教育部高等教育司推荐
国外优秀生命科学教学用书

生态学

（第7版）（影印版）

ECOLOGY

Concepts and Applications

(Seventh Edition)

McGraw Hill Education

Manuel C. Molles Jr.

高等教育出版社

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生态学

（影印版）

Manuel C.Molles Jr.

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About the Author

Manuel C. Molles Jr. is an emeritus Professor of Biology at the University of New Mexico, where he has been a member of the faculty and curator in the Museum of Southwestern Biology since 1975 and where he continues to write and conduct ecological research. He received his B.S. from Humboldt State University and his Ph.D. from the Department of Ecology and Evolutionary Biology at the University of Arizona. Seeking to broaden his geographic perspective, he has taught and conducted ecological research in Latin America, the Caribbean, and Europe. He was awarded a Fulbright Research Fellowship to conduct research on river ecology in Portugal and has held visiting professor appointments in the Department of Zoology at the University of Coimbra, Portugal, in the Laboratory of Hydrology at the Polytechnic University of Madrid, Spain, and at the University of Montana's Flathead Lake Biological Station.

Originally trained as a marine ecologist and fisheries biologist, the author has worked mainly on river and riparian ecology at the University of New Mexico. His research has covered a wide range of ecological levels, including behavioral ecology, population biology, community ecology, ecosystem ecology, biogeography of stream insects, and the influence of a large-scale climate system (El Niño) on the dynamics of southwestern river and riparian ecosystems. His current research concerns the influence of climate change and climatic variability on the dynamics of populations and communities along steep gradients of temperature and moisture in the mountains of the Southwest. Throughout his career, Dr. Molles has attempted to combine research, teaching, and service, involving undergraduate as well as graduate students in his ongoing projects. At the University of New Mexico, he has taught a broad range of lower division, upper division, and graduate courses, including Principles of Biology, Evolution and Ecology, Stream Ecology, Limnology and Oceanography, Marine Biology, and Community and Ecosystem Ecology. He has taught courses in Global Change and River Ecology at the University of Coimbra, Portugal, and General Ecology and Groundwater and Riparian Ecology at the Flathead Lake Biological Station. Dr. Manuel Molles was named Teacher of the Year by the University of New Mexico for 1995–1996 and Potter Chair in Plant Ecology in 2000. In 2014, he received the Eugene P. Odum Award from the Ecological Society of America based on his "ability to relate basic ecological principles to human affairs through teaching, outreach and mentoring activities."

Dedication

To Mary Anne
and
Keena

Preface

This book was written for students taking their first undergraduate course in ecology. I have assumed that students in this one-semester course have some knowledge of basic chemistry and mathematics and have had a course in general biology, which included introductions to physiology, biological diversity, and evolution.

Organization of the Book

An evolutionary perspective forms the foundation of the entire textbook, as it is needed to support understanding of major concepts. The textbook begins with a brief introduction to the nature and history of the discipline of ecology, followed by section I, which includes two chapters on natural history—life on land and life in water and a chapter on population genetics and natural selection. Sections II through VI build a hierarchical perspective through the traditional subdisciplines of ecology: section II concerns adaptations to the environment; section III focuses on population ecology; section IV presents the ecology of interactions; section V summarizes community and ecosystem ecology; and finally, section VI discusses large-scale ecology and includes chapters on landscape, geographic, and global ecology. These topics were first introduced in section I within a natural history context. In summary, the book begins with the natural history of the planet, considers portions of the whole in the middle chapters, and ends with another perspective of the entire planet in the concluding chapter. The features of this textbook were carefully planned to enhance the students' comprehension of the broad discipline of ecology.

Features Designed with the Student in Mind

All chapters are based on a distinctive learning system, featuring the following key components:

Student Learning Outcomes: Educators are being asked increasingly to develop concrete student learning outcomes for courses across the curriculum. In response to this need and to help focus student progress through the content, all sections of each chapter in the seventh edition begin with a list of detailed student learning outcomes.

Introduction: The introduction to each chapter presents the student with the flavor of the subject and important background information. Some introductions include historical events related to the subject; others present an example of an ecological process. All attempt to engage students and draw them into the discussion that follows.

Concepts: The goal of this book is to build a foundation of ecological knowledge around key concepts. I have found that while beginning ecology students can absorb a few central concepts well, they can easily get lost in a sea of details. The key concepts are listed at the beginning of each chapter to alert the student to the major topics to follow and to provide a place where the student can find a list of the important points covered in each chapter. The sections in which concepts are discussed focus on published studies and, wherever possible, the scientists who did the research are introduced. This case-study approach supports the concepts with evidence, and introduces students to the methods and people that have created the discipline of ecology. Each concept discussion ends with a series of concept review questions to help students test their knowledge and to reinforce key points made in the discussion.

SECTION II | Adaptations to the Environment

Chapter 5

Temperature Relations

A group of Japanese macaques, *Macaca fuscata*, huddles together, conserving their body heat in the midst of driving snow. The capacity to regulate body temperature, using behavioral, anatomical, and physiological adaptations, enables these monkeys to live through the cold winters in Nagano, Japan, site of the 1998 Winter Olympics.

CHAPTER CONCEPTS

5.1 Macroclimate interacts with the local landscape to produce microclimatic variation in temperature. 100
Concept 5.1 Review 103

5.2 Adapting to one set of environmental conditions generally reduces a population's fitness in other environments. 103
Concept 5.2 Review 104

5.3 Most species perform best in a fairly narrow range of temperatures. 105

Investigating the Evidence 5: Laboratory Experiments 106
Concept 5.3 Review 109

5.4 Many organisms have evolved ways to compensate for variations in environmental temperature by regulating body temperature. 109
Concept 5.4 Review 119

5.5 Many organisms survive extreme temperatures by entering a resting stage. 119
Concept 5.5 Review 121

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Review Questions 124

LEARNING OUTCOMES

After studying this section you should be able to do the following:

5.1 Distinguish between temperature and heat.
5.2 Explain the ecological significance of environmental temperatures.

The thermometer was one of the first instruments to appear in the scientific tool kit and we have been measuring and reporting temperatures ever since. However, what do thermometers actually quantify? **Temperature** is a

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Illustrations: A great deal of effort has been put into the development of illustrations, both photographs and line art. The goal has been to create more effective pedagogical tools through skillful design and use of color, and to rearrange the traditional presentation of information in figures and captions. Much explanatory material is located within the illustrations, providing students with key information where they need it most. The approach also provides an ongoing tutorial on graph interpretation, a skill with which many introductory students need practice.

Detailed Explanations of Mathematics: The mathematical aspects of ecology commonly challenge many students taking their first ecology course. This text carefully explains all mathematical expressions that arise to help students overcome these challenges. In some cases, mathematical expressions are dissected in illustrations designed to complement their presentation in the associated narrative.

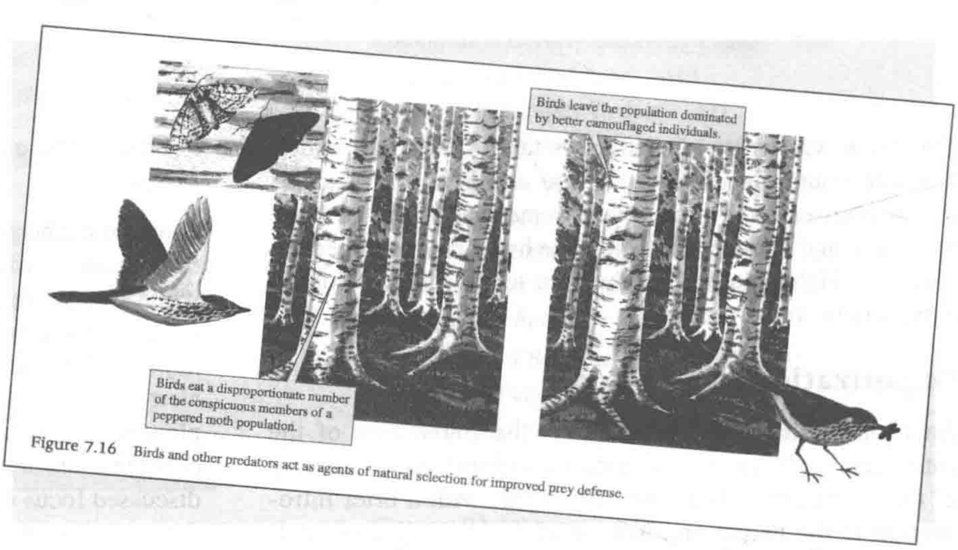
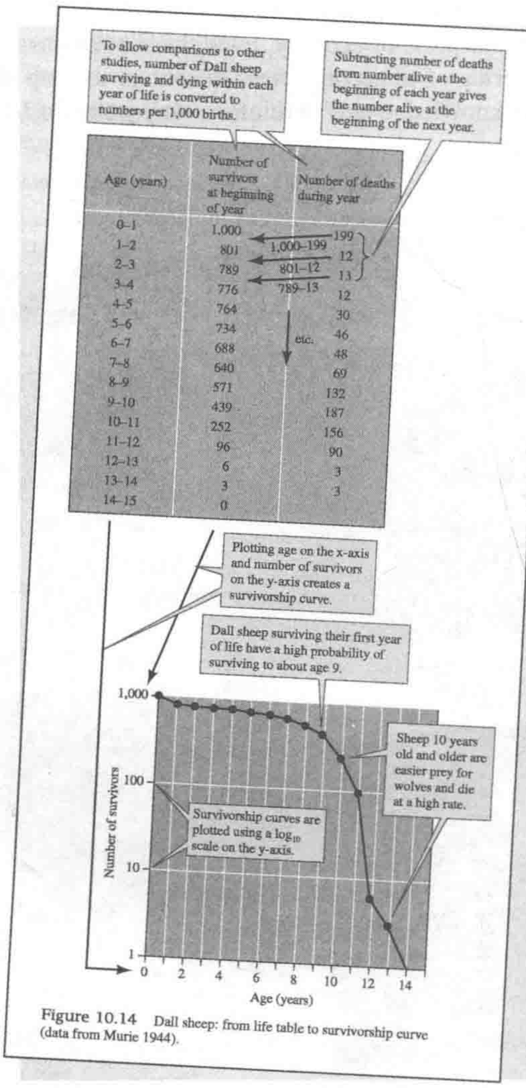


Figure 7.16 Birds and other predators act as agents of natural selection for improved prey defense.

Visualizing a process involving a predator and its prey.



Age (years)	Number of survivors at beginning of year	Number of deaths during year
0–1	1,000	199
1–2	801	12
2–3	789	13
3–4	776	12
4–5	764	30
5–6	734	46
6–7	688	48
7–8	640	69
8–9	571	132
9–10	439	187
10–11	252	156
11–12	96	90
12–13	6	3
13–14	3	3
14–15	0	

Figure 10.14 Dall sheep: from life table to survivorship curve (data from Murie 1944).

Helps students work with and interpret quantitative information, involving converting numerical information into a graph.

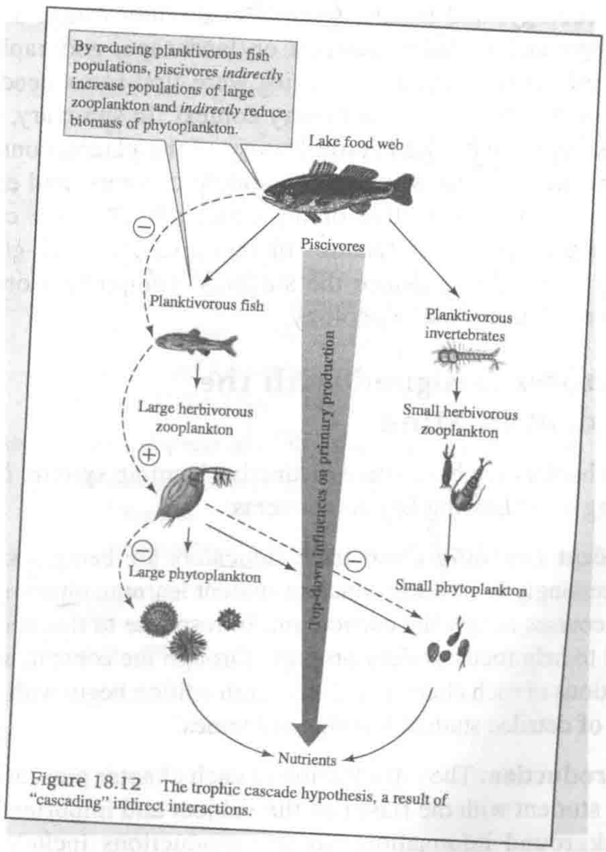


Figure 18.12 The trophic cascade hypothesis, a result of "cascading" indirect interactions.

Provides a visual representation of a hypothesis involving a set of complex ecological interactions.

"Investigating the Evidence" Boxes: These readings offer "mini-lessons" on the scientific method, emphasizing statistics and study design. They are intended to present a broad outline of the process of science, while also providing step-by-step explanations. The series of boxes begins in chapter 1 with an overview of the scientific method, which establishes a conceptual context for more specific material in the next 21 chapters. The last reading wraps up the series with a discussion of electronic literature searches. Each Evidence box ends with one or more questions, under the heading "Critiquing the Evidence." This feature is intended to stimulate critical thinking about the box content.

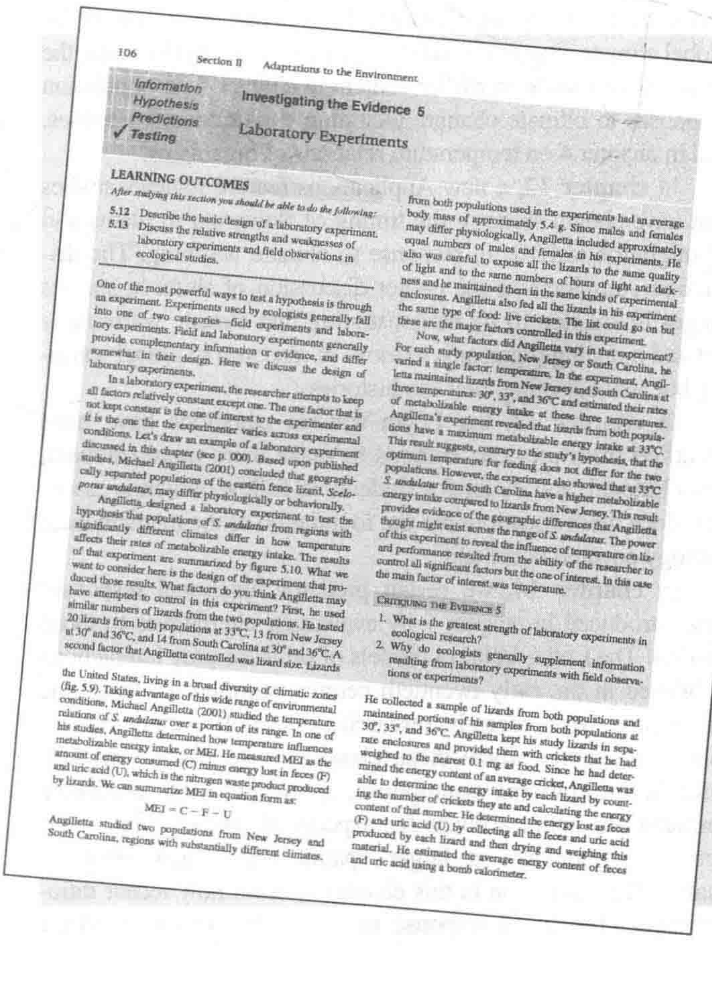
Applications: Many undergraduate students want to know how abstract ideas and general relationships can be applied to the ecological problems we face in the contemporary world. They are concerned with the practical side of ecology and want to know more about how the tools of science can be applied. Including a discussion of applications in each chapter motivates students to learn more of the underlying principles of ecology. In addition, it seems that environmental problems are now so numerous and so pressing that they have erased a once easy distinction between general and applied ecology.

End-of-Chapter Material:

- ***Summary*** The chapter summary reviews the main points of the content. The concepts around which each chapter is organized are boldfaced and redefined in the summary to reemphasize the main points of the chapter.
- ***Key Terms*** The listing of key terms provides page numbers for easy reference in each chapter.
- ***Review Questions*** The review questions are designed to help students think more deeply about each concept and to reflect on alternative views. They also provide a place to fill in any remaining gaps in the information presented and take students beyond the foundation established in the main body of the chapter.

End-of-Book Material:

- ***Appendixes*** One appendix, "Statistical Tables," is available to the student for reference. Answers to Concept Review questions and answers to Critiquing the Evidence are now available with the book's instructor resources.
- ***Glossary*** List of all key terms and their definitions.
- ***References*** References are an important part of any scientific work. However, many undergraduates are distracted by a large number of references within the text. One of the goals of a general ecology course should be to introduce these students to the primary literature without burying them in citations. The number of citations has been reduced to those necessary to support detailed discussions of particular research projects.
- ***Index***



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Information
Hypothesis
Predictions
✓ Testing

Investigating the Evidence 5

Laboratory Experiments

LEARNING OUTCOMES

After studying this section you should be able to do the following:

5.12 Describe the basic design of a laboratory experiment.
5.13 Discuss the relative strengths and weaknesses of laboratory experiments and field observations in ecological studies.

One of the most powerful ways to test a hypothesis is through an experiment. Experiments used by ecologists generally fall into one of two categories—field experiments and laboratory experiments. Field and laboratory experiments generally provide complementary information or evidence, and differ somewhat in their design. Here we discuss the design of laboratory experiments.

In a laboratory experiment, the researcher attempts to keep all factors relatively constant except one. The one factor that is not kept constant is the one of interest to the experimenter and it is the one that the experimenter varies across experimental conditions. Let's draw an example of a laboratory experiment discussed in this chapter (see p. 000). Based upon published studies, Michael Angilletta (2001) concluded that geographically separated populations of the eastern fence lizard, *Sceloporus undulatus*, may differ physiologically or behaviorally.

Angilletta designed a laboratory experiment to test the hypothesis that populations of *S. undulatus* from regions with significantly different climates differ in how temperature affects their rates of metabolizable energy intake. The results of that experiment are summarized by figure 5.10. What we want to consider here is the design of the experiment that produced those results. What factors do you think Angilletta may have attempted to control in this experiment? First, he used similar numbers of lizards from the two populations. He tested 20 lizards from both populations at 33°C, 13 from New Jersey at 30° and 36°C, and 14 from South Carolina at 30° and 36°C. A second factor that Angilletta controlled was lizard size. Lizards from both populations used in the experiments had an average body mass of approximately 5.4 g. Since males and females may differ physiologically, Angilletta included approximately equal numbers of males and females in his experiments. He also was careful to expose all the lizards to the same quality of light and to the same numbers of hours of light and darkness and he maintained them in the same kinds of experimental enclosures. Angilletta also fed all the lizards in his experiment the same type of food: live crickets. The list could go on but these are the major factors controlled in this experiment.

Now, what factors did Angilletta vary in that experiment? For each study population, New Jersey or South Carolina, he varied a single factor: temperature. In the experiment, Angilletta maintained lizards from New Jersey and South Carolina at three temperatures: 30°, 33°, and 36°C and estimated their rates of metabolizable energy intake at these three temperatures. Angilletta's experiment revealed that lizards from both populations have a maximum metabolizable energy intake at 33°C. This result suggests, contrary to the study's hypothesis, that the optimum temperature for feeding does not differ for the two populations. However, the experiment also showed that at 33°C *S. undulatus* from South Carolina have a higher metabolizable energy intake compared to lizards from New Jersey. This result provides evidence of the geographic differences that Angilletta thought might exist across the range of *S. undulatus*. The power of this experiment to reveal the influence of temperature on lizard performance resulted from the ability of the researcher to control all significant factors but the one of interest. In this case the main factor of interest was temperature.

CRITIQUING THE EVIDENCE 5

1. What is the greatest strength of laboratory experiments in ecological research?
2. Why do ecologists generally supplement information resulting from laboratory experiments with field observations or experiments?

the United States, living in a broad diversity of climatic zones (fig. 5.9). Taking advantage of this wide range of environmental conditions, Michael Angilletta (2001) studied the temperature relations of *S. undulatus* over a portion of its range. In one of his studies, Angilletta determined how temperature influences metabolizable energy intake, or MEI. He measured MEI as the amount of energy consumed (C) minus energy lost in feces (F) and uric acid (U), which is the nitrogen waste product produced by lizards. We can summarize MEI in equation form as:

$$MEI = C - F - U$$

Angilletta studied two populations from New Jersey and South Carolina, regions with substantially different climates. He collected a sample of lizards from both populations and maintained portions of his samples from both populations at 30°, 33°, and 36°C. Angilletta kept his study lizards in separate enclosures and provided them with crickets that he had weighed to the nearest 0.1 mg as food. Since he had determined the energy content of an average cricket, Angilletta was able to determine the energy intake by each lizard by counting the number of crickets they ate and calculating the energy content of that number. He determined the energy lost as feces (F) and uric acid (U) by collecting all the feces and uric acid produced by each lizard and then drying and weighing this material. He estimated the average energy content of feces and uric acid using a bomb calorimeter.

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Applications

Local Extinction of a Land Snail in an Urban Heat Island

LEARNING OUTCOMES

After studying this section you should be able to do the following:

5.21 Outline changes in the distribution of the snail *Arianta arbustorum* around Basel, Switzerland, between 1900 and 1990.
5.22 Explain how urbanization generally creates a "heat island."
5.23 Review the evidence that temperature changes around the city of Basel are responsible for local extinctions of the snail *Arianta arbustorum*.

Between 1906 and 1908, a Ph.D. candidate named G. Bollinger (1909) studied land snails in the vicinity of Basel, Switzerland. Eighty-five years later, Bruno and Anette Baur (1993) carefully resurveyed Bollinger's study sites near Basel for the presence of land snails. In the process, they found that at least one snail species, *Arianta arbustorum*, had disappeared from several of the sites. This discovery led the Baurs to explore the mechanisms that may have produced extinction of these local populations.

A. arbustorum is a common land snail in meadows, forests, and other moist, vegetated habitats in northwestern and central Europe. The species lives at altitudes up to 2,700 m in the Alps. The Baurs report that the snail is sexually mature at 2 to 4 years and may live up to 14 years. Adult snails have shell diameters of 16 to 20 mm. The species is hermaphroditic. Though individuals generally mate with other *A. arbustorum*, they can fertilize their own eggs. Adults produce one to three batches of 20 to 80 eggs each year. They deposit their eggs in moss, under plant litter, or in the soil. Eggs generally hatch in 2 to 4 weeks, depending upon temperature. The egg is an especially sensitive stage in the life cycle of land snails. *A. arbustorum* often lives alongside *Cepea nemoralis*, a land snail with a broader geographic distribution that extends from southern Scandinavia to the Iberian peninsula.

How did the Baurs document local extinctions of *A. arbustorum*? If you think about it a bit, you will probably realize that it is usually easier to determine the presence of a species than its absence. If you do not encounter a species during a survey, it may be that you just didn't look hard enough. Fortunately, the Baurs had over 13 years of experience doing fieldwork on *A. arbustorum* and knew its natural history well. For instance, they knew that it is best to search for the snails after rainstorms, when up to 70% of the adult population is active. Consequently, the Baurs searched Bollinger's study sites after heavy rains. They concluded that the snail was absent at a site only after two 2-hour surveys failed to turn up either a living individual or an empty shell of the species.

The Baurs found *A. arbustorum* still living at 13 of the 29 sites surveyed by Bollinger near Basel. Eleven of these remaining populations lived in deciduous forests and the other two lived on grassy riverbanks. However, the Baurs could not find the snail at 16 sites. Eight of these sites had been urbanized, which made the habitat unsuitable for any land snails because natural vegetation had been removed. Between 1900 and 1990 the urbanized area of Basel had increased by 500%. However, the eight other sites where *A. arbustorum* had disappeared were still covered by vegetation that appeared suitable. Four of these sites were covered by deciduous forest, three were on riverbanks, and one was on a railway embankment. These vegetated sites also supported populations of five other land snail species, including *C. nemoralis*.

What caused the extinction of *A. arbustorum* at sites that still supported other snails? The Baurs compared the characteristics of these sites with those of the sites where *A. arbustorum* had persisted. They found no difference between these two groups of sites in regard to slope, percent plant cover, height of vegetation, distance from water, or number of other land snail species present. The first major difference the Baurs uncovered was in altitude. The sites where *A. arbustorum* was extinct had an average altitude of 274 m. The places where it survived had an average altitude of 420 m. The places where the snail had survived were also cooler.

A thermal image of the landscape taken from a satellite showed that surface temperatures in summer around Basel ranged from about 17° to 32.5°C. Surface temperatures where *A. arbustorum* had survived averaged approximately 22°C, while the sites where the species had gone extinct had surface temperatures that averaged approximately 25°C. The sites where the snail was extinct were also much closer to very hot areas with temperatures greater than 29°C. Figure 5.34 is based on the Baurs' thermal image of the area around Basel and shows where the snail was extinct and where it persisted.

The Baurs attributed the higher temperatures at the eight sites where the snail is extinct to heating by thermal radiation from the urbanized areas of the city. Buildings and pavement store more heat than vegetation. In addition, the cooling effect of evaporation from vegetation is lost when an area is built over. Increased heat storage and reduced cooling make urbanized landscapes thermal islands. Heat energy stored in urban centers is transferred to the surrounding landscape through thermal radiation, H_r.

The Baurs documented higher temperatures at the sites near Basel where *A. arbustorum* is extinct and identified a well-studied mechanism that could produce the higher temperatures of these sites. However, are the temperature differences they observed sufficient to exclude *A. arbustorum* from the warmer sites? The researchers compared the temperature relations of *A. arbustorum* and *C. nemoralis* to find some clues. They concentrated their studies on the influence of temperature on reproduction by these two snail species.

The eggs of each species were incubated at four temperatures—19°, 22°, 25°, and 29°C. Notice that these temperatures fall within the range measured by the satellite image (see fig. 5.34). The eggs of both species hatched at a high rate at 19°C. However, at higher temperatures, their eggs hatched at significantly lower rates. At 22°C, less than 50% of *A. arbustorum* eggs hatched, while the eggs of *C. nemoralis* continued to hatch at a high rate. At 25°C, no *A. arbustorum* eggs hatched, while approximately 50% of the *C. nemoralis* eggs hatched. At 29°C,

New to the Seventh Edition

The seventh edition expands the pedagogy by beginning all sections of every chapter with a list of student learning outcomes—over 450 student learning outcomes in all. These outcomes are largely based on fundamental learning outcomes for material covered in the text:

1. Define key terms.
2. Explain the main concepts.
3. Evaluate the strength of research presented in support of main concepts, including a critique of study design.
4. Interpret statistical evidence bearing on concepts, expressed in graphical and numerical form.
5. Apply the main concepts to interpretation of new situations.

A content thread focused on global change has been developed and distributed across chapters, emphasizing global climate change. Students and instructors increasingly look for ways to connect the concepts and practice of ecological science to environmental issues arising from global climate change. The present edition explores how species are adjusting their distributions and their critical life history events as climate changes. The final chapter ends with a review of projected impacts of climate change on ecosystems and human populations, infrastructure, and economic systems.

This edition also builds on previous discussions of human disturbance of ecosystems to consider how damaged ecosystems can be restored. The extent and intensity of human impact on the biosphere grows with our population and expanding global economy. While climate change is the most prominent aspect of contemporary global change, other facets, such as damage or destruction of ecosystems, also call for solutions. As a result, there is greater need to restore damaged communities and ecosystems. In this context, the new edition adds an introduction to the practice of ecological restoration, focusing on how the process of restoring ecosystems can benefit from concepts developed in academic studies of community and ecosystem succession.

The relationship between biodiversity and ecosystem function is introduced through the positive influence of primary producer diversity on rates of primary production. Studies of biodiversity and ecosystem function are key elements in ecology's foundation. Connecting these elements helps create conceptual coherence across the discipline. A growing body of recent research does just that. Therefore, this edition includes a new section on the connection between biodiversity and ecosystem function.

The seventh edition introduces developments in trophic ecology that build on classical models of predator-prey interactions. The early to middle twentieth century was a golden age for theoretical ecology. However, those developments have not stopped. Contemporary ecologists continue to build on that legacy, improving our representation and understanding of ecological systems as they do so. The seventh edition updates the discussion of consumer functional response by introducing alternative models based on the ratio of prey to predator numbers rather than prey density per se. This discussion is coupled with reviews of experimental and field studies that support the ratio-dependent models.

The present edition connects ratio-dependent models of functional response to patterns of consumer abundance and secondary production in ecosystems. Previous editions have provided thorough coverage of the ecology of primary production in terrestrial and aquatic ecosystems, but secondary production has received much less attention. This seventh edition addresses this deficiency by including a section that covers the fundamentals of secondary production. The introduction to secondary production in this edition is presented in the context of consumer responses to variations in primary production.

New supplementary materials are placed online. Materials cut from the sixth edition and those previously cut from the fifth and fourth editions are available online. Suggested readings have been updated and placed online, along with answers to Concept Review and Critiquing the Evidence questions.

Significant Chapter-by-Chapter Changes

In **chapters 1 to 23,** numbered learning outcomes were added to all concept discussions and Evaluating the Evidence and Applications features. The average number of learning outcomes added to each chapter is 20.

In **chapter 10,** a new Applications feature explores evidence that plant and animal ranges have shifted northward and to higher latitudes in the Northern Hemisphere during the recent period of rapid global warming. This is the beginning of the global climate change thread in the seventh edition. However, the presentation builds on earlier content in chapter 1 on population responses to climate change, including evolutionary responses, and in chapter 4 on temperature relations of organisms.

In **chapter 12,** a new Applications feature reviews studies that have shown shifts in the timing of flowering in plants and of migration in birds in response to climate warming. The discussion complements the earlier discussion of shifts in species ranges in chapter 10 by demonstrating that climate warming is not just inducing organisms to move in response to global warming but also adjusting their life histories.

In **chapter 13,** the Lotka-Volterra equations have been modified from previous editions to make them more standard, less cluttered, and easier for students to follow, which is essential, since these equations are the foundation of the mathematical ecology covered in the text.

In **chapter 14,** we revisit predator functional responses first introduced in chapter 7 by evaluating alternatives to those models. The Lotka-Volterra models of predator-prey interactions published in the early twentieth century stimulated a long line of research. More recently, researchers have offered alternatives that help identify where those classical mathematical models, with their simplifying assumptions, apply and where alternative formulations better account for aspects of predator-prey interactions, particularly at larger spatial and longer temporal scales. The discussion in this chapter reviews how recent ratio-dependent functional response models better predict predator functional responses in experimental and natural settings. The discussion helps to dispel the idea that mathematical ecology ceased to develop in the mid-twentieth century and reinforces the complementary roles of theoretical, experimental, and observational studies.

In **chapter 18,** a new concept connects primary producer diversity to higher levels of primary production. The chapter also includes a new concept featuring the relationship between levels of primary production and secondary production. This discussion provides a basis for introducing the fundamentals of secondary production. This addition also revisits the ratio-dependent functional responses introduced in chapter 14 by extending the implications of those models beyond predator functional response to the trophic structure of ecosystems. The treatment also formally introduces secondary production, filling a conceptual gap in previous editions.

In **chapter 20,** the fields of ecological restoration and restoration ecology are introduced for the first time. Human impact on the environment has altered ecological communities and ecosystems in nearly every corner of the planet. Restoring structure and function to these systems emerges as one of the great contemporary ecological challenges. Increasingly ecologists addressing this challenge are turning to the conceptual framework of ecological succession to guide their work. Examples of such work are included in this chapter to help bridge the historical divide between ecological theory and restoration practice.

In **chapter 23,** the discussion of the Antarctic ozone hole has been updated to 2013, including 35 years of data from NASA on the size of the ozone hole. The pattern shows that the maximum size of the Antarctic ozone hole has stabilized, signaling a basis for ozone recovery predicted by atmospheric scientists over the next 50 years, providing a bit of good planetary news. The growing body of climate change research, published since the earlier editions of *Ecology Concepts and Applications,* has greatly improved understanding of how earth's changing climate will impact ecosystems and human populations, if not stabilized. A discussion of these impacts concludes this edition, underscoring the relevance of ecological knowledge to sustaining natural as well as human-centered systems.

Abbreviations Used in This Text

°C	degrees Centigrade
$^0/_{00}$	grams of salt per kilogram of water
λ	geometric rate of increase
kPa	kilopascal
MPa	megapascal
N	newton
Pa	pascal
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
g	gram
kg	kilogram
mg	milligram
mg/L	milligrams per liter
µg/L	micrograms per liter
Tg	terragrams
ha	hectare
km	kilometer
km^2	square kilometer
km^3	cubic kilometer
m	meter
m^2	square meter
m^3	cubic meter
µm	micrometer
mm	millimeter
nm	nanometer
µmol	micromole
L	liter
ml	milliliter
µl	microliter
Ca^{2+}	calcium ion
Cl^-	chloride ion
Fe	iron
K	potassium
Mg	magnesium
Mg^{2+}	magnesium ion
N	nitrogen
Na	sodium
Na^+	sodium ion
P	phosphorus
AET	actual evapotranspiration
PAR	photosynthetically active radiation
°S	degrees south
°N	degrees north
CPOM	coarse particulate organic matter
FPOM	fine particulate organic matter
PDSI	Palmer Drought Severity Index
MEI	metabolizable energy intake
$\bar{X}$	sample mean
n	sample size
ΣX	sum of measurements or observations
Ψ	water potential of a solution
$\Psi_{solutes}$	reduction in water potential due to dissolved substances

Ψ_{matric}	reduction in water potential due to matric forces within plant cells
$\Psi_{pressure}$	reduction in water potential due to negative pressure created by water evaporating from leaves
Ψ_{soil}	water potential of soil
Ψ_{plant}	water within plant cells
δX	± the relative concentration of the heavier isotope, for example: D, ^{13}C, ^{15}N, or ^{34}S in $^0/_{00}$
H_s	total heat stored in the body of an organism
H_m	heat gained from metabolism
H_{cd}	heat gained or lost through conduction
H_{cv}	heat lost or gained by convection
H_r	heat gained or lost through electromagnetic radiation
H_e	heat lost through evaporation
MgH_2O/L	milligrams of water per liter
MgH_2O/m^3	milligrams of water per cubic meter
gH_2O/m^3	grams of water per cubic meter
W_d	water taken by drinking
W_f	water taken in with food
W_a	water absorbed from the air
W_e	water lost by evaporation
W_s	water lost with various secretions and excretions
W_r	water taken from soil by roots
W_t	water lost by transpiration
W_i	internal water
PEP	phosphoenolpyruvate
PGA	phosphoglyceric acid
RuBP	ribulose bisphosphate
NH_4^+	ammonium
NO_2^-	nitrite
NO_3^-	nitrate
Fe	elemental iron
Fe^{2+}	ferrous iron
CO	carbon monoxide
P_{max}	maximum rate of photosynthesis
I_{sa}	irradiance required to saturate photosynthesis
N_{e1}	number of prey 1 encountered per unit of time
E_1	energy gained by feeding on an individual prey 1 minus the costs of handling
C_s	cost of searching for the prey
H_1	time required for "handling" an individual of prey 1
S^2	sample variance
RAPD	randomly amplified polymorphic DNA
h^2	heritability of a trait
V_G	genetic variance
V_P	phenotypic variance

V_E	variance in phenotype due to environmental effects on the phenotype
V_T	total variation
V_{GE}	variation due to gene-by-environment interactions
V_R	unexplained residual variation
X	independent variable
Y	dependent variable
a	Y intercept
b	regression coefficient; slope of the line
PCR	polymerase chain reaction
R_0	net reproductive rate
T	generation time
r	per capita rate of increase
r_{max}	maximum per capita rate of increase; intrinsic rate of increase
N	population size
N_t	number of individuals at time t
N_0	initial number of individuals
e	base of natural logarithms
χ^2	chi-square
O	observed frequency of a particular phenotype
E	expected frequency
K	carrying capacity
GSI	gonadosomatic index
N_1 and N_2	population sizes of species 1 and 2
K_1 and K_2	carrying capacities of species 1 and 2
r_{max1} and r_{max2}	intrinsic rates of increase for species 1 and 2
$s_{\bar{x}}$	standard error
s	sample standard deviation
N_h	number of hosts
N_p	number of parasites or predators
α	significance level
μ	true population mean
t	value of the statistic t, either calculated or determined from a Student's t table
H′	the value of the Shannon-Wiener diversity index
p_i	the proportion of the ith species
$\log_e$	the natural logarithm
kcal	kilocalories
R_{sample}	the isotopic ratio in the sample, for example, ^{13}C:^{12}C or ^{5}N:^{14}N
$R_{standard}$	the isotopic ratio in the standard, for example, ^{13}C:^{12}C or ^{15}N:^{14}N
m_t	mass of leaves at time t
m_0	initial mass of leaves
e	base of the natural logarithms
k	daily rate of mass loss
U	Mann-Whitney statistic
CFC	chlorofluorocarbons

Brief Contents

Contents