Life at the Limits
Organisms in extreme environments

We are fascinated by the seemingly impossible places in which organisms can live. There are frogs that can freeze solid, worms that dry out and bacteria that survive temperatures over 100 °C. These organisms have an extreme biology, which involves many aspects of their physiology, ecology and evolution. In this captivating account, the reader is taken on a tour of extreme environments, and shown the remarkable abilities of organisms to survive a range of extreme conditions, such as high and low temperatures and desiccation. This book considers how organisms survive major stresses, and what extreme organisms can tell us about the origin of life and the possibilities of extraterrestrial life.

DAVID WHARTON is a Senior Lecturer in the Department of Zoology at the University of Otago, New Zealand, where his research has centred on the extraordinary survival abilities of animals. His interest in extreme environments has been stimulated by visits to the Antarctic, and by a year spent at the British Antarctic Survey in Cambridge, as a Royal Society Guest Research Fellow. In 1997, his contribution to science was recognised by the award of Doctor of Science, by the University of Bristol.

He is also an expert in the use of light and electron microscopy in natural history filmmaking, and was a principal instigator of the Diploma in Natural History Filmmaking and Communication at the University of Otago, in partnership with Natural History New Zealand.

Life at the Limits

Organisms in extreme environments

DAVID A. WHARTON
Department of Zoology
University of Otago
New Zealand

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011–4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 2002

Printed in the United Kingdom at the University Press, Cambridge

Typeface Trump Mediaeval 9.5/15 pt. *System* QuarkXPress™ [SE]

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

Library of Congress Cataloguing in Publication data

ISBN 0 521 78212 0 hardback

This book is dedicated to my children Rebecca and Simon. May the Earth they inherit not be made more extreme by the actions of humanity.

Contents

Preface

I hope you will excuse me starting by talking about myself but it might help to explain some of my background and how I came to write this book. When I was doing my bachelor's degree in Zoology at the University of Bristol in England, one of my final year projects was on the structure of the eggshell, and the hatching mechanisms of the eggs, of a nematode parasite of cockroaches that rejoices in the splendid name of *Hammerschmidtiella diesingi* (named after a German nematologist, Hammerschmidt). Nematodes are a group of worm-like invertebrate animals. The eggshell turned out to have complex systems of pores and spaces in its outer layers. I stayed on at Bristol to do a PhD that followed up this work and looked at the eggshells of a variety of parasitic nematodes. The nematode eggshell is one of the most resistant of all biological structures. In some cases, it can even survive immersion in concentrated sulphuric acid. The eggshell has a layer of lipid, which restricts the exchange of materials between the egg and its environment. The eggs lose water very slowly when exposed to desiccation, enabling the larvae enclosed within them to survive the total loss of water from the egg. The pores in the eggshell of *H. diesingi* are involved in this process.

The free-living stages of some parasitic nematodes (those developing after the hatching of the egg), and of some free-living nematodes, show extraordinary abilities to survive extreme environmental stresses. They will tolerate freezing, complete desiccation and exposure to chemicals that are fatal to most other organisms (such as the fixatives used to kill and stabilise specimens for microscopy). Most of my career has been involved in trying to determine the mechanisms by which nematodes survive these extreme insults. I have gradually transformed from being a parasitologist (who studies the biology of

parasites) into an environmental physiologist (who studies the interactions between organisms and their environment). When I moved to New Zealand in 1985, I had the opportunity to visit the Antarctic. The organisms that live in the rare terrestrial Antarctic sites that will support life are living in one of the most extreme environments on Earth. Experiencing such conditions myself stimulated my interest in extreme life even more.

Nematodes, of course, are not the only organisms that are able to survive in extreme environments. Since about the 1960s, we have become aware that a variety of microorganisms can flourish in all sorts of extreme conditions and that life is possible where it was previously thought to be impossible. This has broadened our understanding of the nature of life on Earth and the possibility of life elsewhere in the universe. In this book, I attempt to cover all types of organisms (animals, plants and microbes), the different types of extreme environments and the different aspects of their biology in these environments. I will also try to develop a framework for deciding what is extreme for life and for thinking about the biology of extreme organisms. This has been a large task – I will leave it to you to decide how well I have succeeded! Most people who have written about organisms in extreme environments are microbiologists or biochemists. As a zoologist, I am perhaps aware of a wider (or at least a different) range of organisms and approaches. I thus hope to bring a different perspective to the subject.

The book is written to be understandable by a non-expert (and hopefully even those with little background in biology or science). I have tried to explain things as I've gone along, but there is also a glossary to clarify unfamiliar terms. In order to keep the readability of the text, I have not formally cited references to original research papers. Instead, I have tried to include in the bibliography those that will enable the source of original research to be found and also mention in the text some of the major workers in the relevant areas. If any of my scientific colleagues feel that their work should have been directly cited, and was not, my apologies to them.

I would like to thank especially my wife Ann who, apart from supporting me during the writing of the book, read every chapter and, since she is not a scientist, helped me to make it more readable and understandable. Thanks also to my (now ex-) research student, Brent Sinclair, who also read every chapter and who was not shy about making suggestions for improvements. I would also like to thank those who read and commented on individual chapters and/or the book proposal: Carolyn Burns, Colin Townsend, Dev Nyogi, Bill Block, Don Gaff, Hans Ramløv, Craig Cary, Rick Lee and Graham Young. It was John Montgomery, of the University of Auckland, who started me thinking about resistance and capacity adaptations in relation to extreme environments. Jo Ogier has produced some wonderful illustrations and Ken Miller and Matthew Downes assisted me with those I prepared myself. Don Gaff and Craig Cary kindly supplied me with copies of their illustrations. The sources of material for illustrations, and relevant permissions, are acknowledged in the figure legends, where appropriate. Finally, I would like to thank my editors at Cambridge University Press, Alice Houston and Simon Mitton (and their team), for guiding me through the process of producing this book.

David A. Wharton
Dunedin
New Zealand