

How do we explain the remarkably abrupt changes that sometimes occur in nature and society—and can we predict why and when they happen? This book offers a comprehensive introduction to critical transitions in complex systems—the radical changes that happen at tipping points when thresholds are passed.

Marten Scheffer accessibly describes the dynamical systems theory behind critical transitions, covering catastrophe theory, bifurcations, chaos, and more. He gives examples of critical transitions in lakes, oceans, terrestrial ecosystems, climate, evolution, and human societies. And he demonstrates how to deal with these transitions, offering practical guidance on how to predict tipping points, how to prevent “bad” transitions, and how to promote critical transitions that work for us and not against us. Scheffer shows the time is ripe for understanding and managing critical transitions in the vast and complex systems in which we live. This book can also serve as a textbook and includes a detailed appendix with equations.

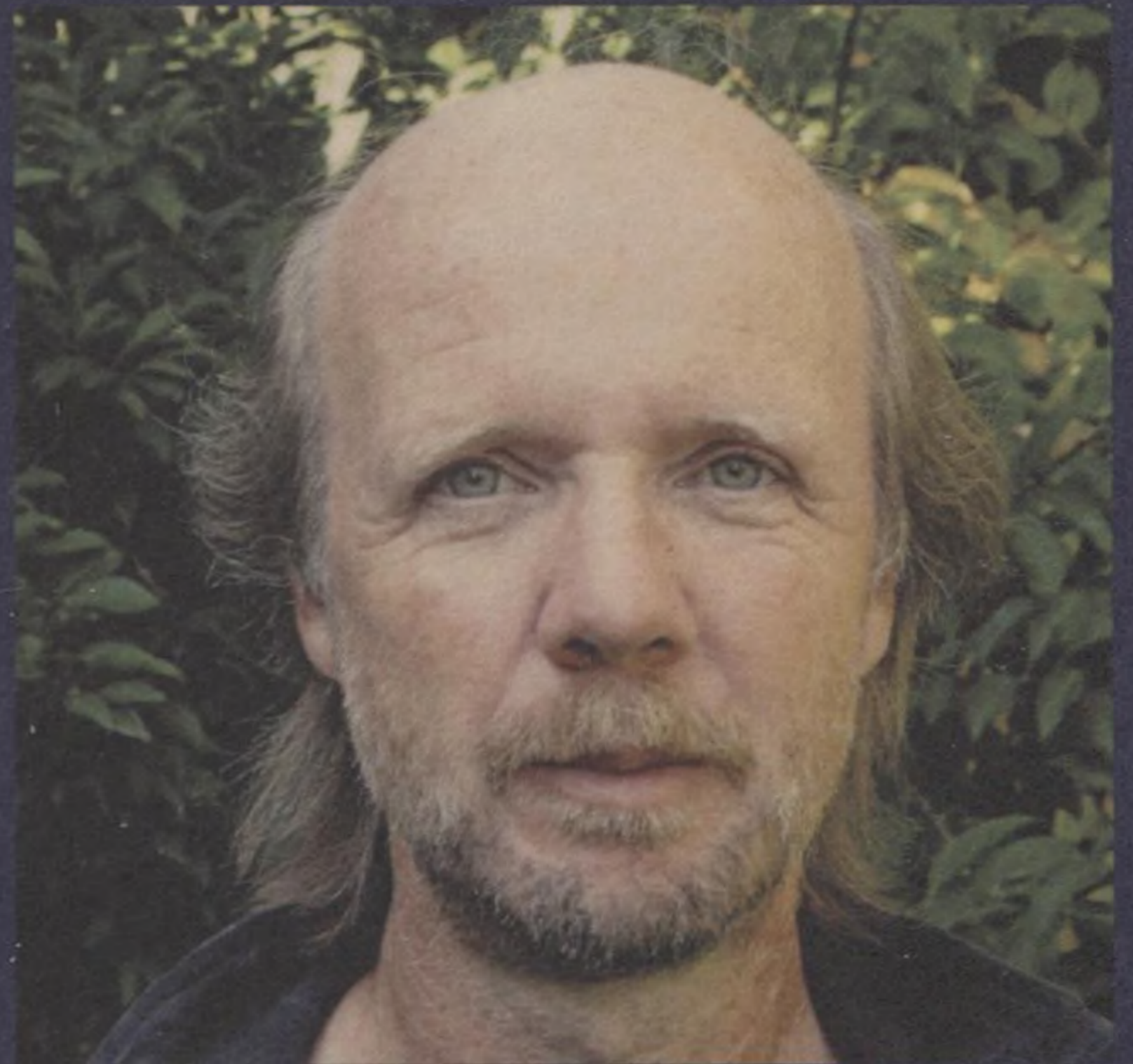
- Provides an accessible introduction to dynamical systems theory
- Covers critical transitions in lakes, oceans, terrestrial ecosystems, the climate, evolution, and human societies
- Explains how to predict tipping points
- Offers strategies for preventing “bad” transitions and triggering “good” ones
- Features an appendix with equations

#### PRINCETON STUDIES IN COMPLEXITY

Simon A. Levin and Steven H. Strogatz,  
Series Editors

Author Photo by Milena Holmgren  
Cover Photo by Marten Scheffer

 **PRINCETON**  
press.princeton.edu



**MARTEN SCHEFFER** is professor of environmental sciences at Wageningen University in the Netherlands. He is the author of *Ecology of Shallow Lakes*.

“This is an important book. Critical transitions and resilience are powerful explanatory tools in ecology today, and it is significant that Scheffer, the leading expert in the applications of critical transitions in ecology, has written a monograph in this area. Scheffer is an excellent writer, and a very good expositor of theoretical concepts in ecology. The ideas in this book should be part of every educated person’s mental framework.”  
—Donald L. DeAngelis, *University of Miami*

“This is a timely book that will have considerable impact on multiple disciplines, including ecology, the social sciences, and economics. It focuses on the theory, examples, and implications of complex systems, particularly critical transitions resulting from positive feedbacks. Scheffer has always been a master at presenting complex issues in a simple way, and this book is no exception. This is a rare gem.”  
—Jon Norberg, *Stockholm University*

ISBN: 978-0-691-12204-5



9 780691 122045

## **Acknowledgments**

xiii

## **CHAPTER 1. Introduction**

1.1 Coral Reef Collapse	1
1.2 The Birth of the Sahara Desert	2
1.3 Shifts in Societies	3
1.4 Content of this Book	5
	6

## **Part I**

# **THEORY OF CRITICAL TRANSITIONS**

## **CHAPTER 2. Alternative Stable States**

	11
2.1 The Basics	13
2.2 Some Mechanisms	25
2.3 Synthesis	36

## **CHAPTER 3. Cycles and Chaos**

	37
3.1 The Limit Cycle	37
3.2 Complex Dynamics	42
3.3 Basin Boundary Collision	50
3.4 Synthesis	54

<b>CHAPTER 4. Emergent Patterns in Complex Systems</b>	55
4.1 Spatial Patterns	56
4.2 Stability of Complex Interacting Networks	65
4.3 The Adaptive Cycle Theory	75
4.4 Synthesis	79

<b>CHAPTER 5. Implications of Fluctuations, Heterogeneity, and Diversity</b>	81
5.1 Permanent Change	82
5.2 Spatial Heterogeneity and Modularity	85
5.3 Diversity of Players	90
5.4 Synthesis	95

<b>CHAPTER 6. Conclusion: From Theoretical Concepts to Reality</b>	96
6.1 Alternative Stable States	96
6.2 Basins of Attraction	98
6.3 Resilience	101
6.4 Adaptive Capacity	103
6.5 Critical Transitions	104
6.5 Synthesis	104

## Part II CASE STUDIES

<b>CHAPTER 7. Lakes</b>	109
7.1 Transparency of Shallow Lakes	110
7.2 Dynamics	125
7.3 Other Alternative Stable States	131
7.4 Synthesis	138

<b>CHAPTER 8. Climate</b>	139
8.1 Deep Time Climate Shifts	141
8.2 Glaciation Cycles	149
8.3 Abrupt Climate Change on Shorter Timescales	157
8.4 Synthesis	164

<b>CHAPTER 9. Evolution</b>	166
9.1 Introduction	166
9.2 Early Animal Evolution and the Cambrian Explosion	168
9.3 The End-Permian Extinction	172
9.4 The Angiosperm Radiation	174
9.5 From Dinosaurs to Mammals	176
9.6 Global Warming and the Birth of Primates, Deer, and Horses	177
9.7 In Search of the Big Picture	178
9.8 Synthesis	184
<b>CHAPTER 10. Oceans</b>	186
10.1 Open Ocean Regime Shifts	187
10.2 Coastal Ecosystems	201
10.3 Synthesis	213
<b>CHAPTER 11. Terrestrial Ecosystems</b>	216
11.1 Vegetation–Climate Shifts in Dry Regions	216
11.2 Small-Scale Transitions in Semiarid Vegetation	221
11.3 Boreal Forests and Tundra	226
11.4 The Rise and Fall of Raised Bogs	230
11.5 Species Extinction in Fragmented Landscapes	234
11.6 Epidemics as Critical Transitions	237
11.7 Synthesis	239
<b>CHAPTER 12. Humans</b>	240
12.1 Shifting Cells	242
12.2 Shifting Minds	243
12.3 Behavioral Lock-In	244
12.4 Inertia and Shifts in Group Attitudes	246
12.5 Societies in Crisis	250
12.6 Synthesis	257
<b>CHAPTER 13. Conclusion: Critical Transitions in a Complex World</b>	259

## Part III

# DEALING WITH CRITICAL TRANSITIONS

<b>CHAPTER 14. How to Know if Alternative Basins of Attraction Exist</b>	265
14.1 Hints from Field Data	265
14.2 Experimental Evidence	270
14.3 Mechanistic Insight	273
14.4 Synthesis	280
<b>CHAPTER 15. How to Know if a Threshold Is Near</b>	282
15.1 The Theory: Signs of Upcoming Transitions	283
15.2 Precursors of Transitions in Real Systems	290
15.3 Reliability of the Signals	293
15.4 Synthesis	294
<b>CHAPTER 16. The Winding Road from Science to Policy</b>	296
16.1 Exploiting Nature in the Smartest Way	297
16.2 Barriers to Good Solutions	303
16.3 Synthesis	309
<b>CHAPTER 17. New Approaches to Managing Change</b>	311
17.1 Promoting Good Transitions	312
17.2 Preventing Bad Transitions	320
17.3 Synthesis	324
<b>CHAPTER 18. Prospects</b>	326
18.1 The Delicate Issue of the Burden of Proof	326
18.2 Toward a Practical Science of Critical Transitions	327
<b>Appendix</b>	329
A.1 Logistic Growth	329
A.2 Allee Effect	332
A.3 Overexploitation	332
A.4 Competition between Two Species	334
A.5 Multispecies Competition	338

A.6 Predator–Prey Cycles	339
A.7 The Hopf Bifurcation	341
A.8 Stabilization by Spatial Heterogeneity	341
A.9 Basin Boundary Collision	344
A.10 Periodic Forcing	344
A.11 Self-Organized Patterns	345
A.12 Alternative Stable States in Shallow Lakes	347
A.13 Floating Plants	348
A.14 Contingency in Behavior	350
<b>Glossary</b>	353
<b>Notes</b>	359
<b>Index</b>	379