## Contents

Preface vii  
Acknowledgements ix  

1. Expert consensus 
   G. Rees, J. Bartram and D. Kay  
   1  

2. Bivalves: Global production and trade trends 
   S. Pawiro  
   11  

3. Adverse health outcomes 
   T.K. Graczyk, K. Sureshand D. Lees  
   21  

4. Driving forces and risk management 
   G. Rees, I. Karunasagar and J. Santo Domingo  
   39  

5. Identification of primary sources of faecal pollution 
   J.W. Santo Domingo and T.A. Edge  
   51  

6. Components of microbiological monitoring programmes 
   R. Lee and L. Murray  
   91  

7. Real-time monitoring technologies for indicator bacteria 
   and pathogens in shellfish and shellfish harvesting waters 
   A.P. Dufour and G.N. Stelma Jr.  
   109  

8. Sanitary profiling of shellfish harvesting areas 
   R. Lee, D. Kay, M. Wyer, L. Murray and C. Stapleton  
   121  

9. Depuration and relaying 
   D. Lees, A. Younger and B. Doré  
   145  

10. Overview of legislative principles and measures 
    L. Murray and R. Lee  
    183  

11. Official control monitoring programmes for live bivalve 
    molluscs – legislative and regulatory approaches: Scotland 
    L. Murray  
    205  

12. Official control monitoring programmes for live bivalve 
    molluscs – legislative and regulatory approaches: Canada 
    G. Sauvé  
    217  

13. Official control monitoring programmes for live bivalve 
    molluscs – legislative and regulatory approaches: New Zealand 
    P. Busby  
    233
14. Current management practices 245  
   *G. Rees, H. Liu, J. Fang and L. Karasungar*

15. Experience from recreational waters 267  
   *D. Kay, R. Lee, M. Wyer and C. Stapleton*

16. Microbial modelling in coastal environments and early warning systems: useful tools to limit shellfish microbial contamination 297  
   *M. Gourmelon, P. Lazure, D. Hervio-Heath, J.C. Le Saux, M.P. Caprais, F.S. Le Guyader, M. Catherine and M. Pommepuy*

17. Framework for change 319  
   *D. Kay and G. Rees*

Index 331
Preface

This publication presents the contributions made, conclusions reached and the consensus statement agreed upon at a workshop on safe management of shellfish and harvest waters held 30 November–2 December 2004 in Kuala Lumpur, Malaysia. The workshop was organised by the Water, Sanitation, Hygiene and Health Unit of the World Health Organization, in cooperation with the US Environmental Protection Agency, Office of Research and Development. This publication is one in a series of expert workshops, reports and monographs on Emerging Issues in Water and Infectious Disease managed by the two organizations. Other titles in the series include:

- Heterotrophic Plate-Counts and Drinking-Water Supply
- H₂S Method for Detection of Faecal Contamination
- Water Recreation and Disease
- Toxic Cyanobacteria in Water
- Waterborne Zoonoses: Identification, Causes and Controls
- Pathogenic Mycobacteria in Water
- Legionella and the Prevention of Legionellosis.

All publications are available from the World Health Organization website (www.int/water_sanitation_health/) or from the International Water Association (www.iwapublishing.com).

Invaluable support for the workshop was provided by the University of Malaya. A total of 22 experts from 10 different countries representing a wide range of academic disciplines, ranging from clinical and aquatic microbiology, hygiene and public health, food safety, risk assessment, epidemiology to bivalve shellfishery management attended the workshop. Meeting participants jointly examined the issues of sewage contamination of bivalve shellfish and their harvest waters. The meeting did not address biotoxins or naturally-occurring microbial contamination of shellfish.

At the workshop participants were asked to produce key technical inputs on the range of issues affecting the sewage contamination of bivalve shellfish and their harvest waters and the resultant infectious diseases. The participants were
also tasked with determining whether the existing management and control measures could, if necessary, be improved.

The global bivalve shellfish industry is a multimillion dollar industry, varying from highly commercial organizations in countries such as New Zealand to small scale, locally organized and artisanal collections in many other countries. In the latter case there are often no established methods of safeguarding the health of consumers.

This publication reflects the technical inputs made to the Kuala Lumpur workshop, associated deliberations at the workshop which may have amended those inputs and the revisions made to those amended inputs at the suggestion of the expert technical reviewers, to whom the editors are extremely grateful. A small number of additional contributions were commissioned after the Kuala Lumpur workshop from experts in additional fields and with varying perspectives to ensure the comprehensive and topical nature of the monograph – and these too were subject to external expert technical review.

This publication aims to provide relevant guidance to the appropriate agencies and stakeholders in the bivalve shellfish industry in an effort to ensure that the risks to health from consumption of shellfish associated with possible sewage contamination are minimized.

We earnestly hope that practitioners in the field will find this topical and exhaustive coverage of the subject of value to them as they strive to ensure that human health is adequately protected. We also hope that this publication will facilitate a new approach to the management of bivalve shellfish and harvest waters so that shellfish consumption is as safe and as risk-free as possible.
The World Health Organization wishes to express its appreciation to all those whose efforts made the production of this monograph possible. An international group of experts met in Kuala Lumpur, Malaysia and from that meeting provided the material for the book and undertook a process of mutual review. While authorship of individual chapters is noted below, the quality of the volume as a whole is due in large part to the review and comments provided by many individuals. Intellectual input and review by the following individuals is gratefully acknowledged:

Giuseppe Arcangeli, Istituto Zooprofilattico Sperimentale delle Venezie, Adria (Ro), Italy.
Nicholas J. Ashbolt, Office of Research and Development, U.S. Environmental Protection Agency, 26 W. Martin Luther King Drive, National Exposure Research Laboratory (MD-564), 45268 – Cincinnati, OH, United States.
David Bruce Conn, School of Mathematical and Natural Sciences, Berry College, Mount Berry, GA, United States.
Enzo Funari, National Institute of Health, Istituto Superiore di Sanita, Rome, Italy.
Frances Lucy, Department of Environmental Science, Institute of Technology, Sligo, Ireland.
Shona H. Magill, Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, Dunbeg, Oban, Scotland.
George Kamizoulis, Senior Scientist, WHO/EURO Project Office Coordinating Unit for the Mediterranean Action Plan, Athens, Greece.
Richard Muirhead, AgResearch, Invermay Agricultural Centre, Private Bag, Mosgiel, New Zealand.
Ronnie Russell, The Moyne Institute of Preventive Medicine, University of Dublin, Trinity College, Dublin, Ireland.
Klaus Schallie, Independent Fishery Professional, Vancouver, Canada.
Jill Stewart, Environmental Sciences and Engineering, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, USA.

The following authors are acknowledged for their major contributions to the chapters of this book:

**Jamie Bartram**, Director, Water Institute, Gillings School of Global Public Health, The University of North Carolina at Chapel Hill, North Carolina, USA.

**Phil Busby**, Senior Programme Manager (Seafood) New Zealand Standards, New Zealand Food Safety Authority, New Zealand.

**Marie-Paul Caprais**, Laboratoire de Microbiologie, EMP, Ifremer, Plouzané, France.

**Martial Catherin e**, Laboratoire National de Référence “Microbiologie des coquillages”, Ifremer, Nantes, France.

**Bill Doré**, Team Leader Shellfish Microbiology, Marine Institute, Rinville, Oranmore, Co. Galway, Ireland.

**Jorge W. Santo Domingo**, U. S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, Ohio, USA.

**Alfred P. Dufour**, US Environmental Protection Agency, National Exposure Research Laboratory, Cincinnati, Ohio, USA.


**Jianguang Fang**, Director of Ecology Department, Yellow Sea Fisheries Research Institute, Qingdao China.

**Michèle Gourmelon**, Laboratoire de Microbiologie, EMP, Ifremer, Plouzané, France.

**Thaddeus K. Graczyk**, Johns Hopkins Center for Water and Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA.

**Soizick Françoise Le Guyader**, Laboratoire de Microbiologie, EMP, Ifremer, Nantes, France.

**Dominique Hervio-Heath**, Laboratoire de Microbiologie, EMP, Ifremer, Plouzané, France.

**Iddya Karasungar**, Senior Fishery Industry Officer, Fish Utilization and Marketing Service, Food and Agriculture Organization, Rome, Italy.

**Indrani Karasungar**, Director, UNESCO-MIRCEN for Marine Biotechnology, Karnataka Veterinary, Animal and Fisheries Sciences Laboratory, College of Fisheries, Mangalore, India.

**David Kay**, Centre for Research into Environment and Health, Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth, Wales, United Kingdom.
Acknowledgements

Pascal Lazure, Dyneco, Ifremer, Plouzané, France.
Ron Lee, Centre for Environment, Fisheries and Aquaculture Science, Weymouth, United Kingdom.
David Lees, Group Manger Food Safety, Centre for Environment, Fisheries and Aquaculture Science, Weymouth, Dorset, United Kingdom.
Hui Liu, Deputy Director of Science and Technology Division, Yellow Sea Fisheries Research Institute, Qingdao China.
Lorna Murray, Local Authority Food Law Enforcement Branch Food Standards Agency Scotland, Aberdeen, Scotland.
Sudari Pawiro, Trade Promotion Division, INFOFISH, Asia and Pacific Region, Kuala Lumpur, Malaysia.
Monique Pommepeuy, Laboratoire de Microbiologie, EMP, Ifremer, Plouzané, France.
Gareth Rees, Director, Robens Centre for Public and Environmental Health, University of Surrey, Guildford, Surrey, United Kingdom.
Gilbert Sauvé, Spécialiste de Programme/Program Specialist, Division du Poissons, des Produits de la Mer et de la Production/Fish, Seafood and Production Division, Agence Canadienne D’inspection des Aliments/Canadian Food Inspection Agency 2954, Québec, QC, Canada.
Jean-Claude Le Saux, Laboratoire de Microbiologie, EMP, Ifremer, Plouzané, France.
Carl Stapleton, Centre for Research into Environment and Health, Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth, Wales, United Kingdom.
Gerard N. Stelma Jr., US Environmental Protection Agency, National Exposure Research Laboratory, Cincinnati, Ohio, USA.
Kumar Suresh, Department of Parasitology, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia.
Mark Wyer, Centre for Research into Environment and Health, Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth, Wales, United Kingdom.
Andrew Younger, Senior Shellfish Hygiene Scientist, Centre for Environment, Fisheries and Aquaculture Science, Weymouth Laboratory, Weymouth, Dorset, United Kingdom.

The studies on molluscan shellfish described in chapter 3 were supported in part by the Maryland Sea Grant College Park, MD, (grant no. R/F-88), The Center for a Livable Future, Johns Hopkins University, Baltimore, MD, (grant no. H040-951-0180), NOAA Chesapeake Bay Office (grant no.
NA04NMF4570426), the NATO Collaborative Linkage Grant (grant no. CLG 979765), and the STRIVE Programme (grant no. 2007-PhD-EH-3).

This publication is dedicated to the memory of Professor Gareth Rees who died on 31 October 2008. Gareth was a committed and highly-respected microbiologist with an international reputation who worked tirelessly to complete this book. Gareth’s larger than life contribution to the field of public and environmental health will be sorely missed.