

Jonathan Adams

VEGETATION–CLIMATE INTERACTION

How Plants Make
the Global Environment

Second Edition

Jonathan Adams

Vegetation–Climate Interaction

How Plants Make the Global Environment

(Second Edition)



 **Springer**

Published in association with
Praxis Publishing
Chichester, UK

 **PRAXIS**

Dr Jonathan Adams
Assistant Professor in Biological Sciences
Seoul National University
Gwanak-Ro
Seoul
Republic of Korea

SPRINGER-PRAXIS BOOKS IN ENVIRONMENTAL SCIENCES
SUBJECT *ADVISORY EDITOR*: John Mason, M.B.E., B.Sc., M.Sc., Ph.D.

ISBN 978-3-642-00880-1 Springer Berlin Heidelberg New York

Springer is part of Springer-Science + Business Media (springer.com)

Library of Congress Control Number: 2009933599

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

© Praxis Publishing Ltd, Chichester, UK
Second Edition published 2010
First Edition published 2007
Reprinted in 2008 twice

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: Jim Wilkie
Project management: OPS Ltd, Gt Yarmouth, Norfolk, UK

Printed in Germany on acid-free paper

Vegetation–Climate Interaction

How Plants Make the Global Environment

(Second Edition)

Preface to the Second Edition

In the two years since the First Edition of this book, the study of climate and vegetation has continued to advance rapidly, with many new and interesting things to write about. I have also been able to benefit from the comments and suggestions of colleagues who have read the book. And, furthermore, I have thought up some new—and hopefully better—ways to explain things, including various new diagrams and photographs. All these seem like good reasons to attempt a new edition, which I hope will continue to serve as an up-to-date review of the complex role of vegetation in our planet's environment. Once again, my wife Mei Ling and my daughters have been a great help in encouraging my efforts, trying to improve my limited photographic skills, and politely listening as I try to explain earth system science to them.

Jonathan Adams
Seoul, Republic of Korea, 2009

Preface to the First Edition

I had wanted to write something like this book for many years, but would probably never have dared to attempt it unless I had been asked to by Clive Horwood at Praxis Publishing. As it is, this has been a rewarding experience for me personally, something which has forced me to read literature that I would not otherwise have read, and to clarify things in my head that would have remained muddled.

What I have set out to do here is provide an accessible textbook for university students, and a generalized source of current scientific information and opinion for both academics and the interested lay reader. I have myself often found it frustrating that there have been no accessible textbooks on most of the subjects dealt with here, and I hope that this book will fill the gap.

My friends and colleagues have provided valuable comment, amongst them David Schwartzman, Axel Kleidon, Alex Guenther, Ellen Thomas, Tyler Volk, Ning Zeng, Hans Renssen, Mary Killilea, Charlie Zender, Rich Norby, Christian Koerner and Roger Pielke Sr. I could not stop myself from adding to the manuscript even after they had sent me their careful advice, and any embarrassing errors that have slipped through are of course a result of my doing this. I am also very grateful to everyone who has generously given me permission to use their own photographs as illustrations in this book, and I have named each one in the photo caption. Lastly but very importantly, Mei Ling Lee has provided the encouragement to show that what I have been writing is of interest to somebody, somewhere.

Thanks in particular to Neil Cobb for providing the photo of a mountain scene, used on the cover of this book.

Jonathan Adams
Newark, New Jersey, 2007

Foreword

This book has been written with the aim of providing an accessible introduction to the many ways in which plants respond to and form the environment of our planet. As an academic scientist, and yet as a teacher, I have tried to balance conflicting needs between something which can be trusted and useful to my colleagues, and something which can enthuse newcomers to the subject. For too long, I feel, earth system science has been a closed door to students because of its jargon, its mathematics and its emphasis on meticulous but rather tedious explanations of concepts. I hate to think how many good potential scientists we have lost because of all this, and how many students who could have understood how the living earth worked have gone away bored or baffled. At a time when we may be facing one of the greatest challenges to our well-being in recent history, from global warming, it is essential that we recruit all the good researchers that we can. If we want the public, business people and politicians to understand the problems they are facing, we need to disseminate knowledge of earth system processes as widely as possibly.

In line with the aims of Praxis—and with my own aims too—I have not attempted a complete referenced literature review in this book. Instead, selected papers of authors named in the text are listed in a bibliography, to provide the reader with some useful leads into the literature. Many important studies are not directly referenced even if their findings are mentioned in the text, and I hope that the authors of these studies will not feel snubbed (because my selection of papers to reference was often fairly arbitrary). The text is written in an informal way, reflecting my own dislike of pomposity in academia. Jargon in science gives precision, but it also takes away understanding if newcomers to the subject are driven away by it. As part of my balancing act, I have tried to keep jargon to a minimum. I have also used some homey and traditional categories such as “plants” to apply to all photosynthesizers, bacterial or eukaryotic (I regard being a plant as a lifestyle, not a birthright), and somehow I could not bear to keep throwing the word “archaea” around when I could just call them “bacteria”.

*Dedicated to the irreverent and brilliant
Hugues Faure (1928–2003)*

Abbreviations and acronyms

CAM	Crassulacean Acid Metabolism
CDIAC	Carbon Dioxide Information and Analysis Center
CSIRO	Commonwealth Scientific and Industrial Research Organization
FACE	Free Air CO ₂ Experiment
GCM	General Circulation Model
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
LAI	Leaf Area Index
LGM	Last Glacial Maximum
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Aerospace Administration
NPP	Net Primary Production
UV	UltraViolet
VOC	Volatile Organic Compound

About the author

Jonathan Adams was born in England and studied Botany at St Catherine's College of the University of Oxford. His PhD was in Geology from the University of Aix-Marseilles II, France, where his mentor was the distinguished Quaternary geologist Hugues Faure.

After postdoctoral studies at Cambridge University and at Oak Ridge National Laboratory (Tennessee), Jonathan Adams has taught at the University of Adelaide (Australia), Rutgers University (New Jersey), and latterly at Seoul National University (South Korea).

Contents

Preface to the Second Edition	xi
Preface to the First Edition	xiii
Foreword	xv
List of figures	xvii
List of tables	xxiii
List of abbreviations and acronyms	xxv
About the author	xxvii
1 The climate system	1
1.1 Why does climate vary from one place to another?	2
1.1.1 Why mountains are colder	4
1.2 Winds and currents: the atmosphere and oceans	6
1.3 The ocean circulation	9
1.3.1 Ocean gyres and the “Roaring Forties” (or Furious Fifties)	9
1.3.2 Winds and ocean currents push against one another . . .	10
1.4 The thermohaline circulation	10
1.5 The great heat-transporting machine	15
1.5.1 The “continental” climate	17
1.5.2 Patterns of precipitation	18
2 From climate to vegetation	27
2.1 Biomes: the broad vegetation types of the world	27
2.2 An example of a biome or broad-scale vegetation type: tropical rainforest	28

2.3	The world's major vegetation types	31
2.4	Understanding the patterns	37
2.5	What favors forest vegetation	39
2.5.1	Why trees need more warmth	39
2.5.2	Why trees need more water.	40
2.6	Deciduous or evergreen: the adaptive choices that plants make. .	43
2.7	Cold-climate evergreenness	48
2.8	The latitudinal bands of evergreen and deciduous forest	50
2.9	Nutrients and evergreenness.	50
2.10	Other trends in forest with climate	52
2.11	Non-forest biomes	53
2.12	Scrub biomes	53
2.13	Grasslands	53
2.14	Deserts	54
2.15	Biomes are to some extent subjective.	54
2.16	Humans altering the natural vegetation, shifting biomes	55
2.17	"Predicting" where vegetation types will occur	55
2.18	Species distributions and climate	59
2.18.1	Patterns in species richness	60
3	Plants on the move	67
3.1	Vegetation can move as the climate shifts.	67
3.2	The Quaternary: the last 2.4 million years	67
3.3	Biomes in the distant past.	75
3.3.1	Sudden changes in climate, and how vegetation responds	75
3.4	The increasing greenhouse effect, and future vegetation change. .	81
3.5	Response of vegetation to the present warming of climate.	81
3.6	Seasons as well as vegetation distribution are changing.	86
3.7	What will happen as the warming continues?	88
3.7.1	Movement of biomes under greenhouse effect warming	92
4	Microclimates and vegetation	97
4.1	What causes microclimates?	97
4.1.1	At the soil surface and below	98
4.1.2	Above the surface: the boundary layer and wind speed	99
4.1.3	Roughness and turbulence	102
4.1.4	Microclimates of a forest canopy	103
4.1.5	Under the canopy.	106
4.1.6	Big plants "make" the microclimates of smaller plants.	108
4.1.7	The importance of sun angle.	110
4.1.8	Bumps and hollows in the landscape have their own microclimate	112
4.1.9	Life within rocks: endolithic lichens and algae	114
4.1.10	Plants creating their own microclimate	115
4.1.11	Dark colors	115

4.1.12	Protection against freezing	115
4.1.13	Internal heating	115
4.1.14	Volatiles from leaves	116
4.1.15	Utilization of microclimates in agriculture	116
4.2	From microclimates to macroclimates	117
5	The desert makes the desert: Climate feedbacks from the vegetation of arid zones	121
5.1	Geography makes deserts	121
5.2	But deserts make themselves	122
5.2.1	The Sahel and vegetation feedbacks	127
5.2.2	Have humans really caused the Sahelian droughts?	132
5.3	Could the Sahara be made green?	132
5.4	A human effect on climate? The grasslands of the Great Plains in the USA	136
5.5	The Green Sahara of the past	139
5.6	Could other arid regions show the same amplification of change by vegetation cover?	143
5.7	Dust	145
5.7.1	Sudden climate switches and dust.	149
5.8	The future	150
6	Forests	153
6.1	Finding out what forests really do to climate	155
6.2	What deforestation does to climate within a region	161
6.3	Re-afforestation	169
6.4	The remote effects of deforestation	169
6.5	The role of forest feedback in broad swings in climate	170
6.5.1	Deforestation and the Little Ice Age.	170
6.5.2	Deforestation around the Mediterranean and drying in North Africa	173
6.5.3	Forest feedbacks during the Quaternary	173
6.6	Volatile organic compounds and climate	176
6.7	Forest–climate feedbacks in the greenhouse world	177
7	Plants and the carbon cycle	181
7.1	The ocean	183
7.2	Plants as a control on CO ₂ and O ₂	185
7.3	Methane: the other carbon gas	187
7.3.1	Carbon and the history of the earth's temperature.	188
7.3.2	Plants, weathering and CO ₂	189
7.3.3	Plants, CO ₂ and ice ages	193
7.4	Humans and the carbon store of plants	198

7.5	The present increase in CO ₂	201
7.5.1	The oceans as a carbon sink	204
7.5.2	Seasonal and year-to-year wiggles in CO ₂ level	205
7.6	The signal in the atmosphere	210
7.7	The strength of the seasonal “wiggle” in CO ₂	212
7.8	Accounting errors: the missing sink	213
7.9	Watching forests take up carbon	215
7.9.1	Predicting changes in global carbon balance under global warming	217
8	The direct carbon dioxide effect on plants	221
8.1	The two direct effects of CO ₂ on plants: photosynthesis and water balance	221
8.2	Increased CO ₂ effects at the scale of a leaf	222
8.3	Modeling direct CO ₂ effects	223
8.4	What models predict for increasing CO ₂ and global vegetation.	224
8.5	Adding climate change to the CO ₂ fertilization effect	225
8.6	Experiments with raised CO ₂ and whole plants	227
8.6.1	The sort of results that are found in CO ₂ enrichment experiments	230
8.6.2	A decline in response with time	233
8.7	Temperature and CO ₂ responses interacting	233
8.8	A few examples of what is found in FACE experiments	234
8.8.1	Forests	234
8.8.2	Semi-desert and dry grassland vegetation	236
8.8.3	Will C ₄ plants lose out in an increased CO ₂ world?	237
8.9	Other FACE experiments	242
8.9.1	FACE studies on agricultural systems	242
8.10	Some conclusions about FACE experiments	244
8.10.1	Will a high CO ₂ world favor C ₃ species over C ₄ species?	244
8.10.2	What factors tend to decrease plant responses to CO ₂ fertilization?	245
8.11	There are other effects of enhanced CO ₂ on plants apart from growth rate	245
8.12	CO ₂ fertilization and soils	246
8.13	CO ₂ fertilization effects across trophic levels	247
8.13.1	Looking for signs of a CO ₂ fertilization effect in agriculture	248
8.13.2	Looking for signs of a CO ₂ fertilization effect in natural plant communities	249
8.13.3	The changing seasonal amplitude of CO ₂	252
8.14	CO ₂ levels and stomata out in nature	253
8.15	Direct CO ₂ effects and the ecology of the past	253
8.15.1	Direct CO ₂ effects on longer geological timescales	256
8.15.2	Ancient moist climates or high CO ₂ effects?	257

8.16 Other direct CO ₂ effects: in the oceans	258
8.17 The future direct CO ₂ effect: a good or a bad thing for the natural world?	259
8.18 Conclusion: The limits to what we can know	260
Bibliography	261
Index	265

Figures

(asterisks indicate color images)

1.1	Why the tropics are colder than the poles	3
1.2	How the tilt of the earth's axis affects the angle of the sun, giving the seasons	4
1.3	Why the upper parts of mountains are colder	5
1.4	How mid-altitude warm belts form	5
1.5	The general position of the ITCZ along the equator.	6
1.6	The intertropical convergence zone, a belt of rising air heated by the equatorial sun.	7
1.7	The Coriolis effect, and the Ekman spiral	8
1.8	Thermohaline circulation in the Atlantic	11
1.9	Ocean gyres	13
1.10	How the greenhouse effect works	14
1.11	Antarctica is cut off by a continuous belt of winds and currents	16
1.12	The annual temperature cycle of an oceanic and a continental location compared	17
1.13	How the rain-making machine of the tropics works	18
1.14	How the monsoon rains move north then south of the equator during the year, following the zone where the sun is directly overhead	19
1.15	Two seasonal rainfall peaks at the equator	20
1.16	The passage of peak rains from south to north of the equator with the seasons	20
1.17*	A satellite image of the density of vegetation across northernmost South America (upper part of image can also be found in the colour section)	22
1.18	The Mediterranean climate. In winter, moist westerly winds cross southern Europe and bring rain. In summer, rain-bearing winds are pushed away by descending air from the "desert belt" of North Africa	23
1.19	Where cold seawater wells up off the coast, air cools and then is warmed as it passes over land; and the way in which coastal deserts form	24
1.20*	A view off the coast of Peru.	25
1.21	The rainshadow effect	25
2.1*	(a) Map of major biome distributions	28
2.1*	(b) Areas of the most intense human alteration of vegetation	29

2.2*	Buttress roots in a tropical rainforest tree	30
2.3*	Drip tips on leaves of a rainforest tree shortly after a thunderstorm	31
2.4*	An epiphyte growing on a tropical rainforest tree.	32
2.5	General form of vegetation	33
2.6*	Tropical rainforest, Malaysia	34
2.7*	Cold climate conifer forest, mountains of California.	34
2.8*	Semi-deciduous forest during the dry season, with some trees leaf-less, Malaysia, near Thai border	35
2.9*	Tropical montane forest with a cloud layer blanketing the upper parts of the forest, Sabah, Borneo	35
2.10*	Deciduous oak scrub, western Iran	36
2.11*	Grassland, California.	36
2.12*	Tundra, above tree line in the Andes, Chile	37
2.13*	Semi-desert, Mohave Desert, Arizona	38
2.14*	Semi-desert, Iran	38
2.15	A tree's large area of leaves places a high demand in terms of evaporation, and a shrub loses less water by evaporation	41
2.16*	Tree line on a mountain.	43
2.17*	Autumn leaves in a northern temperate deciduous tree, Norway maple (<i>Acer platanoides</i>).	45
2.18	The relationship between January temperature and leafing out date in a range of North American trees	47
2.19*	Toothed or lobed leaves are far more prevalent in cooler climate forests . . .	48
2.20	Typical leaf of red maple (<i>Acer rubrum</i>) population in Canada compared with one from Florida.	49
2.21	The proportion of species of trees with "entire" leaves depends closely on the warmth of the climate	49
2.22	Latitudinal bands of alternating evergreen and deciduous forest	51
2.23	Map of eastern Asia with zones of evergreen vs. deciduous forest	51
2.24	Holdridge's predictive scheme for relating biomes to climate.	58
2.25a*	The cross-leaved heath (<i>Erica tetralix</i>), a plant with an oceanic distribution .	61
2.25b	The cross-leaved heath (<i>Erica tetralix</i>) shows a typical "oceanic" range, along the western side of Europe next to the Atlantic Ocean	61
2.26*	<i>Rhododendron ponticum</i>	62
2.27	Tree species richness map of parts of eastern Asia	63
2.28	Wild tree species richness for North America.	64
3.1	The global temperate history of the last 450,000 years showing a sawtooth pattern which appeared by 700,000 years ago	68
3.2	Distribution of forest vs desert	70
3.3	Biome distributions of Europe, North America at the present day and last glacial maximum.	72
3.4*	Temperature zones in the USA for the last glacial maximum 20,000 years ago and present day compared	74
3.5	Maps of migration rate of trees	76
3.6	Temperature history of the late glacial	77
3.7*	The hazel tree (<i>Corylus avellana</i>)	79
3.8	Increase in pollen abundance of Scots pine (<i>Pinus sylvestris</i>) in eastern England after the end of the ice age.	80
3.9*	The greening trend around the Arctic from satellite data	82