ENVIRONMENTAL SCIENCE AND ENGINEERING

Michel De Lara · Luc Doyen

Sustainable Management of Natural Resources

Mathematical Models and Methods

Springer

Environmental Science and Engineering
Subseries: Environmental Science

Michel De Lara · Luc Doyen

Sustainable Management of Natural Resources

Mathematical Models and Methods

Michel De Lara
Universite Paris-Est, CERMICS
6-8 avenue Blaise Pascal
77455 Marne la Vallee Cedex 2
France
delara@cermics.enpc.fr

Luc Doyen
Centre National de la Recherche Scientifique
CERSP, Muséum National d'Histoire Naturelle
55 rue Buffon
France 75005 Paris
lucdoyen@mnhn.fr

ISBN: 978-3-540-79073-0 e-ISBN: 978-3-540-79074-7

Environmental Science and Engineering ISSN: 1863-5520

Library of Congress Control Number: 2008928724

Cover Design: deblik, Berlin

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface

Nowadays, environmental issues including air and water pollution, climate change, overexploitation of marine ecosystems, exhaustion of fossil resources, conservation of biodiversity are receiving major attention from the public, stakeholders and scholars from the local to the planetary scales. It is now clearly recognized that human activities yield major ecological and environmental stresses with irreversible loss of species, destruction of habitat or climate catastrophes as the most dramatic examples of their effects. In fact, these anthropogenic activities impact not only the states and dynamics of natural resources and ecosystems but also alter human health, well-being, welfare and economic wealth since these resources are support features for human life. The numerous outputs furnished by nature include direct goods such as food, drugs, energy along with indirect services such as the carbon cycle, the water cycle and pollination, to cite but a few. Hence, the various ecological changes our world is undergoing draw into question our ability to sustain economic production, wealth and the evolution of technology by taking natural systems into account.

The concept of "sustainable development" covers such concerns, although no universal consensus exists about this notion. Sustainable development emphasizes the need to organize and control the dynamics and the complex interactions between man, production activities, and natural resources in order to promote their coexistence and their common evolution. It points out the importance of studying the interfaces between society and nature, and especially the coupling between economics and ecology. It induces interdisciplinary scientific research for the assessment, the conservation and the management of natural resources.

This monograph, *Sustainable Management of Natural Resources, Mathematical Models and Methods*, exhibits and develops quantitative and formal links between issues in sustainable development, decisions and precautionary problems in the management of natural resources. The mathematical and numerical models and methods rely on dynamical systems and on control theory.

The basic concerns taken into account include management of fisheries, agriculture, biodiversity, exhaustible resources and pollution.

This book aims at reconciling economic and ecological dimensions through a common modeling framework to cope with environmental management problems from a perspective of sustainability. Particular attention is paid to multicriteria issues and intergenerational equity.

Regarding the interdisciplinary goals, the models and methods that we present are restricted to the framework of discrete time dynamics in order to simplify the mathematical content. This approach allows for a direct entry into ecology through life-cycles, age classes and meta-population models. In economics, such a discrete time dynamic approach favors a straightforward account of the framework of decision-making under uncertainty. In the same vein, particular attention has been given to exhibiting numerous examples, together with many figures and associated computer programs (written in Scilab, a free scientific software). The main approaches presented in the book are equilibrium and stability, viability and invariance, intertemporal optimality ranging from discounted utilitarian to Rawlsian criteria. For these methods, both deterministic, stochastic and robust frameworks are examined. The case of imperfect information is also introduced at the end. The book mixes well known material and applications, with new insights, especially from viability and robust analysis.

This book targets researchers, university lecturers and students in ecology, economics and mathematics interested in interdisciplinary modeling related to sustainable development and management of natural resources. It is drawn from teachings given during several interdisciplinary French training sessions dealing with environmental economics, ecology, conservation biology and engineering. It is also the product of numerous scientific contacts made possible by the support of French scientific programs: GDR COREV (Groupement de recherche contrôle des ressources vivantes), ACI Ecologie quantitative, IFB-GICC (Institut français de la biodiversité - Gestion et impacts changement climatique), ACI MEDD (Modélisation économique du développement durable), ANR Biodiversité (Agence nationale de la recherche).

We are grateful to our institutions CNRS (Centre national de la recherche scientifique) and ENPC (École nationale des ponts et chaussées) for providing us with shelter, financial support and an intellectual environment, thus displaying the conditions for the development of our scientific work within the framework of extensive scientific freedom. Such freedom has allowed us to explore some unusual or unused roads.

The contribution of C. Lobry in the development of the French network COREV (Outils et modèles de l'automatique dans l'étude de la dynamique des écosystèmes et du contrôle des ressources renouvelables) comprising biologists and mathematicians is important. We take this opportunity to thank him and express our gratitude for so many interesting scientific discussions. At INRIA (Institut national de recherche en informatique et automatique) in Sophia-Antipolis, J.-L. Gouzé and his collaborators have been active in

developing research and continue to influence our ideas on the articulation of ecology, mathematics and the framework of dynamic systems and control theory. At the Université Paris-Dauphine, we are much indebted to the very active team of mathematicians headed by J.-P. Aubin, who participated in the CEREMADE (Centre De Recherche en Mathématiques de la Décision) and CRVJC (Centre de Recherche Viabilité-Jeux-Contrôle) who significantly influenced our work on control problems and mathematical modeling and decision-making methods: D. Gabay deserves special acknowledgment regarding natural resource issues. At École nationale supérieure des mines de Paris, we are quite indebted to the team of mathematicians and automaticians at CAS (Centre automatique et systèmes) who developed a very creative environment for exploring mathematical methods devoted to real life control problems. We are particularly grateful to the influence of J. Lévine, and his legitimate preoccupation with developing methods adapted and pertinent to given applied problems. At ENPC, CERMICS (Centre d'enseignement et de recherche en mathématiques et calcul scientifique) hosts the SOWG team (Systems and Optimisation Working Group), granting freedom to explore applied paths in the mathematics of sustainable management. Our friend and colleague J.-P. Chancelier deserves a special mention for his readiness in helping us write Scilab codes and develop practical works available over the internet. The CMM (Centro de Modelamiento Matemático) in Santiago de Chile has efficiently supported the development of an activity in mathematical methods for the management of natural resources. It is a pleasure to thank our colleagues there for the pleasant conditions of work, as well as new colleagues in Peru now contributing to such development. A nice discussion with J. D. Murray was influential in devoting substantial content to uncertainty issues.

At CIRED (Centre international de recherche sur l'environnement et le développement), we are grateful to O. Godard and J.-C. Hourcade for all we learnt and understood through our contact with them regarding environmental economics and the importance of action timing and uncertainties. Our colleagues J.-C. Pereau, G. Rotillon and K. Schubert deserve special thanks for all the sound advice and challenging discussions concerning environmental economics and bio-economics to which this book owes so much.

Regarding biodiversity management, the stimulating interest and support shown for our work and modeling activities by J. Weber at IFB (Institut français de la biodiversité) has constituted a major motivation. For the modeling in fisheries management and marine biodiversity, it is a pleasure to thank F. Blanchard, M.-J. Rochet and O. Thébaud at IFREMER (Institut français de recherche pour l'exploitation de la mer) for their active investment in importing control methods in the field. We also thank J. Ferraris at IRD (Institut de recherche pour le développement). The cooperation with S. Planes (CNRS and École pratique des hautes études) has always been fruitful and pleasant. The contributions of C. Béné (World Fish Center) are major and scattered throughout several parts of this monograph.

At INRA (Institut national de recherche en agriculture), a very special thanks to M. Tichit and F. Léger for fruitful collaboration despite the complexity of agro-environmental topics. A. Rapaport deserves special mention for his long investment in control methods in the field of renewable resources management. At MNHN (Muséum national d'histoire naturelle), and especially within the Department Écologie et gestion de la biodiversité , we want to point out the support of R. Barbault and D. Couvet. Their interest in dynamic control and co-viability approaches for the management of biodiversity was very helpful. At CEMAGREF, we thank our colleague J.-P. Terreaux. At ENPC, the CEREVE (Centre d'enseignement et de recherche eau ville environnement) has been a laboratory for confronting environmental problems and mathematical methods with various researchers. Those at the Ministère de l'Équipement and at the Ministère de l'Environnement, who have allowed, encouraged and helped the development of interdisciplinary activities are too numerous to be thanked individually.

The very active and fruitful role played by young PhD and postdoc researchers such as P. Ambrosi, P. Dumas, L. Gilotte, T. Guilbaud, J.-O. Irisson and V. Martinet should be emphasized. Without the enthusiasm and work of young Master's students like F. Barnier, M. Bosseau, J. Bourgoin, I. Bouzidi, A. Daghiri, M. C. Druesne, L. Dun, C. Guerbois, C. Lebreton, A. Le Van, A. Maure, T. Mahé, P. Rabbat, M. Sbai, M.-E. Sebaoun, R. Sabatier, L. Ton That, J. Trigalo, this monograph would not have been the same. We thank them for helping us explore new tracks and developing Scilab codes.

Paris,
April 2008

Michel De Lara
Luc Doyen

Contents