

Contents

ACKNOWLEDGMENTS	xiii
------------------------------	-------------

Section 1	Introduction
------------------	---------------------

CHAPTER 1	A new discipline: climate change biology	3
	A greenhouse planet	5
	Boundaries of life	6
	Shifting interactions	8
	Chemistry of change	8
	Linkages back to climate	9
	Climate change biology	10

CHAPTER 2	The climate system and climate change	13
	The climate system	13
	Evolution of the earth's climate	15
	Natural drivers of change	19
	Major features of present climate.....	25
	Stable states of the system	28
	Human-driven change: rising CO ₂	30
	Rapid climate change.....	37
	The velocity of climate change	40
	Modeling the climate system	41
	Regional climate models.....	45
	Commonly used GCMs	48
	Emissions pathways	50
	GCM outputs	50

Biological assessments with downscaled data.....	52
Further reading	52

Section 2 **The impacts of human induced climate change**

CHAPTER 3	Species range shifts.....	57
	First sign of change: coral bleaching.....	58
	First changes on land.....	62
	Mounting evidence of range shifts	64
	Patterns within the patterns	72
	Extinctions	74
	Freshwater changes.....	76
	Pests and pathogens	78
	Further reading	81
CHAPTER 4	Phenology: changes in timing of biological events due to climate change.....	83
	Arrival of spring.....	87
	Freshwater systems	89
	Spring ahead, fall behind	91
	Tropical forest phenology.....	91
	Marine systems	94
	Mechanisms: temperature and photoperiod	95
	Life-cycles of insect herbivores	96
	Timing mismatches between species.....	99
	Further reading	102
CHAPTER 5	Ecosystem change.....	103
	Tropical ecosystem changes	103
	Cloud forests	106
	Temperate ecosystem change	109
	High mountain ecosystems.....	113
	Glacier and snowpack-dependent ecosystems	115
	Polar and marine systems	118
	Polar food webs: changes in the southern ocean.....	122

Tropical marine systems	124
Pelagic marine systems	126
Ocean acidification	128
Ecosystem feedbacks to climate system	131
Further reading	133

Section 3 **Lessons from the past**

CHAPTER 6	Past terrestrial response	137
	Scope of change	137
	The earth moves	138
	Climate runs through it	140
	Fast and far: the record of the ice ages	145
	Ice racing in north america and europe.....	146
	Out of land: the southern temperate response	149
	North meets south	150
	Rapid change: the Younger <i>Dryas</i>	153
	Tropical responses	156
	Milankovitch forcing in the biological record	159
	Lessons of past change	160
	Further reading	160
CHAPTER 7	Past marine ecosystem changes	163
	Effects of temperature change	163
	Effects of sea-level change	166
	Changes in ocean circulation	169
	Changes in ocean chemistry	171
	Further reading	177
CHAPTER 8	Past freshwater changes	179
	Lakes as windows to past climate	180
	Types of freshwater alteration with climate	185
	Freshwater biotas, habitats, and food chains	189
	Deep time: pace of evolution and species accumulation	190
	Recent-time (tertiary and pleistocene) records of change.....	192

	Fast forward.....	193
	Further reading	194
CHAPTER 9	Extinctions	195
	The five major mass extinctions	195
	Causes of extinction events.....	199
	Climate as the common factor in major extinctions.....	200
	Impacts and climate	200
	Does climate change always cause extinction?.....	202
	Climate and extinctions in deep time.....	202
	The past 100 million years	204
	The past 2 million years: extinction at the dawn of the ice ages and the pleistocene extinctions	206
	The missing ice age extinctions	209
	Patterns in the losses.....	209
	Further reading	210
Section 4	Looking to the future	
CHAPTER 10	Insights from experimentation	213
	Theory.....	213
	Laboratory and greenhouse experiments.....	217
	Field experiments.....	225
	Results of whole-vegetation experiments	228
	Results of field CO ₂ experiments	230
	Freshwater experiments	233
	Arctic experiments	233
	Further reading	235
CHAPTER 11	Modeling species and ecosystem response	237
	Types of models.....	239
	Dynamic global vegetation models	243
	Species distribution models.....	247
	Gap models.....	253
	Modeling aquatic systems.....	256

	Earth system models	261
	Further reading	262
CHAPTER 12	Estimating extinction risk from climate change.....	263
	Evidence from the past.....	266
	Estimates from species distribution modeling.....	267
	Species–area relationship.....	269
	A question of dispersal.....	271
	The problem with endemics.....	271
	Checking the estimates.....	273
	Not just about polar bears anymore	275
	Are a million species at risk?.....	276
	Why the future may not be like the past	278
	Further reading	279
CHAPTER 13	Ecosystem services.....	281
	Food provision—marine fisheries	281
	Water provisioning.....	285
	Carbon sequestration.....	288
	Fire.....	290
	Tourism.....	291
	Ecosystem-based adaptation.....	293
	Coastal protection	294
	Water supply	297
	Food production.....	298
	Disaster risk reduction.....	299
	Further reading	300
Section 5	Implications for conservation	
CHAPTER 14	Adaptation of conservation strategies.....	303
	Early concepts of protected areas and climate change.....	304
	Protected area planning.....	307
	Planning for persistence.....	312
	Resistance and resilience	313

	Protected-area management.....	315
	Marine protected areas	317
	Protected areas for climate change.....	323
	Further reading	325
CHAPTER 15	Connectivity and landscape management.....	327
	Area-demanding species	330
	Migratory species	332
	Species range shifts	333
	Planning for connectivity.....	335
	Managing connectivity in human-dominated landscapes	338
	Planning for climate “blowback”	339
	Regional coordination	340
	Monitoring	342
	Further reading	343
CHAPTER 16	Species management.....	345
	Threatened species	345
	Climate change impacts on threatened species.....	348
	Species threatened by climate change	348
	Assessing species threatened by climate change	348
	An iconic example.....	351
	Managing species threatened by climate change	353
	Resources for the job	360
	Further reading	361
Section 6	Finding solutions: international policy and action	
CHAPTER 17	International climate policy	365
	United nations framework convention on climate change	365
	Intergovernmental panel on climate change	368
	Carbon markets.....	369
	Reduced emissions from deforestation and degradation.....	372
	Adaptation.....	374

Why doesn't it work?	376
Further reading	377

CHAPTER 18	Mitigation: reducing greenhouse gas emissions, sinks, and solutions	379
	Stabilizing atmospheric greenhouse gas concentrations	379
	Practical steps for the next 50 years	380
	Energy efficiency	382
	Renewable energy sources	382
	Nuclear power	387
	The end of oil	388
	Clean coal?	389
	Tar sands, oil shales and fracking	390
	Geoengineering	391
	Extinction risk from climate change solutions	393
	Land use requirements of alternate energy	395
	Short-term wedges and long-term pathways	401
	Further reading	402

CHAPTER 19	Carbon sinks and sources	403
	The carbon cycle	403
	Slow carbon	404
	Fast carbon	405
	Ocean carbon cycle	406
	Terrestrial carbon cycle	409
	Human influence on the carbon cycle	411
	Recent trends in terrestrial sources and sinks	413
	Carbon cycle and carbon sequestration	415
	Getting CO ₂ back	420
	Further reading	422

CHAPTER 20	Assessing risks, designing solutions	423
	Impacts, risks, and adaptation	423
	The assessment process	423

Domain and grain	424
Biological assessment	425
Stand-alone biological assessment	427
Design of adaptation solutions.....	428
Two examples of adaptation solutions.....	429
And do it again	431
REFERENCES	433
INDEX	445