

Environmental Science and Engineering
Subseries: Environmental Science

Series Editors: R. Allan • U. Förstner • W. Salomons

L. Håkanson · A.C. Bryhn

Tools and Criteria for Sustainable Coastal Ecosystem Management

Examples from the Baltic Sea
and Other Aquatic Systems

 Springer

Prof. Dr. Lars Håkanson
Uppsala University
Dept. Earth Sciences
Villavägen 16
SE-752 36 Uppsala
Sweden
lars.hakanson@geo.uu.se

Dr. Andreas C. Bryhn
Uppsala University
Dept. Earth Sciences
Villavägen 16
SE-752 36 Uppsala
Sweden
Andreas.Bryhn@geo.uu.se

ISBN: 978-3-540-78361-9

e-ISBN: 978-3-540-78363-3

Environmental Science and Engineering ISSN: 1863-5520

Library of Congress Control Number: 2008924331

© 2008 Springer-Verlag Berlin Heidelberg

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable to prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover Design: deblik, Berlin

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Contents

Prologue	1
1 Introduction and Aim	3
2 Effect-Load-Sensitivity Analyses – Basic Concepts	13
3 Coastal Classifications and Key Abiotic Variables Regulating Target Bioindicators	19
3.1 Coastal Classifications	19
3.2 Coastal Morphometry	22
3.2.1 Topographical Openness or Exposure	25
3.2.2 Size Parameters	32
3.2.3 Form Parameters	33
3.2.4 Depth Conditions and Coastal Sensitivity	35
3.2.5 A Sensitivity Index (SI) Based on Morphometric Parameters	40
3.3 Water Exchange	42
3.3.1 Surface and Deep-Water Exchange	42
3.3.2 Tides	45
3.3.3 Coastal Currents	45
3.4 Salinity	50
3.5 Water Temperature	54
3.6 Summary	58
4 Nutrients and Representativity of Data	59
4.1 Nutrient Sources and Remedial Actions	59
4.2 Limiting Nutrient – Phosphorus or Nitrogen or Both?	63
4.3 Nitrogen and Phosphorus – Hot Spots	69
4.4 Data Variability and Uncertainty – A Review of Key Concepts	70
4.4.1 Basic Statistical Questions	72
4.4.2 The Sampling Formula	75
4.4.3 Patterns in Variations for Different Water Variables	76

4.4.4	Empirically Based Highest r^2 , r_c^2	82
4.4.5	Highest Reference r^2 , r_r^2	84
4.4.6	Regressions and Confidence Intervals	85
4.4.7	Frequency Distributions and Transformations	88
4.4.8	Multiple Regressions	91
4.4.9	Stability Tests	96
4.4.10	The Optimal Size of Practically Useful Predictive Models ..	98
4.4.11	Variations and Spurious Correlations Related to DIN, DIP, TN, TN, DIN/DIP and TN/TP	102
4.5	Should Nitrogen or Phosphorus be Removed to Combat Coastal Eutrophication?	111
4.5.1	Key Questions	111
4.5.2	Arguments, Data and Results Pro and Con N and P	112
4.6	Example of Mass-Balance and Foodweb Modeling in a Target Ecosystem at the Local Scale	119
4.7	Summary and Conclusions	121
5	Operational Bioindicators for Coastal Management	125
5.1	Secchi Depth and Suspended Particulate Matter (SPM)	125
5.2	Oxygen Saturation in the Deep-Water Zone (O_2 Sat in %)	131
5.3	Chlorophyll-a	135
5.4	Cyanobacteria	140
5.5	Macrophytes	148
5.6	Index of Biological Value (IBV)	153
5.7	Summary and Conclusions	157
6	Case-Studies	159
6.1	Introduction and Aim	159
6.2	How Important are Local Nutrient Emissions to Eutrophication in Coastal Areas Compared to Fluxes from the Outside Sea?	161
6.2.1	Aim of the Case-Study	161
6.2.2	Information on the Himmerfjärden Bay	163
6.2.3	The Dynamic CoastMab-Model Used in the Case-Study	167
6.2.4	Results	174
6.2.5	Predicting the Dynamic Response of the System to Changes in Nutrient Loading	178
6.2.6	Concluding Remarks	182
6.3	An Approach to Estimate Relevant Reference Values for Key Bioindicators	183
6.3.1	Aim of the Case-Study	183
6.3.2	Basic Data from the Gulf of Riga	185
6.3.3	Results	190
6.3.4	Comments	198
6.4	Reconstruction of Eutrophication History	199
6.4.1	Aim of the Case-Study	199

6.4.2	Data from the Gulf of Finland and Information on the Model Structure	201
6.4.3	Dynamic Modeling	204
6.4.4	Concluding Remarks	221
6.5	Summary	222
Epilogue	223
References	229
Appendix	245
A.1	The Process-Based Mass-Balance Model, CoastMab	245
A.1.1	Introduction and Aim	245
A.1.2	Data and Methods	246
A.1.3	The CoastMab-Model for TP	253
A.1.4	Results	270
A.1.5	Comments	281
A.2	Nutrient Input from Land Uplift	282
Index	285

Prologue

This book addresses sustainable coastal management with a focus on practically useful (= operational) tools, methods, models and criteria and how targets variables for monitoring and management vary among and within coastal ecosystems (at the ecosystem scale). The ecosystem scale is, we would argue, an important scale in aquatic management, e.g., in contexts of impact assessment, when remedial measures are discussed and when basic questions are asked, e.g.: What is the status of this ecosystem? What can be done to improve the conditions? Which positive and negative consequences could be linked to a given or suggested remedial measure? Few people would be interested in the content of a sampling bottle; most people in science and management are interested in what this content may actually represent. That is, the interest is on a larger entity, the ecosystem. But there is no contradiction between work at this larger ecosystem scale and sampling and work at smaller scales, since the mean or median values characterizing ecosystem conditions and the standard deviations in empirical data characterizing the variability around such mean values of necessity must emanate from sampling at individual sites.

The aim of this book is to address important questions related to the role a number of operational bioindicators (such as the Secchi depth, concentrations of chlorophyll-a and cyanobacteria, the oxygen concentration in the deep-water zone and the macrophyte cover) and how the variability within and among coastal areas of these bioindicators is related to differences in coastal morphometry, salinity, temperature and nutrient loading. We discuss an index of coastal area sensitivity to nutrient loading (eutrophication) and an index of the “biological value” of coastal areas. These are central aspects of coastal eutrophication studies and also key questions related to the European Water Framework Directive. There is a long tradition in lake studies to carry out comparative investigations and look for factors causing variations in functional characteristics among lakes. This work follows that tradition for marine systems.

This book is mainly based on results from the Thresholds-project, an EU-project on threats to European coastal ecosystems, coordinated by Carlos Duarte, CSIC University, Mallorca. The aim has been to try to write a state-of-the-art book for coastal scientists and managers with different educational backgrounds (biology,

ecology, geosciences, oceanography, physics, chemistry, economics, etc.). Both simple and more advanced models are used, but this volume is not a textbook in modeling, and there are, for example, no differential equations in the running text. It is enough to know addition, subtraction, multiplication and division to follow this text. But it is not possible to understand how coastal systems function without a basic knowledge of the transport processes (inflow, outflow, sedimentation, resuspension, biouptake, etc.) that exist in all aquatic systems and apply to all substances.

Most of the data discussed in this book emanate from comprehensive “data-mining” of public sources available via the Internet. Several persons in our group at Uppsala University have participated in the data-mining and the work to develop and test the models and tools discussed in this work, especially Dan Lindgren, Jenny Eklund, Julia Hytteborn, Thorsten Blenckner and Maria Stenström-Khalili. This book is also a compilation and review of the results from our group during the last 4 years related to coastal studies.