

The top half of the cover features a wide aerial photograph of a large estuary system. The water is a deep, dark blue, and the surrounding land is a mix of green and brown. The sky is filled with dramatic, dark clouds, with a bright orange and yellow glow from the setting or rising sun on the horizon.

# COASTS AND ESTUARIES

## THE FUTURE

The bottom half of the cover shows a closer aerial view of a coastal city and its estuary. The city is densely packed with buildings, and the estuary is a wide, light-colored body of water. The sky is a pale, hazy blue.

EDITED BY  
**ERIC WOLANSKI**  
**JOHN W. DAY**  
**MICHAEL ELLIOTT**  
**RAMESH RAMACHANDRAN**

# Coasts and Estuaries

The Future

---

This page intentionally left blank

# Coasts and Estuaries

The Future

---

Edited by

**Eric Wolanski**

**John W. Day**

**Michael Elliott**

**Ramesh Ramachandran**



Elsevier  
Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands  
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom  
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Copyright © 2019 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: [www.elsevier.com/permissions](http://www.elsevier.com/permissions).

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

#### Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

#### Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

#### British Library Cataloging-in-Publication Data

A catalogue record for this book is available from the British Library

ISBN: 978-0-12-814003-1

For information on all Elsevier publications visit our website at <https://www.elsevier.com/books-and-journals>



*Publisher:* Candice Janco  
*Acquisition Editor:* Louisa Hutchins  
*Editorial Project Manager:* Lindsay Lawrence  
*Production Project Manager:* Omer Mukthar  
*Cover Designer:* Matthew Limbert

Typeset by SPi Global, India

# Dedication

**We dedicate this book to our grandchildren: Oliver, Grace, and Harry Wolanski; Olly, Dylan, and Mycah Elliott; and Daisy and Sunny Day; and to Ramachandran's children Gowtham and Niveda Ramesh; we hope that they will enjoy healthy estuaries and coastal waters by 2050 and beyond and we hope that these will remain healthy to entrust to their children.**

This page intentionally left blank

# Contents

Contributors	xix	7.4 National Planning	19
About the Editors	xxiii	7.5 International Water Governance	20
Preface: Why This Book?	xxv	7.6 Coastal Cities	20
		7.7 Examples of Arguably the Earth's Last Pristine Catchment to Estuarine Ecosystems	20
<b>1. A Synthesis: What Is the Future for Coasts, Estuaries, Deltas and Other Transitional Habitats in 2050 and Beyond?</b>		<b>8 Changes to Stressors: Responses to Increasing Coastal Populations, Their Environment, and Infrastructure</b>	22
<i>Michael Elliott, John W. Day, Ramesh Ramachandran, Eric Wolanski</i>		<b>9 Sustainable Solutions</b>	23
		<b>10 Conclusions</b>	25
		References	26
<b>1 Introduction</b>	1		
<b>2 Setting the Scene: The DAPSI(W)R(M) Framework</b>	2		
<b>3 Current Status of Estuarine and Coastal Ecosystems</b>	4		
3.1 Estuaries	4		
3.2 Deltas	7		
3.3 Wetlands, Lagoons, and Catchments	9		
3.4 Enclosed, Semienclosed, and Open Coasts	11		
3.5 Coral Reefs	12		
<b>4 Quantifying Changes: The Need to Accommodate Moving Baselines</b>	13		
<b>5 Changes to Stressors: The Input of Physical, Chemical, and Biological Pollutants and the Extraction of Biological Resources</b>	13		
5.1 Dredging	13		
5.2 Legacy Pollution	13		
5.3 Invasive Species	15		
<b>6 Additional Future Threats and Challenges</b>	16		
6.1 Increasing Globalization and Human Population Growth	16		
6.2 Climate Change	17		
<b>7 Tools and Approaches for the Management of New Changes</b>	17		
7.1 Monitoring to Inform Management	17		
7.2 Environmental Impact Modeling to Guide Management	19		
7.3 Community Involvement and Culture	19		
		<b>Section A Estuaries</b>	
		<b>2. An Assessment of Saltwater Intrusion in the Changjiang (Yangtze) River Estuary, China</b>	
		<i>Maotian Li, Zhongyuan Chen</i>	
		<b>1 Introduction</b>	31
		1.1 Water Transfer Projects	31
		1.2 Three Gorges Dam: Changing Hydrology at Seasonal Scales	33
		1.3 Sea Level Rise	33
		<b>2 Data Sources and Observation</b>	34
		2.1 Discharge Variations	34
		2.2 Salinity Variations	34
		2.3 Water Diversion	36
		2.4 Tide Level	37
		<b>3 Discussions</b>	39
		3.1 Freshwater Sources—Dry Season Shortage	39
		3.2 Salinity Distribution in Relation to Freshwater Availability	39
		3.3 Water Diversion—Present and Future Case	39
		3.4 Sea Level Rise—Equivalent to Increase in Salinity and Decrease in Discharge	40
		<b>4 Future Scenarios</b>	40



5 The Way Forward	41		
Acknowledgment	42		
References	42		
<b>3. Río De La Plata: A Neotropical Estuarine System</b>			
<i>Javier García-Alonso, Diego Lercari, Omar Defeo</i>			
1 General Introduction	45		
1.1 Geographical and Morphological Features	45		
1.2 Biodiversity	46		
1.3 Management	47		
2 Major Anthropogenic Driving Forces at RDLP	48		
2.1 Food Supply	48		
2.2 Marine Traffic	50		
3 Minor Drivers: Industry, Urbanization, and Tourism	52		
4 The Future of the RdIP Estuary	53		
References	54		
<b>4. Estuaries and Coastal Zones in the Northern Persian Gulf (Iran)</b>			
<i>Moslem Sharifinia, Moslem Daliri, Ehsan Kamrani</i>			
1 Geology and Geomorphology of the Persian Gulf	57		
2 Climatic Conditions and Recent Changes	57		
3 Hydrology and Circulation in the Persian Gulf	57		
4 Biodiversity of the Iranian Coastal Waters of the Persian Gulf	60		
4.1 Coral Reefs	60		
4.2 Mangrove Forests	61		
4.3 Phytoplankton Community	61		
4.4 Macrobenthic Community	62		
5 Anthropogenic Stresses in the Northern Persian Gulf	63		
5.1 Oil Pollution	63		
5.2 Fisheries and Overfishing	63		
6 The Future Changes to the Persian Gulf	63		
6.1 Increasing Urban Populations	64		
6.2 An Unstable Political Situation	64		
6.3 Fisheries and Fish Species Conservation	65		
6.4 Impacts of Climate Change on the Persian Gulf Ecosystem	65		
References	65		
<b>5. Protecting Water Quality in Urban Estuaries: Australian Case Studies</b>			
<i>Ryan J.K. Dunn, Nathan J. Waltham, Jianyin Huang, Peter R. Teasdale, Brian A. King</i>			
1 Introduction	69		
2 Case Study Examples	72		
2.1 Port Jackson	72		
2.2 Gold Coast Broadwater (Southern Moreton Bay)	77		
2.3 Ross River Estuary	80		
3 Considerations and Summary	82		
References	84		
<b>6. Management of Megafauna in Estuaries and Coastal Waters: Moreton Bay as a Case Study</b>			
<i>Janet M. Lanyon</i>			
1 Introduction	87		
2 Moreton Bay: A Megafauna Case Study	87		
3 Moreton Bay—Physical Characteristics	89		
4 Moreton Bay Megafauna	89		
4.1 Sea Turtles	89		
4.2 Dugongs	90		
4.3 Whales and Dolphins	91		
4.4 Humpback Whales	92		
4.5 Southern Right Whales	92		
4.6 Dolphins	93		
5 Protective Measures for Moreton Bay Megafauna	94		
5.1 Protective Legislation	94		
5.2 Management of Water Quality	94		
5.3 Monitoring Population Size and Trends	95		
5.4 Health Assessment of Wildlife	96		
6 The Future	96		
References	97		
<b>7. Peel-Harvey Estuary, Western Australia</b>			
<i>Valesini, F.J., Hallett, C.S., Hipsey, M.R., Kilminster, K.L., Huang, P., Hennig, K.</i>			
1 Overview	103		
2 The Peel-Harvey System	103		
3 Historical Socio-Ecological Developments	105		
4 Estuary Responses Over Recent Decades	107		
4.1 Hydrology and Water Quality	107		
4.2 Sediment Condition	109		

4.3 Submerged and Fringing Vegetation	110
4.4 Benthic Macroinvertebrates	110
4.5 Fish	111
<b>5 Current Socio-Ecological Characteristics</b>	111
5.1 Catchment Land Use	111
5.2 Estuary Condition	112
5.3 Socioeconomic System	112
5.4 Management and Science	113
<b>6 Looking Forward</b>	114
6.1 Population Growth	114
6.2 Climate and Hydrology Predictions	114
6.3 Ecological Responses	116
6.4 Strategies to Mitigate Impacts of a Drying Trend	116
<b>7 Concluding Remarks</b>	117
<b>Acknowledgments</b>	117
<b>References</b>	118

## Section B Deltas

### 8. Arctic Deltas and Estuaries: A Canadian Perspective

*Donald L. Forbes*

<b>1 Introduction</b>	123
1.1 Sediment Balance and Delta Stability	124
1.2 Arctic Estuaries	125
<b>2 Environmental Forcing</b>	125
2.1 Crustal Motion	125
2.2 Ice in Arctic Deltas	127
<b>3 Arctic Estuaries and Deltas</b>	132
3.1 Fjords	132
3.2 Proglacial Deltas in Fjords	133
3.3 Incised Terraced Deltas on Low-Relief Coasts	135
3.4 Breached-Lake Estuaries of the Arctic Coastal Plain	135
3.5 Small Transgressive Deltas	137
3.6 Large Transgressive Deltas	138
<b>4 Discussion</b>	141
4.1 Arctic Tidewater Ice Fronts and Ice Shelves	141
4.2 Arctic Deltas	141
4.3 Sediment Supply	141
4.4 Vulnerability to Environmental Change	142
<b>5 Conclusions</b>	142
<b>Acknowledgments</b>	143
<b>References</b>	143

### 9. Delta Winners and Losers in the Anthropocene

*John W. Day, Ramesh Ramachandran, Liviu Giosan, James Syvitski, G. Paul Kemp*

<b>1 Introduction</b>	149
<b>2 A Framework for Understanding the Development, Functioning, and Sustainability of Deltas and the Role of Energetic Forcing Events in the Functioning of Deltas</b>	149
<b>3 Perspectives on Delta Sustainability</b>	150
<b>4 Impact of Climate Change and Resource Scarcity on Deltas</b>	151
<b>5 Classification of Delta Types in Relationship to Sustainability</b>	151
<b>6 Delta Winners and Losers—Sustainability of Individual Deltas</b>	153
<b>7 Sustainability of Individual Deltas</b>	154
<b>8 Asian Deltas</b>	154
8.1 Yangtze (Changjiang)	154
8.2 Mekong	154
8.3 Ganges	156
8.4 Other Indian Deltas	156
8.5 Mahanadi	156
8.6 Godavari-Krishna	157
8.7 Cauvery	157
8.8 Indus	157
<b>9 European and African Deltas</b>	157
9.1 Mediterranean Deltas	157
9.2 The Nile	158
9.3 Senegal and Pangani Deltas	158
9.4 Danube	159
9.5 Rhine-Meuse-Scheldt	159
<b>10 American Deltas</b>	159
10.1 Mississippi Delta	159
10.2 Usumacinta-Grijalva Delta	160
10.3 Rio de la Plata and the Parana Delta	160
10.4 Mackenzie Delta	160
<b>11 Ranking Sustainability</b>	161
<b>12 Conclusions</b>	161
<b>Acknowledgments</b>	162
<b>References</b>	162

### 10. Mississippi Delta Restoration and Protection: Shifting Baselines, Diminishing Resilience, and Growing Nonsustainability

*John W. Day, Craig Colten, G. Paul Kemp*

<b>1 Introduction</b>	167
<b>2 Development of the Delta</b>	167

<b>3 Deterioration of the Delta</b>	170	3.2 SLR and Delta Subsidence	193
<b>4 Global Change Constraints on Coastal Protection and Restoration</b>	171	3.3 Coastal Erosion	193
<b>5 Coastal Protection and Restoration</b>	172	3.4 Impacts of Coastal Effects on the Ganges Delta	193
<b>6 Coastal Protection and Restoration in a Climate-Challenged, Energy-Scarce Future</b>	173	3.5 Anthropogenic Challenges	195
6.1 Flood and Storm Protection	174	3.6 Integrated Management of the Ganges delta	201
6.2 Hurricane Surge and Waves	174	<b>4 Conclusions</b>	203
6.3 The Mississippi River	175	<b>Annex 1</b>	204
6.4 Flooding Due to Extremely Heavy Rainfall	176	Facts and Figures and Pollution Status Along the Coast of West Bengal with Particular Reference to the Ganges Delta	204
6.5 A Truly Sustainable New Orleans	176	Harmful Algal Blooms	207
<b>7 Moving Forward on Coastal Protection</b>	176	<b>References</b>	209
7.1 Managed Retreat	177		
7.2 Delta Restoration	178		
7.3 River Diversions—Crevasses, Large Diversions, Reactivated Distributaries	178		
7.4 Marsh Creation	178		
7.5 Abandonment of Lower Delta	179		
7.6 The Atchafalaya River Delta Region—An Underused Resource	179		
7.7 The Chenier Plain—Potential for Sustainable Management	180		
7.8 Coastal Forested Wetlands—A Vanishing Resource	180		
7.9 Wasted Freshwater Resources	181		
7.10 Restoration of Basin Inputs	181		
<b>8 Shifting Baselines and Diminishing Resilience</b>	181		
<b>9 Comprehensive Planning—The Importance of Global Change</b>	182		
<b>Acknowledgments</b>	182		
<b>References</b>	182		
<b>11. Integrated Management of the Ganges Delta, India</b>		<b>12. The Indus Delta—Catchment, River, Coast, and People</b>	
<i>Ramesh Ramachandran, Ahana Lakshmi, Swati Mohan Sappal, Bonthu S.R., Mary Divya Suganya, D. Ganguly, R.S. Robin, R. Purvaja</i>		<i>Samina Kidwai, Waqar Ahmed, Syed Mohsin Tabrez, Jing Zhang, Liviu Giosan, Peter Clift, Asif Inam</i>	
<b>1 Introduction</b>	187	<b>1 Origin of the River</b>	213
1.1 The Ganges and the GBM Delta	187	<b>2 Geomorphology and Hydrology</b>	213
1.2 Challenges in the Ganges Delta	189	2.1 Catchment, Fluvial, Estuary/Delta, Coastal Offshore	213
<b>2 Upstream Effects</b>	189	2.2 Water and Sediment Discharge Downstream	214
2.1 Water Flows	189	<b>3 Upstream, Large, Manmade Structures</b>	214
2.2 Sediment Transport	191	3.1 Political Geography	214
2.3 Impacts of Changes in Water and Sediment Transport Regimes on the Ganges Delta	191	3.2 Indus Treaty—British Raj and Independence	218
<b>3 Coastal Effects</b>	192	3.3 Transboundary Water Issues	219
3.1 Floods and Inundation	192	3.4 Distribution—Vested Interests and Resolving Internal Conflict	219
		<b>4 Catchment Areas</b>	220
		4.1 Agrogeography	220
		4.2 Agrarian Economy and Dependence on the River	221
		4.3 Brackish Lakes—Issues and Solutions	221
		<b>5 River Indus Delta Ecosystem</b>	221
		<b>6 In the Last 50 Years</b>	224
		<b>7 The Delta Faces Climate Change (Variability in Arabian Sea Monsoon)</b>	224
		<b>8 Saving the Delta and Its People</b>	226
		<b>9 Fishers and Fishery From the Delta</b>	227
		<b>10 Dependence on the River</b>	228
		<b>11 What to Save First? What Will Work—Political Will or Management Strategy?</b>	229
		<b>12 Stakeholders—Coming Together</b>	229
		<b>References</b>	229

**13. A Brief Overview of Ecological Degradation of the Nile Delta: What We Can Learn**

*Zhongyuan Chen*

<b>1 Introduction</b>	233
1.1 Human Impact on the River Basin: Reducing Sediment and Fresh Water, but Increasing Nutrients	233
1.2 Delta-Estuarine Responses	233
<b>2 What We Can Learn?</b>	234
Acknowledgments	236
References	236

**14. Status and Sustainability of Mediterranean Deltas: The Case of the Ebro, Rhône, and Po Deltas and Venice Lagoon**

*John W. Day, Carles Ibáñez, Didier Pont, Francesco Scarton*

<b>1 Introduction</b>	237
<b>2 The Ebro Delta</b>	239
<b>3 The Rhône Delta</b>	241
<b>4 The Po Delta and Venice Lagoon</b>	243
<b>5 Discussion</b>	246
<b>6 Summary and Conclusions</b>	247
References	247

**Section C  
Wetlands, Lagoons and Catchments**

**15. Coastal Lagoons: Environmental Variability, Ecosystem Complexity, and Goods and Services Uniformity**

*Angel Pérez-Ruzafa, Isabel M. Pérez-Ruzafa, Alice Newton, Concepción Marcos*

<b>1 Introduction</b>	253
<b>2 Coastal Lagoons: Definition and Distribution</b>	253
<b>3 Lagoon Functioning and Environmental Variability</b>	255
<b>4 Lagoon Biota and Ecology</b>	256
<b>5 The Lagoon Paradox</b>	260
<b>6 Influence of Coastal Lagoons on the Adjacent Sea</b>	261
<b>7 Ecosystem Services Provided by Coastal Lagoons: Actual Status and Perspectives</b>	261

<b>8 The Future of Coastal Lagoons: Main Pressures and Impacts on the Lagoon Systems</b>	266
<b>9 Outstanding Future Threats: Eutrophication</b>	267
9.1 Global Climate Change: Consequences for Coastal Lagoons	267
<b>10 Final Remarks</b>	268
<b>Acknowledgments</b>	270
<b>References</b>	270

**16. The Everglades: At the Forefront of Transition**

*Fred H. Sklar, John F. Meeder, Tiffany G. Troxler, Tom Dreschel, Steve E. Davis, Pablo L. Ruiz*

<b>1 Introduction</b>	277
<b>2 The Geological Setting</b>	278
<b>3 The Eco-Hydrological Setting</b>	281
<b>4 The Eco-Economic Setting</b>	284
<b>5 Transition Awareness</b>	286
<b>Acknowledgments</b>	288
<b>References</b>	288

**17. Population Growth, Nutrient Enrichment, and Science-Based Policy in the Chesapeake Bay Watershed**

*Christopher F. D’Elia, Morris Bidjerano, Timothy B. Wheeler*

<b>1 Introduction</b>	293
<b>2 Description of the Watershed and Its Estuary</b>	294
2.1 Environmental History Prior to 1950s	294
<b>3 Nutrient Enrichment in the Chesapeake</b>	295
3.1 The “Heinle” Report	297
3.2 Historical Trends in Nutrient Enrichment in the PR	297
<b>4 The PR Case as a Driver of Chesapeake Bay Policy</b>	302
<b>5 The State of the Bay: What Was Accomplished Since 2020 Report Was Published, and What Is to be Expected in 2020 and Beyond?</b>	304
<b>References</b>	308

## 18. The Senegal and Pangani Rivers: Examples of Over-Used River Systems Within Water-Stressed Environments in Africa

*Awa Niang, Peter Scheren, Salif Diop, Coura Kane, Cheikh Tidiane Koulibaly*

<b>1 Introduction</b>	311
<b>2 The Senegal River Basin</b>	311
2.1 Site Description	311
2.2 The Damming of the River as a Response to Environmental Degradation	314
2.3 The Consequences: Changes in the Hydrological Regime and Morphology, Hyper-Salinization of Lands, Flooding, Changes in Fish Population	315
2.4 Adaptation: How People Respond by Relocating and Developing Alternative Economic Activities	316
<b>3 The Pangani River Basin</b>	317
3.1 Site Description	317
3.2 Consequences: Environmental Degradation	317
3.3 Management Strategies	318
<b>4 Conclusion</b>	318
<b>References</b>	319

## 19. Damming the Mekong: Impacts in Vietnam and Solutions

*Nguyen Huu Nhan, Nguyen Ba Cao*

<b>1 Introduction</b>	321
<b>2 Hydropower Dam Network in the Mekong River Basin</b>	321
<b>3 The Vietnamese Mekong Delta</b>	324
<b>4 Dam Impacts on the Mekong Delta in Vietnam</b>	327
4.1 The Impact on Water Resource in the Flood Season	327
4.2 The Impact on Water Resource in the Dry Season	327
4.3 Impact on Sediment Resources	329
4.4 The Morphological Changes	331
4.5 The Other Dam Impacts on the VMD	332
<b>5 The Conceptual Solutions</b>	334
5.1 Constraints and Approaches	334
5.2 The Nonengineering Solutions	335
5.3 Some Engineering Solutions Inland of the VMD	337

<b>6 Conclusion</b>	337
<b>References</b>	339

## Section D Enclosed, Semi-enclosed, and Open Coasts

### 20. Baltic Sea: A Recovering Future From Decades of Eutrophication

*Anna-Stiina Heiskanen, Erik Bonsdorff, Marko Joas*

<b>1 Introduction</b>	343
1.1 Centennial of Changes in the Baltic Sea	343
1.2 Changing Governance Structures	344
1.3 Changing Ecosystem of the Baltic Sea	346
1.4 Holistic Framework for management of the Baltic Sea	347
<b>2 Eutrophication</b>	351
2.1 Drivers of Eutrophication	351
2.2 Urbanization and Wastewaters	351
2.3 Industrial Wastewaters	351
<b>3 Food Production</b>	352
3.1 Agriculture	352
3.2 Aquaculture	352
<b>4 Nutrient Loading Pressures</b>	352
<b>5 Eutrophication Status</b>	353
<b>6 Eutrophication Impact on Human Welfare</b>	353
<b>7 Responses to Counteract and Manage Eutrophication</b>	354
<b>8 Future Outlook in Eutrophication Development</b>	355
<b>9 New Innovations Toward Sustainable Baltic Sea Future</b>	356
<b>Acknowledgments</b>	357
<b>References</b>	358

### 21. The Black Sea—The Past, Present, and Future Status

*Abdulaziz Güneroğlu, Osman Samsun, Muzaffer Feyzioğlu, Mustafa Dihkan*

<b>1 Introduction</b>	363
<b>2 Geographic Setting and Coastal Geomorphology</b>	364
<b>3 Ecological State and Health of the Sea</b>	366
<b>4 Fisheries</b>	370
<b>5 Pollution (Marine Litter)</b>	371

6 Recommendations and Conclusions	372	2.2 Bizen City (Hinase Area)	405
Acknowledgments	373	2.3 Kagawa Prefecture	405
References	373	<b>3 Future Perspective</b>	406
<b>22. Ecosystem Functioning and Sustainable Management in Coastal Systems With High Freshwater Input in the Southern Gulf of Mexico and Yucatan Peninsula</b>		3.1 Clean, Productive, and Prosperous Coastal Sea	407
<i>Jorge A. Herrera-Silveira, Ana L. Lara-Domínguez, John W. Day, Alejandro Yáñez-Arancibia, Sara Morales Ojeda, Claudia Teutli Hernández, G. Paul Kemp</i>		3.2 Management Method	409
<b>1 Introduction</b>	377	<b>Acknowledgments</b>	410
<b>2 The High River Discharge Zone and the Grijalva-Usumacinta Delta</b>	377	<b>References</b>	410
2.1 Environmental Diagnosis	380	<b>24. Challenges of Restoring Polluted Industrialized Muddy NW European Estuaries</b>	
<b>3 Laguna De Terminos</b>	380	<i>R. Kirby</i>	
3.1 Habitat Diversity	382	<b>1 Introduction</b>	413
3.2 Water Quality and Biogeochemistry	382	<b>2 Estuary Management</b>	413
3.3 Consumers	383	<b>3 Future Sea-Level Impacts</b>	414
3.4 Human Impact and Management	383	<b>4 Future Costs</b>	416
<b>4 Yucatan Groundwater Coastal Karstic Ecosystems—Environmental Risk and Management Opportunities</b>	384	<b>5 Degraded Major Estuaries of NW Europe and Their Restoration</b>	416
4.1 Aquatic Coastal Ecosystems in Karstic Settings	384	<b>6 Generic Sediment Management Systems</b>	421
4.2 Main Features and Ecosystem Characteristics	385	6.1 Entrance Flow Optimization Structures	421
4.3 Coastal Lagoons	385	6.2 Trickle Auto-flushing Systems (TASs)	421
4.4 Nearshore Coastal Systems	389	6.3 Passive Nautical Depth (PND)	421
4.5 Land Use and Coastal Ecosystem Risk of the Yucatan Peninsula	392	6.4 Active Nautical Depth	422
<b>5 Management Perspectives for the Yucatan Peninsula and Southern Gulf of Mexico</b>	393	<b>7 Cleansing of Mud in Contaminated Industrialized Estuaries</b>	423
References	394	<b>8 Conclusions</b>	423
		<b>Acknowledgments</b>	425
		<b>References</b>	425
<b>Section E</b>		<b>25. Can Bivalve Habitat Restoration Improve Degraded Estuaries?</b>	
<b>Restoration of Estuaries</b>		<i>Ian Michael McLeod, Philine S.E. zu Ermgassen, Chris L. Gillies, Boze Hancock, Austin Humphries</i>	
<b>23. Restoration of Estuaries and Bays in Japan—What’s Been Done So Far, and Future Perspectives</b>		<b>1 Introduction: Bivalves—The Forgotten Habitat Builders</b>	427
<i>Osamu Matsuda, Tetsuo Yanagi</i>		<b>2 What Are Bivalve Habitats?</b>	428
<b>1 Introduction</b>	401	<b>3 Ecosystem Services</b>	429
<b>2 Restoration and Related Activities Performed to Date</b>	403	<b>4 Historic Extent and Fisheries</b>	430
2.1 Shima City	403	<b>5 Global Decline of Bivalve Habitats</b>	431
		<b>6 Restoration</b>	431
		6.1 Large Scale Restoration Works	433
		6.2 Community Restoration	434
		6.3 Restoration for Coastal Protection	436
		6.4 Should Nonnative Bivalve Species Be Used for Restoration?	437

<b>7 The Future of Bivalve Habitat Restoration</b>	438
7.1 Social, Economic, and Environmental Benefits	438
7.2 Global Expansion	438
7.3 Opportunities for Innovation	438
<b>8 Conclusion</b>	440
<b>References</b>	440

## Section F Coral Reefs

### 26. Successful Management of Coral Reef-Watershed Networks

*Robert H. Richmond, Yimnang Golbuu,  
Austin J. Shelton III*

<b>1 Introduction: Importance of Land-Sea Interactions</b>	445
<b>2 Major Contributors to Watershed Discharges</b>	446
<b>3 Contents of Watershed Discharges</b>	446
3.1 Freshwater	446
3.2 Sediment	447
3.3 Toxicants	447
3.4 Nutrients	448
3.5 Pharmaceuticals	448
3.6 The Sum of Stressors and Implications for Interventions on Land	448
<b>4 The Key Role of Coastal Oceanography</b>	448
<b>5 Case Histories</b>	449
5.1 Maunalua Bay, Hawaii	449
5.2 La Sa Fu'a Watershed in Humatak, Guam	449
<b>6 Remediation Measures</b>	452
6.1 Humatak Project	452
6.2 Community Engagement	452
6.3 Watershed Restoration Efforts and Its Effectiveness	453
<b>7 Continuing Efforts</b>	453
7.1 Palau: Ngerikiil Bay	454
7.2 Enipein Watershed, Pohnpei	455
<b>8 A Synthesis: Success and Failures of Different Approaches</b>	456
<b>9 Major Socioeconomic-Cultural Lessons Learned</b>	456
<b>10 The Future: Climate Change Issues</b>	457
<b>11 Evaluation of Mitigation: Metrics of Success</b>	457
<b>12 Conclusions</b>	457
<b>References</b>	458

### 27. Challenges and Opportunities in the Management of Coral Islands of Lakshadweep, India

*Purvaja, R., Yogeswari, S., Debasis, T., Hariharan, G., Raghuraman, R., Muruganandam, R., Ramesh Ramachandran*

<b>1 Introduction</b>	461
1.1 India's Lakshadweep Islands	461
<b>2 SWOT Analysis</b>	462
<b>3 Challenges</b>	463
<b>4 Interventions and Opportunities</b>	469
<b>5 Integrated Island Management Plan</b>	470
5.1 Freshwater Requirement	470
5.2 Sewage	470
5.3 Solid Waste Management	471
5.4 Island Shoreline Protection	473
5.5 Conservation of Corals	473
<b>6 Conclusions</b>	475
<b>Acknowledgements</b>	475
<b>References</b>	475

### 28. The Future of the Great Barrier Reef: The Water Quality Imperative

*Brodie, J., Grech, A., Pressey, B., Day, J., Dale, A.P., Morrison, T., Wenger, A.*

<b>1 Introduction—The State of the Great Barrier Reef</b>	477
<b>2 Terrestrial Pollution and Sources</b>	479
<b>3 Stressors and the Impacts</b>	480
3.1 Fine Sediment	480
3.2 Nutrients	481
3.3 Pesticides	483
3.4 Other Pollutants	483
3.5 Risk Summary	483
<b>4 The Current Water Quality Management Response and Progress</b>	484
4.1 Governance	484
4.2 Ports and Shipping	484
4.3 Pollutant Loads Reduction	485
4.4 Crown-of-Thorns Starfish Management	487
4.5 Tree Clearing	487
<b>5 The Future Based on Current Management Regime</b>	488
<b>6 What Would Success Look Like?</b>	488
<b>7 What Could Be Done to Improve Governance and Management?</b>	490
<b>8 A Way Forward</b>	491
<b>Acknowledgment</b>	492
<b>References</b>	492

## Section G Over-Arching Topics

### 29. Estuarine Ecohydrology Modeling: What Works and Within What Limits?

*Eric Wolanski*

<b>1 Introduction: The Need for Models</b>	503
<b>2 Models of Physical Processes</b>	505
2.1 Water Circulation Models	505
2.2 Sediment Dynamics Models	505
<b>3 Models of Nutrient Sequestration by Fine Sediment</b>	508
<b>4 Estuarine Ecohydrology Models</b>	508
4.1 Introduction	508
4.2 The LOICZ Model	509
4.3 NPZ Estuarine Ecosystem Models	510
4.4 The UNESCO Estuarine Ecohydrology Model	511
4.5 The Ecopath Model	512
4.6 Harmful Algae Blooms Models	514
4.7 Hypoxia Models	516
<b>5 A Synthesis</b>	516
<b>References</b>	518

### 30. Hypersalinity: Global Distribution, Causes, and Present and Future Effects on the Biota of Estuaries and Lagoons

*James R. Tweedley, Sabine R. Dittmann, Alan K. Whitfield, Kim Withers, Steeg D. Hoeksema, Ian C. Potter*

<b>1 Introduction</b>	523
<b>2 Meta-analysis of Hypersaline Estuaries, Lagoons and Coastal Embayments</b>	524
<b>3 Laguna Madre</b>	525
3.1 Morphology and Physicochemical Environment	525
3.2 Anthropogenic Influences and Hypersalinity	528
3.3 Effects of Hypersalinity on the Biota	529
3.4 The Future With Climate Change	529
<b>4 Lake St Lucia</b>	530
4.1 Morphology and Physicochemical Environment	530
4.2 Anthropogenic Influences and Hypersalinity	530
4.3 Effects of Hypersalinity on the Biota	532
4.4 The Future With Climate Change	533
<b>5 Coorong</b>	533

5.1 Morphology and Physicochemical Environment	533
5.2 Anthropogenic Influences and Hypersalinity	535
5.3 Effects of Hypersalinity on the Biota	536
5.4 The Future With Climate Change	537
<b>6 Stokes, Hamersley and Culham Inlets</b>	537
6.1 Morphology and Physicochemical Environment	537
6.2 Anthropogenic Influences and Hypersalinity	537
6.3 Effects of Hypersalinity on the Biota	539
6.4 The Future With Climate Change	540
<b>7 Summary</b>	541
<b>Acknowledgments</b>	541
<b>References</b>	541

### 31. Alien Species Invasion: Case Study of the Black Sea

*Nickolai Shalovenkov*

<b>1 Introduction</b>	547
<b>2 Alien Species Invasion of the Black Sea</b>	547
2.1 Phytoplankton Alien Species	547
2.2 Zooplankton Alien Species	550
2.3 Zoobenthos Alien Species	552
2.4 Fish Alien Species	552
<b>3 Gradients of Temperature and Salinity as Ecological Barriers</b>	555
<b>4 Large-Scale Currents and Alien Species</b>	557
<b>5 Trends of Invasion of Alien Species</b>	558
<b>6 Invasive Corridors of the Black Sea Basin</b>	560
6.1 The Atlantic and Indo-Pacific Corridors	560
6.2 Ponto-Caspian Corridor	561
<b>7 Invasions of Alien Species in the Black Sea—The Future</b>	561
<b>References</b>	562

### 32. Coastal Fisheries: The Past, Present, and Possible Futures

*Maria-Lourdes D. Palomares, Daniel Pauly*

<b>1 Introduction</b>	569
<b>2 Coastal Fisheries as a Key Component of Global Fisheries</b>	569
<b>3 Regional and Temporal Difference in Coastal Fisheries</b>	571
<b>4 Large-Scale Industrial Versus Small-Scale Artisanal and Recreational Fisheries</b>	572



5 A Neglected Sector: Subsistence Fisheries	572	8.1 Waste Management and Marine Plastic	600
6 “Fishing Down” and Other Ecosystem Impacts of Coastal Fisheries	573	8.2 Reducing Plastic Pollution in the Oceans	604
7 Coastal Fisheries and Climate Change	574	9 Reducing Marine Plastic Pollution: Case Studies	604
8 The Governance of Coastal Fisheries	575	10 Case Study 1: Banning Microbeads in Personal Care and Cleaning Products	604
Acknowledgments	575	11 Case Study 2: EPR	605
References	576	12 Behavioral Change—Littering and Plastic Pollution	605
		13 Conclusion	606
		References	607
<b>33. Temperate Estuaries: Their Ecology Under Future Environmental Changes</b>			
<i>Ducrottoy J.-P., Michael Elliott, Cutts N.D., Franco A., Little S., Mazik K., Wilkinson M.</i>			
1 Introduction	577	<b>35. Changing Hydrology: A UK Perspective</b>	
2 The Response of Estuarine Ecological Components to Climate Change	578	<i>Peter E. Robins, Matt J. Lewis</i>	
2.1 Phytoplankton Primary Production	578	1 Introduction	611
2.2 Zooplankton	580	2 Sensitivity of UK Estuaries to River Flows	612
2.3 Macroalgae and Microphytobenthos	580	3 Past Trends and Future Projections for Hydrology	613
2.4 Angiosperms	582	4 Potential Impacts to Estuaries From Changing Hydrology	614
2.5 Benthic Invertebrates	583	4.1 Flooding and Inundation	614
2.6 Fish	585	4.2 Water Quality	615
2.7 Birds	587	4.3 Habitats	615
3 Final Discussion and Conclusions	589	5 Summary	615
References	590	References	616
<b>34. Plastic Pollution in the Coastal Environment: Current Challenges and Future Solutions</b>			
<i>K. Critchell, A. Bauer-Civiello, C. Benham, K. Berry, L. Eagle, M. Hamann, K. Hussey, T. Ridgway</i>			
1 Plastic Pollution in the Marine Environment: An Emerging Contaminant of Global Concern	595	<b>36. Global Change Impacts on the Future of Coastal Systems: Perverse Interactions Among Climate Change, Ecosystem Degradation, Energy Scarcity, and Population</b>	
2 Sources and Methods of Dispersal of Microplastic Pollution in the Coastal and Marine Environment	596	<i>John W. Day, John M. Rybczyk</i>	
3 Loss of Virgin Microplastics During Manufacture or Transport	596	1 Introduction	621
4 Microplastics From Households—Fibers and Microbeads	596	2 Global Climate Change: Past Trends, Future Predictions, and System Impacts	622
5 Breakdown of Large Plastics	596	2.1 Temperature	622
6 Microplastic Pollution in the Coastal and Marine Environment	598	2.2 Sea-Level Rise	622
6.1 Dispersal and Accumulation Patterns	599	3 Coastal Wetland Response to Temperature and Accelerated SLR	624
7 Governance Challenges and Current Approaches	599	4 The Impacts of Changes in Freshwater Input on Coastal Ecosystems	625
8 A Circular Economy Approach for Marine Plastic Pollution	600	5 Tropical Cyclones	626
		6 Extreme Weather Events	627

## Section H Management of Change

7	Energy Scarcity and Coastal Adaptation and Restoration	627		
8	Coastal Environmental Degradation as a Societal Energy Sink	630		
8.1	Population	630		
8.2	Ranking Coastal Sustainability	631		
8.3	Sea-Level Rise	631		
8.4	Changes in Freshwater Input	631		
8.5	Tropical Cyclones	632		
8.6	Below Sea-Level Coastal Areas	632		
8.7	Arid and Semiarid Areas	632		
8.8	Arctic Coastal Systems	632		
9	Ecological Engineering and Ecohydrology—System Functioning as a Basis for Sustainable Management of Coastal Systems	633		
9.1	Ocean Acidification	633		
9.2	Human Activity and Coastal Management	633		
10	Conclusions: Ecosystem Goods and Services and Cost of Energy	634		
	References	634		
<b>37.</b>	<b>Human-Nature Relations in Flux: Two Decades of Research in Coastal and Ocean Management</b>			
	<i>Bernhard Glaeser</i>			
1	Preamble: Aim and Overview	641		
2	Human-Nature Relations: Why COM?	641		
3	Stakeholder Identification and Conflict Resolution: The Example of Sweden	642		
4	National Coastal and Ocean Strategies: The Example of Germany	644		
5	Natural Calamities and Coastal Hazards	646		
5.1	The Example of the 2004 Tsunami in South-East Asia	646		
5.2	The Example of the 2005 Hurricane Katrina in New Orleans, USA	648		
6	Climate Change: The Example of Indonesia	650		
7	Coastal and Ocean Typologies: An Analytical Instrument and Planning Tool	653		
8	Summary and Conclusion	657		
	References	657		
<b>38.</b>	<b>Megacities and the Coast: Global Context and Scope for Transformation</b>			
	<i>Sophie Blackburn, Mark Pelling, César Marques</i>			
1	Introduction	661		
2	Locating Coastal Megacities	661		
3	Challenges in Defining Coastal Megacities	663		
4	Risk, Vulnerability, and Resilience in Coastal Megacities	664		
4.1	Drivers of Risk in Coastal Megacities	664		
4.2	Possibilities for Resilience and Transformation	665		
5	Conclusions: Urban Transitions, Urban Futures	667		
	Acknowledgments	668		
	References	668		
<b>39.</b>	<b>Arctic Coastal Systems: Evaluating the DAPSI(W)R(M) Framework</b>			
	<i>Amy Lauren Lovecraft, Chanda L. Meek</i>			
1	Introduction	671		
1.1	The Rapidly Changing Arctic	671		
1.2	Arctic Ecosystem Services	672		
2	The Arctic Coastal Margin and Its Social-Ecological System	674		
2.1	Arctic Coastal Ecological Systems	675		
2.2	Social Systems Among Arctic Coastlines	676		
2.3	The Significance of Arctic Coasts for Subsistence Livelihoods	677		
3	The Complexity of Ecosystem Management	678		
3.1	Applying the DAPSI(W)R(M) Framework to Arctic Coasts	679		
3.2	Measures and the Advent of the Arctic Council	682		
4	The Possible Futures of Arctic Coastal Environmental Management	682		
4.1	Managing Change or Changing Management?	682		
5	Conclusion	683		
	References	684		
	Index			687

This page intentionally left blank

# Contributors

*Numbers in parentheses indicate the pages on which the authors' contributions begin.*

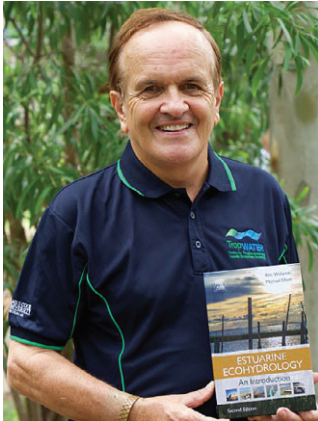
- Waqar Ahmed** (213), National Institute of Oceanography, Karachi, Pakistan
- A. Bauer-Civiello** (595), College of Science and Engineering, James Cook University, Townsville, QLD, Australia
- C. Benham** (595), College of Science and Engineering, James Cook University, Townsville, QLD, Australia
- K. Berry** (595), College of Science and Engineering, James Cook University, Townsville, QLD, Australia
- Morris Bidjerano** (293), School of Public Policy and Administration, Walden University, Greenville, SC, United States
- Sophie Blackburn** (661), Department of Geography, King's College London, London, United Kingdom
- Erik Bonsdorff** (343), Åbo Akademi University, Turku, Finland
- J. Brodie** (477), ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
- Nguyen Ba Cao** (321), Vietnam Academy of Water Resources, Hanoi, Vietnam
- Zhongyuan Chen** (31, 233), State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, People's Republic of China
- Peter Cliff** (213), Louisiana State University, Baton Rouge, LA, United States
- Craig Colten** (167), Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA, United States
- K. Critchell** (595), College of Science and Engineering, James Cook University, Townsville; Marine Spatial Ecology Lab, University of Queensland, Brisbane, QLD, Australia
- N.D. Cutts** (577), Institute of Estuarine and Coastal Studies, University of Hull, Hull, United Kingdom
- Christopher F. D'Elia** (293), College of the Coast and Environment, Louisiana State University, Baton Rouge, LA, United States
- A.P. Dale** (477), The Cairns Institute, James Cook University, Cairns, QLD, Australia
- Moslem Daliri** (57), Department of Fisheries, Faculty of Marine and Atmospheric Sciences and Technologies, University of Hormozgan, Bandar Abbas, Iran
- Steve E. Davis** (277), Everglades Foundation, Palmetto Bay, FL, United States
- John W. Day** (1, 149, 167, 237, 377, 621), Department of Oceanography and Coastal Sciences, College of the Coast and Environment, Louisiana State University, Baton Rouge, LA, United States
- J. Day** (477), ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
- T. Debasis** (461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Omar Defeo** (45), UNDECIMAR, Faculty of Sciences, University of the Republic, Montevideo, Uruguay, Montevideo, Uruguay
- Mustafa Dihkan** (363), Department of Geomatics, Faculty of Engineering, Karadeniz Technical University, Çamburnu, Trabzon
- Salif Diop** (311), Cheikh Anta Diop University, Dakar-Fann, Senegal
- Sabine R. Dittmann** (523), College of Science & Engineering, Flinders University, Adelaide, SA, Australia
- Tom Dreschel** (277), Everglades Systems Assessment Section, South Florida Water Management District, West Palm Beach, FL, United States
- J.-P. Ducrotot** (577), Institute of Estuarine and Coastal Studies, University of Hull, Hull, United Kingdom
- Ryan J.K. Dunn** (69), Ocean Science & Technology, RPS, Gold Coast, QLD, Australia

- L. Eagle** (595), College of Business, Law and Governance, James Cook University, Townsville, QLD, Australia
- Michael Elliott** (1, 577), Institute of Estuarine and Coastal Studies, University of Hull, Hull, United Kingdom
- Muzaffer Feyzioğlu** (363), Department of Marine Science and Technology, Faculty of Marine Sciences, Karadeniz Technical University, Çamburnu, Trabzon
- Donald L. Forbes** (123), Geological Survey of Canada, Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada; Department of Geography, Memorial University of Newfoundland, St. John's, NL; Department of Earth Sciences, Dalhousie University, Halifax, NS, Canada
- A. Franco** (577), Institute of Estuarine and Coastal Studies, University of Hull, Hull, United Kingdom
- D. Ganguly** (187), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Javier García-Alonso** (45), Department of Ecology, CURE, University of the Republic, Maldonado, Uruguay
- Chris L. Gillies** (427), The Nature Conservancy, Carlton, VIC; James Cook University, Townsville, QLD, Australia
- Liviu Giosan** (149, 213), Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA, United States
- Bernhard Glaeser** (641), Freie Universität; German Society for Human Ecology (DGH), Berlin, Germany
- Yimnang Golbuu** (445), Palau International Coral Reef Center, Koror, Palau
- A. Grech** (477), ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
- Abdulaziz Güneroğlu** (363), Department of Marine Ecology, Faculty of Marine Sciences, Karadeniz Technical University, Çamburnu, Trabzon
- C.S. Hallett** (103), Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University, Perth, WA, Australia
- M. Hamann** (595), College of Science and Engineering, James Cook University, Townsville, QLD, Australia
- Boze Hancock** (427), The Nature Conservancy, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, United States
- G. Hariharan** (461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Anna-Stiina Heiskanen** (343), Finnish Environment Institute, Helsinki, Finland
- K. Hennig** (103), Department of Water and Environmental Regulation, Perth, WA, Australia
- Claudia Teutli Hernández** (377), Center for Research and Advanced Studies of the National Polytechnic Institute, Merida Campus, Mexico
- Jorge A. Herrera-Silveira** (377), Center for Research and Advanced Studies of the National Polytechnic Institute, Merida Campus, Mexico
- M.R. Hipsey** (103), Aquatic Ecodynamics, UWA School of Agriculture and Environment, The University of Western Australia, Perth, WA, Australia
- Steeg D. Hoeksema** (523), Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University, Murdoch; Department of Biodiversity, Conservation and Attractions, Bentley Delivery Centre, Western Australia, Australia
- Jianyin Huang** (69), Natural and Built Environments Research Centre, School of Natural and Built Environments; Future Industries Institute, University of South Australia, Adelaide, SA, Australia
- P. Huang** (103), Aquatic Ecodynamics, UWA School of Agriculture and Environment, The University of Western Australia, Perth, WA, Australia
- Austin Humphries** (427), Department of Fisheries, Animal and Veterinary Science, University of Rhode Island, Kingston; Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, United States
- K. Hussey** (595), Centre for Policy Futures, Faculty of Humanities and Social Sciences, The University of Queensland, St Lucia, QLD, Australia
- Carles Ibáñez** (237), Aquatic Ecosystems Program, IRTA, San Carles de la Rapita, Catalonia, Spain
- Asif Inam** (213), National Institute of Oceanography, Karachi, Pakistan
- Marko Joas** (343), Åbo Akademi University, Turku, Finland
- Ehsan Kamrani** (57), Department of Fisheries, Faculty of Marine and Atmospheric Sciences and Technologies, University of Hormozgan, Bandar Abbas, Iran
- Coura Kane** (311), Cheikh Anta Diop University, Dakar-Fann, Senegal
- G. Paul Kemp** (149, 167, 377), Department of Oceanography and Coastal Sciences, College of the Coast and Environment, Louisiana State University, Baton Rouge, LA, United States
- Samina Kidwai** (213), National Institute of Oceanography, Karachi, Pakistan
- K.L. Kilminster** (103), Department of Water and Environmental Regulation, Perth, WA, Australia
- Brian A. King** (69), Ocean Science & Technology, RPS, Gold Coast, QLD, Australia

- R. Kirby** (413), Ravensrodd Consultants Ltd., Liverpool, United Kingdom
- Cheikh Tidiane Koulibaly** (311), Cheikh Anta Diop University, Dakar-Fann, Senegal; University of Ibadan, Ibadan, Nigeria
- Ahana Lakshmi** (187), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Janet M. Lanyon** (87), School of Biological Sciences, The University of Queensland, St. Lucia, QLD, Australia
- Ana L. Lara-Domínguez** (377), Institutue of Ecology, Veracruz, Mexico
- Diego Lercari** (45), UNDECIMAR, Faculty of Sciences, University of the Republic, Montevideo, Uruguay, Montevideo, Uruguay
- Matt J. Lewis** (611), School of Ocean Sciences, Marine Centre Wales, Bangor University, Menai Bridge, United Kingdom
- Maotian Li** (31), State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, People's Republic of China; Institute of Eco-Chongming Shanghai, China
- S. Little** (577), School of Animal, Rural and Environmental Sciences, Nottingham Trent University, Nottinghamshire, United Kingdom
- Amy Lauren Lovecraft** (671), Center for Arctic Policy Studies, University of Alaska Fairbanks, Fairbanks, AK, United States
- Concepción Marcos** (253), Department of Ecology and Hydrology, Regional Campus of International Excellence "Mare Nostrum", University of Murcia, Murcia, Spain
- César Marques** (661), National School of Statistical Science—Brazilian Institute of Geography and Statistics (ENCE/IBGE), Rio de Janeiro, Brazil
- Osamu Matsuda** (401), Graduate School of Biosphere Sciences, Hiroshima University, Higashihiroshima, Japan
- K. Mazik** (577), Institute of Estuarine and Coastal Studies, University of Hull, Hull, United Kingdom
- John F. Meeder** (277), Sea Level Solutions Center and Southeast Environmental Research Center, Florida International University, Miami, FL, United States
- Chanda L. Meek** (671), Department of Political Science, University of Alaska Fairbanks, Fairbanks, AK, United States
- Ian Michael McLeod** (427), TropWATER, Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University, Townsville, QLD, Australia.
- T. Morrison** (477), ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
- R. Muruganandam** (461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Alice Newton** (253), NILU-IMPACT, Kjeller, Norway; CIMA-Centre for Marine and Environmental Research, Gambelas Campus, University of Algarve, Faro, Portugal
- Nguyen Huu Nhan** (321), Vietnam Academy of Water Resources, Hanoi, Vietnam
- Awa Niang** (311), Cheikh Anta Diop University, Dakar-Fann, Senegal
- Sara Morales Ojeda** (377), Center for Research and Advanced Studies of the National Polytechnic Institute, Merida Campus, Mexico
- Maria-Lourdes D. Palomares** (569), Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada
- Daniel Pauly** (569), Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada
- Mark Pelling** (661), Department of Geography, King's College London, London, United Kingdom
- Angel Pérez-Ruzafa** (253), Department of Ecology and Hydrology, Regional Campus of International Excellence "Mare Nostrum", University of Murcia, Murcia, Spain
- Isabel M. Pérez-Ruzafa** (253), Department of Plant Biology I, Complutense University of Madrid, Madrid, Spain
- Didier Pont** (237), Institute of Hydrobiology and Aquatic Ecosystem Management (IHG), University of Natural Resources and Life Sciences, Vienna, Austria
- Ian C. Potter** (523), Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute; School of Veterinary and Life Sciences, Murdoch University, Murdoch, Western Australia, Australia
- B. Pressey** (477), ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
- R. Purvaja** (187, 461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- R. Raghuraman** (461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Ramesh Ramachandran** (1, 149, 187, 461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India

- Robert H. Richmond** (445), Kewalo Marine Laboratory, University of Hawaii at Manoa, Honolulu, HI, United States
- T. Ridgway** (595), Global Change Institute, The University of Queensland, St Lucia, QLD, Australia
- R.S. Robin** (187), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Peter E. Robins** (611), School of Ocean Sciences, Marine Centre Wales, Bangor University, Menai Bridge, United Kingdom
- Pablo L. Ruiz** (277), South Florida Caribbean Network, National Park Service, Palmetto Bay, FL, United States
- John M. Rybczyk** (621), Department of Environmental Science, Western Washington University, Bellingham, WA, United States
- Bonthu S.R.** (187), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Osman Samsun** (363), Faculty of Fisheries, Sinop University, Sinop, Turkey
- Swati Mohan Sappal** (187), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Francesco Scarton** (237), SELC Società Cooperativa, Venezia, Italy
- Peter Scheren** (311), WWF Regional Office for Africa, Nairobi, Kenya
- Nickolai Shalovenkov** (547), The Centre for Ecological Studies, Russia
- Moslem Sharifinia** (57), Iranian National Institute for Oceanography and Atmospheric Science (INIOAS), Gulf of Oman and Indian Ocean Research Center, Marine Biology Division, Chabahar, Iran
- Austin J. Shelton III** (445), Center for Island Sustainability and Sea Grant Program, University of Guam, Mangilao, Guam
- Fred H. Sklar** (277), Everglades Systems Assessment Section, South Florida Water Management District, West Palm Beach, FL, United States
- Mary Divya Suganya** (187), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- James Syvitski** (149), Community Surface Dynamics Modeling System, University of Colorado, Boulder, CO, United States
- Syed Mohsin Tabrez** (213), National Institute of Oceanography, Karachi, Pakistan
- Peter R. Teasdale** (69), Natural and Built Environments Research Centre, School of Natural and Built Environments; Future Industries Institute, University of South Australia, Adelaide, SA, Australia
- Tiffany G. Troxler** (277), Sea Level Solutions Center and Southeast Environmental Research Center, Florida International University, Miami, FL, United States
- James R. Tweedley** (523), Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute; School of Veterinary and Life Sciences, Murdoch University, Murdoch, Western Australia, Australia
- F.J. Valesini** (103), Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University, Perth, WA, Australia
- Nathan J. Waltham** (69), Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), Division of Tropical Environments and Societies, James Cook University, Douglas, QLD, Australia
- A. Wenger** (477), School of Earth and Environmental Sciences, University of Queensland, St. Lucia, QLD, Australia
- Timothy B. Wheeler** (293), Bay Journal, Seven Valleys, PA, United States
- Alan K. Whitfield** (523), South African Institute for Aquatic Biodiversity, Grahamstown, South Africa
- M. Wilkinson** (577), Institute of Life and Earth Sciences, Heriot-Watt University, Edinburgh, United Kingdom
- Kim Withers** (523), Department of Life Sciences, Texas A&M University, Corpus Christi, TX, United States
- Eric Wolanski** (1, 503), TropWATER and College of Marine & Environmental Sciences, James Cook University and Australian Institute of Marine Science, Townsville, QLD, Australia
- Tetsuo Yanagi** (401), International EMECS Center, Kobe, Japan
- Alejandro Yáñez-Arancibia** (377), Institutue of Ecology, Veracruz, Mexico
- S. Yogeswari** (461), National Centre for Sustainable Coastal Management, Ministry of Environment, Forest and Climate Change, Government of India, Anna University Campus, Chennai, India
- Jing Zhang** (213), State Key Laboratory in Estuarine and Coastal Research, Shanghai, China
- Philine S.E. zu Ermgassen** (427), School of GeoSciences, University of Edinburgh, Edinburgh, United Kingdom

# About the Editors



**Professor Eric Wolanski**

Eric Wolanski is an estuarine oceanographer and ecohydrologist at James Cook University and the Australian Institute of Marine Science. His research interests range from the oceanography of coral reefs, mangroves, and muddy estuaries to the interaction between physical and biological processes determining ecosystem health in tropical waters. He has over 400 scientific publications, including 12 books, and technical reports. Eric is a fellow of the Australian Academy of Technological Sciences and Engineering, the Institution of Engineers Australia (ret.), and l'Académie Royale des Sciences d'Outre-Mer. He was awarded a Doctorate Honoris Causa by the catholic University of Louvain, another Doctorate Honoris Causa by the University of Hull, a Queensland Information Technology and Telecommunications Award for Excellence, and a Lifetime Achievement Award by the Estuarine & Coastal Sciences Association. Eric is an Editor-in-Chief of *Wetlands Ecology and Management*, *Treatise on Estuarine and Coastal Science*, the Honorary Editor of *Estuarine, Coastal and Shelf Science*, and a member of the editorial board of four other journals. He is also a member of the Scientific and Policy Committee of Japan's EMECS (focusing on the Seto Inland Sea) and the European Union DANUBIUS-PP Scientific and Technical Advisory Board, which is a pan-European distributed research infrastructure dedicated to interdisciplinary studies of large river–sea systems throughout Europe.



**Professor John Day**

John Day is distinguished professor emeritus in the Department of Oceanography and Coastal Sciences at Louisiana State University. He has over 400 publications focusing on the ecology and management of coastal and wetland ecosystems, with emphasis on the Mississippi delta, as well as, among many, coastal ecosystems in Mexico and the impacts of climate change on wetlands in Venice Lagoon and in the Po, Rhone, and Ebro deltas in the Mediterranean. John is the coeditor of 14 books including *Estuarine Ecology*, *Ecological Modeling in Theory and Practice*, *The Ecology of the Barataria Basin*, *An Estuarine Profile*, *Ecology of Coastal Ecosystems in the Southern Mexico: The Terminos Lagoon Region*, *Ecosystem Based Management of the Gulf of Mexico*, *America's Most Sustainable Cities and Regions—Surviving the 21st Century Megatrends*. John served as chair of the Science and Engineering Special Team on restoration of the Mississippi delta, on the Scientific Steering Committee of the Future Earth Coasts program, and a National Research Council panel on urban sustainability.





**Professor Michael Elliott**

Michael Elliott is the professor of Estuarine and Coastal Sciences at the University of Hull, United Kingdom. He is a marine biologist with a wide experience and interests and his teaching, research, advisory, and consultancy work includes estuarine and marine ecology, policy, governance, and management. Mike has published widely, coauthoring/coediting 18 books/proceedings and >270 scientific publications. This includes coauthoring *The Estuarine Ecosystem: Ecology, Threats and Management*, *Ecology of Marine Sediments: Science to Management*, and *Estuarine Ecohydrology: An Introduction* and as a volume editor and contributor to the *Treatise on Estuarine & Coastal Science*. He has advised on many environmental matters for academia, industry, government, and statutory bodies worldwide. Mike is a past-President of the international Estuarine & Coastal Sciences Association (ECSA) and is an Editor-in-Chief of the international journal *Estuarine, Coastal & Shelf Science*; he has been adjunct professor and held research positions at Murdoch University (Perth), Klaipeda University (Lithuania), the University of Palermo (Italy), and the South African Institute for Aquatic Biodiversity, Grahamstown. He was awarded Laureate of the Honorary Winberg Medal of the Russian Hydrobiological Academic Society in 2014.



**Professor Ramesh Ramachandran**

Ramesh Ramachandran is director of the National Centre for Sustainable Coastal Management at the Ministry of Environment, Forest and Climate Change, Government of India. His expertise includes coastal/marine biogeochemistry, conservation of coastal/marine biodiversity, and Integrated Coastal Zone Management. He has over 135 research publications and over 100 technical reports. Among the several awards Professor Ramesh has received are the University Grants Commission UGC-Swami Pranavananda Saraswathi Award in Environmental Sciences and Ecology for the Year 2007 (awarded in February 2010). He was the chair of the Scientific Steering Committee of LOICZ (currently renamed as Future Earth Coasts), member of the Scientific Steering Committee of the Monsoon Asia Integrated Regional Study, chairman of the International Working Group on Coastal Systems on the Role of Science in International Waters Projects of UNEP-GEF, as well as being affiliated with the Bay of Bengal Large Marine Ecosystem Programme of the FAO. He is currently the chair of the Global Partnership in Nutrient Management (GPNM) of UNEP.

# Preface: Why This Book?

Coastal ecosystems are at the nexus of the Anthropocene, with enormous environmental issues, and inhabited by nearly half of the human population. These coastal systems and the surrounding human societies form coastal social-ecological systems that increasingly face enormous environmental issues from multiple pressures, which threaten their ecological and economical sustainability. The pressures are derived from hazards which then become risks where they impact the society and where, in some cases, human responses exacerbate the risks. There is only one big idea in managing these systems—how to maintain and protect the natural ecological structure and functioning and yet at the same time allow them to deliver ecosystem services which produce societal goods and benefits. The pressures include basically all human activities within the river catchments such as changes to land use and hydrology in the river catchment, and directly on coastal ecosystems from land claim, coastal sand mining, harbor dredging, pollution and eutrophication, overexploitation such as overfishing and extraction of groundwater, gas and petroleum extraction. In addition, coastal zones are impacted by climate change—this is not just the ‘usual’ culprits of sea level rise, ocean acidification, and increased temperature but also, just as important, changes in the rainfall-runoff of the river catchments, stronger coastal storms, and the changes to species distributions, including the influx of invasive species.

The problems faced by half of the humanity worldwide living near coasts are truly a worldwide challenge as well as an opportunity for science to study commonality and differences and provide solutions. During the five decades of monitoring the degradation of estuaries and coastal waters in the 20th century, coastal scientists studied the problems and issues arising along the coasts worldwide. Now, in the 21st century, the scientists need to use their science to help find solutions to these problems through science-informed management and innovation. The issues to solve are complex because they involve large areas, many users, and sociopolitical-environmental mosaics.

This book provides a typology of the human interaction with estuaries and coastal waters worldwide as a comprehensive description of what works and what does not work for estuaries and coastal waters worldwide and what remediation measures are possible and likely to succeed within limits. This is the first time that such a worldwide approach to estuarine and coastal sustainability has been initiated.

Thus the book addresses these real-life issues in order to learn from each other, by having a series of chapters written by the leading local experts detailing case studies from estuaries and coastal waters worldwide in the full range of natural variability and human pressures. The study sites are located in all the continents, except for the Antarctic, and several oceanic islands. This is followed by a series of chapters written by scientific leaders worldwide synthesizing the problems and offering solutions for specific issues graded within the framework of the socioeconomic-environmental mosaic. These include coastal fisheries, climate change, biophysical limits and energy costs, coastal megacities, evolving human-nature interactions, remediation measures for a number of worldwide issues such as mud and metal legacy as well as plastic pollution, integrated coastal management, and international water conflicts affecting estuaries, deltas, and coastal waters.

We wish to thank Jaelyn Truesdell and Lindsay Lawrence at Elsevier for their help in producing this book.

**Eric Wolanski**  
**John Day**  
**Michael Elliott**  
**Ramesh Ramachandran**

This page intentionally left blank