

CONTENTS

CONTRIBUTORS ix

PREFACE AND ACKNOWLEDGMENTS xix

WARME AND TERRESTRIAL MAPS OF CALIFORNIA xxi-xxii

1 Introduction / 1

BRUNO ZWILLER and HAROLD WOONEY

The Need for This Book / 1

The Early Development of Ecology in California:
A Different Path Taken / 2

Emergent Patterns / 2

Structure of the Book / 4

Recommended Reading / 5

References / 5

2 Climate / 7

2.1 Climate / 7

DAVID MICHELLE, DANIEL RICHARD, JOHN T. KENTZGLOU,

and HAROLD WOONEY

The Nature of the California Climate / 7

General Climate Features / 10

Warm Season / 10

Cool Season / 14

Atmospheric Rivers / 14

Ocean Influence / 14

El Niño and La Niña / 15

The Wide Range of Climates in California / 16

Spatial Variability of Temperature / 17

Seasonal and Diurnal Temperature Variation / 17

Spatial Variability of Precipitation / 18

Interannual Variability of Precipitation / 19

Spatial Variation of Incoming Surface Solar
Radiation / 20

Regional Features / 20

Summary / 22

Acknowledgments / 23

Recommended Reading / 23

Glossary / 24

References / 24

3 Fire as an Ecosystem Process / 27

JON E. KEELEY and HUGH D. SAFFORD

Introduction / 27

Fire Intensity or Severity / 29

Fire in a Historical Context / 32

Landscape Patterns of Burning / 33

Fire Departure Index / 34

Postfire Recovery of Plant Communities / 35

Fire Effects on Soils, Hydrology, and Carbon
Storage / 38

Fire in Social Context / 39

Fire Management / 39

Global Changes / 40

Summary / 41

Acknowledgments / 41

Recommended Reading / 41

Glossary / 42

References / 42

4 Geomorphology and Soils / 47

ROBERT C. GRAHAM and A. TOBY O'GEEN

Overview of Geologic Processes / 47

Sierra Nevada / 48

The Central Valley / 51

Coast Ranges / 55

Klamath Mountains / 56

Cascade Range / 58

Modoc Plateau / 60

Basin and Range Province / 60

Transverse and Peninsular Ranges / 64

Coastal California / 66

Summary / 68

Recommended Reading / 68

Glossary / 68

References / 70

5 Population and Land Use / 75

PETER S. ALAGONA, TIM PAULSON, ANDREW B. ESCH, and
JESSICA MARTER-KENYON

Introduction / 75

The Relationships between Population and
Land Use / 76

Population / 78

Land Use / 82

Conclusion / 90

Summary / 90

Recommended Reading / 91

Glossary / 91

References / 92

6 Oceanography / 95

STEVEN J. BOGRAD, ANDREW W. LEISING, and ELLIOTT L.
HAZEN

Introduction / 95

Atmospheric Forcing / 95

Oceanic Response / 96

Future Changes in the California Current
System / 99

Summary / 100

Acknowledgments / 101

Recommended Reading / 101

Glossary / 101

References / 101

7 Atmospheric Chemistry / 107

ANDRZEJ BYTNEROWICZ, MARK FENN, EDITH B. ALLEN, and
RICARDO CISNEROS

Introduction / 107

Temporal and Spatial Patterns of Air Quality:
An Overview / 108

Statewide Atmospheric Circulation Patterns and
Their Implications for Air Pollution Transport / 110

Ozone Distribution in Space and Time / 112

Biological Effects of Ozone / 113

Nitrogen Air Pollution and Atmospheric Deposition:
Forms and Spatial Trends / 114

Ecological Effects of Nitrogen Deposition / 116

Other Pollutants / 117

Dust, Aerosols, and Black Carbon / 118

Fire Effects on Air Quality / 119

Interactive Effects of Air Pollution and Climate
Change and Projections for the Future / 120

Human Health Effects of Key Pollutants / 120

Conservation, Adaptation, and Mitigation / 121

Summary / 122

Acknowledgments / 123

Recommended Reading / 123

Glossary / 123

References / 124

PART TWO. HISTORY

8 Ecosystems Past: Vegetation Prehistory / 131

CONSTANCE I. MILLAR and WALLACE B. WOOLFENDEN

Introduction / 131

Reconstructing the Past: Methods of Historical
Ecology / 133

Misty Origins: Mesozoic Ecosystems
(252–66 Ma) / 134

Recognizable Taxa with Nonanalogue Associations:
Paleogene and Neogene (66–2.6 Ma) / 136

The Ice Age Rollercoaster: Quaternary Environments
(<2.6 Ma) / 139

Zooming In: Retreat from the last Ice Age
(~20 ka to present) / 145

Lessons from the Past for the Future / 148

Summary / 149

Acknowledgments / 149

Recommended Reading / 149

Glossary / 149

References / 150

9 Paleovertebrate Communities / 155

ELIZABETH A. HADLY and ROBERT S. FERANEC

Introduction / 155

Fossil History of Mammals / 156

Summary / 164

Acknowledgments / 164

Recommended Reading / 165

Glossary / 165

References / 165

10 Indigenous California / 169

TERRY L. JONES and KACEY HADICK

Introduction / 169

History of Research / 170

The Peopling of California: A Framework / 171

Alternate Views on Indigenous Ecology / 177

Summary / 180

Acknowledgments / 181

Recommended Reading / 181

References / 181

PART THREE. BIOTA

11 Biodiversity / 187

BERNIE TERSHY, SUSAN HARRISON, ABRAHAM BORKER,
BARRY SINERVO, TARA CORNELISSE, CHENG LI, DENA SPATZ,
DONALD CROLL, and ERIKA ZAVALETA

Introduction / 187

Flora / 190

Invertebrates / 193

Reptiles and Amphibians / 196

Birds / 199

Mammals / 203

Conservation Context / 204

Summary / 207

Acknowledgments / 207

Recommended Reading / 207

Glossary / 207

References / 208

- 12 **Vegetation / 213**
CHRISTOPHER R. DOLANC, TODD KEELER-WOLF, and
MICHAEL G. BARBOUR
Introduction / 213
Climatic and Environmental Gradients / 214
Vegetation Classification / 216
Summary of Major Vegetation Types / 217
Summary / 226
Acknowledgments / 228
Recommended Reading / 226
Glossary / 226
References / 227
 - 13 **Biological Invasions / 229**
ERIKA ZAVALITA, ELISSA M. OLIMPI, AMELIA A. WOLF,
BRONWEN STANFORD, JAE R. PASARI, SARAH A. SKIKNE,
PAULO QUADRI BARBA, KATHERINE K. ENNIS, and FLAVIA C.
DE OLIVEIRA
Introduction / 229
Invasion Ecology / 230
California's Invasion History / 231
Ecological and Anthropogenic Drivers of Invasions
in California / 232
Degree of Invasion in California's Ecosystems / 235
Impacts of Invasive Species in California / 236
Invader Management: Challenges and Success
Stories / 238
The Future of Biological Invasions in California / 242
Summary / 243
Acknowledgments / 243
Recommended Reading / 244
Glossary / 244
References / 244
 - 14 **Climate Change Impacts / 251**
CHRISTOPHER B. FIELD, NONA R. CHIARIELLO, and
NOAH S. DIFFENBAUGH
Introduction / 251
Climate Change in California / 251
Climate Change in a Multistressor Context / 252
Observed Impacts of Climate Change to Date / 253
Impacts of Future Climate Changes / 256
The Velocity of Climate Change / 257
Species Ranges / 257
Biome Boundaries/Species Ranges / 258
Interacting Factors: Climate Change as a Threat
Multiplier / 259
Biotic Interactions / 260
Invasive Species / 260
Biodiversity / 261
Managing California Ecosystems in the Changing
Future / 261
Summary / 262
Acknowledgments / 262
Recommended Reading / 262
Glossary / 262
References / 263
 - 15 **Introduction to Concepts of Biodiversity, Ecosystem
Functioning, Ecosystem Services, and Natural
Capital / 265**
REBECCA CHAPLIN-KRAMER, LISA MANDLE, ELIZABETH
RAUER, and SUZANNE LANGRIDGE
Introduction / 265
Biodiversity: The Variety of Life on Earth / 265
Ecosystem Functions / 267
Ecosystem Services / 269
Examples of Ecosystem Functions and Services
in Californian Ecosystems / 271
Supporting Agricultural Services: Pollination and
Pest Control / 271
Biodiversity, Ecosystem Functioning, and Ecosystem
Services in Decision Making / 275
Conclusion / 278
Summary / 278
Acknowledgments / 278
Recommended Reading / 278
Glossary / 278
References / 279
- ## PART FOUR. ECOSYSTEMS
- 16 **The Offshore Ecosystem / 287**
STEVEN J. BOGRAD, ELLIOTT L. HAZEN, SARA M. MAXWELL,
ANDREW W. LEISING, HELEN BAILEY, and RICHARD D. BRODEUR
Introduction / 287
Offshore Ecosystems and Food Webs
of the California Current System / 288
Ecosystem Services, Threats, and Management
Structure in the Offshore California Current / 297
Summary / 302
Acknowledgments / 302
Recommended Reading / 302
Glossary / 302
References / 303
 - 17 **Shallow Rocky Reefs and Kelp Forests / 311**
MARK H. CARR and DANIEL C. REED
Introduction / 311
Geographic Distribution of Kelp Forests / 313
Trophic Structure and Functional Attributes
of Kelp Forest Ecosystems / 316
Determinants of Community Structure / 323
Disturbance, Forest Dynamics, and Shifts
in Community Structure / 325
Kelp Forest Ecosystem Services / 325
Human Impacts to Kelp Forests and Management
Responses / 326
Invasive Species / 327
Ecosystem-based Management and Marine Protected
Areas / 328
Summary / 329
Acknowledgments / 330
Recommended Reading / 330
Glossary / 330
References / 331

- 18 Intertidal / 337**
CAROL A. BLANCHETTE, MARK W. DENNY, JOHN M. ENGLE,
BRIAN HELMUTH, LUKE P. MILLER, KARINA J. NIELSEN, and
JAYSON SMITH
Introduction / 337
Significance and History of Rocky Intertidal
Research / 338
The California Coast / 338
Organisms of California's Rocky Intertidal
Ecosystems / 343
Benthic-Pelagic Coupling / 344
Intertidal Ecology / 346
Human Impacts / 349
Climate Change / 350
Summary / 351
Acknowledgments / 352
Recommended Reading / 352
Glossary / 352
References / 352
- 19 Estuaries: Life on the Edge / 359**
JAMES E. CLOERN, PATRICK BARNARD L., ERIN BELLER,
JOHN CALLAWAY, J. LETITIA GRENIER, EDWIN D. GROSHOLZ,
ROBIN GROSSINGER, KATHRYN HIEB, JAMES T. HOLLIBAUGH,
NOAH KNOWLES, MARTHA SUTULA, SAMUEL VELOZ,
KERSTIN WASSON, and ALISON WHIPPLE
Introduction / 359
Complex Patterns of Ecosystem Variability / 367
Biota and Their Roles in the Ecosystem / 368
The Human Dimension / 376
A Long View of California's Estuaries / 380
Summary / 381
Acknowledgments / 382
Recommended Reading / 382
Glossary / 382
References / 384
- 20 Sandy Beaches / 389**
JENIFER E. DUGAN and DAVID M. HUBBARD
Introduction / 389
Geomorphic Properties and Characteristics / 389
Beach Profiles and Features / 391
Key Drivers, Processes, and Patterns / 393
Ecosystem Attributes and Food Webs / 394
Ecosystem Functions / 400
Human Impacts and Influences / 401
Conservation and Restoration Strategies / 402
Summary / 403
Acknowledgments / 403
Recommended Reading / 403
Glossary / 403
References / 405
- 21 Coastal Dunes / 409**
PETER ALPERT
Introduction / 409
Geography / 409
Dune Formation and Shape / 410
Physical Conditions for Organisms / 413
Macroorganisms / 414
Population and Evolutionary Ecology / 415
Ecosystem Services / 418
Effects of Humans / 418
Management Strategies / 420
Future Scenarios / 421
Summary / 423
Acknowledgments / 423
Recommended Reading / 423
Glossary / 423
References / 424
- 22 Coastal Sage Scrub / 429**
ELSA E. CLELAND, JENNIFER L. FUNK, and EDITH B. ALLEN
Introduction / 429
Key Community Interactions / 435
Variation of the System in Time and Space / 437
Human Impacts from the Postcolonial Era
to Present / 439
Management and Restoration / 442
Future Scenarios / 443
Summary / 444
Acknowledgments / 444
Recommended Reading / 444
Glossary / 444
References / 444
- 23 Grasslands / 449**
VALERIE T. EVINER
Introduction / 449
Primary Factors Controlling the Distribution
of California's Grasslands / 450
Interacting Factors: Transition of California's
Grasslands to a Non-Native-Dominated State / 460
Ecosystem Functioning / 461
Ecology and Management of Ecosystem
Services / 465
Impacts of Humans on Grasslands / 468
Management under Future Conditions / 469
Summary / 470
Acknowledgments / 471
Recommended Reading / 471
Glossary / 471
References / 471
- 24 Chaparral / 479**
V. THOMAS PARKER, R. BRANDON PRATT, and JON E. KEELEY
Introduction / 479
Geography of Chaparral / 480
Origins / 482
Principal Organisms Found in Chaparral / 483
Life Histories and Wildfire / 486
Physiology of Chaparral Shrubs / 489
Chaparral in the Long Absence of Fire / 494
Biogeochemical and Hydrological Dynamics / 496
The Future of Chaparral / 499

Summary / 499	Glossary / 571
Acknowledgments / 499	References / 571
Recommended Reading / 500	
Glossary / 500	
References / 501	
25 Oak Woodlands / 509	28 Subalpine Forest / 579
FRANK W. DAVIS, DENNIS D. BALDOCCHI, and CLAUDIA M. TYLER	CONSTANCE I. MILLAR and PHILIP W. RUNDEL
Introduction / 509	Introduction / 579
Distribution / 509	Environmental Controls / 582
Oak Woodland Climate / 510	Ecosystems of the Subalpine Forest Zone / 588
Biodiversity and Characteristic Species / 510	Origins of Subalpine Forest Species and Ecosystems / 596
Ecosystem Structure and Processes / 516	Ecosystem Dynamics / 598
Disturbance and Ecosystem Resilience / 521	Ecosystem Services / 600
Land Use Conversion and Ecosystem Fragmentation / 523	Agents of Anthropogenic Change / 602
Ecosystem Services / 524	Management Issues and Climate Adaptation / 604
Scenarios of Oak Woodlands in the Mid-twentieth Century / 525	Future Climate Scenarios / 604
Research Needs and Priorities / 527	Summary / 605
Summary / 528	Acknowledgments / 605
Acknowledgments / 528	Recommended Reading / 605
Recommended Reading / 528	Glossary / 606
Glossary / 528	References / 606
References / 529	
26 Coast Redwood Forests / 535	29 Alpine Ecosystems / 613
HAROLD MOONEY and TODD E. DAWSON	PHILIP W. RUNDEL and CONSTANCE I. MILLAR
Introduction / 535	Introduction / 613
Physiographic Setting / 535	Defining Alpine Ecosystems / 613
General Vegetation Extent and History of the Pacific Coastal Forest / 536	Geographic Distribution of Alpine Ecosystems in California / 614
Ecosystem Services / 547	Climate Regimes and Abiotic Stress / 617
History of Redwood Exploitation / 548	Geologic and Geomorphic Setting / 619
The Fight to Save the Redwoods / 548	Geomorphic Settings and Habitats / 620
What Will the Future Bring? / 550	Processes and Ecosystem Dynamics / 622
Summary / 550	Vegetation, Flora and Fauna / 624
Acknowledgments / 551	Human Interactions / 628
Recommended Reading / 551	Invasive Species / 629
Glossary / 551	Conservation / 629
References / 551	Climate Adaptation / 629
	Summary / 630
	Acknowledgments / 630
	Recommended Reading / 630
	Glossary / 630
	References / 631
27 Montane Forests / 553	30 Deserts / 635
MALCOLM NORTH, BRANDON COLLINS, HUGH SAFFORD, and NATHAN L. STEPHENSON	JAYNE BELNAP, ROBERT H. WEBB, TODD C. ESQUE, MATTHEW L. BROOKS, LESLEY A. DEFALCO, and JAMES A. MACMAHON
Introduction / 553	Introduction / 635
Physiographic Setting / 554	Biogeography / 636
Montane Forest Types / 555	Drivers of Ecosystem Processes in Space and Time / 636
Fauna / 561	Ecosystem Components and Processes / 642
Ecosystem Characteristics / 563	Primary Producers: The Vascular Plants / 646
Current Management Strategies / 567	Key Consumers / 648
Restoration Successes / 569	Major Ecosystem Services / 658
Future Scenarios / 569	Impacts of Humans during the Postcolonial Period / 659
Summary / 570	Future Scenarios / 660
Acknowledgments / 570	Incorporating Future Scenarios into Land Management / 661
Recommended Reading / 571	

	Summary / 662
	Acknowledgments / 662
	Recommended Reading / 662
	Glossary / 662
	References / 662
31 Wetlands / 669	
	WALTER G. DUFFY, PHILIP GARONE, BRENDA J. GREWELL, SHARON KAHARA, JOSEPH FLESKES, BRENT HELM, PETER MOYLE, ROSEMARY RECORDS, and JOSEPH SILVEIRA
	Introduction / 669
	Historical Ecology / 671
	Geographic Distribution / 673
	Drivers and Patterns of Variability / 677
	Habitats, Biological Communities, and Their Interactions / 678
	Biogeochemical Processes / 682
	Wetland Ecosystem Services / 683
	Wetland Management / 684
	Future Scenarios / 685
	Summary / 687
	Recommended Reading / 687
	Glossary / 688
	References / 688
32 Lakes / 693	
	JOHN MELACK and S. GEOFFREY SCHLADOW
	Introduction / 693
	Limnological Concepts / 694
	Regional Characteristics of California Lakes / 696
	Ecological Services Provided by Lakes / 705
	Future Scenarios As a Function of Climate and Land Use Changes / 705
	Summary / 706
	Acknowledgments / 706
	Recommended Reading / 706
	Glossary / 707
	References / 708
33 Rivers / 713	
	MARY E. POWER, SARAH J. KUPFERBERG, SCOTT D. COOPER, and MICHAEL L. DEAS
	Introduction / 713
	Overview of Key Taxa in Food Webs of Californian Rivers / 716
	The Past and Alternative Futures of Californians and Their Rivers / 729
	Summary / 740
	Acknowledgments / 741
	Recommended Reading / 741
	Glossary / 741
	References / 742

PART FIVE. MANAGED SYSTEMS

34 Managed Island Ecosystems / 755	
	KATHRYN MCEACHERN, TANYA ATWATER, PAUL W. COLLINS, KATE FAULKNER, and DANIEL V. RICHARDS
	Introduction / 755
	Southern California's Geologic History / 760
	Patterns of Variability among Islands / 762
	Endemism, Vulnerability, and Resilience / 764
	Human History / 766
	How Development Changed the Functioning of Island Ecosystems / 768
	Islands in Transition / 770
	How Resilient Are the Islands? / 774
	Summary / 774
	Acknowledgments / 774
	Recommended Reading / 774
	Glossary / 774
	References / 775
35 Marine Fisheries / 779	
	ERIC P. BJORKSTEDT, JOHN C. FIELD, MILTON LOVE, LAURA ROGERS-BENNETT, and RICK STARR
	Introduction / 779
	An Introduction to Fisheries Science and Management / 781
	Ecological Effects of Fishing / 784
	California's Marine Fisheries: Now and Then / 788
	Continuing Pressures / 797
	Pathways to Sustainable, Resilient Fisheries / 798
	Outlook for Marine Fisheries and Ecosystems of California / 804
	Summary / 804
	Acknowledgments / 805
	Recommended Reading / 805
	Glossary / 805
	References / 806
36 Forestry / 817	
	WILLIAM STEWART, BENKTESH SHARMA, ROB YORK, LOWELL DILLER, NADIA HAMEY, ROGER POWELL, and ROBERT SWIERS
	Introduction / 817
	A Natural Experiment / 818
	History of California's Timberlands / 820
	Global Ecosystem Services under Different Forest Management Regimes / 822
	Local Ecosystem Services under Different Forest Management Regimes / 822
	Summary / 830
	Acknowledgments / 830
	Recommended Reading / 830
	Glossary / 830
	References / 830

37 Range Ecosystems / 835

SHERI SPIEGAL, LYNN HUNTSINGER, PETER HOPKINSON, and
JAMES W. BARTOLOME

- Introduction / 835
- The Geography of Livestock Grazing / 836
- History of Range Management in California / 841
- Range Ecology / 843
- Range Ecology and Management / 845
- Ecosystem Services and Livestock Production / 846
- Future of Range Management in California / 854
- Summary / 857
- Acknowledgments / 857
- Recommended Reading / 857
- Glossary / 857
- References / 858

38 Agriculture / 865

ALEX MCCALLA and RICHARD HOWITT

- Introduction / 865
- Overview of California Agriculture / 866
- A Brief History of California Agriculture / 868
- The Balance of Water Use and Supply
in California / 876
- Principal Functions of the California Agricultural
Ecosystem / 876
- The Structure of California's Organic Agricultural
Production / 877
- Ecological Malfunctions of the System / 878
- Groundwater Contamination by Nitrogen / 879
- Agricultural Interactions with Natural
Ecosystems / 880
- Synergies and Trade-offs / 881
- The Future of California's Agroecosystem / 881
- Summary / 882
- Recommended Reading / 883
- Glossary / 883
- References / 883

39 Urban Ecosystems / 885

DIANE E. PATAKI, G. DARREL JENERETTE, STEPHANIE PINCEL, and
TARA L. E. TRAMMELL, and LA'SHAYE ERVIN

- Introduction / 885
- Urban Ecosystems of California / 885
- The Biotic Environment of California's Cities / 886
- Urban Metabolism, Ecological Footprints, and
Life Cycle Assessment / 888
- Integrating Biotic and Abiotic Components
of Cities / 889

Impacts of Urban Activities on Surrounding
Areas / 890

The Future of California's Urban Areas / 891

Summary / 892

Acknowledgments / 892

Recommended Reading / 892

Glossary / 893

References / 893

PART SIX. POLICY AND STEWARDSHIP

40 Land Use Regulation for Resource Conservation / 899

STEPHANIE PINCEL, TERRY WATT, and MARIA J. SANTOS

- Introduction / 899
- Key Concepts in Land Use Planning / 899
- History of Conservation Land Acquisition / 901
- Evolution of Land Use Planning and Policy
in California / 907
- Twenty-first Century: Continued Conservation
Challenges / 916
- Innovations toward a Change / 918
- Future Challenges / 920
- Where Do We Go from Here? / 920
- Summary / 921
- Recommended Reading / 921
- Glossary / 922
- References / 923

**41 Stewardship, Conservation, and Restoration in the
Context of Environmental Change / 925**

ADINA M. MERENLENDER, DAVID D. ACKERLY, KATHERINE
SUDING, M. REBECCA SHAW, and ERIKA ZAVALETA

- Introduction / 925
- Ecological Responses to Environmental
Change / 926
- Stewardship, Conservation, and Restoration / 927
- Future Directions for Stewardship and Policy across
California's Ecosystems / 934
- Future Research, Education, and Outreach
for Addressing Environmental Change / 937
- Summary / 939
- Acknowledgments / 939
- Recommended Reading / 939
- References / 939

INDEX 943