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Treatise on Estuarine and Coastal Science

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Academic Press is an imprint of Elsevier
32 Jamestown Road, London NW1 7BY, UK
225 Wyman Street, Waltham, MA 02451, USA
525 B Street, Suite 1900, San Diego, CA 92101-4495, USA

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

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

ISBN: 978-0-12-374711-2

Printed and bound in Italy

12 13 14 15 10 9 8 7 6 5 4 3 2 1

Editorial: Hannah Rutland, Gemma Mattingley
Production: Laura Jackson

VOLUME EDITORS

Volume 1

Classification of Estuarine and Nearshore Coastal Ecosystems

C Simenstad, University of Washington, USA and T Yanagi, Kyushu University, Japan

Volume 2

Water and Fine-Sediment Circulation

RJ Uncles, Plymouth Marine Laboratory, UK and SG Monismith, Stanford University, USA

Volume 3

Estuarine and Coastal Geology and Geomorphology

BW Flemming, Senckenberg Institute, Germany and JD Hansom, University of Glasgow, UK

Volume 4

Geochemistry of Estuaries and Coasts

G Shimmield, Bigelow Laboratory, USA

Volume 5

Biogeochemistry

RWPM Laane, Deltares, The Netherlands
and JJ Middelburg, Utrecht University and The Netherlands Institute of Ecology (NIOO-KNAW), The Netherlands

Volume 6

Trophic Relationships of Coastal and Estuarine Ecosystems

JG Wilson, Trinity College Dublin, Republic of Ireland and JJ Luczkovich, East Carolina University, USA

Volume 7

Functioning of Ecosystems at the Land–Ocean Interface

CHR Heip, NIOZ, The Netherlands,
JJ Middelburg, Utrecht University and The Netherlands Institute of Ecology (NIOO-KNAW), The Netherlands,
and CJM Philippart, NIOZ, The Netherlands

Volume 8

Human-Induced Problems (Uses and Abuses)

MJ Kennish, Rutgers University, USA and M Elliott, Institute of Estuarine and Coastal Studies (IECS), University of Hull, UK

Volume 9

Estuarine and Coastal Ecosystem Modeling

D Baird, Stellenbosch University, South Africa and AJ Mehta, University of Florida, USA

Volume 10

Ecohydrology and Restoration

L Chícharo, University of Algarve, Portugal and M Zalewski, Lodz University, Poland

Volume 11

Management of Estuaries and Coasts

HH Kremer, LOICZ, Germany and JL Pinckney, University of South Carolina, USA

Volume 12

Ecological Economics of Estuaries and Coasts

M van den Belt, Massey University, New Zealand and R Costanza, Portland State University, Portland, OR, USA

EDITORS-IN-CHIEF: BIOGRAPHIES

Eric Wolanski, FTSE, FIE Aust, is a coastal oceanographer and ecohydrologist. His research interests include the oceanography and sediment dynamics of coral reefs, mangroves, and muddy estuaries. They also include the interaction between physical and biological processes determining the ecosystem health in tropical riverine, estuarine, and waters. Wolanski led the UNESCO-ROSTE estuarine ecohydrology modeling efforts to quantify the impact from farming, dams, irrigation, and urbanization on the ecological services that estuaries provide to humanity. The ecohydrology models that have resulted have been applied to assess the human impact on coral cover in the Great Barrier Reef, Darwin Harbour, coastal waters of Micronesia, and Tanzania savannah ecosystems. Wolanski has more than 330 scientific papers and seven books. He is a fellow of the Australian Academy of Technological Sciences and Engineering, the Institution of Engineers Australia, and l'Académie Royale des Sciences d'Outre-Mer. He was awarded an Australian Centenary medal for services in estuarine and coastal oceanography, a Doctorate *Honoris Causa* from the Catholic University of Louvain, and a Queensland Information Technology and Telecommunication award for excellence. Wolanski is the chief editor of *Estuarine, Coastal and Shelf Science, Wetlands Ecology and Management*, and the *Treatise on Estuarine and Coastal Science*. He is a member of the editorial board of *Journal of Coastal Research, Journal of Marine Systems*, and *Ecohydrology and Hydrobiology*. He is a member of the Scientific and Policy Committee of the International Geosphere-Biosphere Programme (IGBP)'s LOICZ (Land Ocean Interactions in the Coastal Zone) and of EMECS (Japan-based International Center for Environmental Management of Enclosed Coastal Seas).

Donald McLusky was for many years a senior lecturer in marine biology at the University of Stirling, Scotland, UK. He also served as the Head of Department and Vice-Dean of the Faculty of Science. He holds a BSc degree in zoology from the University of Aberdeen and a PhD degree on estuarine ecophysiology from the University of Stirling. While at Stirling his research interests were centered on the biology of the Forth estuary, with many studies of the intertidal fauna including the annelids, molluscs, and crustaceans. For over 25 years, he was responsible for the monitoring of the effects on the intertidal environment of a large petrochemical complex at Grangemouth on the Forth. He also studied the impact of two marine oil terminals on the surrounding marine environment. He supervised the PhD programs of many young estuarine and marine scientists both at Stirling and in Sri Lanka, Bahrain, and Portugal.

Away from Stirling University, he was a visiting fellow at the University of Copenhagen's marine laboratory at Helsingør on several occasions, as well as a visiting professor at the University of Paris and Rivers State University, Nigeria. He was the honorary secretary of the Estuarine and Coastal Sciences Association (ECSA) and remains their trustee. He was a member of the Council of the Scottish Marine Biological Association and a member of the Scientific Advisory Committee of Scottish Natural Heritage.

He is the author of over 60 scientific papers on marine, estuarine, and freshwater biology. He is the author of the well-established textbook *The Estuarine Ecosystem*, which is now in its third edition, as well as *Ecology of*

Estuaries, and the editor of several volumes including *The Freshwaters of Scotland*, *North Sea – Estuarine Interactions*, and *The Environment of the Estuary and Firth of Forth*. He was the editor of the journal *Estuarine and Coastal Shelf Science* for ten years, from 2000.

VOLUME EDITORS: BIOGRAPHIES

Dan Baird is a Senior Professor in the Department of Botany and Zoology at the Stellenbosch University, South Africa. Prior to his appointment at Stellenbosch University in 2008 he was Chair of the Department of Zoology, Nelson Mandela Metropolitan University (formerly the University of Port Elizabeth) since 1981. He obtained the PhD degree from the University of Stellenbosch in fisheries science, and has published more than 100 papers in refereed journals, a number of chapters in books, and was co-editor of a volume on the *Estuaries of South Africa* (Cambridge University Press). Professor Baird conducted research and published widely with fellow academics, amongst others, from the University of Maryland, MD, the East Carolina University, NC, University of North Carolina, NC, the Alfred Wegener Institute for Polar and Marine Research, Germany. Professor Baird specializes in the fields of ecosystem theory, analysis and modelling, marine and coastal zone ecology, and management, water quality of, and nutrient dynamics in, shallow water ecosystems.

Luís Chícharo is Professor of Ecology at the University of Algarve, Portugal. He is the Director of the International Centre for Coastal Ecohydrology, under the auspices of UNESCO. He coordinates the LOICZ node in Europe for Middle East and North Africa regions and is Chairman of the Steering Committee of the UNESCO Ecohydrology Program, as well as the European Working Group on Estuaries and Coastal Ecohydrology. He is the coordinator of the International Erasmus Mundus Master Course in Ecohydrology. He coordinated several international projects and published more than 50 papers in international journals and several book chapters. He is member of the scientific editorial board of the Journals *Estuarine Coastal and Shelf Science, Ecohydrology and Hydrobiology* and of *ISRN Ecology*. His interests are the development of land-ocean integrated ecohydrologic solutions, harmonized with the human dimensions, for the sustainable management of estuaries and coastal areas.

Robert Costanza is Professor of Sustainability, Institute for Sustainable Solutions at Portland State University. Before moving to PSU in 2010, he was the Gund Professor of Ecological Economics and founding director of the Gund Institute for Ecological Economics at the University of Vermont. Before Vermont, he was on the faculty at Maryland and LSU, and visiting scientist at the Beijer Institute in Sweden, and the Illinois Natural History Survey. Dr. Costanza is also currently a Distinguished Research Fellow at Ecological Economics Research New Zealand (EERNZ), Massey University, Palmerston North, New Zealand, a Senior Fellow at the National Council on Science and the Environment, Washington, DC, and a Senior Fellow at the Stockholm Resilience Center, Stockholm, Sweden.

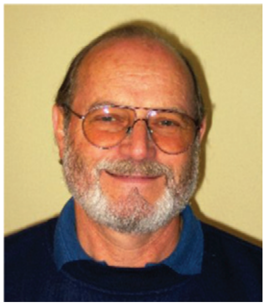
Dr. Costanza received BA and MA degrees in Architecture and a PhD in Environmental Engineering Sciences (Systems Ecology with Economics minor) all from the University of Florida.

Dr. Costanza's transdisciplinary research integrates the study of humans and the rest of nature to address research, policy, and management issues at multiple time and space scales, from small watersheds to the global system. Dr. Costanza is co-founder and past-president of the International Society for Ecological Economics, and was chief editor of the society's journal, *Ecological Economics* from its inception in 1989 until 2002. He is founding co-editor (with Karin Limburg and Ida Kubiszewski) of *Reviews in Ecological Economics*. He currently serves on the editorial board of ten other international academic journals. He is also founding editor-in-chief of *Solutions* a new hybrid academic/popular journal.

His awards include a Kellogg National Fellowship, the Society for Conservation Biology Distinguished Achievement Award, a Pew Scholarship in Conservation and the Environment, the Kenneth Boulding Memorial Award for Outstanding Contributions in Ecological Economics, and honorary doctorates from Stockholm University and the Ecole Normale Supérieure de Lyon.

Dr. Costanza is the author or co-author of over 500 scientific papers and 22 books. His work has been cited in more than 7,000 scientific articles and he has been named as one of ISI's Highly Cited Researchers since 2004. More than 200 interviews and reports on his work have appeared in various popular media.

Mike Elliott is the Director of the Institute of Estuarine and Coastal Studies and Professor of estuarine and coastal sciences at the University of Hull and a marine biologist with a wide experience of marine and estuarine biology and its environment, management, and policy. His teaching, research, and advisory and consultancy work have included studies of most ecological components as well as policy, governance, and management. In many instances, he has concentrated on the interactions between these aspects, usually in relation to human activities and on the way in which environmental change influences organisms and vice versa. He has taken a particular interest in the way in which water bodies are defined and analyzed for policy and management. Mike has produced more than 140 peer-reviewed scientific publications and has co-authored or edited 11 books and conference proceedings on estuarine and marine issues. This includes co-authoring *The Estuarine Ecosystem: Ecology, Threats and Management* (with DS McLusky, OUP, 2004) and *Ecology of Marine Sediments: Science to Management* (with JS Gray, OUP, 2009). He has been/is a chair and/or member of many advisory panels for teaching and research both in the UK and elsewhere and is a member of the editorial boards of several international scientific journals as well as the Editor-in-Chief of *Estuarine, Coastal and Shelf Science*. He was previously employed by the Forth River Purification Board (now the Scottish Environmental Protection Agency), Tidal Waters Section as the Senior Marine Biologist. Professor Elliott has recently been appointed to the UK governmental Marine Conservation Zone Science Advisory Panel.



Burghard W. Flemming began his academic education at the University of Kiel (Germany) where he graduated in 1972 (MSc equivalent), majoring in marine geology and sedimentology. While in Kiel, he qualified as a scientific diver, his master's thesis having essentially been an underwater project on wave abrasion and deposition in the western Baltic Sea. Early in 1973, a foreign student exchange scholarship took him to the University of Cape Town (South Africa) where he engaged in a PhD project on depositional processes in Saldanha Bay and Langebaan Lagoon located along the west coast of South Africa. He was awarded his PhD degree in 1977. In 1975 he became a member of the newly created National Research Institute for Oceanology (CSIR) where he assisted in building up a marine geoscience division, which he took over as Divisional Head in 1980. During this time his research focused on regional current-generated bedforms and sediment dispersal along the southeast African continental margin driven by the Agulhas Current. In October 1984, he followed in the footsteps of Hans-Erich Reineck as Head of the Senckenberg Marine Research Station in Wilhelmshaven (Germany), being mainly engaged in the investigation of tidal depositional processes. At the same time he gave undergraduate courses in sedimentology at the University of Bremen, being honoured for his teaching engagement with an extramural professorship in 1998. Burg Flemming retired in 2009 at the age of 65, having published over 150 papers in scientific journals and books.

Jim Hansom is Reader in Geographical and Earth Sciences at the University of Glasgow, Scotland and Professor of Geography at the University of Canterbury, Christchurch, New Zealand. He graduated with MA (Hons) from Aberdeen University, before continuing at Aberdeen with his PhD on spatial variations in sub-Antarctic coastal geomorphology. He has held lecturing positions at the National University of Ireland (University College Dublin) (1977-1979), University of Sheffield, England (1979-1990), University of Canterbury (1991) and, since 1991, at the University of Glasgow. His research and consultancy interests lie in the geomorphology and coastal zone management of mid and high latitude coasts, particularly in the light of recent variations in the drivers of coastal change. He is the author of over 150 research publications and reports as well as three books: Hansom, J.D. 1988. Coasts Cambridge University Press; Hansom, J.D. and Gordon, J.E. 1998. Antarctic Environments and Resources: a Geographical Perspective. Addison, Wesley, Longman; May, V.J, and Hansom J.D. 2003. Coastal Geomorphology of Great Britain, Geological Conservation Review Series. 28. UK Joint Nature Conservation Committee.

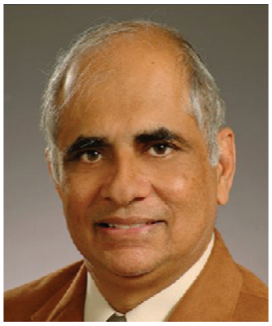
Carlo Heip is former Director of the Royal Netherlands Institute of Sea Research NIOZ and former director of the Centre of Estuarine and Marine Ecology of the Netherlands Institute of Ecology. He is also emeritus professor at the Universities of Gent (Belgium) and Groningen (The Netherlands), teaching biological oceanography and estuarine ecology. His research at the University of Gent, where he founded the Marine Biology Section, centered on the ecology of (meio)benthos. In 1992 he created the department of Ecosystem Studies at the NIOO in Yerseke that focuses on processes at the interface between biogeochemistry and benthic biology. He has over 360 publications including 138 papers in peer-reviewed journals (Hirsch index 40, over 5000 citations) and edited six books. He was PI in many national and EU-sponsored projects, a member of the editorial board of 12 scientific journals and a member of several peer review committees and scientific advisory boards. As President of the European Marine Research Stations MARS network (1995-2004), he has been heavily involved in creating a marine biodiversity research programme in Europe. He was co-ordinator of the EU Network of Excellence MARBEF (Marine Biodiversity and Ecosystem Functioning) and active in the Scientific Steering Committee of SCOPE, the DIVERSITAS programme and the Census of Marine Life. He is now president of the European Institute for the Study of Marine Biodiversity and Ecosystem Functioning MarBEF+, member of the Executive Committee of the ESF Marine Board and the chair of WG5 Marine Biodiversity of GEO BON.

Michael J. Kennish is a research professor and faculty member in the Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. He is also the research director of the Jacques Cousteau National Estuarine Research Reserve in Tuckerton, New Jersey. Dr. Kennish has conducted biological and geological research on estuarine, coastal ocean, and deep-sea environments for more than 30 years, and has taught marine science classes at Rutgers for many years. Much of his research has involved the development and application of innovative methods to determine the condition and overall ecosystem health of aquatic systems. He is internationally known for his work on human impacts in estuarine and marine environments. In the US, Dr. Kennish has served on many environmental panels and workgroups assessing anthropogenic problems in coastal marine environments, while also collaborating extensively with state and federal government agencies to remediate degraded habitats. Most notably, he has been heavily engaged in integrative ecosystem assessment, particularly investigations of impairment and remediation of impacted estuarine systems. These include studies of the natural and anthropogenic stressors that affect environmental change, and the dynamics of environmental forcing factors that generate imbalances in biotic community structure and ecosystem function. His research is multidisciplinary in scope, addressing a wide range of internationally significant problems such as the effects of watershed development on coastal bays and nearshore ocean waters, wastewater discharges, habitat loss and alteration of aquatic systems, nutrient enrichment and eutrophication, hypoxia and anoxia, organic pollution, chemical contaminants, climate change, sea-level rise, overfishing, invasive species, watercraft effects, dredging and dredged material disposal, freshwater diversions, calefaction of estuarine waters, and entrainment and impingement of electric generating stations. He has also examined the effects of construction and operation of industrial facilities, maintenance of shorelines and waterways, and human use of coastal space and aquatic systems. Much of his basic research has entailed investigations of benthic communities and habitats, as well as seafloor mapping and habitat characterization. In addition, he has studied the biology and geology of mid-ocean ridges and hydrothermal vent systems as a member of the Center for Deep-Sea Ecology and Biotechnology at Rutgers. As the co-chair of the Coastal Climate Change Group in Rutgers' Climate and Environmental Change Initiative, he is involved in the study of long-term climate change impacts on the New Jersey coast. In 2009, he was appointed by Governor Corzine to serve on the New Jersey Coastal and Ocean Protection Council. He was awarded the 2009 NOAA and NERRA national award for outstanding contributions to the National Estuarine Research Reserve System. In 2010, he was awarded the Graham Macmillan National Award of the American Littoral Society for outstanding contributions to marine science and conservation in the United States. While maintaining a wide range of research interests in marine ecology and marine geology, Dr. Kennish has been most actively involved in leading research teams investigating estuarine and coastal marine environments. He has published 12 scholarly books and more than 160 research articles in science journals and books. In addition, he has edited six compendium journal volumes on various topics in marine science.

Hartwig H. Kremer is Chief Executive Officer of Land-Ocean Interactions in the Coastal Zone (LOICZ), an Earth system research project of the International Geosphere-Biosphere Program, IGBP, and the International Human Dimensions Programme on Global Environmental Change, IHDP, based at the Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, Germany. His background covers biological and physical oceanography, fisheries, and trace metal analysis. He received his master's degree (1988) and PhD (1994) in marine zoology, physical oceanography and fisheries at the University of Kiel. He holds a second degree as a senior public advisor for fisheries economy received from the Ministry for Food, Agriculture, Fisheries and Forestry. He was the manager responsible for a training program for Integrated Coastal Zone Management and Food Security tailored to public institutions worldwide. Scientifically he focuses on the interplay of coasts and river-catchments, changing social-ecological systems with complex interaction between nature and society. He has promoted a new research in LOICZ looking into institutional dimensions, governance and the science policy interface on various scales. He co-authored and published the new Science and Implementation Strategy of LOICZ, today the only global research cluster mandated to analyze Earth system change in coasts taking a holistic and interdisciplinary natural and social science perspective.

Remi Laane is a senior scientist with DELTARES, which is an independent Dutch knowledge institute for applied research in the field of water, subsurface and infrastructure. Professor of marine biogeochemistry at the University of Amsterdam and author of more than 300 scientific papers and reports, and six popular books on various aspects of the North Sea.

Joseph Luczkovich graduated with a BS degree in Biology in 1978 at Lehigh University in Bethlehem, Pennsylvania. He began graduate study at Rutgers University in New Brunswick, New Jersey, where he studied Ichthyology under Professor Kenneth Able and Fish Behavior with Bori Olla. During that period, Joseph worked as a fishery technician in the Behavior Department at the Sandy Hook Laboratory of the National Marine Fisheries Service, part of the US National Oceanic and Atmospheric Administration. His thesis concerned the commensal relationship of juvenile red hake *Urophycis chuss* and sea scallops, *Placopecten magellanicus*, and the behavior and ecology of that relationship. After completing his MS in Ecology at Rutgers in 1982, he moved to the Florida State University, in Tallahassee, to pursue a doctoral degree. He worked with Dr. Robert J. Livingston on juvenile fishes living in seagrasses, which is an important nursery habitat for many species of economically important species of fishes. He was focused on selective use of resources by these fishes, and eventually focused on pinfish, *Lagodon rhomboides*, completing the degree in 1987. After finishing his doctoral degree, Dr. Luczkovich moved to a post-doctoral fellowship at the Harbor Branch Oceanographic Institute, in Ft. Pierce, Florida with R. Grant Gilmore on mangrove fishes, specifically the common snook, *Centropomus undecimalis*, which are selective feeders on mangrove fishes like mosquitofish, *Gambusia holbrooki*. Working on this species, and comparing the snook's ram-feeding behavior to the biting feeding mode used by pinfish, led to the eventual publication of the book *Ecomorphology of Fishes* (2005). It was at Harbor Branch that he was introduced to work Dr. Gilmore was doing with passive acoustics and the Sciaenidae (drums and croakers). He left Florida in 1988 to teach at Humboldt State University, Department of Fisheries, in Arcata, California. There he gained valuable insights on the trophic ecology and fisheries of the coastal systems of the Pacific Ocean. He returned to the East Coast to work on seagrass experimental ecosystems in North Carolina as a research associate at NC State University in 1989-1990. In 1990, Dr. Luczkovich became a Visiting Assistant Professor of Biology and an Assistant Scientist at the Institute for Coastal and Marine Resources (ICMR) at East Carolina University (ECU). He initially researched the biology of the pinfish, with special interest in how these fishes are able to use algae and seagrasses in their diets (commensal, cellulose-producing bacteria in the intestinal tract of the fish allow them to gain energy). He was promoted to Visiting Associate Professor in Biology and Associate Scientist with ICMR in 1997, his current position. At ECU he has worked on two lines of research: 1) passive acoustics and sound production in fishes, and 2) food web models of fishes and fisheries.



Ashish Mehta obtained his bachelor's degree in chemical engineering from the University of California at Berkeley (1966), and his doctoral degree in Civil Engineering (1973) from the University of Florida in Gainesville, where he is professor emeritus in the Department of Civil and Coastal Engineering. His areas of teaching and research include the application of physical principles and engineering to coasts, estuaries and lakes, especially in Florida. He has investigated the hydraulics of finegrained sediment transport in which the behaviour of cohesive flocs in turbulent flows requires an understanding of the basics of physical chemistry. He has also examined the hydraulics and sediment transport at numerous tidal inlets in Florida.

Jack J. Middelburg (1963) studied biogeology at the University of Groningen, geochemistry at Utrecht University, and obtained his PhD from Utrecht University in 1990. After that he worked at the Centre for Estuarine and Marine Ecology of the Netherlands Institute of Ecology in Yerseke before returning to Utrecht University in 2009. His research is at the interface of biogeochemistry and ecology and covers the whole aquatic continuum from lakes and rivers, via estuaries, to the coastal and open ocean, including the sediments. He combines field observations, field and laboratory experiments and numerical models to further biogeochemical process knowledge. Besides holding the geochemistry chair at Utrecht University, he has adjunct positions at the Centre for Estuarine and Marine Ecology in Yerseke and Gent University, Belgium.

Professor Stephen Monismith's research in environmental and geophysical fluid dynamics involves the application of fluid mechanics principles to the analysis of flow processes operating in rivers, lakes, estuaries, and the oceans. Making use of laboratory experimentation, numerical modeling, and field measurements, his current research includes studies of estuarine hydrodynamics and mixing processes, flows over coral reefs, wind wave–turbulent flow interactions in the upper ocean, turbulence in density-stratified fluids, and physical–biological interactions in phytoplankton and benthic systems. Because his interest in estuarine processes is intertwined with an interest in California's water policy issues, he has been involved with efforts at developing management strategies for improving the health of San Francisco Bay through regulation of freshwater flow into the Bay. Professor Monismith is currently Director of the Environmental Fluid Mechanics Laboratory at Stanford University. He is a 1989 recipient of the USA's Presidential Young Investigator award. Prior to coming to Stanford, he spent 3 years in Perth (Australia) as a research fellow at the University of Western Australia.

Catharina J. M. Philippart (1960) studied biology at Wageningen University (The Netherlands) and obtained her PhD on *Eutrophication as a possible cause of decline in the seagrass Zostera noltii of the Dutch Wadden Sea* in 1994. Between 1990 and 1994, she combined her seagrass studies with research on the effects of marine eutrophication on phytoplankton and macroalgae at the Institute for Forestry and Nature Research on the island of Texel. Since 1994, she has been working as an estuarine ecologist at the Royal Netherlands Institute for Sea Research. Here, she studies the trophic interactions between marine primary producing microalgae (phytoplankton and microphytobenthos) and primary consumers (with a focus on marine bivalves) of shallow temperate coastal waters such as the Wadden Sea. This research is performed by means of various techniques such as automated monitoring networks, field surveys, remote sensing (airborne and satellite) techniques, and laboratory experiments under controlled environmental conditions. She presently coordinates several large multidisciplinary national and European research programs on primary production, climate change, and marine monitoring networks.

James L. Pinckney is an associate professor in the Department of Biological Sciences at the University of South Carolina. He received his Bachelor of Science degree in Biology (1983) and Master of Science degree in Marine Biology (1987) from the College of Charleston in Charleston, SC. In 1992, he received his Doctor of Philosophy degree in Ecology from the University of South Carolina in Columbia, SC. From 1992 to 1998 he was a Research Assistant Professor at the University of North Carolina at Chapel Hill, Institute of Marine Sciences in Morehead City, NC. Dr. Pinckney accepted a faculty position in the Department of Oceanography at Texas A&M University in College Station in 1998. Both he and his wife, Tammi Richardson, accepted faculty positions in the Department of Biological Sciences at the University of South Carolina in 2005 and have a primary appointment in the Marine Science Program.

Estuarine and coastal studies form the core of research activities performed by Dr. Pinckney. General areas of interest include marine ecology, microbial ecology, microalgal ecophysiology, phytoplankton-nutrient interactions, harmful algal blooms, and ecosystem eutrophication in estuarine and coastal habitats. Specific interests are centered around the ecophysiological factors and processes that influence carbon partitioning, allocation (growth), and interspecific competition in multispecies assemblages. Most of Dr. Pinckney's work over the past 25 years has emphasized investigations of the ecophysiology of benthic and phytoplanktonic communities and their contribution to ecosystem function. Analytical approaches involve manipulative field and laboratory experiments for examining the ecological physiology and responses of microalgal communities.

Graham Shimmield graduated from the University of Durham in Geology, and received a PhD in Marine Geochemistry from the University of Edinburgh in 1985, where he remained until 1996 as part of the academic staff. He then became the combined director of Scottish Association of Marine Science (SAMS) and the NERC-funded Institute, within the Dunstaffnage Marine Laboratory (DML) for 12 years.

Graham's particular interest is in marine geochemistry, which includes the fundamental studies of geochemical processes operating in oceans through identifying indicators of ocean and climate change, and examining human impacts and contamination in coastal and deep seas. He has had significant involvement in marine biotechnology as the Managing Director of the European Centre for Marine Biotechnology, and Chairman of the Board of GlycoMar Ltd, a small biotech start-up.

Graham has served on many European national and international committees, including the UK Natural Environment Research Council (NERC) Science Strategy Board. He has been president and vice-president of the European Federation of Marine Science and Technology Societies (EFMS). He was also Chairman of the European Census of Marine Life Program.

In 2000, Graham was awarded the title of Honorary Professor at the University of St Andrews. He is a Fellow of the Royal Society of Edinburgh, and the Society of Biology. He has published over 65 scientific peer-reviewed articles. He joined Bigelow Laboratory for Ocean Sciences in March 2008. In November 2011 Graham was named by MaineBiz as one of ten "Nexters" helping to shape the future of Maine's economy.

Charles ("Si") Simenstad is a Research Professor in the University of Washington's School of Aquatic and Fishery Science, where he coordinates the Wetland Ecosystem Team. He holds a BS and MS from the University of Washington. Prof. Simenstad is an estuarine and coastal marine ecologist who has studied estuarine and coastal marine ecosystems throughout Puget Sound, the Washington coast, and Alaska for over 30 years. He is an American Association for the Advancement of Science Fellow, associate editor of three scientific journals and recipient of the 2009 NOAA-AFS Nancy Foster Award for Habitat Conservation.

His research has focused on food webs of estuaries and coastal ecosystems, and particularly their support of juvenile Pacific salmon and other nekton, and the associated ecological processes that are responsible for enhancing nekton production and life history diversity. Recent research has integrated basic ecosystem interactions with applied aspects of restoration, creation and enhancement of estuarine and coastal wetland ecosystems, and ecological approaches to evaluating the success of coastal wetland restoration at ecosystem and landscape scales, including the role of coastal restoration in benefitting ecosystems functions, goods and services. Prof. Simenstad's current research includes studies of juvenile salmon rearing in, and restoration of, estuarine/coastal ecosystems in estuaries of the Pacific Northwest – Columbia River, San Francisco Bay – Delta, Russian River – Alaska, Fox River, Kachemak Bay – Alaska, USA; developing and testing an estuarine ecosystem classification system for the Columbia River estuary; initiating a new, interdisciplinary study of restoration process at Liberty Island in the Sacramento River delta; and serving as Chair of the Nearshore Science Team (NST) of the Puget Sound Nearshore Ecosystem Research Program (PSNERP) that is providing scientific guidance in developing a feasibility plan for large-scale restoration of estuarine and nearshore ecosystems of Puget Sound.

Reginald James Uncles obtained a BSc Hons. (First Class) in Physics from Imperial College, University of London, in 1969 and stayed there to complete a PhD in Theoretical and Computational Plasma Physics in 1972. He is an Associate of the Royal College of Science and a Fellow of the Institute of Physics. Currently, he is President of the Estuarine and Coastal Sciences Association (ECSA). He has led research teams at the Plymouth Marine Laboratory and served on its Senior Management Team. His current work is devoted to research and research applications. His personal research activities include theoretical and experimental work on physical processes in estuaries and shallow coastal waters, with applications to biology, chemistry and ecology. Special areas of interest include the mechanisms responsible for fine sediment accumulation and saltwater intrusion in the upper reaches of estuaries. He has worked overseas for extended periods of time in Australia, Africa, Argentina, Germany, Malaysia and the USA on problems concerned with estuaries, publishing more than 125 peer reviewed research articles in international journals and books.

Marjan van den Belt is the Director of Ecological Economics Research New Zealand at Massey University. She is an Ecological Economist and an Associate Professor. She is a Science Leader of Sustainable Pathways 2, an urban program aiming to design a toolbox for spatial planning. She is also involved in Manaaki Taho Moana (MTM), focusing on coastal ecosystem services, responsible for a Mediated Modeling component in this program. A third program on Integrated Freshwater Solutions is anticipated; all three programs are geared toward collaborative and adaptive management. Prior to her arrival in Palmerston North in early 2009, Marjan was an independent consultant with Mediated Modeling Partners, LLC in Vermont, USA, which she founded. She authored the book *Mediated Modeling: A System Dynamics Approach to Environmental Consensus Building*, published by Island Press in 2004. Between 2003 and 2008, she taught an Adjunct Professor at the University of Vermont. She also co-developed a co-housing/eco-village in Vermont during this period.

She is currently a strategy advisor for a European hedge fund specializing in sustainability investing – Roodhals Capital.

Native of the Netherlands, Marjan has a Master's in Business Economics from Erasmus University in Rotterdam (1991). In 2000, she received a PhD in Marine Estuarine and Environmental Sciences and a Certificate in Ecological Economics from the University of Maryland, USA. She co-founded the consultancy firm Ecological Economics Research & Applications Inc. in Maryland, USA.

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James G. Wilson is an Associate Professor in Zoology and Environmental Science at Trinity College, University of Dublin (TCD).

Prof. Wilson graduated from the University of Glasgow in 1976 with a PhD in Zoology (Marine Biology) before moving to TCD. There, he devised two synoptic indices of estuarine quality, the BQI and the PLI, which have now been applied in the Republic of Ireland, France and the USA as well as the Black Sea.

Prof. Wilson main research interests center on the fitness (in the Darwinian sense) of organisms and this is a key concept to understanding natural systems and anthropogenic impacts. From this arises his work in bioenergetics, bioindicators and indices, and in the network analysis of ecosystems.

Prof. Wilson has written or edited six books and over 100 peer-reviewed papers covering the whole range of his research interests. These have been supported by national and international funding and have included collaborations with colleagues throughout the European Union as well as Russia, Ukraine, Georgia, USA, and Australia.

In addition to his duties in the university, including five years as Head of Department, Prof. Wilson has been an active member of, and held executive posts in, many outside organizations, such as the Irish Marine Sciences Association, the Institute of Ecology and Environmental Management, the Environmental Sciences Association of Ireland, the Life Sciences Committee of the Royal Irish Academy, and the Estuarine and Coastal Sciences Association.

He is a qualified cricket umpire, and still plays for the TCD Taverners side (for fixtures please contact).

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He received the Prize of Japan-France Oceanographic Society in 1986 and the Prize of Good Book in Ehime Prefecture in 1989. He was a SAP member of IGBP/START/SARCS from 1993 to 1997 and SSC member of IGBP/LOICZ from 1993 to 1998.

His main books are Coastal Oceanography (1999) Kluwer Academic Publishers, Dordrechtand Sato-Umi; A new concept for coastal sea management (2007) TERRAPUB, Tokyo.

Professor Maciej Zalewski is a Director of the International Institute of the Polish Academy of Sciences – European Regional Centre for Ecohydrology under the auspices of UNESCO and a Chairman of the Department of Applied Ecology University of Lodz. He is the Chief Editor of the international scientific journal Ecohydrology and Hydrobiology and a leading scientist of the UNESCO International Hydrological Programme – Ecohydrology. His scientific research includes use of ecosystem processes as management tool for sustainable development, economic growth and conservation of biodiversity, use of ecosystem processes in river and lake basins for reduction of eutrophication, elimination of toxic algal blooms, reduction of sedimentation rate and bioenergy production, and restoration of water and ecosystem resources in urbanized spaces for economic development, human health and quality of life improvement. He is also a Coordinator of international projects in 6FP, 7FP, and Life+ Programmes.

From the mid-1980s he has been a Coordinator of the International Scientific Programmes and Working Groups in UNESCO, FAO, and UNEP. Recently, he represents Poland in European Commission – European Strategy Forum on Research Infrastructures (ESFRI) and Joint Programming Initiative.

PREFACE

Why a Treatise?

For the inhabitants of many of the world's major cities and towns, estuaries and coasts provide their nearest glimpse of a natural ecosystem which, despite the attempts of man to pollute it or reclaim it, has remained a fascinating insight into a natural world where energy is transformed from sunlight into plant material, and then through the steps of a food chain is converted into a rich food supply for birds and fish. In spite of natural and man-made problems, life in estuaries can be very abundant because estuarine vegetation and muds are a rich food supply, which can support a large number of animals with a large total weight and a high annual production. Indeed, estuaries have been claimed to be among the most productive natural habitats in the world. Estuaries and coastal waters and their shores provide a wealth of food and ecosystems which support fish, birds, and other wildlife and contribute significantly to the quality of life for humanity.

When we talk about the problems and productivity of the sea, for most people this means the estuaries, coasts, and shores that they can see and explore. When students study marine science in all its aspects, they usually study their local estuaries and coasts and rarely set sail for the deep open ocean. When socio-economists study estuaries and coastal waters, they focus on valuing in economic terms the direct (i.e., with direct monetary values) and indirect values of the ecosystem services that these waters provide to humanity; such valuation is essential for planning the future of estuaries and coastal waters in a crowded, full world anthroposphere. Thus, while estuaries and coasts make up only a small fraction of the total area of the world's seas, they are not only responsible for much of the fish production that we consume but, just as important, are also essential for the quality of life of the 50% of the human population on Earth that lives near the coast. The link between the watersheds and the estuaries and coastal seas, the direct human impact on estuaries and coasts, and the resilience of these waters to human impact determines the severity of environmental problems that mankind faces in connection with the sea. In turn, science can offer solutions for improving estuarine and coastal management practices at the local scale and at the watershed scale in order to improve the resilience of the system and mitigate or even reverse, partially at least, environmental degradation. In the context of climate change, some estuaries and coastal seas may be measurably impacted by small changes to sea level, temperature, and pH, but other estuaries and coasts have the potential to adapt to climate change and to provide our culture and economy a level of future protection. For all these reasons, it is vital that scientists use all the information available to them for the management of our estuaries and coasts. All this information was gathered together for this Treatise. All the editors involved in the production of this Treatise believe that complete information about the science of our estuaries and coasts is vital for the future of this planet.

Ecosystem-based science and management has been identified by many communities, most recently in the US Commission on Ocean Policy, as the approach needed for sustainable natural resource management. Our coasts, estuaries, and inland waters are the poster children for why we need this approach. The *Treatise on Estuarine and Coastal Science* provides the most up-to-date reference for system-based coastal and estuarine science and management. It avoids classical, habitat-oriented science, or just biophysical science, to focus on the linked physical–biological–chemistry–ecosystem–human–ecological economics processes. It does that to specifically address the big issues facing the world on how to best use multidisciplinary science to ensure the sustainability of both humanity and the environment. The aim of the publication is to provide a comprehensive scientific resource on estuarine and coastal science, which will be updated biennially to keep up with the newest developments in the field.

Coastal seas, wetlands, estuaries, deltas, and contributing rivers are at the heart of society's cultural, economic, and social development. On a global scale, they provide more than an estimated half of worldwide ecosystem goods and services. As such, the wider coastal zones are a key life support system to humanity. As a consequence, since millennia humans have altered the coastal zone in service of trade, settlement, resource extraction, and recreation.

The *Treatise on Estuarine and Coastal Science*, in an incomparable effort of multidisciplinary synthesis and assessment, elaborates on key features of coasts. It describes and classifies the processes of ecosystem functioning and the fluxes of water and materials, and it also features the human footprint affecting estuarine and coastal characteristics. This outstanding collective effort is bridging across traditionally divided scientific disciplines and worldviews of coastal researchers to reflect coastal functioning and effects of global change on a multiplicity of temporal and spatial scales. The notion of coastal zones as social–ecological systems is promoted.

The Treatise therefore represents a substantial contribution and community effort to the global Earth system sciences namely, the Land–Ocean Interactions in the Coastal Zone (LOICZ) core project of the International Geosphere–Biosphere Program and the International Human Dimensions Program on Global Environmental Change. LOICZ with its global network of researchers and institutions in the natural, social, and humanity sciences is working to support sustainability and adaptation to global change in the coastal zone. Its operations are feeding into the next decade of Earth system research on global sustainability that looks at the feedbacks of human interaction with nature and response options. The Treatise as a living and dynamic source of knowledge is particularly important in this context, providing insight into the latest concepts and findings of coastal change and human dimensions research.

What is in the Treatise?

The *Treatise on Estuarine and Coastal Science* is a 12-volume series which aims to provide a comprehensive scientific resource for all professionals and students in the area of estuarine and coastal science, with up-to-date chapters covering a full range of topics.

The *Treatise on Estuarine and Coastal Science* examines our estuaries and coasts, and its interactions and feedbacks with humanity, from the inland watershed to the ocean shelf. Under the leadership of two chief editors, a physical oceanographer and a marine biologist, and 23 volume editors, each of whom is a recognized worldwide expert in their subject area, the Treatise is a 12-volume series detailing:

1. Classification of Estuarine and Nearshore Coastal Ecosystems (edited by C Simenstad and T Yanagi);
2. Water and Fine-Sediment Circulation (edited by RJ Uncles and SG Monismith);
3. Estuarine and Coastal Geology and Geomorphology (edited by BW Flemming and JD Hansom);
4. Geochemistry of Estuaries and Coasts (edited by G Shimmield);
5. Biogeochemistry (edited by RWPM Laane and JJ Middelburg);
6. Trophic Relationships of Coastal and Estuarine Ecosystems (edited by JG Wilson and JJ Luczkovich);
7. Functioning of Ecosystems at the Land-Ocean Interface (edited by CHR Heip, JJ Middelburg and CJM Philippart);
8. Human-Induced Problems (Uses and Abuses) (edited by MJ Kennish and M Elliott);
9. Estuarine and Coastal Ecosystem Modeling (edited by D Baird and AJ Mehta);
10. Ecohydrology and Restoration (edited by L Chícharo and M Zalewski);
11. Management of Estuaries and Coasts (edited by HH Kremer and JL Pinckney); and
12. Ecological Economics of Estuaries and Coasts (edited by M van den Belt and R Costanza)

Each volume has approximately 10–15 chapters, with each chapter written by an acknowledged expert in that topic. Each chapter provides an up-to-date review of its subject area and is well illustrated with full color available throughout. With the Treatise being available online, supplementary data and information has been added, which has allowed authors to include not only data sets, but also animations, web links, PowerPoint presentations, and any additional multimedia in order to enhance the articles. In addition, the editors of each volume have provided an overview of their subject, summarizing the state of knowledge and the future directions of inquiry.

The *Treatise on Estuarine and Coastal Science* is available electronically through ScienceDirect. The online publication allows increased functionality and includes internal and external links that will enable efficient cross-referencing between related subjects and for referencing to related published material.

The *Treatise on Estuarine and Coastal Science* is unprecedented in its coverage and provides an invaluable resource for researchers, students, engineers, and professionals managing rivers, estuaries, and coastal seas.

In accord with its intent to provide a comprehensive, state-of-the-art description of estuarine and coastal science, the level of discussion is appropriate for researchers and practitioners at the cutting edge. Nevertheless, topics are discussed in sufficient detail that the *Treatise on Estuarine and Coastal Science* will be useful for advanced undergraduates and graduate students and researchers requiring an introductory discussion of a subject.

Geographical limits

In preparing the *Treatise on Estuarine and Coastal Science*, the editors had to agree on where to set the geographical limits.

For estuaries, it was agreed to set the inland limit at the tidal limit (the 'head of tide'). This therefore includes 'tidal freshwaters' following the Dione, as quoted by Fairbridge, definition of an estuary, namely that:

> an estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: (1) a marine or lower estuary, in free connection with the open sea; (2) a middle estuary subject to strong salt and freshwater mixing; and (3) an upper or fluvial estuary, characterized by freshwater but subject to strong tidal action. The limits between these sectors are variable and subject to constant changes in the river discharges.

Other definitions have used the upstream limit of salt penetration, whereas this definition has the upstream limit of tidal penetration. In an unmodified estuary, the limit of tidal penetration will always be further inland than the limit of salt penetration.

The outer limits at mouths of estuaries as they merge into coasts may be more difficult to determine and agree. There may or may not be convenient geographical discontinuities in the coastline and, there may be sub-tidal physical features denoting the marine, tidal conditions, such as linear sandbanks in wide-mouth estuaries, but these may not be present elsewhere. In general, the presence of full-strength seawater is a reliable indicator of the outer limit of an estuary. The topic of estuarine definitions is covered in much more detail in Volume 1 (Classification of Estuarine and Nearshore Coastal Ecosystems (edited by C Simenstad and T Yanagi)).

The Treatise has also included 'closed or intermittently open' estuaries (common in Australia and South Africa, for instance), man-made estuaries (e.g., residential canals and lagoons), lagoons, and marine lakes, and fringing wetlands – salt marshes/mangroves. Where appropriate, using the holistic approach, the watersheds have been included through their influence on the riverine inflow, and the groundwater inflow/outflow as well, and, where appropriate, the factors controlling the variability of this inflow quality and quantity.

For coasts, the editors agreed to include both the intertidal and the sub-tidal on all marine coasts. On the open coast, the offshore limit of one nautical mile was suggested. This follows the UN Law of the Sea and other international definitions: "*out to one nautical mile from landward baseline – except along mouths of estuaries and heads of bays where it cuts across open water.*" This definition permits inclusion of large bays and estuaries, such as Chesapeake Bay and others.

All the volumes were asked to include brackish and semi-enclosed seas, such as the Baltic Sea, and semi-enclosed seas, such as the Seto Inland Sea, but were not expected to include fully enclosed brackish seas, such as the Caspian Sea.

Future editions

We are planning future editions of the Treatise, and will take the opportunity then to fill any gaps which are identified in the present edition. We invite readers to help us identify any additions for future editions.

Acknowledgments

In preparing this Treatise, we have had the help of many colleagues and we wish to thank all the volume editors and authors for their willingness to undertake this major task.

We wish to thank especially Hannah Rutland, Charlotte (Charlie) Kent, and Gemma Mattingley, successive Development Editors at Elsevier Oxford and Laura Jackson and Sue Jakeman, the production team, who have borne the burden of e-mailing authors and editors and sending out reminders when needed, and of preparing the final publication. We also thank Laura Kelleher, the Publishing Editor at Elsevier US, who was responsible for developing the original idea and for appointing the editors. We should also acknowledge that, prior to Laura, the original idea came from Frank Cynar, and after Laura's promotion we thank John Fedor for seeing the Treatise though to its final production.

Eric Wolanski and Donald McLusky

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Figure 18 of Chapter 6.05, Plankton Consumer Groups: Copepods
Figures 3 and 4 of Chapter 8.11, Climate Change: Effects, Causes, Consequences: Physical, Hydromorphological, Ecophysiological, and Biogeographical Changes
Figure 7 of Chapter 10.12, Aquatic Ecosystems, Human Health, and Ecohydrology
Figures 1 and 2 of Chapter 12.06, Estuarine and Coastal Ecosystems and Their Services
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Figure 1 of Chapter 6.03, Primary Producers: Phytoplankton Ecology and Trophic Dynamics in Coastal Waters
Figure 1 of Chapter 8.01, Introduction – Overview
Figure 34 of Chapter 10.06, Interaction of River Basins and Coastal Waters – an Integrated Ecohydrological View
Figures 7 and 8 of Chapter 12.01, Ecological Economics of Estuaries and Coasts
Figure 10 of Chapter 12.13, Enhancing the Resilience of Coastal Communities: Dealing with Immediate and Long-Term Impacts of Natural Hazards

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Figures 12 and 18 of Chapter 4.02, Sediment Record and Storage of Organic Carbon and the Nutrient Elements (N, P, and Si) in Estuaries and Near-Coastal Seas
Figures 1, 2, 3, 5, 8, 10, 12–21, and 23–29 of Chapter 5.03, Particulate Organic Carbon Cycling and Transformation
Figure 8 of Chapter 6.09, High Trophic Level Consumers: Trophic Relationships of Reptiles and Amphibians of Coastal and Estuarine Ecosystems

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1.01 Introduction to Classification of Estuarine and Nearshore Coastal Ecosystems

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Abstract

To introduce this volume on the Classification of Estuarine and Nearshore Coastal Ecosystems, we describe the diverse approaches that scientists and managers have taken to classify estuaries and nearshore coasts. Classification of estuaries and coasts is motivated by different perspectives (e.g., landform geomorphology, evolutionary origins, and formative processes), purposes (e.g., understanding structure, variability and dynamics, functions and values, and interaction with adjoining fluvial and coastal ecosystems), and applications (e.g., categorizing, mapping, and management) over diverse temporal and spatial scales. As experienced throughout the history of most sciences, classification of diverse objects is a foundational step in the progress and application of a discipline, and particularly so in applied sciences. Appreciating how different class of estuaries and coasts evolve and function is a prerequisite to identifying the approaches and tools needed to management issues and drivers and to identify and predict change and assess impacts. However, as useful as these disciplinary classifications are, interdisciplinary classifications remain elusive, especially those linking the geomorphic form and physical structure and dynamics with ecological and water quality or broader ecosystem functions, goods and services.

1.01.1 Purpose and Scope of Volume

Scientists have a long history of seeking to classify their world into discrete components and patterns that allow them not only to distinguish their unique structural properties but also to set apart their place and function in the broader array of components. Although a dictionary definition of classification would describe a "system of classes or groups, or a systematic division of a series of related phenomenon," effective classification must recognize differences, similarities, and gradations in structure, processes, and concepts. Although classification began with differentiating nonliving things from plants and animals, as taxonomic intricacies could be increasingly scrutinized with emerging microscopic capability, classification of landforms, landscapes, regions, and other large-scale components of our earth, including estuaries and coasts, followed. Whether based on quantitative measures or pattern classification, or one or more of the other approaches, classification provides a common footing and language for many, if not most, scientific disciplines. As a result, taxonomies (or 'typologies' in some sciences) have become a fundamental tool to access an understanding of the organization of both living and nonliving systems.

The classification of estuaries and coasts has emerged as a comprehensive tool for understanding not only the diversity in their natural structure and function but also how humans have altered them and the consequences of our management and regulation efforts. At a minimum, classification is intended to provide a framework for objective identification of a system component, and optimally to systematically differentiate the relationships of all components in a definitive system. On the scale of our social and cultural modification of estuaries and coasts, classification has been elaborated to categorize their 'integrity' such as their biogeochemical state in the context of eutrophication, chemical or other contamination, and the recovery from these stressors.

The purpose of this volume is to provide the foundation for subsequent volumes by describing the current classification frameworks used to categorize estuaries and coasts and their component parts. We provide it as a view of the potential universe of estuary and coast classes, from a variety of disciplinary perspectives, such as geomorphology, circulation, geochemistry and productivity, biotic ecosystems and communities, quality and condition, and management. Subsequent volumes will expand considerably on component classes, their inherent processes and interactions, and methods of study. Given the global audience of the treatise, we have encouraged the chapter authors in this volume to be as comprehensive as possible in embracing classes of estuaries and coasts worldwide, although it is understandable that the science is often restricted to the better-studied regions of the globe. In this Introduction, we attempt to identify some of those gaps in our knowledge and application of estuary and coast classifications.

We have not imposed any limitations on the structure of these classifications. They may be purely descriptive, categorical, and neither hierarchical nor derivative of formative processes, or they may be systematically organized based on the origins, change, functions, and even cultural values of different classes of estuaries and coasts.

1.01.2 Concept and Definition of Classification

1.01.2.1 Emergence of Scientific Classification

Classification might be considered to originate in the fourth century BC with Aristotle's basic division of organisms into plants and animals, and animals by their movement – walking, flying, and swimming – but the development of the hierarchical taxonomy of living organism originated much later, based on the Swedish botanist, Carolus Linnaeus', binominal nomenclature classification system originally published in 1735 (Linnaeus, 1735). In his initial, only 11-page, edition, Linnaeus assigned organisms according to a hierarchy, from broad to more specific, of kingdom, class, order, family, genus, and species based on shared physical characteristics; the phylum category was added to the classification scheme later, between kingdom and class. But for the expansion of the kingdom category (from two to five), the structure of Linnaeus' classification has remained relatively unchanged and unchallenged until the emergence of DNA genetics that has altered our original thinking about how organisms are evolutionarily related. Early 'Neptunists', Abraham Gottlob Werner, and Torbern Olaf Bergman, who published related classifications of minerals and rock forms between 1766 and 1786, emerged from the Linnaean roots as well (Beckinsale and Chorley, 1991). But, perhaps the embryonic beginning of the classification of estuaries and coasts was the 'Plutonist' James Hutton's publication of the Theory of the Earth in 1785, which provided the uniformitarianism explanation of landforms and landscape evolution. The emergence of Wladimir Peter Köppen's climate classification system, initially in 1884, was one of the first classifications to tie dynamic environmental processes such as climate to the structure (i.e., types of vegetation) on the land.

Similar to the evolution of living organisms, the emerging geomorphic classifications were challenging because the most informative classifications were concerned with the antecedents of natural phenomena, not just the state of geological materials and formations fixed in space and time. This conundrum is not easily resolved even today, as we still struggle to map estuaries and coasts and retain some categorization of their origins and dynamism. Much of the tension in different classification originated from the tradeoffs between grouping or ordering (Hempel, 1952) of discrete categories, or a continuous gradation of variable types (Rodgers, 1950), although most classifications of estuaries and coasts generally follow ordering.

1.01.2.2 Rationale and Need for Classification

The coastal seas in the world have suffered from many kinds of environmental problems such as eutrophication, frequent occurrence of harmful algal bloom and hypoxia and anoxia, decrease of biodiversity, decrease of fish catch, coastal erosion, decrease of water transparency, decrease of seagrass beds, increase of finer sediments in the tidal flats, appearance of mutated fish, impo-sex of snail by environmental hormone, discolored cultured seaweed, massive explosion of giant jellyfish, many drifting sea debris landing to the coast, damage by oil spill, breaching of coral reefs, destruction of mangrove forest, and natural hazards of storm surge and tsunami.

To resolve such environmental problems in the coastal seas and to take suitable countermeasure, we have to understand scientifically the geological, physical, chemical, and biological characteristics of the costal seas where the environmental problems occur. However, the characteristics of coastal sea cannot be understood correctly by investigating the target coastal sea itself. It may, for example, be possible for the people to understand correctly the characteristics of the target coastal sea by comparing it with other coastal seas.

For a suitable classification of coastal seas in the world, it is necessary to understand the characteristics of coastal seas, and the classification is carried out from several viewpoints such as geological, physical, chemical, and biological aspects.

1. *Geological characteristics*. How about the historical background of the formation of the coastal sea? Was it uplifted by the isostatic movement or submerged by the increasing mean sea level after the ice age? Does it have a complicated geometry or a simple geometry? Is it shallow or deep? Does it have a sill at the mouth? Is it a sand beach or a rock beach? Does it have the steep sea bed or shallows in the offshore area?

2. *Physical characteristics*. Is it on the open coast with an alongshore current or is there stagnant water due to low wave height? What kind of estuarine circulation is dominant in the target estuary: vertically well-mixed, moderately mixed, or stratified? How about the dominance of tidal current, wind-driven current, and density-driven current? Is it semi-enclosed or open to the outer ocean?

3. *Chemical characteristics*. How about the concentration of nutrients, is it eutrophic or oligotrophic? How about the environmental hormone concentrations? How about the turbidity and oil concentrations? How about the dissolved oxygen concentration? How about the acidification?

4. *Biological characteristics*. Is it a tidal flat or a seagrass bed? What is the main primary producer: phytoplankton, benthic algae, seagrass or sea algae? What is the main nutrition path: microbial loop or grazing food chain? How about the transfer efficiency?

All the above characteristics affect the material cycling and the ecosystem in the target coastal sea. Based on these characteristics, we will need to take counter-measures to sustain the most fruitful ecosystem services that are unique to the class of estuary and coastal sea.

1.01.2.3 Approaches and Criteria

As with biological and geological classifications, the approaches to classifying estuaries and coasts surpass just their component elements or geomorphic structure, and now encompass as well their evolution, change, relationship to watersheds, and support of human social and economic needs. The UK's Estuary Guide (DEFRA/EA 2008) provides insight into at least eight factors that are worthy of consideration for classifying estuaries and coasts at multiple scales, from their geomorphic elements to the entire system:

1. *General form*. Characteristic shape (or component shapes).
2. *Formation and evolution*. Processes that lead to formation and how it develops and evolves over time.
3. *Evolution and constraints*. Factors that may alter or constrain development.
4. *Forcing factors*. Key processes (e.g., wave climate) responsible for shaping and maintaining the general form.
5. *Function*. Role within the physical system in terms of exchanges of energy and mass.
6. *General behavior*. Responses to varying forcing factors.
7. *Behavioral timescales*. Characteristic responses of differing timescales.
8. *Interactions with other elements, estuaries and coasts*. Interactions in terms of flows of energy and/or matter among linked systems.

1.01.3 Contents of Volume 1: Diverse Approaches to Estuary and Nearshore Coast Classification

To a large degree, the following chapters in this initial volume of the treatise describe classification of estuaries and coasts from the standpoint of one or a few disciplines, attributes, and processes. We have attempted to identify authors from the universe of estuarine and nearshore coastal scientists as those who are particularly skilled at integrating across their disciplines. We have tried to arrange the order of the chapters in the volume to provide the reader with an initial view of the global scope of estuary/coast classes and their origins, with a progressive description of the classifications that are commonly applied to describe their current structure, and ultimately the use of classifications in describing and managing anthropogenic modifications and stressors. A resource base is provided in the last chapter as a source for more detailed information on the estuaries/coasts, and also including those listed in the following volumes.

1.01.3.1 Introduction to Classification of Estuarine and Nearshore Coastal Ecosystems – Charles Simenstad and Tetsuo Yanagi

Simenstad an Yanagi provide introduce the concepts and applications of estuarine and nearshore coastal ecosystems classifications (this chapter).

1.01.3.2 Global Variability in Estuaries and Coastal Settings – Gerardo M.E. Perillo and M. Cintia Piccolo (see also Chapter 1.02)

Perillo and Piccolo describe the global variability of the structure and change in natural estuarine and coastal systems within prescribed temporal and spatial scales. Although most coastal settings display temporal and spatial periodicity that returns at least partially, if not fully, to the initial condition compared to changes occurring in settings in which hydrological and erosional processes result in definitive and unrecoverable modifications in state after crossing certain thresholds. These thresholds are related to the systems' resilience. Classification of these coastal settings can be framed around the set of factors that control the variability. Dominance of a group of them (seldom only one is determinant) defines the particular environment and its resilience. As a result of the natural variability of each of the factors and the nonlinear interaction among them, no coastal setting will be equal to another. Consequently, the authors note that responses of such variable coastal settings to large-scale disturbances, such as climate change, which could exceed resilience thresholds, will require independent assessment.

1.01.3.3 Tectonic and Geomorphic Evolution of Estuaries and Coasts – David Kennedy (see also Chapter 1.03)

Kennedy examines estuaries as depositional environments which receive and store sediment from both fluvial and marine sources, each leading to a characteristic set of facies. Their evolution is primarily linked to eustatic sea-level fluctuations which flood coastal embayments, creating accommodation space for sediment accumulation. The distribution of each sedimentary and geomorphic unit within an estuary is determined by the process boundary conditions that dominate the fluvial and marine environments as well as the available accommodation space. He describes how the pattern and rate of sediment infilling depend on the five boundary condition processes of the estuary: (1) tidal range; (2) wave climate; (3) tectonic stability; (4) glacial history; and (5) magnitude of fluvial inflow. The relative dominance of each process will determine the type of landforms that form within an estuary and resulting sediment facies which progressively infill the drowned coastal embayment. The author describes how such longer-term geological factors, and their interplay with contemporary dynamics and accommodation space, determine the geomorphic and sedimentary character of different estuarine environments, as well as their ability to adjust and respond to human-induced climate change.

1.01.3.4 Classes of Nearshore Coasts – Megan Dethier and John Harper (see also Chapter 1.04)

In discussing global variation in types or classes of coastal environments, Dethier and Harper address the complex issues of purpose, scale, and complexity of existing classification systems, and how mapping systems differ from classifications. They discuss problems that stem from defining marine/estuarine boundaries, constraining the level of detail in classification systems, and introduce the challenging issue of whether or not biota should be incorporated into a coastal classification system. In defining the key variables that are important in distinguishing coastal environments and in affecting marine organisms, humans, and responses to climate change, the authors also describe how the challenge of inventorying marine environments is still limited by technological challenges.

1.01.3.5 Classification of Estuarine Circulation – Arnoldo Valle-Levinson (see also Chapter 1.05)

Valle-Levinson builds on traditional approaches to classifying estuarine circulation as dynamic entities rather than basin entities. Unlike the more gradual, if not static change in estuarine or coast landform and geomorphology, classifying the dynamic circulation of any one estuary is a challenge because most estuaries will exhibit stratified or destratified, and different circulation patterns, according to phases of intratidal (ebb or flood) and subtidal (springs or neaps) tides, buoyancy conditions (dry or wet season), and atmospheric forcing (cooling/heating, wind direction). Although focusing on typical gravitational circulation, the author emphasizes the interacting effect of tidal residual circulation, the circulation induced by asymmetric tidal mixing, and the unique effect of distortions on the tidal signal that result in tidal asymmetries in vertical mixing which reinforce gravitational circulation. Accordingly, the closing message of the chapter is that estuarine circulation is not necessarily gravitational circulation and characterization and classification of estuarine mixing must also take into account tidal rectification and tidally asymmetry.

1.01.3.6 Variation among Estuarine Geochemistry and Productivity – Wally Fulweiler and M. Bartoli (see also Chapter 1.06)

Fulweiler and Bartoli bring to the volume the first intersection of circulation, geochemistry, primary productivity and many of the functions that relate to a primary management issue of our estuaries and coasts, that is, eutrophication. Their theme is that these complex systems cannot be defined using just nitrogen loading or annual primary productivity but urge the need to search for an integrative classification scheme that encompasses the physical, geological, chemical, and biological characteristics of estuaries. Perhaps one of their more insightful, but more challenging, perspectives is the importance of considering benthic respiration and bioturbation by benthic macrofauna, which ultimately need to be integrated into a classification of system metabolism. A summary point is that many uncertainties remain about what accounts for variation in estuarine geochemistry and productivity, including both sufficiency of data and methodology, but that a conceptual framework and classification(s) would advance the science.

1.01.3.7 Ecosystem and Biotic Classifications of Estuaries and Coasts – Alan Whitfield and Michael Elliott (see also Chapter 1.07)

Commensurate with Perillo and Piccolo's (*see* Chapter 1.02) global view of estuarine and coastal settings, Whitfield and Elliott describe the diverse aquatic environments between the land and sea that are described as 'transitional waters'. The unique continuum of ecosystems that occupy that transition zone between inland freshwater and coastal marine environments retains some characteristics of both freshwater and the seawater (Figure 1 in Chapter 1.07) and also have unique properties that argue for a classification perspective. In examining the breadth of definitions of estuaries, the authors argue that three important components need to be incorporated into the definition of an estuary: coastal containment, the mixing of freshwater with seawater, and the presence of an estuarine biota. Accordingly, in reviewing the breadth of estuarine classifications, they relate them to ecosystems defined by dominant biota, such as macrophytic vegetation – seaweeds, seagrasses, saltmarshes, and mangals. Ultimately, they argue for a primary classification system of three classes – (1) valley estuary; (2) lagoon and lake; and (3) river mouth – but question whether species diversity and associations or nutrient and productivity might provide valuable secondary diagnostics when comparing the structure and functioning of adjacent ecosystems or classifying systems according to broad ecological characteristics.

1.01.3.8 Classifying Ecological Quality and Integrity of Estuaries – Angel Borja, Alberto Basset, Suzanne Bricker, Jean-Claude Dauvin, Mike Elliott, Trevor Harrison, Joao-Carlos Marques, Stephen B. Weisberg, and Ron West (see also Chapter 1.08)

Borja et al. carry the concept and application of estuary classification into the more recent, but perhaps still inexact realm of ecological quality and integrity. Surveying recent efforts to assess individual biological elements and the associated integrative tools used to apply them, the authors found that the reductionist approach requires integration of different disciplines to reach agreement on the final assignment of ecological status. Perhaps one of the more important observations of this chapter is that most efforts still focus on historically important legacy stressors for which management actions have already been undertaken, rather than on issues that managers are or should be contemplating action, such as climate change. This reinforces the authors' culminating emphasis that more effort needs to be directed at understanding the complexities of estuarine system functioning rather than simplifying and scaling down the system into smaller components.

1.01.3.9 Application of Estuarine and Coastal Classifications in Marine Spatial Management – Simon Pittman, David Connor, Lynda Radke, and Dawn Wright (see also Chapter 1.09)

Pittman et al. carry estuary and nearshore coast classifications to their applied nexus, mapping, inventory, and interpretation for management purposes. They examine how classified maps once confined to simple change analysis are now used in complex analyses to communicate biological, physical, social, economic, and jurisdictional patterns that inform management decisions, what has recently been described as spatial planning. This chapter points out both the benefits, as well as the challenges, inherent in the rapid technological improvements and diversification of air-, space-, and water-borne sensors combined, global positioning systems, and geographical information systems (GIS) that are now integral components in modern coastal management. One of the more unique aspects of estuary and nearshore coast classification that is described in this chapter is their role in setting priorities for conservation and restoration site selection. Although the success of these techniques is heavily dependent on the type, amount and quality of biophysical data available, the value of this process to mitigate ecosystem degradation by incorporating information on threatening processes and the relative vulnerability of features or planning units is crucial for effective conservation, and provides an unprecedented opportunity to evaluate both the content and the gaps in an existing conservation portfolio. The numerous case studies provided by the authors exemplify the diverse, global applications of classification in spatial planning and management.

1.01.3.10 Resource Base: Global Distribution and Characteristics of Estuaries and Associated Coastal Shores – Keita Furukawa (see also Chapter 1.10)

In the final chapter of the volume, Furukawa describes the format and system of a 'resource base' that can be used to acquire, store, manage, and analyze estuary and nearshore coast spatial data, and illustrates the worldwide dissemination of GIS-based information, thematic information, and knowledge bases available to both the public as well as coastal scientists and managers. The crux of this chapter is the Worldwide Knowledge Base compilation of publications, data, and analytical tools for estuaries and nearshore coasts from eight regions of the world.

1.01.4 Issues

1.01.4.1 Objectives of Classification

There are many competing objectives of classification, often linked to differences in scale. A basic objective is to characterize simply the unique aspects of a familiar estuary or coastal segment relative to other similar or dissimilar systems; a common motivation of this approach is to explain the relationship among the estuary/coast geomorphic evolution and current form to ecosystem processes. Another of the more common motivations is to map the entire estuarine/coastal landscape by geomorphic and other classes of estuarine/coastal attributes that appear as polygons or pixel classes. The ecosystem classification is not inherently spatially explicit, but the estuary/coast form is explicitly used to explain variation in physical, geochemical, and biological processes. The second approach is more spatially explicit, where the composition and arrangement of estuary/coast components may be used to characterize the condition or landscape-scale connectivity or other indices of ecosystem function.

1.01.4.2 Limiting Factors

The utility of a classification is only as good as the underlying data. In all cases, the available data sets are the ultimate determinants of the completeness, scope, and scale of the classification that can be applied to any estuary and coast. Although geomorphic form is typically available and interpretable from most spatial data of relatively coarse resolution and scale, mapping of fine-scale, high-resolution features is often contingent on a complement of large format data (or require exhaustive merging of multiple data tiles) of common precision and *in situ* training (ground-truthing). In the most *in situ* data-dependent classification, assembling categories of estuary/coast condition, such as water quality and biotic community structure indicative of the level of contaminant or other ecosystem stress, requires spatially and temporally intensive sampling encompassing the inherent variability in the stressors.

Throughout the classifications detailed in this volume, the reader will recognize that while the approaches obviously provide a lot of value to understanding the organization and state of estuarine/coastal ecosystems, few have necessarily been applied beyond the case study systems for which they were initially developed. For instance, despite the need to include tidal freshwater reaches in ecosystems-based definition of estuaries (e.g., see Chapter 1.02), they are often neglected in estuary classifications or relegated to unrelated fluvial classifications. Data limitation is also typical for classifications that would benefit from finely resolved classes of substrates, which usually only occur as broad categories of surface sediments assessed visually; even more limited are classifications based solely on surface cover, where the underlying substrate is not interpreted. Similar to complex classes that cannot be easily interpreted from a single, remote data source such as aerial photography, classes or phenomena that are extremely transient or short term may be consistently excluded from classifications (and particularly mapping) that are not specifically targeted to record them even though they may be extremely important to estuary/coastal ecosystem processes and function.

1.01.4.3 Challenges

Perhaps the three greatest challenges for classification are: (1) integrating classifications of the structure of estuary/coast landscapes at different scales and relating their organization to ecosystem processes; (2) categorizing the magnitude and direction of dynamic change in estuary/coast class and landscape structure, and its significance to ecosystem processes; and (3) classifying few that relate physical and biogeochemical attributes of estuaries and coasts to their social, cultural, and economic attributes (e.g., see Edgar et al., 2000)

1.01.5 Need to Integrate Physical, Geochemical, Ecological, Management, and Social Information

Although it remains difficult to find classifications that integrate many of the factors identified in Section 1.01.2.3, above, it is more difficult to imagine how many, if not most of them, are fundamental to categorizing the estuary/coast setting and how management issues and drivers interact to identify and predict change and assess impacts (DEFRA/EA, 2008). Similarly, while the emergence and availability of remote-sensing imagery, geographic information systems, and rigorous quantitative tools, such as multivariate analyses (e.g., Valesini et al., 2009), empower more and more refined and replicable classifications, there remains the need to incorporate origin, temporal behavior, function and many of the other attributes into the classification of estuaries and coasts. Perhaps an ultimate goal would be to develop for estuarine and coastal management applications an integrated suite of classifications that, while allowing focused identification of the spatial variability in particular estuary/coast attributes, could be applied in concert to reflect ecosystem functions, goods, and services to coastal and regional communities.

1.01.6 Summary

We trust that we and our chapter co-authors have provided in this volume the knowledge and tools for readers to appreciate the variability, and understand and effectively classify the scientific characteristics of their regions' estuaries and coasts. It is our hope that we have provided, and will continue to provide, the critical information that would enable the reader to address local environmental problems and understand the role and condition of estuaries and nearshore coasts at regional and larger scales.

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