Biodiversity

Springer Science+Business Media, LLC

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Biodiversity
An Ecological Perspective

With 75 figures

Springer

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Cover: Biomass size spectra for oceans and lakes. See page 205. From Verh. int Ver. Limnol. 23:234–240, used by permission of E. Schweizerbart'sche Verlagsbuchhandlung.

Library of Congress Cataloging-in-Publication Data
Biodiversity: an ecological perspective / [edited by] Takuya Abe, Simon A. Levin, Masahiko Higashi.
p. cm.
Papers from a conference held in Kyoto in December 1993.
Includes bibliographical references and index.
ISBN 978-1-4612-7334-9 ISBN 978-1-4612-1906-4 (eBook)
DOI 10.1007/978-1-4612-1906-4
1. Biological diversity—Congresses. 2. Biotic communities—Congresses. I. Abe, Takuya, 1945– II. Levin, Simon A. III. Higashi, M. (Masahiko)
QH541.15.B56B56 1996
574.5—dc20 96-13589

Printed on acid-free paper.

Production coordinated by Carlson Co. and managed by Francine McNeill; manufacturing supervised by Jeffrey Taub.
Typeset by Carlson Co., Yellow Springs, OH, from the authors' electronic files.

9 8 7 6 5 4 3 2 1

ISBN 978-1-4612-7334-9

Preface

Biodiversity is and will remain an issue of pressing global concern. The more we know about how changes in biodiversity might affect ecosystem processes, community structure, and population dynamics, the more clearly we understand why and what kind of biodiversity we should conserve. Reciprocally, the more we know about how ecological processes and mechanisms affect the creation and maintenance of biodiversity, the more clearly we understand how we can conserve and even recover biodiversity. Thus, basic understanding of the ecological causes and consequences of changes in biodiversity provides a critical perspective on the applied challenges.

The main purpose of the volume is to present an ecological perspective on biodiversity by examining its two facets, the ecological causes and consequences of biodiversity changes. The book extends its scope to cover the linkage between science and management issues, again from an ecological perspective.

This volume commemorates the awarding of the 1993 International Prize for Biology to Professor Edward O. Wilson. He provides the introductory chapter for the volume and the focus for the other presentations. We hope this volume leads to a new stage of biodiversity research, which Ed Wilson pioneered, and will serve as a suitable tribute to him.

T. ABE, S.A. LEVIN, AND M. HIGASHI

Acknowledgments

This book grew from an international symposium entitled "Ecological Perspective of Biodiversity," held in December 1993 at Kyoto. It was sponsored by the Japan Society for the Promotion of Science and the Japan Ministry of Education, Science, and Culture, whose generous support made possible the symposium on which this volume is based. We would like to thank the organizing committee (chaired by Professor Hiroya Kawanabe) for providing a wonderful opportunity to discuss this issue of compelling current importance. All chapters in this volume have been peer reviewed and reflect a sampling of what was presented at the meeting. We would like to extend our gratitude to the anonymous reviewers for their help and cooperation. Last, but not least, is the debt we owe to our wives and families for their understanding and support.

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Introduction

EDWARD O. WILSON

From the time of Aristotle, biodiversity has been regarded as a central quality of life. Yet only recently has it been made the subject of scientific specialization in its own right, to be measured and evaluated with abstract theory and experimentation. In 1959, G. E. Hutchinson contributed importantly to this end with his now-famous article, "Homage to Santa Rosalia, or Why are there so many kinds of animals?" In the 1960s, the development of the theory of island biogeography offered partial answers to the question posed in the title of Hutchinson's article through the use of models to characterize equilibria of immigration, evolution, and extinction (MacArthur and Wilson 1967). With this work, it became clear that the fundamental properties of biological diversity can be clarified only by judicious and exacting studies that combine systematics and ecology.

After a relatively leisurely beginning, the subject was propelled to widespread scientific and public attention by events occurring during the 1980s. One of the most important was the estimate made by Norman Myers of the rate of tropical deforestation. Adding data country by country, he calculated the global loss of cover during the 1970s to be about 1% per year (Myers 1980). This bit of bad news was especially alarming to conservationists, because the rain forests were (and remain) the premier reservoirs of diversity. They teem with more species of plants and animals than all the other biomes of the world combined, although occupying only a very small part of the world's land surface—7% at the time of Myers' report and 6% now (Wilson 1992). Their area was thus about the same as that of the contiguous 48 states of the United States, and the average amount of cover removed each year in the 1970s was roughly equal to half the area of Florida. The reduction in area translated, in terms of the general area–species relations worked out in oceanic islands and other circumscribed ecosystems, to approximately 0.25% of species extinguished immediately or committed to relatively early extinction each year. The cutting and burning appeared to be accelerating, primarily because of the incursions by land-hungry rural populations and the increasing global demand for timber products.

About this time a "new environmentalism" was emerging in major environmentalist organizations, which included especially the World Wildlife Fund, the International Union for Conservation of Nature and Natural Resources, and the United Nations Environmental Programme. Their staffs set out to shift the institutional focus to place more emphasis on entire ecosystems and proportionately less on "star" species such as the panda and tiger. They also took a more pragmatic approach by combining conservation projects with economic advice and assistance to local human populations most affected by the salvage of biological diversity. By the mid-1980s, conservationists everywhere had come to accept two key principles of the new environmentalism: first, that reserves cannot be protected indefinitely from impoverished people who see no advantage in them, and second, and conversely, the long-term economic prospects of these same people will be imperiled to the extent that the surrounding natural environment is destroyed.

The novelty of the new environmentalism as a credo is indicated by the recency of its talisman, "biodiversity." The word, shorthand for biological diversity, did not exist until the National Forum on BioDiversity was held in Washington, D.C., September 21–24, 1986, under the auspices of the National Academy of Sciences and the Smithsonian Institution. The Forum proceedings, published as the book *BioDiversity* (Wilson and Peter 1988), comprised contributions from more than 60 scholars and officials whose expertise ranged from ecology to economics and government. It was distributed widely around the world, becoming an early vade mecum and textbook of biodiversity management.

In June 1992, when more than a hundred heads of state met at the Earth Summit in Rio de Janeiro to debate and ratify protocols on the global environment, biodiversity had approached the status of a household word. It also became well established as a favorite subject of museum exhibitions and college seminars. President Bush's refusal to sign the Convention on Biodiversity at the Earth Summit brought the subject into the mainstream of politics; controversies surrounding the Endangered Species Act and the northern spotted owl then confirmed it as a part of Americana.

Science, like art, follows patronage. Biologists, alerted to biodiversity as a subject important in both science and public policy, turned to its study in growing numbers. Subscriptions to *Conservation Biology* soared, and a new journal, *Biodiversity and Conservation,* was created. By the early 1990s articles on extinction and other aspects of biodiversity had become commonplace in *Nature, Science,* and other journals that reach a large scientific audience. Much of the writing moved back and forth across the boundaries of biology, the physical sciences, economics, and forestry. The research on which it was based formed the new discipline of biodiversity studies, defined as the systematic analysis of hereditary variation at all levels of biological organization, from genes within populations to species to ecosystems, together with the development of technologies to conserve and manage the diversity for the benefit of humanity (Ehrlich and Wilson 1991).

Sound reasons existed for the rising interest in the practical side of biodiversity studies. The loss of species is wholly distinct from toxic pollution, ozone depletion, climatic warming, and other changes in the physical environment. Unlike these secular trends, *extinction cannot be reversed,* nor can lost species be replaced by new ones created through evolution in any amount of time that has meaning for the human mind. The average life span of a species and its immediate descendants ranges, according to group (such as Tertiary African mammals or Mesozoic ammonites), from half a million to 10 million years (Raup 1984; reviewed by Wilson 1992). Hence the average extinction rate outside major extinction spasms is 10^{-5} to 10^{-7} species per year, orders of magnitude less than that now imposed by human action. For a species to diverge from its sister species sufficiently for the two taxa to be placed by systematists in different genera or families has usually required hundreds of thousands to millions of years. It will continue to do so in the future—providing, in the first place, that the new forms have access to environments large enough and stable enough for sustained existence.

During the 1970s and 1980s, while paleontologists were placing natural extinction within a reliable time scale, biologists and others expanded our understanding of the multiple practical benefits of biodiversity. It was already widely appreciated that agriculture and medicine draw heavily on domesticated organisms that have been derived ultimately from wild species. What became clear from the new research was the enormous potential remaining in the millions of still-unexamined species. The scientists argued that new pharmaceuticals, crops, fiber sources, petroleum substitutes, and other products await discovery and development. And in case it is not practicable to use entire particular species, genes might be taken from the organisms and inserted into already existing domesticated species to enhance favorable traits. In Thomas Eisner's metaphor, we need not employ the whole book, but can instead pull pages from one loose-leaf folder to add to another (Eisner 1985).

Biodiversity studies also contain problems that are of the first intellectual rank in science. We do not know, to mention one important topic, the number of species on Earth even to the nearest order of magnitude. That number is certainly greater than 1 million and less than a billion, but whether it is closer to 10 million or to 100 million cannot be calculated from existing data. The former figure may seem the more reasonable, at least the more prudent, even if we take into account the millions of undescribed insect species inhabiting tropical forests. But what, then, of the legions of symbionts living on the insects? Many of these minute organisms, including nematodes, yeasts, and bacteria, are associated with only one or a very few host species. And what of the myriad of bacterial species, mostly unstudied, that saturate the living world? In a gram of typical soil or aqueous silt live 10 billion individuals, representing as many as 5,000 species, almost none of which is known to science. In general, we know more about the stars in the sky than we do about the organisms at our feet.

Still, it would be a mistake to regard a mere censusing of Earth's species to be the central goal of biodiversity studies. What is needed far more urgently in the immediate future is the thorough biogeographic study of focal groups, such as birds and flowering plants, that are already well enough studied to allow rapid identification of specimens. They are our best entrée to the general patterns of diversity and abundance. Precisely what fraction of species in these proxy groups live, for example, in tropical African rain forests? Or in the dry grasslands of temperate South America? A heartening recent advance has been made by the International Council of Bird Preservation, which assembled the massive data on land birds to pinpoint localities around the world with the highest levels of diversity and endemicity (Bibby et al. 1992). The authors were able to show that the biotically richest 2% of the land surface, if set aside in reserves, would hold 20% of the known land bird species.

Their assessment of such "hot spots" is an important step forward in global conservation planning, but it is only a beginning. As shown by the recent analysis of British data, different groups such as birds, dragonflies, and flowering plants may show discordant patterns (Prendergast et al. 1993). It is therefore important to promote a spreading of systematics research to increase the list of focal groups so as to cultivate comparative biogeography.

Systematics and biogeographic mapping can be enormously enhanced by computer-based information technology. Data on the distribution of species are stored on Geographic Information System (GIS) software, then collated with maps of topography, climate, soil types, vegetation, and other environmental features. Repeated over months and years, the GIS analyses can identify the causes of success and failure of individual species.

Taxonomists will be able to update systematics monographs more easily with entries of new species and changing digitized maps and drawings in CD-ROMs. Integrated into Geographic Information Systems, such data can provide the growing empirical base for the more fundamental biological studies of diversity. The preferred point of entry in each analysis depends on evidence from field or laboratory studies of factors that determine the abundance of the species under study. If, for example, the correlative analysis of GIS data indicates that species in a moss genus fluctuate in densities in close concert with summer rainfall, then humidity and the timing of reproductive cycles are the appropriate focus for further study. If a genus of epiphytes varies in diversity in a pattern close to that of halictid bees, then the specialist can profitably search for oligolectic species among the bees and study their behavior. If certain gesneriads seem to flourish and diversify around ant nests, he may wish to consider symbiosis. And so on through hundreds or thousands of the species, genera, and higher taxa that compose ecosystems.

Most of what today is called ecology is actually a refined version of natural history. That is all to the good, because an intellectually solid ecology can never be built solely from theoretical models, even if faithfully congruent to the biology of a few well-selected species. Even less likely to succeed is the theoretician's abstract view of the wild environment. Ecology as a science will work only if constructed from the bottom up, by piecing together the idiosyncrasies of thousands of species, each lovingly examined for its own sake. Through the contrivance of population models to fit particular species, then guilds and biocoenoses, the true larger patterns and grander trends will emerge. If general laws of ecology exist, they are most likely to be written in the equations of demography shaped to address the issues of biodiversity.

In the interim, large-scale experiments are being effectively performed on entire communities, or sectors of them, to answer some of the most important questions of community ecology. For example, it has been possible to create new habitats or sterilize old ones to test the theory of diversity equilibrium. Watersheds have been deforested to determine the effects of the perturbation on nutrient cycles. And most recently, as reported by John Lawton and his associates in this volume (Chapter 12), diversity can be varied in climate-controlled microcosms to measure the effect of the numbers and composition of species on productivity. But even these successful endeavors still require identification of the elements of the fauna and flora. They can be most effectively extended by close studies of the physiology and demography of the constituent species, pieced together to depict the dynamism of ecosystems. Ultimately, all ecological research must be from the bottom up.

The contributions of the authors of the 1993 Kyoto symposium illustrate very well the scientific "mainstreaming" of natural history under the influence of the new emphasis on biodiversity. The convergence of the specialists was enhanced by a new sense of common purpose, to assemble concepts that unite the disciplines of systematics and ecology and, in so doing, to create a sound scientific basis for the future management of biodiversity.

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