

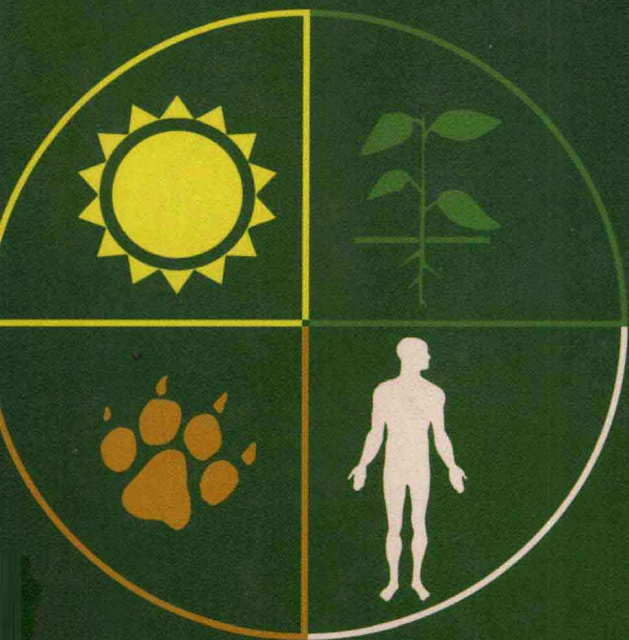
Fundamentals of Ecological Modelling
Applications in Environmental Management and Research (Fourth Edition)

生态建模原理

在环境管理和研究中的应用

(原著第四版)

Sven Erik Jørgensen, Brian D. Fath



原版引进



科学出版社

生态前沿系列

Fundamentals of Ecological Modelling

Applications in Environmental
Management and Research

(Fourth Edition)

生态建模原理

在环境管理和研究中的应用

(原著第四版)

Sven Erik Jørgensen

Brian D. Fath

科学出版社

北 京

图字:01-2011-3726 号

This is an annotated version of
**Fundamentals of Ecological Modelling: Applications in Environmental
Management and Research(Fourth Edition)**

Edited by Sven Erik Jørgensen, Brian D. Fath

Copyright © 2011 Elsevier B. V.
ISBN: 978-0-444-53567-2

All rights reserved.

No part of this publication may be reproduced or transmitted in any form or
by any means, electronic or mechanical, including photocopy, recording, or
any information storage and retrieval system, without permission in writing
from the publisher.

AUTHORIZED EDITION FOR SALE IN P. R. CHINA ONLY

本版本只限于在中华人民共和国境内销售

图书在版编目(CIP)数据

生态建模原理:在环境管理和研究中的应用=Fundamentals of Ecological Model-
ling:第四版:英文/(丹)约恩森(Jørgensen, S. E.)等编著. —北京:科学出版社, 2012
(生态前沿系列)

ISBN 978-7-03-033095-6

I. ①生… II. ①约… III. ①生态环境-系统建模-研究-英文 IV. ①X171.1

中国版本图书馆 CIP 数据核字(2011)第 269589 号

责任编辑:孙红梅/责任印制:钱玉芬

封面设计:耕者设计工作室

科学出版社 出版

北京东黄城根北街 16 号

邮政编码:100717

<http://www.sciencep.com>

北京通州皇家印刷厂 印刷

科学出版社发行 各地新华书店经销

*

2012 年 1 月第 一 版 开本:787×1092 1/16

2012 年 1 月第一次印刷 印张:26 1/2

字数:629 000

定价:128.00 元

(如有印装质量问题,我社负责调换)

应用于环境管理和研究中的生态建模原理

本书《前言》简明扼要地介绍了本书的内容，笔者将《前言》翻译附后，这里就不重复介绍了。

本书主编 Jørgensen 教授是一位国际著名的德高望重的科学家，他的研究和著作推动了国际生态模型和系统生态学的发展。我国系统生态学领域的学者对 Jørgensen 教授并不陌生，1987 年 10 月，他应邀来南京讲学，并连续 3 年考察和指导了太湖流域淀山湖的富营养化研究，与我国学者共同预言，太湖如不认真治理，20 年内将出现重大生态问题，不幸言中了 2007 年的太湖蓝藻爆发事件。近三年，他作为华东师范大学 111 引智项目的国际首席专家，每年在华举办讲习班，并同时关注长江口的湿地生态研究，手把手地指导年轻学者发展了长江口生态工程物种的动态结构模型，取得了重大成果。

国内于 1990 年翻译出版了本书第一版的修订版（《生态模型法原理》，S. E. Jørgensen 著，陆健健、周玉丽译，张利权校，上海翻译出版公司，1990），那是依据 1986 年本书第一版出版后，Jørgensen 通过 1987 年在华的教育和科研实践，于 1988 年出版的修订版翻译出版的。2008 年本书第三版作为高等教育出版社“生态学名著译丛”之一翻译出版（《生态模型基础》，S. E. Jørgensen, G. Bendoricchio 著，何文珊、陆健健、张修峰译，高等教育出版社，2008）。这次原文影印出版第四版，适用于高校和研究单位的研究生教材，也是从事生态学和环境工作的工程技术人员和管理工作者的重要业务参考书，相信会进一步推动我国的系统生态学研究 and 生态文明建设实践。

陆健健

2011 年 9 月 18 日

于华东师范大学

作者简介

约恩森 (Sven Eric Jørgensen) 博士, 哥本哈根大学的名誉教授, 致力于系统生态学、生态模型和生态工程等方面的研究, 已出版专著 66 部, 发表论文 350 余篇。约恩森博士已担任《国际生态模型和系统生态学杂志》(International Journal on Ecological Modelling and System Ecology) 主编 34 年; 他同时还担任《生态学百科全书》(Encyclopedia of Ecology) 的主编。他获得了若干重大奖项 (普利戈金奖 (The Prigoine Award)、帕斯卡奖 (The Pascal Medal), 中国科学院爱因斯坦讲席教授等), 包括极负盛誉的斯德哥尔摩水科学大奖。约恩森博士是哥伦比亚大学、葡萄牙和坦桑尼亚首都达累斯萨拉姆大学的荣誉博士, 欧洲科学院院士, 以及国际生态模型学会 (ISEM) 的主席。

法思 (Brian D. Fash) 博士是美国马里兰州陶森大学 (Towson University) 生物科学系副教授, 国际应用系统分析协会 (拉克森堡, 奥地利) 动态系统项目的研究人员, 在各类期刊上发表论文、报告和研究著作近 100 篇。2007 年 6 月, 法思博士与约恩森博士共同撰写了其第一部著作《新生态学》(A New Ecology), 2008 年, 他们又共同编撰了生态学百科全书的 5 卷内容。自 2009 年 1 月起, 法思博士开始担任《生态学模型》杂志的主编。他在美国陶森开设了生态系统生态学、环境生物学、网络及人类生态学与可持续发展等课程, 还分别在中国、克罗地亚、丹麦、法国、德国和葡萄牙开设了短期课程。法思博士现任巴尔的摩国家环境质量委员会主席。

(陆健健 译)

前 言

这是“生态建模原理”(Fundamentals of Ecological Modelling)的第四版,我们为它取了一个较长的名字:“生态建模原理:在环境管理和研究中的应用”。这么做是为了强调应用和环境管理和生态研究中的一些模型,尤其是本书中涉及的一些模型例证。

本书2001年第三版的共同作者Giuseppe Bendoricchio已于2005年去世,我们借此再版表达对他的怀念,并纪念其在20世纪80~90年代期间对生态模型发展做出的杰出贡献。

本书的第一、二版(分别于1986和1994年出版)着重于学科基础——4个在30~40年里占该领域主要地位的模型类型:(1)生物地球化学动态模型,(2)种群动态模型,(3)生态毒理模型,及(4)生物地球化学稳态与能量模型。这两版让我们对生态模型有了一个初步的全面理解。Bendoricchio为第三版带来了新的内容,聚焦于生态模型中相关生态过程的数学公式。第三版中,生态过程一章包括了118页,而今天相同的内容可能需要200页了,在2008年秋出版的《生态学百科全书》(Encyclopedia of Ecology)中对此做了较好的阐述。

在第四版中,以之前列出的四个模型类型作为基础,扩展到最新开发的一些模型,包括空间模型、结构动态模型及基于个体的模型。这七个类型的模型各不相同,在模型开发过程中需要考虑的内容也有所不同,因此我们认为对于一本最新的教科书而言,为这七个模型类型的每个模型的开发专设一章非常重要。纵观全书内容,案例主要来自于环境管理和研究相关模型应用的文献。本书内容安排如下:

第一章:生态模型导论,提供一个全面的介绍并引入本书后续内容。

第二章:模型概念,介绍一些主要的模型要素,包括框图模型要素(状态变量),关联模型要素(用流程和数学公式来描绘生物学、化学及物理学过程),控制模型要素(参数,常数),以及推动系统的强制函数。本章还会介绍建模过程,从概念模型到验证、校准、证实和灵敏度分析。

第三章:不同类型模型应该或能够被应用的综述。

第四章:调整和确定模型,对使用模型过程进行简短介绍,从而在综合跨学科的项目中引导研究问题和促进利益相关者参与。

第五章:种群动态模型,包括Lotka-Volterra模型在种群增长及两个或多个种群间的相互作用中的应用,以及其他更现实的捕食—被捕食模型和寄生模型。案例包括渔业和收获模型、异质种群动态模型和传染病模型。

第六章:稳态模型,讨论Chemostat模型,Ecopath软件以及生态网络分析。

第七章:生物地球化学动态模型的应用,从最初的Streeter-Phelps模型到目前复杂的富营养化模型。

第八章:生态毒理模型,提供了多种生态毒理模型的详尽试验及它们在风险评估和环境管理中的应用。

第九章：基于个体的模型，讨论该模型作为一个工具来获取个体在环境中所具备的自发特性和个体特征的历史及起源。

第十章：结构动态模型，列举了 21 个案例，对模型参数进行变化和调节以达到高等级目的功能（典型的热力学）。

第十一章：空间模型，涵盖了具有理解和管理系统十分重要的空间特征模型。

作为一本教科书，第四版的每一章节都有许多具体模型例证及其运用。前面的版本已经广泛地被作为教科书用于生态建模课程中，笔者寄希望于本版本能够成为目前生态建模课程中一本优秀的基础教材。

Sven Erik Jørgensen

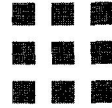
丹麦 哥本哈根

Brian D. Fath

奥地利 拉克森堡

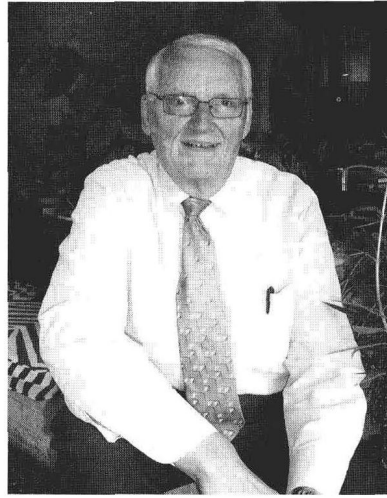
2010 年 7 月

（陆健健 译）

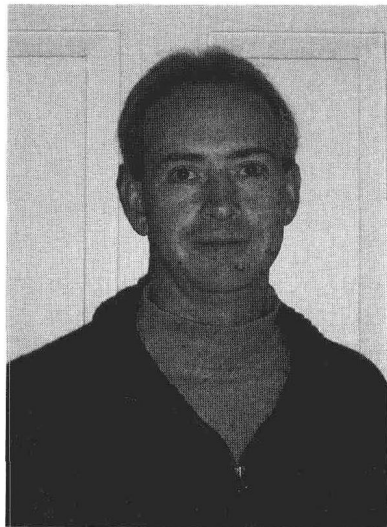


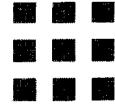
Author Biography

Dr. Jørgensen is Professor Emeritus at the University of Copenhagen and specializes in systems ecology, ecological modelling, and ecological engineering. Dr. Jørgensen has published 66 books and more than 350 papers. He has served as Editor-In-Chief of *Ecological Modelling: International Journal on Ecological Modelling and Systems Ecology* for 34 years. He is also editor-in-chief of *Encyclopedia of Ecology*. He has received several prizes (The Prigoin Award, The Pascal Medal, The Einstein Professorship of Chinese Academy of Sciences) and the very prestigious Stockholm Water Prize. He is honorable doctor of Coimbra University, Portugal and Dar es Salaam University, Tanzania. He is an elected member of the European Academy of Sciences. He is president of ISEM (International Society of Ecological Modelling).



Dr. Fath is an Associate Professor in the Department of Biological Sciences at Towson University (Maryland, USA) and is a research scholar in the Dynamic Systems Program at the International Institute for Applied Systems Analysis (Laxenburg, Austria). He has published almost 100 journal articles, reports, and book chapters. Dr. Fath's first book, *A New Ecology*, was published with S.E. Jørgensen in June 2007 and in 2008 they co-edited a 5-volume *Encyclopedia of Ecology*. Dr. Fath has been Editor-in-Chief of the journal *Ecological Modelling* since January 2009. He teaches regular courses in ecosystem ecology, environmental biology, networks, and human ecology and sustainability at Towson and has given short courses in China, Croatia, Denmark, France, Germany, and Portugal. Dr. Fath is currently the chair of the Baltimore County Commission on Environmental Quality.





Preface

This is the fourth edition of *Fundamentals of Ecological Modelling*, and we have given it a longer title: *Fundamentals of Ecological Modelling: Application in Environmental Management and Research*. This was done to emphasize that models, applied in environmental management and ecological research, are particularly considered in the model illustrations included in this book.

Giuseppe Bendoricchio, co-author of the third edition published in 2001, passed away in 2005. We would therefore like to dedicate this book to his memory and his considerable contributions in the 1980s and 1990s to the development of ecological modelling.

The first two editions of this book (published in 1986 and 1994) focused on the roots of the discipline — the four main model types that dominated the field 30-40 years ago: (1) dynamic biogeochemical models, (2) population dynamic models, (3) ecotoxicological models, and (4) steady-state biogeochemical and energy models. Those editions offered the first comprehensive textbook on the topic of ecological modelling. The third edition, with substantial input from Bendoricchio, focused on the mathematical formulations of ecological processes that are included in ecological models. In the third edition, the chapter called *Ecological Processes* encompasses 118 pages. The same coverage of this topic today would probably require 200 pages, and is better covered in the *Encyclopedia of Ecology*, which was published in the fall of 2008.

This fourth edition uses the four model types previously listed as the foundation and expands the latest model developments in spatial models, structural dynamic models, and individual-based models. As these seven types of models are very different and require different considerations in the model development phase, we found it important for an up-to-date textbook to devote a chapter to the development of each of the seven model types. Throughout the text, the examples given from the literature emphasize the application of models for environmental management and research. Therefore the book is laid out as follows:

Chapter 1: Introduction to Ecological Modelling provides an overview of the topic and sets the stage for the rest of the book.

Chapter 2: Concepts of Modelling covers the main modelling elements of compartments (state variables), connections (flows and the mathematical equations used to represent biological, chemical, and physical processes), controls (parameters, constants), and forcing functions that drive the systems. It

also describes the modelling procedure from conceptual diagram to verification, calibration, validation, and sensitivity analysis.

Chapter 3: An Overview of Different Model Types critiques when each type should or could be applied.

Chapter 4: Mediated or Institutionalized Modelling presents a short introduction to using the modelling process to guide research questions and facilitate stakeholder participation in integrated and interdisciplinary projects.

Chapter 5: Modelling Population Dynamics covers the growth of a population and the interaction of two or more populations using the Lotka-Volterra model, as well as other more realistic predator-prey and parasitism models. Examples include fishery and harvest models, metapopulation dynamics, and infection models.

Chapter 6: Steady-State Models discusses chemostat models, Ecopath software, and ecological network analysis.

Chapter 7: Dynamic Biogeochemical Models are used for many applications starting with the original Streeter-Phelps model up to the current complex eutrophication models.

Chapter 8: Ecotoxicological Models provides a thorough investigation of the various ecotoxicological models and their use in risk assessment and environmental management.

Chapter 9: Individual-based Models discusses the history and rise of individual-based models as a tool to capture the self-motivated and individualistic characteristics individuals have on their environment.

Chapter 10: Structurally Dynamic Models presents 21 examples of where model parameters are variable and adjustable to a higher order goal function (typically thermodynamic).

Chapter 11: Spatial Modelling covers the models that include spatial characteristics that are important to understanding and managing the system.

This fourth edition is maintained as a textbook with many concrete model illustrations and exercises included in each chapter. The previous editions have been widely used as textbooks for past courses in ecological modelling, and it is the hope of the authors that this edition will be an excellent basis for today's ecological modelling courses.

Sven Erik Jørgensen
Copenhagen, Denmark

Brian D. Fath
Laxenburg, Austria

July 2010

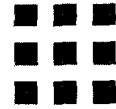
目 录

作者简介	xii
前言	xiii
1. 绪论	1
1.1 物理和数学模型	1
1.2 模型作为管理工具	3
1.3 模型作为研究工具	4
1.4 模型和整体论	7
1.5 生态系统作为研究对象	11
1.6 生态和环境模型的发展	13
1.7 模型应用现状	16
2. 模型概念	19
2.1 引言	19
2.2 模型元素	20
2.3 建模步骤	24
2.4 检验	31
2.5 灵敏度分析	34
2.6 校正	37
2.7 模型不确定性的验证和评估	41
2.8 模型类别	44
2.9 模型复杂度和结构的选择	51
2.10 参数评估	60
2.11 生态建模和量子理论	78
2.12 建模限制	82
思考题	92
3. 不同模型类型概述	95
3.1 引言	95
3.2 模型类型概述	96
3.3 概念模型	100
3.4 最实用模型类型的优缺点	108
3.5 不同模型类型的适用性	116
思考题	118
4. 协调建模或组合化建模	121
4.1 引言：我们为何需要协调建模	121

4.2 组合化建模过程	123
4.3 何时应用组和化或协调建模 (IMM)	125
思考题.....	127
5. 模拟种群动态	129
5.1 引言	129
5.2 基本概念	129
5.3 种群动态中的增长模型	131
示范 5.1	134
5.4 种群间相互关系	135
示范 5.2	141
示范 5.3	142
5.5 矩阵模型	147
示范 5.4	149
5.6 渔业模型	150
5.7 异质种群模型	153
5.8 传染模型	155
思考题.....	157
6. 稳态模型	159
6.1 引言	159
6.2 用一个化学状态模型图解稳态生物地化模型	160
示范 6.1	162
6.3 生态通道模型	162
6.4 生态网络分析	163
思考题.....	174
7. 动态生物地化模型	175
7.1 引言	175
7.2 生物地化动态模型的应用	177
7.3 应用 Stella 模拟河流 Streeter-Phelps BOD/DO 模型	179
7.4 富营养化模型 I：具 2~4 个状态变量的简单富营养化模型.....	184
7.5 富营养化模型 II：一个复杂富营养化模型	192
7.6 湿地潜流模型	208
7.7 全球变暖模型	218
思考题.....	225
8. 生态毒理模型	229
8.1 生态毒理模型的分类和应用	229
8.2 环境风险评估	233
8.3 生态毒理模型的特征和结构	244
8.4 综述：生态毒理学中模型的应用	258

8.5 生态毒理参数的估算	261
8.6 生态毒理案例研究 I：模拟一个丹麦峡湾中铬的分布	271
8.7 生态毒理案例研究 II：农产品中镉和铅污染	278
8.8 逸度归宿模型	284
示范 8.1	287
示范 8.2	288
9. 个体模型	291
9.1 个体模型的历史	291
9.2 个体模型设计	293
9.3 应急行为与强制行为	294
9.4 主导因素	295
9.5 个体模型执行	297
9.6 面向模式建模	299
9.7 用于参数化模型的个体模型	301
9.8 个体模型和空间模型	302
9.9 举例	304
9.10 结论	308
思考题	308
10. 结构动态模型	309
10.1 引言	309
10.2 生态系统特征	310
10.3 如何构建结构动态模型以及能质与生态能质的定义	321
10.4 达尔文雀结构动态模型的发展	333
10.5 生物操纵	335
10.6 一个生态毒理结构动态模型例证	343
思考题	346
11. 空间模型	347
11.1 引言	347
11.2 空间生态学模型：初期	353
11.3 空间生态学模型：现状	356
思考题	368
参考文献	369
附录	385

(陆健健 译)



Contents

Author Biography	xii
Preface	xiii
1. Introduction	1
1.1 Physical and Mathematical Models	1
1.2 Models as a Management Tool	3
1.3 Models as a Research Tool	4
1.4 Models and Holism	7
1.5 The Ecosystem as an Object for Research	11
1.6 The Development of Ecological and Environmental Models	13
1.7 State of the Art in the Application of Models	16
2. Concepts of Modelling	19
2.1 Introduction	19
2.2 Modelling Elements	20
2.3 The Modelling Procedure	24
2.4 Verification	31
2.5 Sensitivity Analysis	34
2.6 Calibration	37
2.7 Validation and Assessment of the Model Uncertainty	41
2.8 Model Classes	44
2.9 Selection of Model Complexity and Structure	51

2.10	Parameter Estimation	60
2.11	Ecological Modelling and Quantum Theory	78
2.12	Modelling Constraints	82
	Problems	92
3.	An Overview of Different Model Types	95
3.1	Introduction	95
3.2	Model types — An Overview	96
3.3	Conceptual Models	100
3.4	Advantages and Disadvantages of the Most Applied Model Types	108
3.5	Applicability of the Different Model Types	116
	Problems	118
4.	Mediated or Institutionalized Modelling	121
4.1	Introduction: Why Do We Need Mediated Modelling?	121
4.2	The Institutionalized Modelling Process	123
4.3	When Do You Apply Institutionalized or Mediated Modelling (IMM)?	125
	Problems	127
5.	Modelling Population Dynamics	129
5.1	Introduction	129
5.2	Basic Concepts	129
5.3	Growth Models in Population Dynamics	131
	Illustration 5.1	134
5.4	Interaction Between Populations	135
	Illustration 5.2	141

Illustration 5.3	142
5.5 Matrix Models	147
Illustration 5.4	149
5.6 Fishery Models	150
5.7 Metapopulation Models	153
5.8 Infection Models	155
Problems	157
6. Steady-State Models	159
6.1 Introduction	159
6.2 A Chemo state Model to Illustrate a Steady-State Biogeochemical Model	160
Illustration 6.1	162
6.3 Ecopath Models	162
6.4 Ecological Network Analysis	163
Problems	174
7. Dynamic Biogeochemical Models	175
7.1 Introduction	175
7.2 Application of Biogeochemical Dynamic Models	177
7.3 The Streeter-Phelps River BOD/DO Model, Using STELLA	179
7.4 Eutrophication Models I: Simple Eutrophication Models with 2–4 State Variables	184
7.5 Eutrophication Models II: A Complex Eutrophication Model	192
7.6 Model of Subsurface Wetland	208
7.7 Global Warming Model	218
Problems	225

8. Ecotoxicological Models	229
8.1 Classification and Application of Ecotoxicological Models	229
8.2 Environmental Risk Assessment	233
8.3 Characteristics and Structure of Ecotoxicological Models	244
8.4 An Overview: The Application of Models in Ecotoxicology	258
8.5 Estimation of Ecotoxicological Parameters	261
8.6 Ecotoxicological Case Study I: Modelling the Distribution of Chromium in a Danish Fjord	271
8.7 Ecotoxicological Case Study II: Contamination of Agricultural Products by Cadmium and Lead	278
8.8 Fugacity Fate Models	284
Illustration 8.1	287
Illustration 8.2	288
9. Individual-Based Models	291
9.1 History of Individual-Based Models	291
9.2 Designing Individual-Based Models	293
9.3 Emergent versus Imposed Behaviors	294
9.4 Orientors	295
9.5 Implementing Individual-Based Models	297
9.6 Pattern-Oriented Modelling	299
9.7 Individual-Based Models for Parameterizing Models	301
9.8 Individual-Based Models and Spatial Models	302
9.9 Example	304
9.10 Conclusions	308
Problems	308