Shipping is responsible for transporting 90 per cent of the world’s trade. This book provides a comprehensive review of the impact shipping has on the environment. Topics covered include pollutant discharges, such as atmospheric emissions, oil, chemical waste, sewage and biocides, as well as non-pollutant impacts, including invasive species, wildlife collisions, noise, physical damage and the environmental effects associated with shipwrecks and shipbreaking. The history of relevant international legislation is also covered. With chapters written by eminent international authors, this book provides a global perspective on the environmental impact of ships, making it a useful reference for advanced students and researchers of environmental science, as well as practitioners of maritime law and policy and marine business.

STEPHEN DE MORA recently retired as the chief executive of the Plymouth Marine Laboratory (PML) and PML Applications Ltd. Previously, he taught chemistry, environmental science and oceanography at universities in the UK (University of Lancaster), New Zealand (University of Auckland) and Canada (University of Quebec at Rimouski), and he worked at the International Atomic Energy Agency (IAEA) Marine Environment Laboratory in Monaco. Through the IAEA, he worked on several Regional Seas Programme and Global Environment Facility projects around the world. He was presented with a Distinguished Service Award in 2005, the same year in which the IAEA was a co-recipient of the Nobel Prize. He is the only ad hominem member of the UK Marine Science Coordination Committee. He serves as a Sargasso Sea Commissioner and on a number of other national and international committees.

TIMOTHY FILEMAN is a marine scientist, centre manager for the Ballast Water Centre and technical manager at PML Applications Ltd. He has more than 30 years’ experience in marine science and was initially trained as an analytical chemist working on marine pollution-related issues for the UK government. He later moved into research in order to follow his interests in organic contaminant behaviour through estuaries and marine biogeochemistry before developing commercial services for PML. He developed the Ballast Water Centre, which grew from his experience in working with the shipping industry to deliver environmental
services. He is a chartered scientist and marine scientist, as well as a member of the Institute of Marine Engineering, Science and Technology (IMarEST).

Thomas Vance is Centre Manager of the Centre for Marine Biofouling and Corrosion. He specializes in marine fouling community ecology and biofouling control. He has experience in designing, conducting and interpreting field- and laboratory-based experiments on marine invertebrate and algal assemblages, both in the UK and internationally. His practical experience includes diving surveys, field-based manipulative experimentation, marine invertebrate taxonomy, advanced image analysis, physiological assessments of fouling species and molecular analysis of biofilms, together with multivariate statistics and reporting.
CAMBRIDGE ENVIRONMENTAL CHEMISTRY SERIES

This wide-ranging series covers all areas of environmental chemistry, placing emphasis on both basic scientific and pollution-orientated aspects. It comprises a central core of textbooks, suitable for those taking courses in environmental sciences, ecology and chemistry, as well as more advanced texts (authored or edited) presenting current research topics of interest to graduate students, researchers and professional scientists. Books cover atmospheric chemistry; chemical sedimentology; freshwater chemistry; marine chemistry; and soil chemistry.

Series Editors:
S. J. de Mora Plymouth Marine Laboratory, Plymouth, UK
P. G. C. Campbell Institut National de la Recherche Scientifique, Quebec, Canada
T. Lyons University of California, Riverside, USA
L. Sigg Eawag Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland
P. Ariya McGill University, Montreal, Canada
R. Prince ExxonMobil Biomedical Sciences, New Jersey, USA

Latest books published in the series:
T. Nakajima et al., Environmental Contamination from the Fukushima Nuclear Disaster
W. Davison, Diffusive Gradients in Thin-Films for Environmental Measurements
P. G. Coble et al., Aquatic Organic Matter Fluorescence
S. Roy et al., Phytoplankton Pigments: Characterization, Chemotaxonomy and Applications in Oceanography
E. Tipping, Cation Binding by Humic Substances
D. Wright and P. Welbourn, Environmental Toxicology
ENVIRONMENTAL IMPACT OF SHIPS

Edited by

STEPHEN DE MORA
Plymouth Marine Laboratory

TIMOTHY FILEMAN
PML Applications Ltd

THOMAS VANCE
PML Applications Ltd
Contents

List of Contributors \hspace{1cm} \textit{page} ix
Preface \hspace{1cm} \textit{xi}

1 Shipping, Ships and the Environment \hspace{1cm} 1
\hspace{1cm} \textit{Thomas Vance, Timothy Fileman and Stephen de Mora}

2 Atmospheric Emissions from Ships \hspace{1cm} 11
\hspace{1cm} \textit{Thomas G. Bell, Mingxi Yang and Simon J. Ussher}

3 Oil Pollution from Operations and Shipwrecks \hspace{1cm} 56
\hspace{1cm} \textit{Roger C. Prince}

4 Waste and Sewage \hspace{1cm} 75
\hspace{1cm} \textit{C. Michael Hall}

5 Ballast Water \hspace{1cm} 96
\hspace{1cm} \textit{Stephan Gollasch and Matej David}

6 Biocides from Marine Coatings \hspace{1cm} 112
\hspace{1cm} \textit{Samantha Eslava Martins, Isabel Oliveira, Katherine Langford and Kevin Thomas}

7 Invasive Species \hspace{1cm} 165
\hspace{1cm} \textit{John A. Lewis}

8 Physical Effects of Ships on the Environment \hspace{1cm} 216
\hspace{1cm} \textit{Timothy Fileman, Stephen de Mora and Thomas Vance}
## Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Ship Noise</td>
<td>Salvatore Viola and Virginia Sciacca</td>
<td>225</td>
</tr>
<tr>
<td>10</td>
<td>Vessel Strikes and North Atlantic Right Whales</td>
<td>Caroline H. Fox and Christopher T. Taggart</td>
<td>250</td>
</tr>
<tr>
<td>11</td>
<td>Nuclear-Powered Vessels</td>
<td>Richard John (Jan) Pentreath</td>
<td>282</td>
</tr>
<tr>
<td>12</td>
<td>Environmental Impacts of Shipbreaking</td>
<td>M. Maruf Hossain</td>
<td>303</td>
</tr>
<tr>
<td>13</td>
<td>International Legislative Framework</td>
<td>Gorana Jelic Mrcelona, Nikola Mandic and Ranka Petrinovic</td>
<td>329</td>
</tr>
<tr>
<td>14</td>
<td>Shipping Industry’s Perspective</td>
<td>Peter Hinchliffe</td>
<td>352</td>
</tr>
<tr>
<td>15</td>
<td>Environmental Impacts of Shipping: Can We Learn?</td>
<td>Stephen de Mora, Timothy Fileman and Thomas Vance</td>
<td>367</td>
</tr>
</tbody>
</table>

Index 374
Contributors

Thomas G. Bell
Plymouth Marine Laboratory, Plymouth, United Kingdom

Matej David
David Consult D.O.O., Izola, Slovenia

Caroline H. Fox
Dalhousie University, Halifax, Nova Scotia, Canada

Stephan Gollasch
Gollasch Consulting, Hamburg, Germany

C. Michael Hall
University of Canterbury, Christchurch, New Zealand

Peter Hinchliffe
International Chamber of Shipping, London, United Kingdom

M. Maruf Hossain
University of Chittagong, Chittagong, Bangladesh

Katherine Langford
3 Moorfields Street, Fig Tree Pocket, Australia

John A. Lewis
ES Link Services Pty Ltd, Castlemaine, Australia
List of Contributors

Nikola Mandic
University of Split, Split, Croatia

Samantha Eslava Martins
Norwegian Institute for Water Research (NIVA), Oslo, Norway; Federal University of Rio Grande, Rio Grande do Sul, Brazil

Gorana Jelic Mrcelic
University of Split, Split, Croatia

Isabel Oliveira
University of Aveiro, Aveiro, Portugal

Richard John (Jan) Pentreath
Ropewalk, Penpol, Camelot House, Truro, Cornwall, United Kingdom

Ranka Petrinovic
University of Split, Split, Croatia

Roger C. Prince
Roger Prince, Pittstown, NJ, USA

Virginia Sciacca
Laboratori Nazionali del Sud (INFN), Catania, Italy

Christopher T. Taggart
Dalhousie University, Halifax, Nova Scotia, Canada

Kevin Thomas
University of Queensland, Brisbane, Australia

Simon J. Ussher
Plymouth University, Plymouth, United Kingdom

Salvatore Viola
Laboratori Nazionali del Sud (INFN), Catania, Italy

Mingxi Yang
Plymouth Marine Laboratory, Plymouth, United Kingdom
Preface

Environmental impacts of shipping arise through port and channel development, and ships, of which only the latter are considered in this book. Shipping is a vital industry supporting global trade, with over 90 per cent of goods transported by sea. Most of the worldwide fleet comprises 90,000 cargo vessels of one type or another, but ships are diverse in type, function and region of operation. Given that cruise liners, fishing vessels, research ships and naval vessels are not necessarily confined to the major shipping lanes, but rather travel throughout the world's oceans, the impact of ships on the marine environment is present everywhere that ships can go. Moreover, these effects can be felt in inland waters that are navigable and/or are connected directly or indirectly to the seas, such as the Great Lakes and the Caspian Sea.

This edited book provides a comprehensive review of the multifarious effects that ships can have on the environment. Currently, no such authoritative text exists. Whilst the emphasis is on pollutant discharges (air, oil, waste, sewage and biocides) from normal operations, other effects are considered (invasive species, wildlife collisions, noise and physical damage). With respect to end of life, chapters are devoted to the environmental effects of both shipwrecks and shipbreaking. Finally, the history of relevant international legislation is covered, together with a perspective from the shipping industry. This holistic approach recognizes the need in the community to understand fully the environmental consequences of shipping.

The drivers, pressures, state, impact and response (DPSIR) framework provides a useful conceptual model for assessing and managing the problems arising from the interactions between ships and the environment. Research into marine pollution (including noise) and other deleterious consequences, such as wildlife collisions, has led to numerous requirements to alter behaviour and practices at sea. The most important responses involve legal instruments to mitigate, remediate and/or prevent...
Preface

the impact of ships on the environment. Mechanisms encompass local by-laws, national regulations and international conventions, notably those of the International Maritime Organization. Thereafter, appropriate and responsible implementation by the shipping industry helps to protect marine and coastal environments.