Freshwater Biodiversity

Growing human populations and higher demands for water impose increasing impacts and stresses upon freshwater biodiversity. Their combined effects have made freshwater animals more endangered than their terrestrial or marine counterparts. Overuse and contamination of water, overexploitation and overfishing, introduction of alien species, and alteration of natural flow regimes have led to a 'great thinning' and declines in abundance of freshwater animals, a 'great shrinking' in body size with reductions in large species, and a 'great mixing' whereby the spread of introduced species has tended to homogenize previously dissimilar communities in different parts of the world. Climate change and warming temperatures will alter global water availability and exacerbate the other threat factors. What conservation action is needed to halt or reverse these trends, and preserve freshwater biodiversity in a rapidly changing world? This book offers the tools and approaches that can be deployed to help conserve freshwater biodiversity.

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ECOLOGY, BIODIVERSITY AND CONSERVATION

The world's biological diversity faces unprecedented threats. The urgent challenge facing the concerned biologist is to understand ecological processes well enough to maintain their functioning in the face of the pressures resulting from human population growth. Those concerned with the conservation of biodiversity and with restoration also need to be acquainted with the political, social, historical, economic and legal frameworks within which ecological and conservation practice must be developed. The new Ecology, Biodiversity, and Conservation series will present balanced, comprehensive, up-to-date, and critical reviews of selected topics within the sciences of ecology and conservation biology, both botanical and zoological, and both 'pure' and 'applied'. It is aimed at advanced final-year undergraduates, graduate students, researchers, and university teachers, as well as ecologists and conservationists in industry, government and the voluntary sectors. The series encompasses a wide range of approaches and scales (spatial, temporal, and taxonomic), including quantitative, theoretical, population, community, ecosystem, landscape, historical, experimental, behavioural and evolutionary studies. The emphasis is on science related to the real world of plants and animals rather than on purely theoretical abstractions and mathematical models. Books in this series will, wherever possible , consider issues from a broad perspective. Some books will challenge existing paradigms and present new ecological concepts, empirical or theoretical models, and testable hypotheses. Other books will explore new approaches and present syntheses on topics of ecological importance.

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Freshwater Biodiversity

Status, Threats and Conservation

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I cannot but remember such things were, That were most precious to me. Did heaven look on, And would not take their part?

(William Shakespeare (1606), *Macbeth*

. . . it is essential to recognize the probable result of what we have done and are doing, but when we have seen that . . . the menaced world may seem to be more treasured than ever. Certainly, the anguish we feel at the threat to it and the sleepless despoiling of it can lose their tragic complexity and become mere bitterness when we forget that their origin is a passion for the momentary countenance of the unrepeatable world.

W.S. Merwin (1993; p. 5), *The Second Four Books of Poems*

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Foreword

Why is a book on freshwater biodiversity conservation necessary? Less than 3% of the Earth's water is fresh, and most of it is frozen as ice or is inaccessible underground. A mere 0.3% of global fresh water is available as habitat for plants and animals, and much of it constitutes the only water that is readily accessible to meet human needs. Since human use reduces the amount of water in rivers, lakes and wetlands, or degrades its quality, or both, growing human populations and higher demands for water impose increasing impacts and stresses upon freshwater biodiversity. One reason this matters is that a significant proportion of global biodiversity is confined to fresh water. As a rough approximation, in terms of round numbers, these environments cover no more than 1% of the Earth's surface, but host almost 10% of all non-microbial species described by scientists. The fact that fresh waters are disproportionately rich in biodiversity, relative to their small global area, is inescapable. When it is viewed in the context of the many threats human activities pose to the integrity of freshwater bodies, and the knowledge that humans already appropriate more than half of global surface runoff, the prognosis for species loss is grim. In essence, freshwater biodiversity is imperilled due to its dependence on a resource subject to unprecedented and ever-increasing human demands. Neither the terrestrial nor the marine realm combines such richness of biodiversity with the magnitude and intensity of anthropogenic threat, and, as this book will show, the rates of population decline and endangerment of freshwater species are both high and far greater than their counterparts on land or in the oceans. The endemic and monotypic Yangtze River dolphin (*Lipotes vexillifer*: Lipotidae), which became the first cetacean to be driven to extinction by humans (Turvey *et al.*, 2007), was not only emblematic of a failure to conserve charismatic freshwater megafauna, but also indicative of the conservation challenges posed by the transformation and degradation of inland waters. If we accept that species persistence is a reasonable criterion for measuring sustainability (defined, broadly, as meeting the needs of

the present without compromising future needs), then the loss of this dolphin not only curtails 20 million years of evolution, but also is clear evidence that human activities are unsustainable from the perspective of preserving freshwater biodiversity.

Why are such species losses taking place? Conservation of freshwater biodiversity is difficult because anthropogenic pressures on fresh waters are already intense and, as human populations continue to grow, clean fresh water will become an ever-more scarce resource. Pollution and habitat modification will also progressively reduce the suitability of fresh waters for aquatic plants and animals. Moreover, since freshwater bodies are downhill from – and embedded within – terrestrial landscapes, conservation efforts require large-scale management of entire drainage basins rather than just the particular localities where imperilled species occur. This is nothing if not challenging: for instance, the basin of the Yangtze and its now-extinct river dolphin is inhabited by more than 400 million people.

To make matters worse, ongoing reductions in the quality and quantity of water available to sustain freshwater ecosystems will interact with global climate change, which, itself, will have consequences for the patterns of evaporation, transpiration and rainfall, and hence the flow and inundation cycles in rivers, lakes and wetlands. Many places in a warmer world will experience a greater frequency of floods and droughts, as well as hastened glacial melting. Subsequent shifts in hydrological regimes, and human responses to them (such as dams built for water storage and flood control), will greatly alter conditions in freshwater ecosystems. Furthermore, there is a very real possibility that the ranges of cold-blooded (ectothermic) animals will have to shift upward in latitude or altitude to compensate for warming. That will be especially problematic for freshwater species. Many cannot disperse overland or along the coast to potentially habitable, cooler water bodies and, hence, will be 'stranded' in conditions of ever-decreasing suitability.

The synergistic interactions of global climate change with other human-induced threats or stressors will be profound, with the potential to change the rules of existence for freshwater biota. If current trajectories of threat and endangerment continue, they will engender losses of many freshwater species, representing a significant component of what is being recognized as an ongoing, sixth mass extinction event in the Earth's geological history. To put this another way, human transformation of the Earth system and the global water system may well give rise to the first mass extinction event of the Anthropocene (*sensu* Zalasiewicz

et al., 2011). This term was first coined by Nobel Prize winner Paul Crutzen to mark the current epoch and thereby draw attention to the pervasive role of humans in the geology and ecology of the Earth system (Crutzen, 2002).

Freshwater Biodiversity: Status, Threats and Conservation will highlight, explain and account for the present situation with regard to freshwater ecosystems and their biota, and will indicate how the worst effects of anthropogenic impacts might be mitigated or reduced. The message is urgent: there are limited opportunities to protect much of what remains of global freshwater biodiversity. Education and enhanced awareness of the threats and possible solutions to them will be an essential prerequisite for conservation action. However, the general nature of these threats is known, and they are manifest in all non-polar regions of the Earth, although their relative magnitude varies significantly from place to place. But identifying threats has resulted in little action to mitigate or alleviate them. The transfer of knowledge to conservation action has been largely unsuccessful. This failure is related to the special features of freshwater ecosystems – and the biodiversity they support – that makes them especially vulnerable to human activities. There are many instances where humans have caused rapid and significant declines in freshwater species and habitats. These represent opportunity costs that are magnified by losses in the option values of species or reductions in the provision of ecological services that may well be irreversible. The link between freshwater biodiversity and the provision of ecosystem services that underpins human livelihoods will be discussed in some detail herein, as it provides an important justification for conservation. Nonetheless, if conservation action is to be effective, it will require implementation of different components of a variety of management options, as described in Chapter 9. There, I will also highlight the need for a major change in attitude towards freshwater biodiversity and ecosystem management. Bringing about that shift would do much to remove the greatest obstacle to effective conservation.

There have been many books written about the ever-expanding list of dead and dying species. They may have the effect of lessening the abhorrence with which we view extinction, if repetition begins to trivialize these events. But there is a justification for such tomes. If human carelessness or stupidity results in the loss of a species, its evolution will stop, its unique genotype is obliterated, and its name will have no more significance to the next generation than any of the other plants and animals that became extinct long ago – through natural processes.

Forgetting is a luxury we cannot afford: telling and retelling can be seen as a moral imperative. And we must hope that our writings will 'stimulate a unity of compassion' (Schaller, 1993: p. xvi) and promote action to preserve species. This, it seems to me, is a responsibility we must fulfil, because the opportunity to do so exists now; it will diminish the longer that we delay.

This book is an entirely original text representing many years of work, but some ideas and examples have been reworked from some of my earlier publications (e.g. Dudgeon, 2011, 2013, 2014). Threat status, as used herein, follows the IUCN Red List (www.iucnredlist.org). Critically endangered, endangered, vulnerable and near-threatened species are denoted CR, EN, VU or NT – as appropriate – upon first mention, whereupon the scientific binomial name, family designation and, in the case of vertebrates and some plants, the common English name are given also. After stating the scientific name, I have preferentially used the common name where one exists – hence North American beaver rather than *Castor canadensis*. Inevitably, a book on freshwater biodiversity makes frequent mention of fishes, and I have derived biometric data (size and weight) for particular species from FishBase (Froese & Pauly, 2018: www.fishbase.org), which also served as a guide for nomenclature.

The literature on freshwater ecology and conservation is vast, and I have focused mainly on sources post-dating 2005, encompassing the period after publication of the review by Dudgeon *et al.* (2006), in which this book has its (distant) origins, until the end of August 2018 (including some papers in press at that time). Nonetheless, I have referred to earlier key sources where they provide information that has yet to be superseded, or present particularly informative case studies. This timeframe has meant that certain very recent publications have been omitted, including the report setting out the Intergovernmental Panel on Climate Change (IPCC)'s advice that global carbon-neutrality is needed by 2050 to keep the average temperature increase of the Earth to 1.5°C (IPCC, 2018). This document has, understandably, received wide publicity in the public domain and is readily available from online sources (e.g. www.ipcc.ch/sr15/chapter/summary-for-policy-makers/), because it makes a compelling case that both the speed of global warming and the seriousness of its consequences have been underestimated by scientists. Readers are warned that the changes projected in Chapter 7 will inevitably require updating in the light of new information and research findings. The August 2018 cutoff date has meant that some recent work, such as the review by Reid *et al.* (2019) intended as an update to Dudgeon *et al.*

(2006), has been omitted, although contributions I made to that article (e.g. Fig. 2.1 and some topics – e.g. dam removal and environmental DNA – covered in Chapter 9) have been included. It has not been possible to explore the implications of a planned clean up of the Yangtze announced by the Chinese Government in January 2019, nor the intention to introduce a 10-year ban on fishing in the river, although both initiatives are laudable.

Wherever possible, I have drawn examples from places outside the relatively well researched north-temperate zone, although that region has certainly not been neglected. I cannot claim to offer a comprehensive survey of all of the relevant literature – that would necessitate a much longer and rather different book. Chapter 4, which deals with non-native or alien species, is something of an exception in that regard, because I wanted to illustrate the variety of freshwater species that have become established beyond their native ranges, and so draw attention to the 'great mixing' of biotas that has become such a distinctive signature of the Anthropocene.

The gestation of this book has been lengthy. I am grateful to Cambridge University Press for their patience during this period, and to Professor Michael Usher (Stirling University) for judicious application of pointed sticks that ensured the work progressed (albeit slowly). Dominic Lewis, Aleksandra Serocka, Samuel Fearnly, Orvil Matthews and Penny Lyons were collectively responsible for transforming my original manuscript into a published volume. I am also grateful to my colleagues in the Research Division of Ecology and Biodiversity at the University of Hong Kong, especially Billy Hau, Kenny Leung, Gray Williams and Yvonne Sadovy, for their collegiality and encouragement, and to Lily Ng for day-to-day logistical assistance and research support. Zeb Hogan and Yik-Hei Sung were kind enough to allow me to use their photographs, while Steve Ormerod provided helpful email insights into environmental optimism. I also thank my students for their patience and willingness to listen while I tried out some of the ideas and examples included in this volume. Finally, the book would not have been possible without the inspiration, care and kindness of Amanda Whitfort; it is dedicated to her and our daughter Lucinda.

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