Stable Isotopes in Ecological Research

With 164 Illustrations

Springer-Verlag
New York Berlin Heidelberg
London Paris Tokyo
In past years, ecologists and environmental biologists have largely equated the word “isotopes” with short-lived radioactive isotopes useful in tracer studies. However, virtually all of the elements of biological importance occur naturally with two or more stable isotopes. There are two stable isotopes of hydrogen, \(^{1}\)H and D or deuterium. Similarly, there are two stable isotopes of carbon, two of nitrogen, three of oxygen, and four of sulfur. These stable isotopes, which vary in their ratios of natural abundance, offer tremendous potentials for new approaches to research on a wide range of ecological processes.

Natural differences in the stable isotope composition of biological and abiotic compounds of ecological interest result from differences in a variety of predictable factors which influence fractionation. These include source effects, diffusional constraints, enzyme selectivity, and/or interactions between compounds. Stable isotope investigations can thus provide new insights into flux rates among organisms, between organisms and their abiotic environment, and between compartments of the abiotic environment.

Much of the early research on stable isotope ratios in biological tissues came from the geological sciences. This work was a logical outgrowth of pioneering applications of stable isotope analyses to research in geochemistry, sedimentology, and oceanography. Applications of stable isotope analyses in environmental biology were slow to develop, largely due to a combination of ignorance in the field and the difficulty of access to isotope ratio mass spectrometers. Until recently, applications of stable isotope ratios to ecological research were largely in the novelty or descriptive stage. In the last few years, however, in-
novative applications of stable isotope ratios to physiological and process-level studies have been expanding rapidly. This increased pace of research has resulted from improved access by biologists to the necessary instrumentation, and reduced costs of analyses. As a result, there is every indication that stable isotope approaches to ecological research will become increasingly common and will lead to significant new levels of understanding of physiological processes and elemental fluxes through biological and abiotic systems.

Our objective in this volume has been to provide both general background information and illustrative case studies to demonstrate how differences in stable isotope composition can be used as powerful tools for measuring integrated physiological responses and elemental fluxes through both abiotic and biotic compartments of natural ecosystems. Following an introductory chapter of background material on the history, units, and instrumentation used in stable isotope research, we have divided our book into three parts. The first of these deals with ecophysiological studies in plants, focusing on approaches to utilizing isotopes of carbon, hydrogen, and oxygen in research on physiological processes in plants.

In the second section on animal food webs and feeding ecology, seven chapters describe ways in which stable isotope ratios can be used to study food web dynamics. These contributions add to our understanding of the principles that "we are what we eat, plus or minus a few parts per million" as originally demonstrated by Michael DeNiro and Samuel Epstein. Our focus in this section is on natural food chains, with only a single chapter on human diet analysis. Anthropologists and archaeologists, nevertheless, should find this section, as well as other parts of the volume, highly relevant to the rapidly expanding interest in stable isotope approaches to their fields.

The final section of eleven chapters broadly treats ecosystem process studies utilizing stable isotope ratios. Aspects of pedogenic processes, nitrogen fixation, paleoclimate, atmospheric fluxes of gases and particulates, and pollutant transfers are all included. While these chapters only highlight the range of potential applications of stable isotope ratios to investigations of ecosystem-level fluxes, they should provide a good appreciation of the scope of the promise that such applications offer to researchers.

Stable Isotopes in Ecological Research is an outgrowth of a workshop on this subject held at the Lake Arrowhead Conference of the University of California, Los Angeles, in April 1986. We are indebted to Drs. Helen McCammon and Janet Dorigan of the Ecological Research Division of the Office of Health and Environmental Research, U.S. Department of Energy, for sponsoring this workshop. Cosponsorship was provided by the National Center for Intermedia Transport Research at UCLA.

P.W. Rundel
J.R. Ehleringer
K.A. Nagy
Contents

Preface v
Contributors xi

1. Stable Isotopes: History, Units, and Instrumentation 1
   J.R. Ehleringer and P.W. Rundel

Section I Ecophysiological Studies in Plants 17

2. Carbon Isotope Fractionation and Plant Water-Use Efficiency 21
   G.D. Farquhar, K.T. Hubick, A.G. Condon, and
   R.A. Richards

3. Carbon Isotope Ratios and Physiological Processes 41
   in Aridland Plants
   J.R. Ehleringer

4. Stable Carbon Isotope Ratio as an Index of Water-Use 55
   Efficiency in C3 Halophytes—Possible Relationship to Strategies
   for Osmotic Adjustment
   R.D. Guy, P.G. Warne, and D.M. Reid
5. Stable Carbon Isotopes in Vernal Pool Aquatics of Differing Photosynthetic Pathways
   J.E. Keeley

6. Studies of Mechanisms Affecting the Fractionation of Carbon Isotopes in Photosynthesis
   J.A. Berry

7. Intertree Variability of $\delta^{13}C$ in Tree Rings
   S.W. Leavitt and A. Long

8. Hydrogen Isotope Fractionation in Plant Tissues
   H. Ziegler

9. Oxygen and Hydrogen Isotope Ratios in Plant Cellulose: Mechanisms and Applications
   L. da Silveira Lobo Sternberg

10. Stable Hydrogen Isotope Ratios in Plants: A Review of Current Theory and Some Potential Applications
    J.W.C. White

Section II Animal Food Webs and Feeding Ecology

11. Stable Carbon Isotopes in Terrestrial Ecosystem Research
    L.L. Tieszen and T.W. Boutton

12. $\delta^{13}C$ Measurements as Indicators of Carbon Flow in Marine and Freshwater Ecosystems
    B. Fry and E.B. Sherr

13. Natural Carbon Isotope Tracers in Arctic Aquatic Food Webs
    D.M. Schell and P.J. Ziemann

14. Some Problems and Potentials of Strontium Isotope Analysis for Human and Animal Ecology
    J.E. Ericson

15. Natural Isotope Abundances in Bowhead Whale (Balaena mysticetus) Baleen: Markers of Aging and Habitat Usage
    D.M. Schell, S.M. Saupe, and N. Haubenstock

    K.A. Nagy
17. A δ¹³C and δ¹⁵N Tracer Study of Nutrition in Aquaculture: *Penaeus vanamei* in a Pond Growout System
   P.L. Parker, R.K. Anderson, and A. Lawrence

82

Section III Ecosystem Process Studies

18. Stable Isotope Ratios and the Dynamics of Caliche in Desert Soils
   W.H. Schlesinger, G.M. Marion, and P.J. Fonteyn

95

19. The Use of Stable Isotopes in Assessing the Effect of Agriculture on Arid and Semi-Arid Soils
   R. Amundson

105

20. Estimates of N₂ Fixation in Ecosystems: The Need for and Basis of the ¹⁵N Natural Abundance Method
   G. Shearer and D.H. Kohl

124

21. The Use of Variation in the Natural Abundance of ¹⁵N to Assess Symbiotic Nitrogen Fixation by Woody Plants
   R.A. Virginia, W.M. Jarrell, P.W. Rundel, G. Shearer, and D.H. Kohl

142

22. ¹³C/¹²C Ratios in Atmospheric Methane and Some of Its Sources
   S.C. Tyler

167

23. Temperature-Dependent Hydrogen Isotope Fractionation in Cyanobacterial Sheaths: Applications to Studies of Modern and Precambrian Stromatolites
   G.E. Strathearn

196

24. Sulfur Isotope Studies of the Pedosphere and Biosphere
   H.R. Krouse

230

25. Sulfate Fertilization and Changes in Stable Sulfur Isotopic Compositions of Lake Sediments
   B. Fry

252

26. The Use of Stable Sulfur and Nitrogen Isotopes in Studies of Plant Responses to Air Pollution
   W.E. Winner, V.S. Berg, and P.J. Langston-Unkefer

260

27. The Use of Stable Sulfur Isotope Ratios in Air Pollution Studies: An Ecosystem Approach in South Florida
   L.L. Jackson and L.P. Gough

270
28. $^{87}\text{Sr}/^{86}\text{Sr}$ Ratios Measure the Sources and Flow of Strontium in Terrestrial Ecosystems
   W.C. Graustein

Index