS）和决策支持系统（DSS）等，期望有助于推动河流生态修复工程的信息化和数字化。五是突出生态修复技术综合性。本书除详细介绍了栖息地加强技术和生态型护坡技术等常规技术以外，还介绍了洄游鱼类保护技术、兼顾生态保护的水库调度、环境水流评估技术以及河湖水系连通性恢复方法，着力于技术综合性和实用性。总之，本书力求尽可能全面地反映出河流生态修复领域的国内外科技发展前沿，期望对我国方兴未艾的河流生态修复工作有所裨益。

本书是集体智慧的结晶。作者的科研团队成员以极为严谨的科学态度参加了编写工作，为本书作出了贡献。这些作者是孙东亚（2.3、4.1、4.2、4.3）、赵进勇（1.3、2.2、2.4、2.5、5.1、5.3）、张晶（1.4、2.7、3.7、5.2）、王俊娜（2.6、4.5、4.6）、张爱静（2.8、4.7、5.1）、李福田和王宏涛（4.3）。

本书的出版得到了许多朋友和专家的鼎力相助。承蒙水利部高波先生、水利部黄河水利委员会董保华先生、水利部中科院水工程生态所常剑波先生和河北省水利厅张凤林先生慷慨提供精美照片和技术图片；承蒙中国水利水电科学研究院胡平教授级高级工程师、唐克旺教授级高级工程师、中水东北公司科学研究院范宝山教授级高级



工程师提供宝贵技术资料；承蒙水利部中科院水工程生态研究所常剑波研究员、乔晔副研究员、赵先富副研究员、池仕运助理研究员、中科院武汉植物园李伟研究员、中科院水生生物研究所余育和研究员审阅本书有关生物学部分章节；承蒙全球水伙伴（GWP）中国委员会秘书处张代娣女士进行全书文字校核整理；承蒙中国水利水电科学研究院鲍淑君博士进行英文提要和前言的翻译。中国水利水电出版社王照瑜编审在负责编辑过程中倾注了大量心血，李菲美编对本书版式、插图进行了精心设计。在本书出版之际，谨向他们表示诚挚的谢忱。

河流生态修复是一个正在发展中的新兴科技领域，受作者知识水平的局限，对本书的谬误和不足恳请各界读者指正。

作者

2013年9月

于北京木樨地

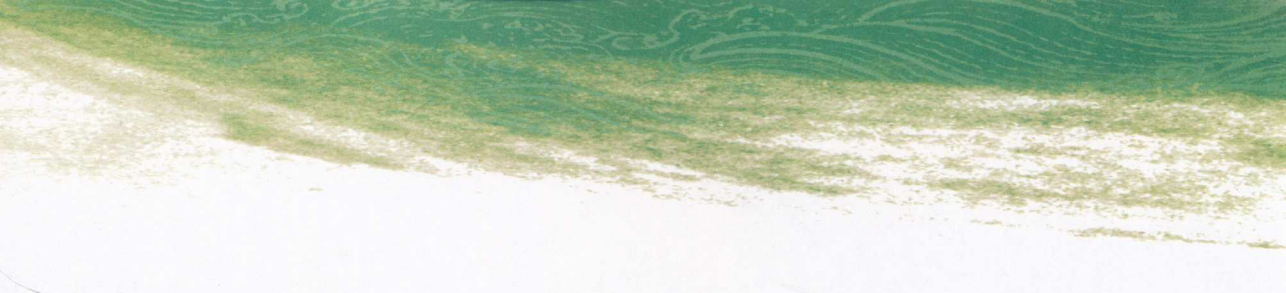


Preface

The source of life lies in rivers.

The river ecosystem provides man with resources of fresh water, food and medicine, etc. It can conserve moisture, regulate climate, store flood and keep water body clean; maintain hydrological and nutrient cycling and primary production; and provide aesthetic values and space for rest, tourism and education. River ecosystem services can not only support and maintain the earth's life-supporting system, but also constitute the basis of human existence and modern civilization, which are closely related to human's well-being.


During the past century, global economic and productive activities developed on an unprecedented scale and at a dreadful rate, bringing great prosperity to human society, but with huge pressures to natural environment and serious disturbances to the river ecosystem. In the industrialized process, human transported various products from factories, dumping sewage and polluted water into rivers. During the urbanization process, patterns of land use and natural water cycle were changed on a large scale. Activities such as over-deforestation, reclamation of rivers and lakes, over-fishing and over-breeding resulted in soil and water erosion, vegetation damage, shrinkage of rivers and lakes as well as bio-diversity reduction. The construction of large-scale infrastructure, such as roads, railways, mines changed the landscape pattern, caused soil and water erosion, land collapse and declined biodiversity. In particular, the construction of water conservancy and hydropower projects, on one hand, played a vital role in guaranteeing water supply, irrigation development, hydropower generation, and flood control security, thus making big contribution to socio-economic development; on the other hand, greatly changed the appearance of rivers and lakes. Dams and various projects constructed on the river greatly changed geomorphology and hydrological regime of the river while the over-exploitation and utilization of water resources caused dry and intercepted rivers, dealing a serious impact on the river eco-system. It will be far-reaching of the impact of disturbances induced



by large-scale economic and productive activities on the river ecosystem. The degradation of river ecosystem and reduced bio-diversity will inevitably do harm to man's well-being and the sustainable development of our offspring.


It has become a consensus to protect global homeland, maintain natural ecology and uphold sustainable development. The Chinese government has regarded conservation culture as the fundamental policy for national development by advocating the concept of conservation culture featuring the respect for, compliance with and protection of the nature. It has promulgated guiding principles and policies of aquatic ecosystem conservation and restoration in order to strengthen the ecological conservation. It is required to deal with the relationship between ecological development and protection, energetically develop hydropower on the basis of protecting ecology and vigorously promote eco-restoration projects in eco-vulnerable areas.

Domestic development of river ecological conservation is inspiring, but still urgently needs theoretical guidance and technical support. There are different understandings and practices on river restoration in China, so it is necessary to scientifically define river restoration. In terms of river restoration, it does not mean the creation of a new river ecosystem, a complete recovery of natural river ecosystem, or garden and landscape construction. However, it means the formulation of rational restoration planning on the basis of investigation, monitoring, evaluation following natural laws and rules; and the maintenance of bio-diversity and improvement of the structure and functions of river ecosystem by moderately interfering in and improving hydrological conditions, river geomorphology and water quality. River eco-restoration thus can be referred to as an ecological conservation action in order to restore the river ecosystem back to partially natural conditions and improve ecological integrity and sustainability by taking structural and non-structural measures on the basis of giving full play to the role of ecosystem self-restoration.




This book aims to provide a theoretical basis and technical methods for the planning, design and ecological management of the river ecosystem. The first chapter expounds the process and function of river ecosystem. Since natural rivers are in the ideal state of river eco-restoration, so the knowledge of natural river features before large-scale artificial interferences constitutes the necessary theoretical preparation for defining river eco-restoration planning targets. In the first chapter, the author analyzes the impact and disturbances of man's various production and construction activities on the river ecosystem. It will be the main content of river eco-restoration planning to remove disturbing factors or implement compensation measures. The second chapter introduces river investigation and analysis methods, which constitute the basis for river eco-restoration planning and design. This chapter firstly discusses the division of ecological zoning and classification of river types, and further gives a detailed discussion on topographic processes, landscape patterns and analytic methods of hydrological processes, introduces physical and chemical rating methods and biotic monitoring methods, and expounds the analytic method of environmental pressure versus biotic response. The third chapter explains river eco-restoration planning methods. To be specific, it defines spatial and temporal scales, constructs rating systems of river ecological conditions, sets targets and tasks of restoration, expounds principles of planning formulation, and proposes technical procedures and the tool box. The fourth chapter gives a detailed introduction to various technologies and applicable conditions to provide technical support for river eco-restoration project design, including the restoration and reinforcement of habitats in river courses, slope protection, migratory fish protection, environmental flow evaluation, reservoir operation considering ecological conservation, treatment of pollution sources and water connectivity restoration. The fifth chapter discusses river ecosystem monitoring and evaluation methods, including the construction of ecological monitoring system, river health evaluation methods and indicator system. It also discusses the uncertainties and adaptive management strategies of river eco-restoration, proposes technical methods of decision-making and supporting system of adaptive management strategies for river eco-restoration on the basis of negative feedback analysis. Many project cases and extension knowledge are also attached. This book also includes excellent pictures and texts and many diagrams and exquisite photos, which are conducive to enhancing readers' understanding and reading interest.

A large number of research achievements with no lack of innovative content have been incorporated into this book thanks to the support from Ministry of Water Resources Special Research Funds for Public Welfare Projects. It is worthwhile pointing out that the author was lucky enough to participate in the technical consultancy for 13 pilot projects of aquatic ecological conservation and restoration



as a consultant, which were carried out nationwide by the MWR and have produced fruitful practical experience for the full implementation of eco-restoration of rivers and lakes. This book has also drawn upon experience from theoretical and technical achievements on river eco-restoration from developed countries. In particular, the author obtained an in-depth understanding and enlightenment in terms of policies and new technical progress on water resources protection and aquatic eco-restoration in EU through thorough communications and discussions with EU counterparts such as Prof. Martin Griffiths, Mr. Simon Spoone, etc. and through consulting numerous scientific papers and technical reports during the past five years as the chair of the senior adviser group of China-EU River Basin Management Programme. It can be said that all above-mentioned efforts embodied in the theoretical exploration, practical experience summary and international exchanges and cooperation have laid a solid foundation for this book.

This book is innovative in the following five aspects: Firstly, it introduces and incorporates the international cutting-edge concepts and achievements in the ecology-related fields, including MA (Millennium Ecosystem Assessment) report, IPCC (Intergovernmental Panel on Climate Change) report and WFD (Water Framework Directive); secondly, it promotes disciplinary crossing and integration. River eco-restoration is a brand-new technological front, covering many related ecosystem subjects, such as ecology, biology, eco-hydrology, eco-hydraulics, river geomorphology, landscape ecology, environmental protection science and water conservancy engineering, etc., with evident cross-disciplinary characteristics. The author has made bold explorations into the integrated application of almost all the above-said subjects. Thirdly, it tries to make the theory quantitative. The subject of restoration ecology is a newly emerging one, and many of its theories, rules, paradigms and patterns have been explained in a qualitative manner. The author tries to conduct a quantitative explanation and analysis as well as computer operation modeling on the evaluation of ecological



factor conditions, prediction analysis, landscape pattern analysis and ecological regulation of reservoirs. Fourthly, it strengthens the application of information technologies. The author tries to apply more information technologies in river restoration, including remote sensing (RS), geographic information system (GIS), global positioning system (GPS) and decision-making system (DMS), which will be expected to promote the informationization and digitization of river eco-restoration projects. Fifthly, it highlights the integral feature of eco-restoration technologies. In addition to a detailed introduction of conventional technologies, including habitat strengthening technology and ecological slope protection technology, the author also introduces migratory fish protection technologies, reservoir regulation and environmental flow evaluation technologies while considering ecological protection, with a focus on the integration and application of technologies. In brief, the author hopes this book can fully reflect the domestic and international fronts about the scientific and technological developments in the river eco-restoration field, which will hopefully benefit China's flourishing development of river eco-restoration.

This book is a crystallization of the collective wisdom. All the research team members led by the author have been engaged in the compilation of this book with a rigorous attitude, contributing their efforts to this book. They are SUN Dongya for 2.3, 4.1, 4.2, 4.3, ZHAO Jinyong for 1.3, 2.2, 2.4, 2.5, 5.1, 5.3, ZHANG Jing for 1.4, 2.7, 3.7, 5.2, WANG Junna for 2.6, 4.5, 4.6, ZHANG Aijing for 2.8, 4.7, 5.1, LI Futian and WANG Hongtao for 4.3.

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River restoration is a new technological front, and we sincerely hope readers from various circles oblige us with your valuable comments and opinions on those in evitable inadequacies or errors due to the authors' knowledge limitations.

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