3rd Edition

Marine Science

Peter Castro | Michael E. Huber

Student Edition Sample Chapter

McGraw Hill

High School Edition

3rd Edition

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Dedication

To all future marine biologists

—Peter Castro—

To Mason and Erin

—Michael Huber—

About the cover photo: A clownfish (*Amphiprion ocellaris*) swimming through a sea anemone.

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MARINE SCIENCE, HIGH SCHOOL 3RD EDITION

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About the Authors

Peter Castro, Ph.D.

Peter Castro realized that he had to become a marine biologist during a high school field trip to the coral reefs in his native Puerto Rico. He obtained a B.S. in biology from the University of Puerto Rico, Mayagüez, but left the warm Caribbean for warm Hawai'i to obtain a Ph.D. in marine zoology from the University of Hawai'i, Mānoa. His first experience with cold water was a year of post-doctoral research at Hopkins Marine Station of Stanford University in Monterey Bay, California. He is currently Professor Emeritus at California State Polytechnic University, Pomona. He also holds a B.A. in history and art history from his home institution, something that took him 18 years to accomplish as a part-time student. He is fluent in four languages and has taught marine biology (in English and Spanish) as a Fulbright Scholar at Odessa State University in the former Soviet Union. His research specialty is the biology of crustaceans symbiotic with reef corals and other invertebrates, research that has taken him anywhere where the water is warm enough to dive. He has also been doing research for almost the last two decades on the systematics of deep-water crabs, mostly, of all places, in Paris, France. Dr. Castro has so far published 70 peer-reviewed papers on his research. He is currently editor-in-chief of the *Journal of Crustacean Biology.*

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Michael Huber, Ph.D.

Michael became fascinated by aquatic organisms when he caught his first trout on an Alaskan lake at age 2. His interest in marine biology grew, and he went on to obtain B.S. degrees in both zoology and oceanography from the University of Washington. He received his doctorate from Scripps Institution of Oceanography for research on a group of symbiotic coral crabs. After his Ph.D., he worked at Scripps on the genetics and cell biology of unicellular algae and bioluminescence in midwater organisms. In 1988 he moved to the Biology Department at the University of Papua New Guinea, where he had the opportunity to work on some of the world's most spectacular coral reefs and was Head of the University's Motupore Island Research Station. He also became increasingly involved in marine environmental science. This interest continued to grow when he left Papua New Guinea in 1994 to become the Scientific Director of James Cook University's Orpheus Island Research Station on Australia's Great Barrier Reef. In 1998 he became a full-time environmental advisor, providing scientific information and advice on marine environmental protection to international agencies, governments, and private industry. Much of his work has been in marine environmental protection at the global level, while regionally much of his work has been in the Asia-Pacific region. He has worked on a wide range of environmental issues including pollution control and waste management, underwater noise, habitat conservation and restoration, marine invasive species, endangered species management, long-term environmental monitoring, effects of mariculture, and deep-sea mining. Dr. Huber is a past Chairman of GESAMP, a United Nations scientific body that advises international agencies on marine environmental issues. Currently, he is helping coordinate GESAMP's role in the United Nations of Ocean Science for Sustainable Development. Mike has worked in more than 40 countries. Mike lives in Brisbane, Australia. His hobbies are fishing, diving, swimming, listening to and attempting to play music, reading, and gardening.

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Preface

Why Marine Science?

Marine science is a fascinating field that brings together people with diverse interests from all over the world. When did your interest in the world ocean start? Perhaps your fascination started after watching a documentary, following a trending whale or hurricane online, or perhaps a visit to a marine theme park. For some it was a visit to the shore, the keeping of a marine aquarium, or while first snorkeling or scuba diving in a coral reef. Or perhaps it was just dreaming about the ocean. Concern with our impact on the marine environment, particularly the conservation of marine life, is another motivation for taking a high school course in marine science.

In this the third edition of *Marine Science*, we have built upon the success of the first two editions. We have kept many of the features that made the text so popular, such as the inclusion of oceanography and biology content, key scientific discoveries, and an interdisciplinary focus. In the third edition we have increased the book's accessibility to high school students by creating a new student-friendly design that includes more eye-catching images to improve readability and engagement.

Marine Science, third edition, adopts a global perspective to emphasize that the world's oceans and seas are an integrated system that cannot be understood by looking in any one person's own backyard. One aspect of our global approach is the deliberate inclusion of examples from many different regions and ecosystems to provide insight into not just North America but the entire world. We hope this will stimulate you to think about the many relationships between your own shores and the one world ocean that so greatly influences all our lives.

What Sets This Book Apart?

High school-friendly design and pedagogy: This book combines the authors' decades of experience in the field and classroom and up-to-date data with a new unique design specifically for high school students and teachers. The Student Edition and supporting teacher materials make it easy for teachers to guide students through a scaffolded approach to the content, without sacrificing the real-life data and scientific rigor.

Demystifying science: We make science accessible by showing how and why data collection is done and by giving examples, practice, and exercises that demonstrate central principles. Marine Science in Action readings and questions prompt critical thinking and empowers students by helping them understand how scientists do their work. These readings give examples of technology and methods in marine science.

Quantitative reasoning: Students need to become comfortable with graphs, data, and comparing numbers. We provide focused discussions on why scientists answer questions with numbers, the nature of statistics and probability, and how to interpret the message in a graph. We give accessible details on population models, satellite imagery, remote sensing, and other quantitative techniques. In-text applications and online, testable Data Analysis Labs give students opportunities to practice with ideas, rather than just reading about them.

Up-to-date concepts and data: Throughout the text we introduce emerging ideas such as blue carbon sinks, developing technologies, and new ways to utilize marine resources, as well as ongoing issues such as global climate change, pollution, and other human activities affecting the marine environment. In addition to basic principles such as climate and biogeochemical processes, organismal anatomy and physiology, and marine ecology, students are introduced to current developments in marine science research, the status of fisheries and other marine resources, the challenges facing conservation efforts, and the impacts of urbanization and development.

Active learning: Learning how scientists approach problems can help students develop habits of independent, orderly, and objective thought. But it takes active involvement to master these skills. This book integrates a range of learning aids—Use the

Practices exercises, Critical Thinking and Discussion questions, and Data Analysis exercises—that push students to think for themselves. Data and interpretations are presented not as immutable truths but rather as evidence to be examined and tested, as they should be in the real world. Taking time to look closely at figures, compare information in multiple figures, or apply ideas in text is an important way to solidify and deepen understanding of key ideas.

Hands-on learning: Pair this book with the printed *Marine Science Laboratory Manual*, written specifically for the high school classroom. This manual contains 42 lab activities that can be conducted in any classroom. The labs include modeling exercises, experiments, and simulations. Students can build their skills with the Guided Inquiry labs and master them with Open Inquiry labs.

Synthesis: Students come to marine science from a multitude of backgrounds and interests. We emphasize that most of our pressing problems, from climate change to conservation of biodiversity, draw on sciences and economics and policy. This synthesis shows students that they can be engaged in marine science, no matter their interests or career path.

Dive deeper: Throughout the book, in-text features ask students to pause and think critically about important topics using specific examples. These features are clearly identified using eye-catching background colors and images, and video clips in the eBook.

Positive perspective: All the ideas noted here can empower students to do more effective work for the issues they believe in. While we don't shy away from the bad news, we highlight positive ways in which groups and individuals are working to improve their environment. A chapter on the impact of humans on the marine environment includes suggestions for simple things students can do to save the oceans.

Thorough coverage: No other book in the field addresses the multifaceted nature of marine science, focusing on disparate yet interconnected topics such as the formation of oceans, the diversity of life in the sea, marine ecology, and humans and the sea, with the thoroughness this book has. We cover not just climate change but also the nature of climate and weather systems that influence our day-to-day experience of climate conditions. We explore both the ecological and economic importance of marine ecosystems including mangroves and kelp forests, traditional and emerging technologies from marine resources such as how we generate energy from the sea, and the application of genetic engineering in aquaculture, fisheries, and scientific research. In these and other examples, this book is a leader in in-depth coverage of key topics.

Unparalleled teacher resources: *Marine Science* is accompanied by a Teacher Manual, available in print and online. This manual includes invaluable resources such as pacing guides, a suggested approach, classroom activities with differentiated instruction, and support for English learners.

Exceptional digital resources: A robust array of media-rich tools brings meaningful experiences and personalized support to the marine science classroom and beyond. The interactive eBook, adaptive SmartBook, videos, activities, simulations, and more enhance student engagement and enrich each lesson as students explore the world ocean and its inhabitants through an interconnected, global perspective. Teachers can organize assignments to suit their students' needs and align to their course outcomes while easily tracking student progress at the individual and/or class level.

New to This Edition

As we prepared for this new edition, we gathered feedback from high school marine science teachers to help us strengthen an already-robust program. We have updated and revised the Student Edition, Laboratory Manual, Teacher Manual, and digital resources to enhance readability, provide more visual interest, include a vast number of hands-on classroom activities, and increase student engagement through an enriched digital experience.

Student Edition

- **Marine Science Career Focus** features have been added to the Unit Openers to introduce students to the wide variety of careers within the field of marine science. This feature also references the **Career Focus Activities** in the digital course. These activities allow students to explore career options related to marine science.
- An **open-ended question with a related photograph** introduces each chapter. These thought-provoking questions activate students' curiosity as they learn about the topics within the chapter.
- The updated **Ripple Effect** feature is a case-study at the beginning of each chapter presenting a tangential marine science concept for students to consider within the context of the chapter content. Students can reflect on the Ripple Effect information throughout the chapter and use the Claim, Evidence, and Reasoning (CER) chart to gather evidence as they read then revisit and reconsider their chart at the end of the chapter.
- **Get It?** question boxes give students a chance to pause and reflect. Some of the boxes also include a photo which is then presented in the eBook as a short video.
- **Use the Practices** activities are featured at the end of each section. These are short activities that allow students to apply Science and Engineering Practices as scientists and engineers would to investigate and solve problems in the natural world.
- **Up-to-date features** reflect new discoveries and technological advances and include critical thinking questions as well as an online inquiry activity.

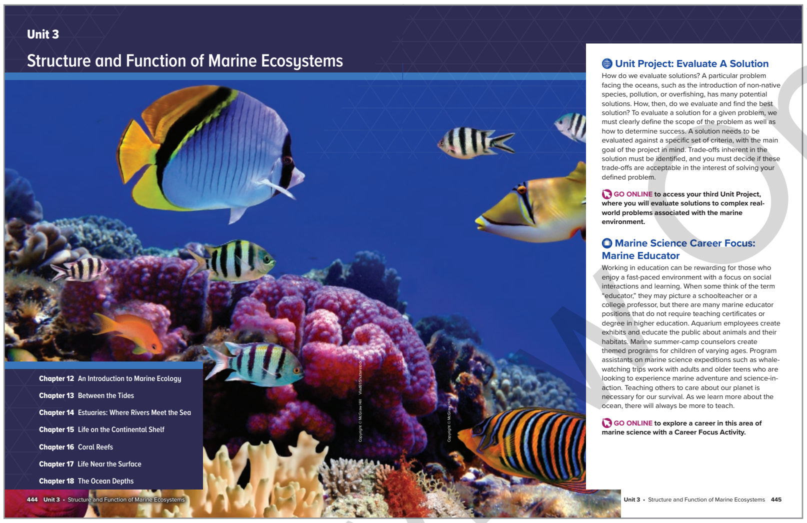
Up-To-Date Content

In addition to its coverage of the living organisms and communities of the oceans, *Marine Science* has three chapters dedicated to the physical and chemical factors that make the oceans unique. The data presented in this book are vetted and the most up-to-date information is presented to students. Updates include:

- Significant revision of the line art improves accessibility for readers with visual challenges.
- Line art that includes the latest available data.
- The presentation of new findings on the existing effects of climate change on marine life health.
- Coverage of cutting-edge marine science in unique feature strands: Marine Science in Action, Humans and the Ocean, Habitat Spotlight, and Nature of Science.
- A feature on the *Polarstern.*
- A feature on The Complex Eyes of Mantis Shrimps.
- A feature on Blue Carbon.

Begin the Exploration

Crafted specifically for a high school course, *Marine Science* presents and explores essential themes, including expanded coverage of oceanography, and offers numerous opportunities for students to practice scientific thinking and active learning. Accessible pedagogical tools lead students to apply science and engineering practices, work with real data, and better understand marine science and all of its complexities. *Marine Science* has been organized into four units.



Unit 3

Structure and Function of Marine Ecosystems

Chapter 12 An Introduction to Marine Ecology
Chapter 13 Between the Tides
Chapter 14 Estuaries: Where Rivers Meet the Sea
Chapter 15 Life on the Continental Shelf
Chapter 16 Coral Reefs
Chapter 17 Life Near the Surface
Chapter 18 The Ocean Depths

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Unit Project: Evaluate A Solution

How do we evaluate solutions? A particular problem facing the oceans, such as the introduction of non-native species, pollution, or overfishing, has many potential solutions. How, then, do we evaluate and find the best solution? To evaluate a solution for a given problem, we must clearly define the scope of the problem as well as how to determine success. A solution needs to be evaluated against a specific set of criteria, with the main goal of the project in mind. Trade-offs inherent in the solution must be identified, and you must decide if these trade-offs are acceptable in the interest of solving your defined problem.

GO ONLINE to access your third Unit Project, where you will evaluate solutions to complex real-world problems associated with the marine environment.

Marine Science Career Focus: Marine Educator

Working in education can be rewarding for those who enjoy a fast-paced environment with a focus on social interactions and learning. When some think of the term "educator," they may picture a schoolteacher or a college professor, but there are many marine educator positions that do not require teaching certificates or degree in higher education. Aquarium employees create exhibits and educate the public about animals and their habitats. Marine summer-camp counselors create themed programs for children of varying ages. Program assistants on marine science expeditions such as whale-watching trips work with adults and older teens who are looking to experience marine adventure and science-in-action. Teaching others to care about our planet is necessary for our survival. As we learn more about the ocean, there will always be more to teach.

GO ONLINE to explore a career in this area of marine science with a Career Focus Activity.

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The **Unit Opener** sets up chapter content that will be covered to provide focused context for the learning ahead. Each chapter covers a topic that relates to the others under the overall theme of the unit.

Unit Project: Evaluate A Solution

How do we evaluate solutions? A particular problem facing the oceans, such as the introduction of non-native species, pollution, or overfishing, has many potential solutions. How, then, do we evaluate and find the best solution? To evaluate a solution for a given problem, we must clearly define the scope of the problem as well as how to determine success. A solution needs to be evaluated against a specific set of criteria, with the main goal of the project in mind. Trade-offs inherent in the solution must be identified, and you must decide if these trade-offs are acceptable in the interest of solving your defined problem.

Each unit opens with a **Unit Project**. The projects build upon each other and allow students to develop their research, synthesis, and analysis skills through the study of global challenges that are related to the content and concepts covered in the text. Teachers have the flexibility to assign these as individual, group, or classroom activities that can be worked on throughout the school year. Students are prompted to work through solutions leveraging additional interactive online resources.

Marine Science Career Focus: The Business of Algae

As conventional fossil-based energy sources become scarce and the human population grows increasingly larger, scientists and engineers are racing to find options for fueling and feeding the world. Algae, organisms that many find to be a nuisance in their backyard pools, have beneficial qualities that make them a realistic answer to major problems that humanity is facing. Working with algae is one of the many growing areas of careers related to marine science. Because the use of algae is so varied, job opportunities are just as diverse. Working with algae might mean you are a researcher at a university, or it could mean you are a cosmetics designer, a chef, an algae farmer, a biofuel engineer, a nutritionist, a pollution mitigation technician, or even a chemist. As the business of algae continues to bloom, more jobs and options for working with algae will appear—it is truly a cutting-edge vocation.

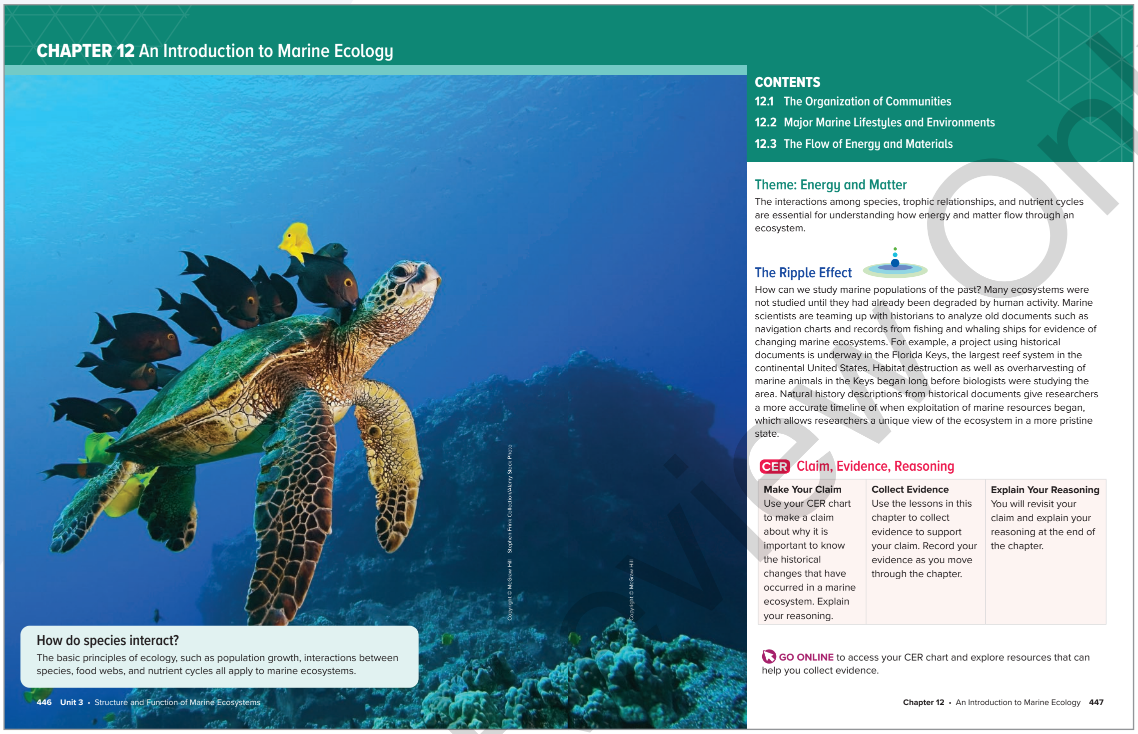
GO ONLINE to explore a career in this area of marine science with a Career Focus Activity.

Marine Science Career Focus features invite students to explore related career options and provide engaging extension activities online for an even deeper dive.

Enhanced Pedagogy and Student Support

The third edition of *Marine Science* has been updated to increase its accessibility, visual appeal, and ease of use for all students. A student-friendly design and the addition of more stunning images enhances student engagement.

The **Chapter Opener** previews what will be covered in the chapter including the topics for each section.



CHAPTER 12 An Introduction to Marine Ecology

How do species interact?
The basic principles of ecology, such as population growth, interactions between species, food webs, and nutrient cycles all apply to marine ecosystems.

446 Unit 3 • Structure and Function of Marine Ecosystems

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12.1 The Organization of Communities
12.2 Major Marine Lifestyles and Environments
12.3 The Flow of Energy and Materials

Theme: Energy and Matter
The interactions among species, trophic relationships, and nutrient cycles are essential for understanding how energy and matter flow through an ecosystem.

The Ripple Effect
How can we study marine populations of the past? Many ecosystems were not studied until they had already been degraded by human activity. Marine scientists are teaming up with historians to analyze old documents such as navigation charts and records from fishing and whaling ships for evidence of changing marine ecosystems. For example, a project using historical documents is underway in the Florida Keys, the largest reef system in the continental United States. Habitat destruction as well as overharvesting of marine animals in the Keys began long before biologists were studying the area. Natural history descriptions from historical documents give researchers a more accurate timeline of when exploitation of marine resources began, which allows researchers a unique view of the ecosystem in a more pristine state.

CER Claim, Evidence, Reasoning

Make Your Claim	Collect Evidence	Explain Your Reasoning
Use your CER chart to make a claim about why it is important to know the historical changes that have occurred in a marine ecosystem. Explain your reasoning.	Use the lessons in this chapter to collect evidence to support your claim. Record your evidence as you move through the chapter.	You will revisit your claim and explain your reasoning at the end of the chapter.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

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Each chapter opens with a stunning photograph accompanying an **open-ended question** that prompts students to start thinking about what they will learn throughout the chapter.

Theme: Energy and Matter
The interactions among species, trophic relationships, and nutrient cycles are essential for understanding how energy and matter flow through an ecosystem.

Each chapter is presented in the context of a **Theme** that unifies the chapter's content and highlights the interdisciplinary nature of marine science. Themes include patterns, cause and effect, energy and matter, and structure and function.

The Ripple Effect
How can we study marine populations of the past? Many ecosystems were not studied until they had already been degraded by human activity. Marine scientists are teaming up with historians to analyze old documents such as navigation charts and records from fishing and whaling ships for evidence of changing marine ecosystems. For example, a project using historical documents is underway in the Florida Keys, the largest reef system in the continental United States. Habitat destruction as well as overharvesting of marine animals in the Keys began long before biologists were studying the area. Natural history descriptions from historical documents give researchers a more accurate timeline of when exploitation of marine resources began, which allows researchers a unique view of the ecosystem in a more pristine state.

The Ripple Effect feature at the beginning of each chapter explores a phenomenon related to the chapter, links to an online Claim, Evidence, Reasoning (CER) chart, and is revisited as part of the Chapter Review. Students are asked to make a claim, collect evidence, and explain their reasoning using their online CER chart.

6.1 The Ingredients of Life

Key Questions

1. What are the four main types of organic molecules that make life possible?
2. What are the reactants and products of photosynthesis and cellular respiration?

Study Strategy

Concept Discussions Describe to a partner the process of photosynthesis and respiration. Answer any questions that your partner has to the best of your ability. If you come to a stumbling block, ask your teacher for help clarifying the concept.

What Is Life?

Now that we have discussed the major features of the marine environment, we can turn our attention to life in the sea. Perhaps the most basic question is: What is life? Most people have a pretty good feel for what the word living means, but biologists have never been able to agree on a precise definition. The best we can do is describe the common properties of living things.

Organisms are not random collections of material but have a precise chemical and physical organization. They all use energy, have the ability to do work, maintain themselves and grow. They do this through a vast number of chemical reactions that are collectively called **metabolism**. Living things also use energy to maintain stable internal conditions different from their surroundings, which is known as **homeostasis**. They sense and react to their external environment. Finally, all life forms reproduce to perpetuate their kind, and use nucleic acids to record their individual characteristics and pass them on to their offspring.

The basic features of living things are shared by all organisms, not just those that live in the sea. Here we will pay particular attention to marine organisms.

The Building Blocks

Life requires an intricate series of interactions among an immense variety of chemicals. The most important of these is one of the simplest: water. As the universal solvent, water provides the medium in which all the other molecules dissolve and interact. Water is the base of a complex "chemical soup" inside all organisms where the chemical reactions of metabolism take place.

Besides water, most of the chemicals that make life possible are **organic compounds**, molecules that contain atoms of carbon, hydrogen, and usually

InContext

Water is called the universal solvent because it can dissolve more different substances than any other liquid.

Molecules are combinations of two or more atoms; most substances are composed of molecules rather than individual atoms.

- Introduced in Section 3.1, The Unique Nature of Pure Water

Each section of the chapter opens with **Key Questions** that are used to guide student reading and introduce the key concepts in the chapter.

Study Strategies include listening, speaking, reading, and peer interactions to provide EL support as well as support for a variety of learning styles.

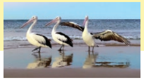
Chapter **vocabulary words** are bolded to draw students' attention to these key terms. The definitions can be found in the glossary at the back of the book.

In Context provides additional information about concepts or vocabulary terms introduced in previous chapters to ensure student comprehension of the text and deeper understanding of the content.

Enhanced Pedagogy and Student Support *(continued)*

Emperor penguins have been known to dive over 200 m deep. As in marine mammals, penguins have a high number of **erythrocytes**, or red blood cells, which have a high concentration of hemoglobin, their muscles contain high amounts of myoglobin to store additional oxygen, and their heart rate is reduced to cut down oxygen consumption while diving. On land it is another story: they are clumsy and awkward. They are nearsighted, having eyes that are adapted for underwater vision.

Get It?
Describe some adaptations found in seabirds.



Reproduction Seabirds typically mate for life. Courtship, partner selection, and recognition by the mated pairs involve elaborate display behaviors, which include calls.

The male emperor penguin incubates a single large egg during the dark Antarctic winter. The female leaves to feed as soon as she lays the egg. The male, standing on ice, must keep the egg warm by holding it on top of his feet and against his body for 64 days. Males huddle together in huge groups to protect themselves from the cold and winter storms. Emperor penguins lay their eggs at the coldest time of the year so that the egg hatches during the productive Antarctic summer, when food is most plentiful. When the single egg hatches, the female finally returns and regurgitates food for the fuzzy chick. After that, both parents take turns feeding the chick. While the parents feed, the fast-growing young are herded into groups guarded by a few adult "babysitters." Returning parents identify their chick among thousands by its voice and appearance. The parents continue to feed the chick for
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contrast
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A threat
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their foo
depend
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their foo
images,
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Albatros
live for
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success

Regions where moist air of low density rises (0°, 60° N, and 60° S) are areas of low pressure that are characterized by clouds, rain, and high humidity. Latitudes where air sinks (30° N, 30° S, 90° N, and 90° S) have higher pressure, drier air, and clearer skies.

Section Review

1. **Illustrate** Draw a diagram that shows the layer of Earth's atmosphere. Include one fact about each layer of the atmosphere in your diagram.
2. **Explain** How do greenhouse gases warm the Earth?
3. **Identify** and describe the major wind patterns on Earth.

Use the Practices

Develop Models The atmosphere is made of four layers and separated by three boundaries. Because they are layered, they have different altitudes and temperatures. Create a graph which shows the layers of the atmosphere and each layer's altitude and temperature. Explain how the atmosphere plays a role in monitoring Earth's climate.

Get It? boxes that appear strategically in the text offer students the opportunity to pause and reflect on what they've just read, check for understanding, and reinforce their learning.

Use the Practices activities allow students to apply the Science and Engineering Practices—such as using models, asking questions, or analyzing data—to the content of each textbook section.

CHAPTER 6 Summary

6.1 The Ingredients of Life

Organisms are made up of four main groups of organic molecules that are responsible for body structure and performing basic life functions.

Key Questions

1. What are the four main types of organic molecules that make life possible?
2. What are the reactants and products of photosynthesis and cellular respiration?

Vocabulary

metabolism	epigenetic marker
homeostasis	photosynthesis
organic compound	chlorophyll
carbohydrate	carbon fixation
protein	autotroph
amino acid	heterotroph
enzyme	respiration
glycoprotein	anaerobic
lipids	aerobic
nucleic acid	primary production
genome	nutrient

6.2 Cellular Structure and Organization

All living things are made of cells and have levels of organization that range from atoms to ecosystems.

Key Questions

1. What are the differences between prokaryotic and eukaryotic cells?
2. What is the difference between a unicellular and a multicellular organism?

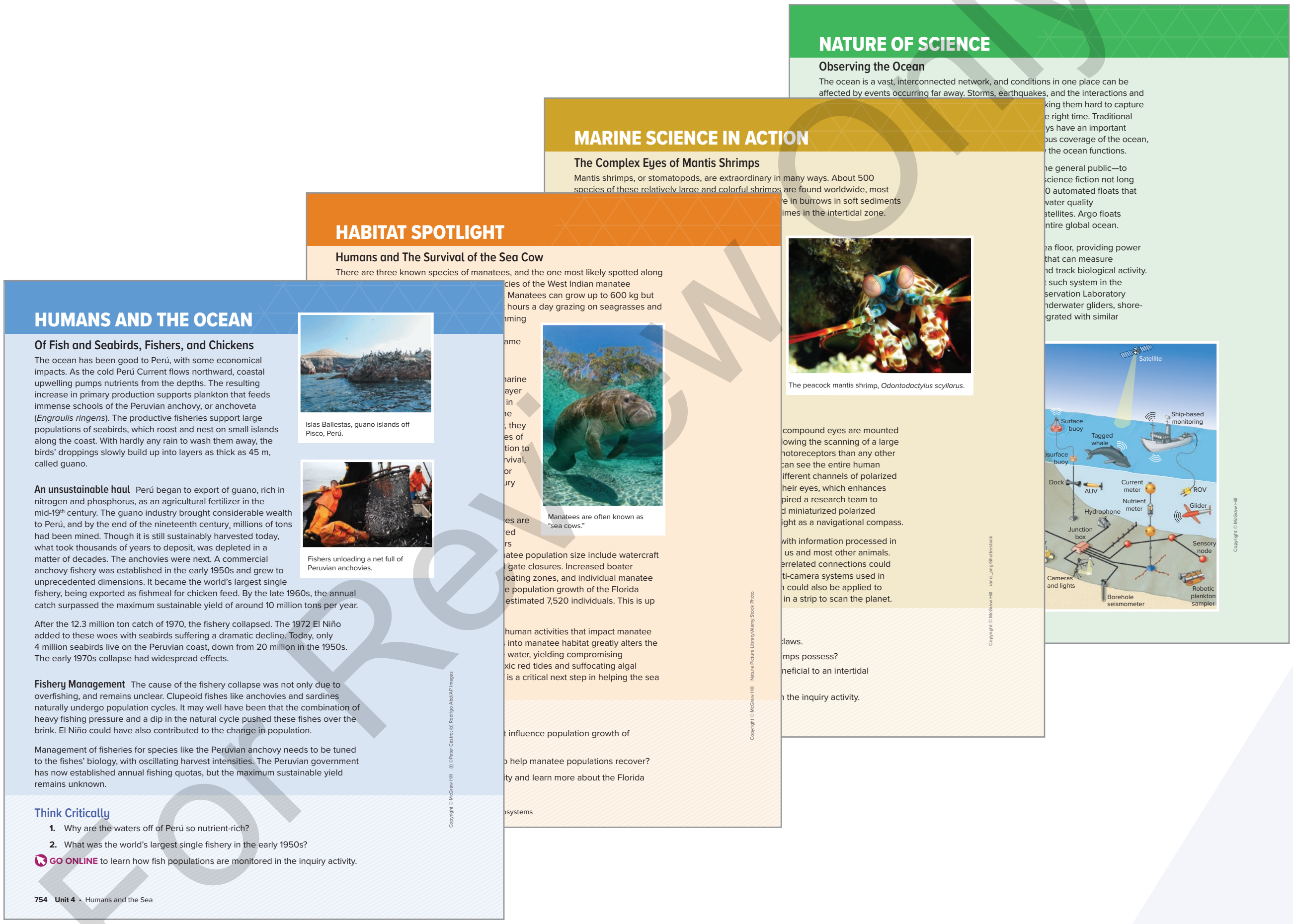
Vocabulary

cell	Golgi apparatus
cell membrane	vacuole
cytoplasm	mitochondrion
organelle	chloroplast
cytoskeleton	tissue
prokaryote	organ
cell wall	organ system
ribosome	population
eukaryote	species
nucleus	community
endoplasmic reticulum	ecosystem

A **Chapter Summary** revisits the chapter and includes the main idea, a reiteration of the key questions, and a list of key vocabulary words for each section.

Real-World Connections

Throughout the text there are four feature strands: **Nature of Science, Marine Science in Action, Habitat Spotlight,** and **Humans and the Ocean**. Each strand includes Think Critically questions and explores a unique topic in marine science such as habitats, human and ocean interaction, and other relevant areas of interest. Each of these features has a corresponding inquiry activity available online that allows students to expand upon and further explore what they have studied.



Think Critically

1. What biotic and abiotic factors most influence population growth of manatees?
2. What is one thing that you can do to help manatee populations recover?

GO ONLINE to access the inquiry activity and learn more about the Florida manatee.

Think Critically questions assess student understanding of the specific topic covered in the feature.

Engaging Visuals

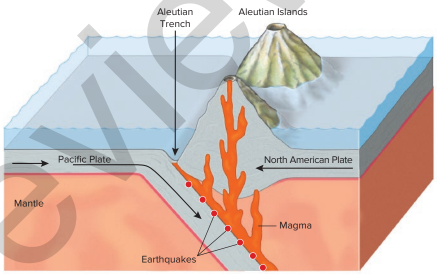
Vibrant and captivating visuals attract and engage students' attention, enhance instruction, support visual learners, and improve comprehension by illustrating or reinforcing the concepts in the text.

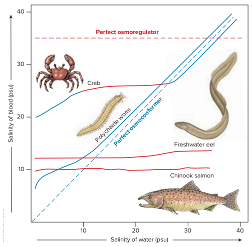
Figure 12.6 The whale shark (*Rhincodon typus*) feeds by straining plankton and small fish from huge mouthfuls of water. It has probably evolved its huge mouth and lost the large teeth of most other sharks not to avoid competition with other sharks but as adaptations for efficient plankton feeding.

Figure 6.3 The bull kelp (*Nereocystis luetkeana*) captures energy from the sunlight streaming down through the water to perform photosynthesis. The kelp uses this energy to grow. Other organisms eat the kelp, making use of the energy that originally came from the Sun.

Figure captions provide additional information and insight into content being addressed.

The **custom artwork** in *Marine Science* is a result of the collaboration between the authors, Peter Castro and Michael Huber, and Bill and Claire Ober. Together they've developed unique and specialized art, graphs, and maps that illustrate the key concepts, bring visual interest to the topics, and ensure accessibility for visual learners.

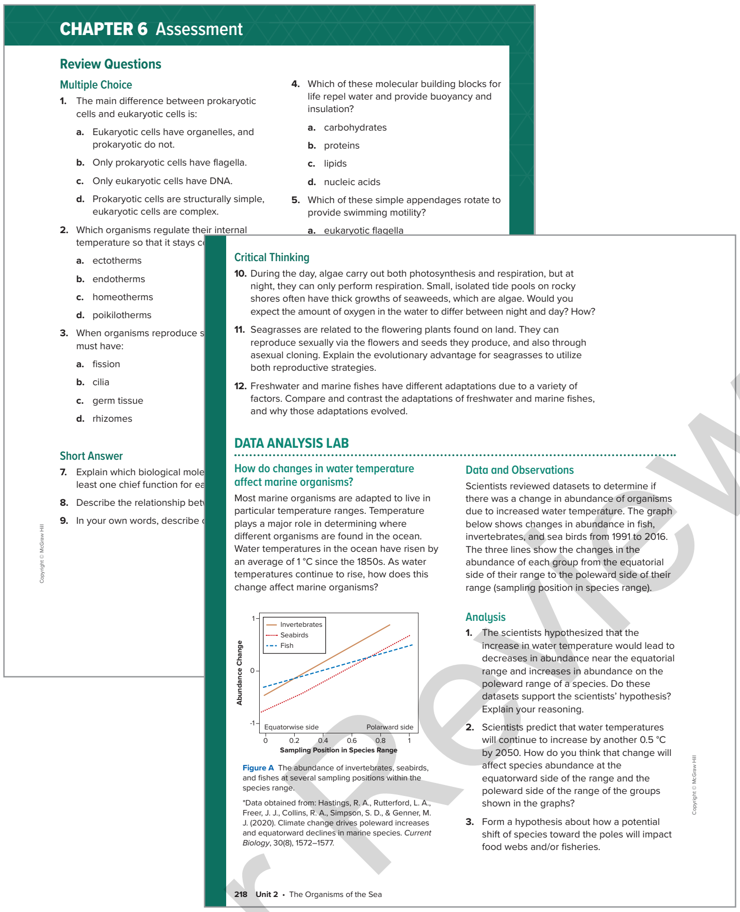




Awe-inspiring photos illustrating the natural world are presented throughout the book. Each unit and chapter opens with a compelling image that provides a visual preview of the topics covered in the unit or chapter. Each image was carefully chosen to enhance student learning of the material.

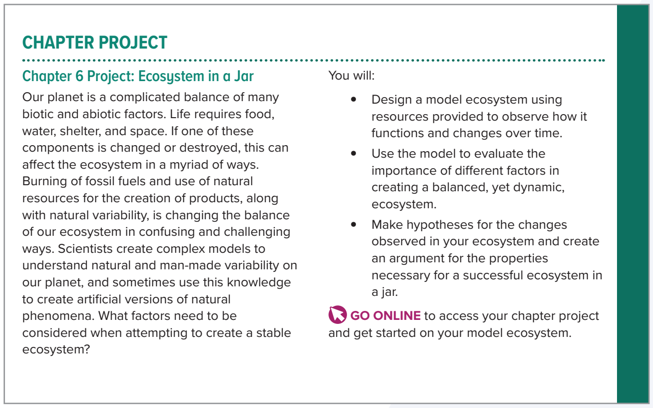
Powerful Assessment

The end-of-chapter **Assessment** helps students master the content and practices included in each chapter. Multiple-choice, short answer, and critical thinking questions ask students to recall and synthesize information covered in the chapter.



Each Chapter Assessment includes a **Data Analysis Lab**. These labs use real-world, current data and are directly related to the content covered in the chapter. Students must use the data provided to state claims, collect evidence, and defend their reasoning while answering questions. These labs are an excellent opportunity for students to develop their critical thinking, synthesis, and data analysis skills.

Each Chapter Assessment introduces the **Chapter Project**. This project asks students to apply the science and engineering practices they have learned about to explore in-depth a topic related to each chapter. Resources that students can use to complete the project are available in the online course that accompanies the Student Edition.



Best-in-Class
Digital Resources

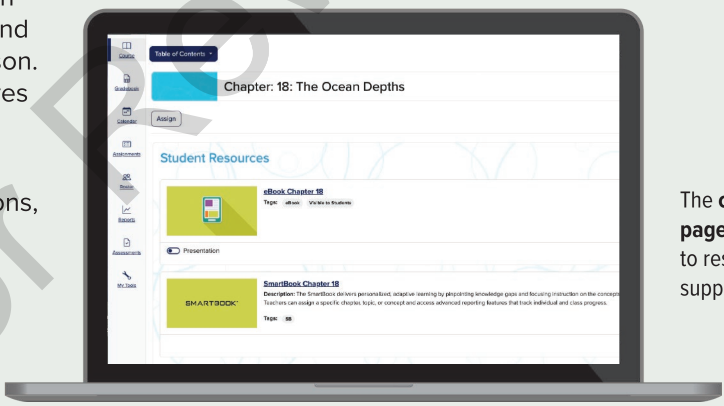
Marine Science **is enriched with multimedia content including videos, animations, and simulations that enhance the teaching and learning experience both inside and outside of the classroom.**

Authored by the world's leading subject matter experts and organized by unit and chapter level, the resources provide students with multiple opportunities to contextualize and apply their understanding. Teachers can save time, customize lessons, monitor student progress, and make data-driven decisions in the classroom with the flexible, easy-to-navigate instructional tools.

Student Assignments

Resources are organized at the unit and chapter level. To enhance the core content, teachers can add assignments, activities, and instructional aides to any lesson. The chapter landing page gives students access to:

- an interactive eBook, with embedded videos, animations, and interactivities;
- an adaptive *SmartBook*®;
- Unit and Chapter Projects;
- Lab Activities;
- Key Question and Inquiry Activities;
- Career Activities;
- and assessment and interactive questions.



The **chapter landing page** links students to resources that support success.

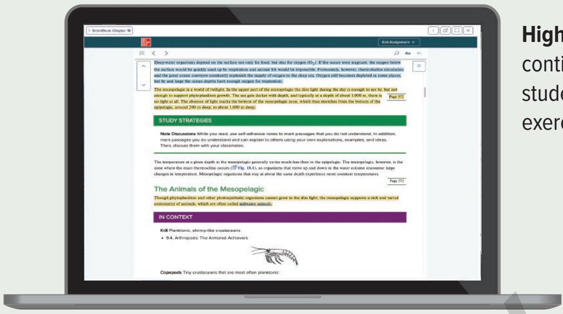
Mobile Ready

Access to course content on-the-go is easier and more effective than ever before with the McGraw Hill K-12 Portal App.

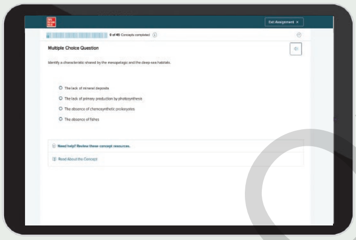
Adaptive Study Tools

SMARTBOOK® is an assignable, adaptive study tool. The interactive features personalize the learning experience with self-guided tools that:

- assess a student's proficiency and knowledge,
- track which topics have been mastered,
- identify areas that need more study,
- deliver meaningful practice with guidance and instant feedback,
- recharge learning with previously completed assignments and personalized recommendations,
- and allow teachers to assign material at the subtopic level.



Highlighted content continuously adapts as students work through exercises.



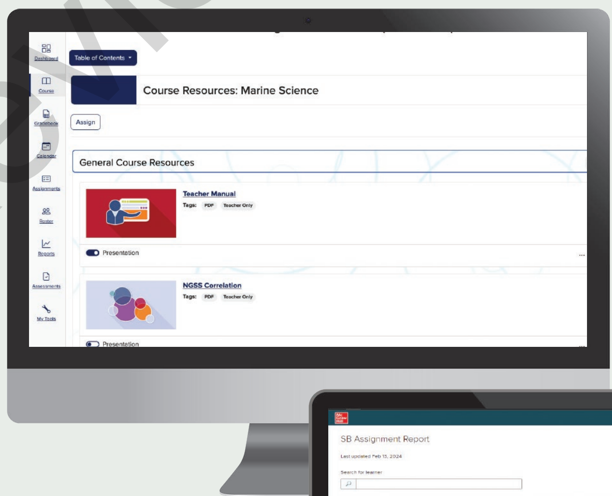
Practice questions measure depth of understanding and present a personalized learning path based on student responses.

Teacher Resources

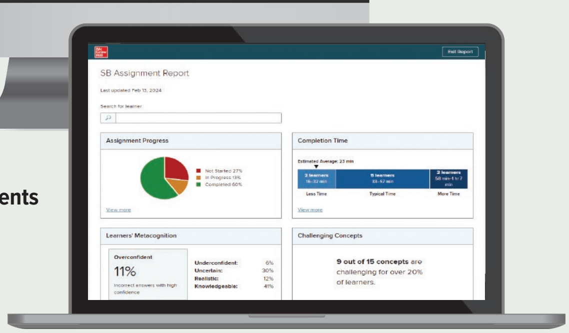
Teachers have access to the interactive eBook and adaptive *SmartBook*®, plus a wealth of customizable chapter resources and powerful gradebook tools.

Resources include:

- an online Teacher Manual with chapter outlines, teaching suggestions, reading strategies, and pacing guides;
- student performance reports to help teachers identify gaps, make data-driven decisions, and adjust instruction;
- customizable PowerPoint presentations;
- labeled diagrams, visual aids, animations, and additional ideas for lecture enrichment;
- and an online Laboratory Manual with alternative suggestions for the lab activities available in the Teacher Manual.



Searchable library makes it easy to find and assign resources.

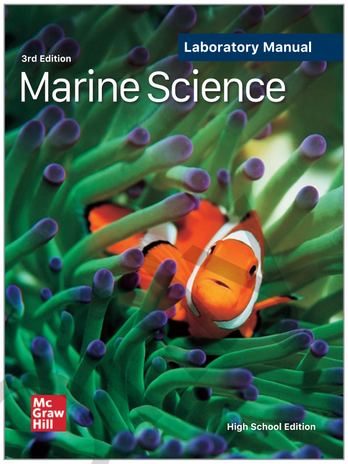


Customizable assignments and **quiz banks** are automatically graded and populate easy-to-read reports.

Harness technology and unlock success with the digital resources for Marine Science *by visiting my.mheducation.com.*

Supplementary Resources

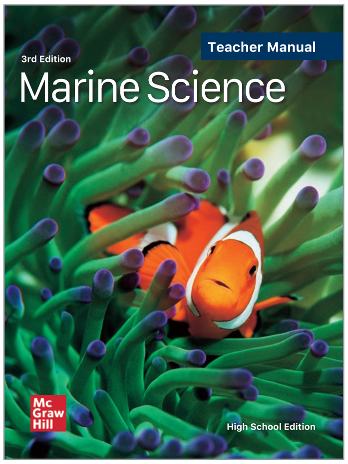
Marine Science Laboratory Manual



The *Marine Science Laboratory Manual* offers 42 labs ideal for any marine science classroom. No ocean needed! These labs are divided into two types: guided inquiry and open inquiry. Each lab is designed to be completed in one class period. The *Marine Science Teacher Manual* identifies the best time to use each lab and provides alternative material lists or procedures for activities to ensure that all teachers can assign these labs regardless of their budget. *Lab Manual Teacher Guides* are accessible online; they provide guidance for teachers on lab procedures as well as answers to the lab questions.

- **Material lists** are provided to help students and teachers prepare the lab and save time.
- Each lab begins with a **Problem** that sets up the purpose of the lab.
- Questions and charts help students demonstrate their takeaways from the lab.

Marine Science Teacher Manual



The *Marine Science Teacher Manual*, available in print and online, will help create and deliver a marine science course that engages students in the content and supports success in concept application and mastery. The manual provides:

- Strategies to introduce, teach, and assess for each chapter.
- Chapter-level and section-level activities including a more tactile/kinesthetic focus.
- Pacing for each chapter, including guidance on the most effective timing for labs.
- Differentiated instruction and EL support to address a variety of learning styles and needs.
- Answers to all Student Edition questions.

Additional online resources include:

- Auto-graded test banks.
- Animations that help explain complex topics and processes.
- Flashcards and Vocabulary Activities to build student vocabulary skills.
- Chapter and Unit Projects.
- Inquiry Activities that build upon the topics covered in the text's special features.
- Career Activities that expose students to different careers in marine science.
- PowerPoint slides with enhanced visuals to help teachers build dynamic presentations.
- A searchable resource library that makes it easy to quickly find, display, and assign resources.
- The powerful gradebook that provides real-time access to the student data teachers need to inform classroom instruction.

Acknowledgements

The illustrations were expertly done by Bill Ober and Claire Ober, who contributed their talent and knowledge to develop the artwork that was exclusively designed for *Marine Science*.

Unit 2

The Organisms of the Sea

Unit Project: Design A Solution

How do we solve complex problems? Global challenges are often too large and complex to address as a single problem. When viewed as collections of challenges that are smaller in scope, the grander problems can feel more approachable, with solutions more achievable. Some solutions might need simultaneous implementation, while others might need to be completed in a stepwise fashion.

GO ONLINE to design a solution to one of the many marine challenges currently facing society into a more approachable problem.

Marine Science Career Focus: The Business of Algae

As conventional fossil-based energy sources become scarce and the human population grows increasingly larger, scientists and engineers are racing to find options for fueling and feeding the world. Algae, organisms that many find to be a nuisance in their backyard pools, have beneficial qualities that make them a realistic answer to major problems that humanity is facing. Working with algae is one of the many growing areas of careers related to marine science. Because the use of algae is so varied, job opportunities are just as diverse. Working with algae might mean you are a researcher at a university, or it could mean you are a cosmetics designer, a chef, an algae farmer, a biofuel engineer, a nutritionist, a pollution mitigation technician, or even a chemist. As the business of algae continues to bloom, more jobs and options for working with algae will appear—it is truly a cutting-edge vocation.

GO ONLINE to explore a career in this area of marine science with a Career Focus Activity.

How do whales hear?

Studying the biology of marine tetrapods helps marine scientists identify how these predominately land animals have adapted to life in the oceans.

CONTENTS

Theme: Patterns

Reptiles, birds, and mammals show adaptations that allow them to occupy many environments both in the ocean and on land.

The Ripple Effect

How does noise pollution affect whales? While most countries no longer allow whaling, whales are still impacted by human activities. They are particularly sensitive to human-made sounds. Sound can travel vast distances across the oceans, and whales use sound to communicate, find prey, and navigate. Human-generated sounds, such as those from shipping, construction, or oil drilling, can damage whale's hearing if they are too close, drown out the sounds that whales need to communicate, or stress and confuse the whales. Government bodies now regulate activities to reduce man-made sounds that impact whales. For example, construction activities sometimes use a "soft start" to warn marine life in the area. By the time the construction ramps up to a noise level that could injure a whale, most whales have already left the area.

CER Claim, Evidence, Reasoning

Make Your Claim	Collect Evidence	Explain Your Reasoning
Use your CER chart to make a claim about how sound pollution may affect other marine reptiles, birds, and mammals.	Use the lessons in this chapter to collect evidence to support your claim. Record your evidence as you move through the chapter.	You will revisit your claim and explain your reasoning at the end of the chapter.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

11.1 Marine Reptiles

Key Questions

1. What are the main characteristics of reptiles?
2. Differentiate between the terms *ectotherm, endotherm,* and *poikilotherm*.

Study Strategy

Interactive Reading As you read, write three questions on sticky notes about marine reptiles. The questions should begin with why, how, where, or when. Use the notes to ask a partner questions about the content in the section.

What Are Tetrapods?

As you learned in Chapter 10, fishes represent the first vertebrates, and it was a fish-like ancestor which gave rise to **tetrapods**—meaning “four-footed” animals with two pairs of limbs. Tetrapods arose from the oceans and populated the terrestrial environment. Having adapted to the land, various groups of reptiles (class Reptilia), birds (class Aves), and mammals (class Mammalia) turned around and reinvaded the ocean. This chapter deals with these marine tetrapods (see Fig. 11.1). The marine animals to be covered in this chapter include some of the most fascinating and awesome creatures on the planet. Unfortunately, many are in danger of disappearing. Some already have become extinct.

Diversity of Marine Reptiles

There are around 7,000 living species of reptiles, including lizards, snakes, turtles, and crocodiles. Most reptiles are adapted to live on land: their dry skin is covered with scales to prevent water loss. Their eggs have a leathery shell that prevents them from drying out, so reptiles can lay their eggs on land. All reptiles are air-breathing. They first appeared roughly 350 million years ago, and several different groups have invaded the seas. Many are long gone, like the ichthyosaurs that thrived in the oceans during the so-called Age of Reptiles. Only a few reptiles still roam the seas.

Sea Turtles Sea turtles belong to an ancient group of reptiles. Their bodies are enclosed by an armor-like shell, or carapace, that is fused to the backbone. Unlike land tortoises and turtles, sea turtles cannot retract their heads into the shell. Their legs, particularly the larger forelimbs, are modified into flippers for swimming.

There are only seven species of sea turtles (though some biologists recognize eight), which live primarily in warm waters. Green turtles (*Chelonia mydas*) were once common in coastal waters throughout the tropics, but like all species of sea turtles, their numbers have drastically declined due to overexploitation and increased mortality. Their shells can grow to 1 m in length. They feed mostly on seagrasses and seaweeds. Like all turtles, green turtles lack teeth, but they have strong biting jaws. The hawksbill turtle (*Eretmochelys imbricata*; see Fig. 11.2a) is smaller, and the shell is reddish brown with yellow streaks. It uses its beak-like mouth to feed on encrusting animals (sponges, sea squirts, barnacles) and seaweeds.

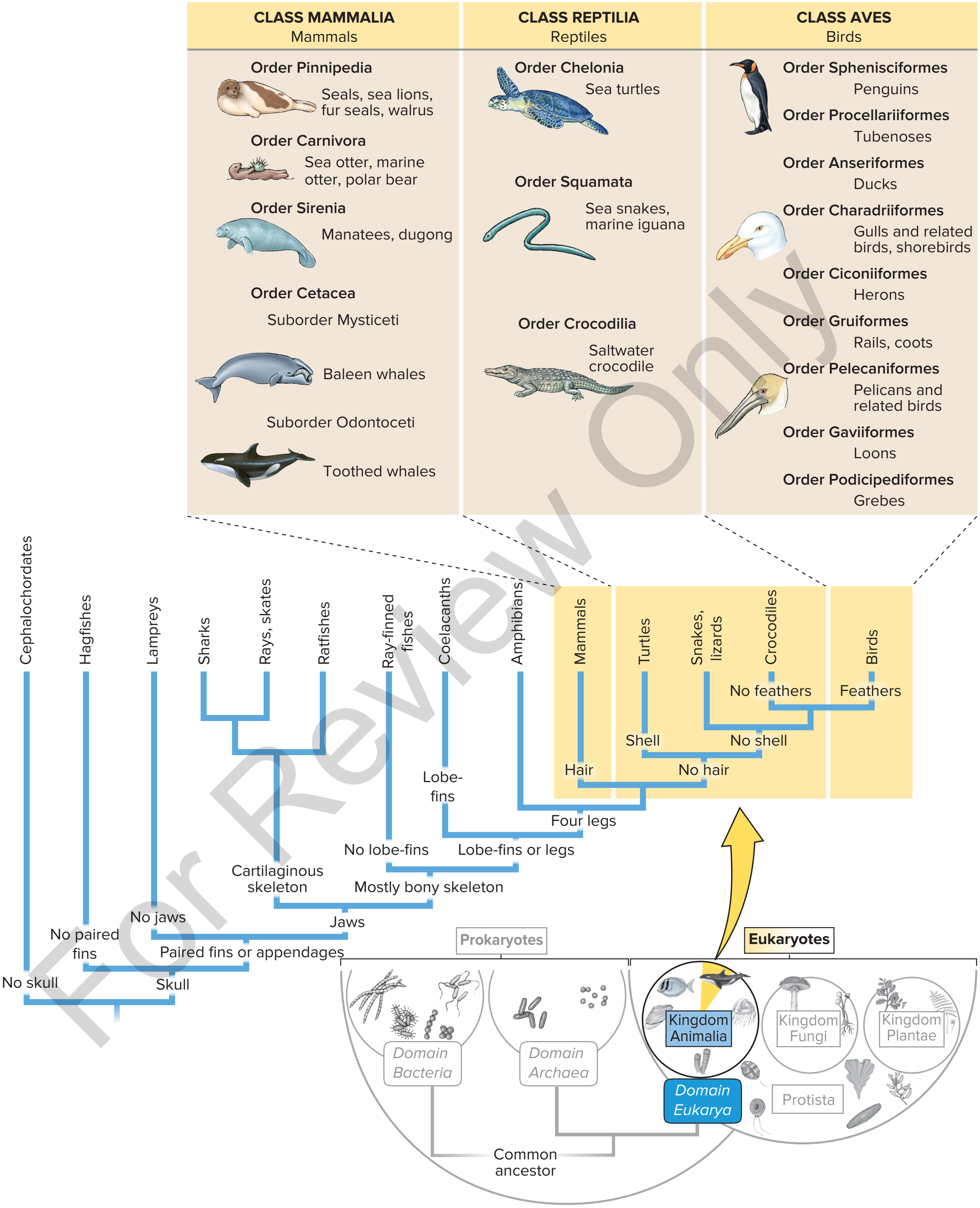
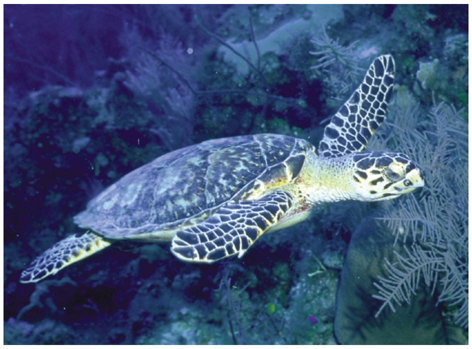


Figure 11.1 Evolutionary relationships and the classification scheme for the groups of organisms in Kingdom Animalia. Highlighted are Class Mammalia (mammals), Class Reptila (reptiles), and Class Aves (birds).

Source: Bill Ober



(a)

(b)

Figure 11.2 (a) The hawksbill turtle (*Eretmochelys imbricata*) takes its name from the shape of its jaw. It is the source of tortoiseshell. (b) The largest of all sea turtles, the leatherback turtle (*Dermochelys coriacea*), is found worldwide and sometimes ventures into cold waters as far north as Newfoundland and Alaska.

The largest sea turtle is the leatherback (*Dermochelys coriacea*; Fig. 11.2b). Individuals can attain a length of nearly 3 m and weigh 900 kg. Instead of a solid shell, they have a series of small bones buried in the dark skin, forming seven distinct longitudinal ridges. Leatherbacks are the widest ranging of all marine reptiles, live in open water, and are rarely seen except on nesting beaches. They are deep divers—one individual was tracked diving to 640 m. Their diet consists largely of jellyfishes.

The remaining species of sea turtles have diverse diets, like the flatback sea turtle (*Natator depressus*) of northern Australia, which feeds on sea cucumbers, soft corals, and other invertebrates. Other sea turtles feed on soft, bottom invertebrates as well as hardier ones like crabs and molluscs. The jaws of most species are adapted for crushing. The leatherback jaws, however, are scissor-like to capture jellyfishes.

Sea Snakes About 70 species of sea snakes are found in the tropical Indian and Pacific oceans (Fig. 11.3). Most are 1 to 1.3 m long. Practically all sea snakes lead a totally marine existence, lacking the belly scales that allow land snakes to move. Like all snakes, sea snakes are carnivores. Most feed on eels and other bottom fishes, but a few specialize on fish eggs, one species on bottom invertebrates.

Sea snakes are closely related to cobras and their allies, the most venomous of all snakes. Sea snake bites can be fatal to humans. Fortunately, they are rarely aggressive, and the mouth is too small to get a good bite. Most casualties are from swimmers accidentally stepping on them and fishers removing them from nets. Sea snakes are also victims of overexploitation. They are hunted for their skins and meat, and some species have become rare in certain areas.

Figure 11.3 The conspicuous coloration of sea snakes could be a warning to potential predators because many fishes learn to associate the bright colors with danger.

Other Marine Reptiles An unusual lizard is among the unique inhabitants of the Galápagos Islands off the Pacific coast of South America. The marine iguana (*Amblyrhynchus cristatus*; Fig. 11.4) spends most of its time basking in large groups on rocks along the coast, warming up after swimming in the cold water. It eats seaweeds and can dive as deep as 10 m to graze.

Figure 11.4 Though seemingly awkward on land, the marine iguana of the Galápagos Islands (*Amblyrhynchus cristatus*) is an elegant swimmer under water. It swims by undulating the body and the laterally flattened tail, the tip of which is shown on the bottom left.

Another marine reptile is the saltwater crocodile (*Crocodylus porosus*), which inhabits mangrove swamps and estuaries in the eastern Indian Ocean, Australia, and some of the western Pacific islands. Saltwater crocodiles are also found in rivers but are known to venture into the open sea. There is a record of an individual 10 m long, but they are rarely over 6 m. They are among the most aggressive of all marine animals and do attack and eat humans. Where they occur, they are more feared than sharks.

The American crocodile (*Crocodylus acutus*) is also considered a marine species. Although it lives mostly in fresh water, it tolerates seawater and can be found in lagoons, river mouths, and other coastal areas in Florida, the West Indies, and on the Pacific and Atlantic coasts of Central America and northern South America. It has also been recorded in the open ocean.

Biology of Marine Reptiles

Most of today's reptiles are adapted to life on land. The oceans present an entirely different set of challenges and require different strategies and adaptations, particularly for locomotion and reproduction.

Thermoregulation Like most fishes and all land reptiles, marine reptiles are poikilotherms because their body temperature varies with that of the environment. With the exception of the leatherback turtle, marine reptiles are ectotherms because they lose most of their metabolic heat to the environment to match their body temperature with the external temperature. Like other poikilotherms, metabolic rate of marine reptiles—and therefore activity level—varies with temperature so they get sluggish in the cold. This tends to keep reptiles out of cold regions, especially on land because the air temperature fluctuates more widely than does the ocean temperature.

InContext

Poikilotherms Organisms where their internal body temperature changes with the temperature of their surroundings.

Ectotherms Organisms in which metabolic heat is lost to the environment and does not raise body temperature.

- Introduced in Section 6.5, Challenges of Life in the Sea

A remarkable exception is the leatherback turtle, which can venture into cold water because of its ability to keep a body temperature higher than that of the surrounding water, which makes it an endotherm. Heat loss is reduced by transferring body heat back to the body by means of a network of blood vessels in the flippers as in the muscles of tunas and other fishes, by being large with a comparatively small surface area, and by storing fat for insulation.

Swimming and Diving Sea turtles, although slow on land, are fast swimmers in water. They use their flattened, flipper-like forelimbs to propel them through the water, while the smaller, paddle-shaped back limbs are mostly used for steering. The heavy shell is streamlined and flattened, but bones are spongy and the accumulation of fat further helps in buoyancy. While most sea turtles are shallow divers, leatherbacks have been tracked diving more than 1,000 m.

Get It?
What characteristics make sea turtles fast swimmers?

The bodies of sea snakes, which are not particularly fast swimmers, are laterally flattened and the tail paddle-shaped for swimming. A similar adaptation is observed in the marine iguana, a stronger swimmer, where the tail is laterally flattened.

Reproduction All sea turtles must return to land to reproduce. After breeding, they typically migrate long distances to lay their eggs on remote or natal sandy beaches, and they have been doing so millions of years before humans appeared on the scene. Green turtles still gather to nest on beaches on the Caribbean coast of Central America, Northern Australia, Southeast Asia, Ascension Island (in the middle of the South Atlantic), and a few other locations.

Marine biologists have tagged adult sea turtles at Ascension Island and have found that the turtles regularly cross 2,200 km of open water from their feeding grounds along the coast of Brazil, a journey that takes a little more than two months. Loggerhead turtles travel as much as 14,500 km between feeding and nesting grounds, and leatherbacks have been tracked as traveling as much as 17,614 km. Green sea turtles (*Chelonia mydas*) near the Red Sea will migrate up to 1,100 km to reach feeding grounds after nesting. Researchers use satellite tracking tags attached to shells and telemetry to investigate migrations. There is evidence that turtles navigate by sensing Earth's magnetic field.

InContext

Endotherms Organisms in which metabolic heat is retained within the body and raises body temperature.

- Introduced in Section 6.5, Challenges of Life in the Sea.

Green turtles return to their nesting areas every two to four years. Copulating pairs of sea turtles are often seen offshore, but only females venture ashore, usually at night. Biologists have mostly tagged females because they can be tagged most easily on land. Evidence that females return to the beaches where they were born has been obtained by analyzing the DNA of breeding populations at sites around the world. The DNA of turtles breeding in one area differs from the DNA of turtles breeding at other sites, indicating turtles keep returning to the same place generation after generation.

The females congregate on the beach, and each excavates a hole in the sand using both pairs of flippers (Fig. 11.5). They lay between 100 and 200 large, leathery eggs in each nest. Molecular studies have demonstrated the multiple paternities of offspring in single clutches of eggs in green turtles and other sea turtles. The female covers the eggs with sand before she returns to the sea. She can make several trips ashore during the breeding season, laying eggs each time.

The eggs hatch after about 60 days of incubation in the sand. The baby turtles must then dig themselves out of the sand and crawl all the way back to the water, protected by darkness if they're lucky. Sea turtle eggs are often eaten by dogs, ghost crabs, wild pigs, and other animals. The hatchlings are easy prey for land crabs and birds, especially during the day. Even more, young turtles are lost in the water, where they are taken by fishes and seabirds.

Figure 11.5 Egg laying in the olive ridley turtle (*Lepidochelys olivacea*) culminates a long and hazardous trip by females. It is at this time that they are most vulnerable. This photograph was taken on the Pacific coast of Costa Rica.

Sea turtles, as in many other reptiles, show **temperature-dependent sex determination**. Almost all eggs incubated at lower temperatures, as in nests covered by vegetation or nests built in light-colored sand, hatch as males; most of those incubated at higher temperatures hatch as females. There are concerns that a global temperature rise could seriously affect sex ratios in sea turtles and other marine reptiles, increasing pressure on already threatened or endangered species. The proportion of female green turtles has already sharply increased in the northern Great Barrier Reef, Australia.

Some sea snakes form large groups while reproducting. They mate in the ocean. Males have two copulatory organs for internal fertilization. Sea snakes are ovoviviparous (the eggs develop inside the mother) who gives birth to live young. A few species, however, still come ashore to lay their eggs. There is evidence that, in contrast to other marine reptiles, the offspring in each sea snake brood share the same father. Female marine iguanas burrow their eggs in sand, as many as six in the larger females and, like sea turtles, abandon their nests after a short time.

MARINE SCIENCE IN ACTION

The Endangered Sea Turtle

Humans directly and indirectly impact sea turtle populations in several ways. Turtles are directly exploited as well as suffer from the effects of climate change, habitat destruction, and overfishing.

The green turtle (*Chelonia mydas*).

Exploitation In the days before refrigeration, sailors kept sea turtles aboard ships as a source of fresh meat but even today, thousands of sea turtles are illegally killed every year for meat and eggs. The green turtle in particular is hunted for turtle soup. Hawksbill turtles are collected for their shells which can be used to make jewelry, combs, and more out of "tortoiseshell." Baby sea turtles are taxidermied and sold as souvenirs. Sea turtle leather, which is soft and durable, is prized for shoes, boots, handbags, and wallets. Sea turtle oil is also used in cosmetics.

Habitat Degradation Many turtle nesting areas have been developed into resorts or public beaches. The lights from these beaches confuse nesting females and disorient hatchlings, extending their time on land and increasing susceptibility to predators. Fishing also impacts sea turtles as turtles become tangled in gill and drift fishing nets and drown. Shrimp nets alone are estimated to kill thousands of sea turtles each year and are especially deadly to the Kemp's Ridley turtle in the Gulf of Mexico. Many turtles also choke to death after swallowing plastic bags they think are jellyfishes.

Conservation The six species of sea turtles found in United States waters are protected under the Endangered Species Act of 1973. Four species are officially classified as endangered: the leatherback, hawksbill, Kemp's Ridley, and the green sea turtle. The number of green turtles has been increasing in some areas, undoubtedly the result of protection. Shrimp nets in the United States are required to have turtle exclusion devices, or TEDs, to allow for escapement if trapped. Stricter worldwide enforcement of fishing and conservation practices, establishment of reserves and national parks to protect nesting beaches, control of pollution, restocking of former nesting areas, and regulation of trade in sea turtle products might help save them.

Think Critically

1. Why are turtles harvested from the wild?
2. Besides harvesting, how do humans harm sea turtles?
3. What are TEDs?

GO ONLINE to access the inquiry activity and learn about sea turtle migration.

Section Review

1. **Summarize** Make a table which summarizes the basic characteristics of the different groups of marine reptiles and provide an example of each.
2. **Discuss** What are the similarities and differences in reproduction in sea turtles, sea snakes, and marine iguana?

Use the Practices

Define Problems Sea turtles are poster animals for the negative impacts human activities have on marine habitats. Describe one direct way in which humans harm sea turtle populations and one indirect way human activities negatively affect sea turtle populations.

11.2 Seabirds

Key Questions

1. What is the definition of "seabird"?
2. What are the main characteristics of seabirds?

Study Strategy

Summaries Review the Biology of Seabirds section in this chapter. Choose two key adaptations and write two sentences that summarize the information.

What Are Seabirds?

Most biologists agree that birds are actually reptiles, having evolved from the same line that includes dinosaurs and crocodiles. Here, however, we follow the traditional classification of placing reptiles and birds in separate classes. Most living birds have the ability to fly, and in contrast to living reptiles, their bodies are covered with waterproof feathers that help conserve body heat. Waterproofing is provided by oil from a gland above the base of the tail, and birds rub the oil into their feathers with their beaks during preening. Flight is made easier by their light, hollow bones. Their eggs have hard shells that are more resistant to water loss than those of reptiles.

Seabirds are birds that spend a significant part of their lives at sea and feed on marine organisms. Most breed in large colonies on land, and often build their nests on the ground, sometimes traveling long distances to get food.

Diversity of Seabirds

Though comprising only about 3% of the estimated 9,700 species of birds, seabirds are distributed worldwide, and their impact on marine life is significant. Most are predators of fishes, squids, and bottom invertebrates, but some feed on plankton. Seabirds have amazing appetites, needing a lot of food to supply the energy required to maintain their body temperature. Seabirds evolved from several groups of land birds. As a result, they differ widely in their flying skills, feeding habits, and ability to live away from land.

Penguins Of all seabirds, penguins (see Fig. 11.6a) are the most radically adapted to live at sea. They are flightless, with wings modified into stubby flippers that allow them to "fly" underwater. All but one of the 18 species of penguins live primarily in Antarctica and other cold temperate regions of the Southern Hemisphere. The exception is the Galápagos penguin (*Spheniscus mendiculus*), which lives right on the Equator. Even so, this penguin is confined to regions in the Galápagos that are bathed by cold currents.

The larger penguins, like the imposing emperor penguin (*Aptenodytes forsteri*; see Fig. 11.6a), hunt for fish and squid. The Adélie (*Pygoscelis adeliae*) and other small penguins feed mostly on krill. Penguins have strong beaks, a characteristic of seabirds that feed on fish and large plankton like krill (see Fig. 11.7b). Some species migrate seasonally between feeding grounds at sea and nesting areas on land or ice. They establish breeding colonies, which in Adélies can number more than a million pairs.

(a)

(b)

(c)

(d)

(e)

Figure 11.6 (a) An emperor penguin (*Aptenodytes forsteri*) and chick. (b) A brown booby (*Sula leucogaster*) nesting in the Caribbean (c) The gannet (*Morus bassanus*) is the largest seabird in the North Atlantic. (d) The black-browed albatross (*Thalassarche melanophrys*) breeds mostly on the Falkland Islands. (e) The Atlantic puffin (*Fratercula arctica*) build their nests on islands in the North Atlantic.

Tubenoses The tubenoses comprise a large group of seabirds with distinctive tube-like nostrils and heavy beaks that are usually curved at the tip (Fig. 11.7a). They spend months and even years on the open sea. Like other seabirds and sea turtles, they have **salt glands** that empty into the nostrils and get rid of excess salts. Tubenoses include the albatrosses (*Thalassarche*; Fig. 11.6d), shearwaters, and petrels (*Pterodroma*; see Fig 11.7a).

Tubenoses are very skillful fliers, often seen flying low over the water. Most catch fish at the sea surface (see Fig. 11.7a), though some, like the giant petrel, scavenge on dead birds or whales. The whalebirds, or prions, feed on krill and other plankton. Albatrosses are magnificent gliders with huge wings that hardly ever seem to flap. They are among the most efficient fliers in the world, allowing them to fly very long distances in search of food. The wandering albatross (*Diomedea exulans*) has wingspans of up to 3.4 m, the largest of any bird alive.

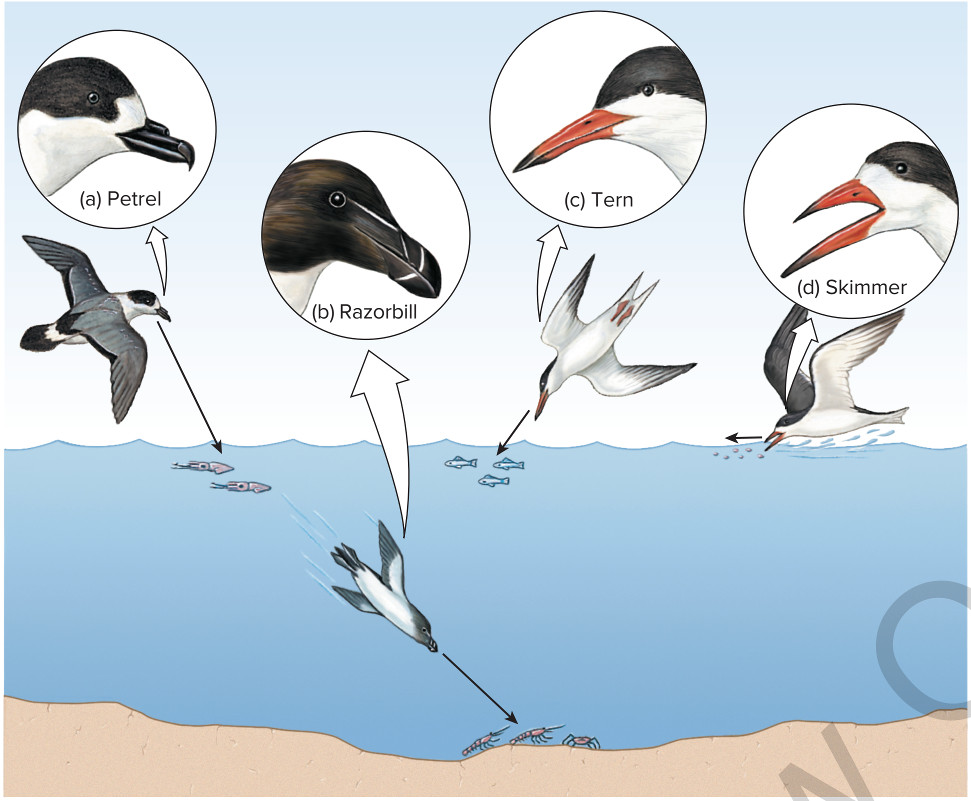


Figure 11.7 The shape of a seabird's beak is related to the bird's food and its feeding style. (a) In petrels (*Pterodroma*) the beak is relatively short, heavy, and hooked for holding and tearing prey that is too big to be swallowed whole. (b) The beak is more streamlined in razorbill (*Alca*) for diving deeper to feed on crustaceans and other prey. (c) Terns (*Sterna*) are plunge divers with a straight and narrow beak for feeding on fish that are swallowed whole. (d) Skimmers (*Rynchops*) are the only birds with a lower beak that is longer than the upper, which permits feeding while flying.

Tubenoses make some of the most spectacular migrations of any animal. Many breed on islands around Antarctica, then migrate across the open ocean to summer feeding grounds near the Arctic. The wandering albatross gets its name from the fact that it spends two years or more traveling, taking advantage of the strong winds that blow across the Southern Ocean, before returning to nesting sites near Antarctica. Some non-breeding individuals wander off and pay visits as far away as California and the Mediterranean.

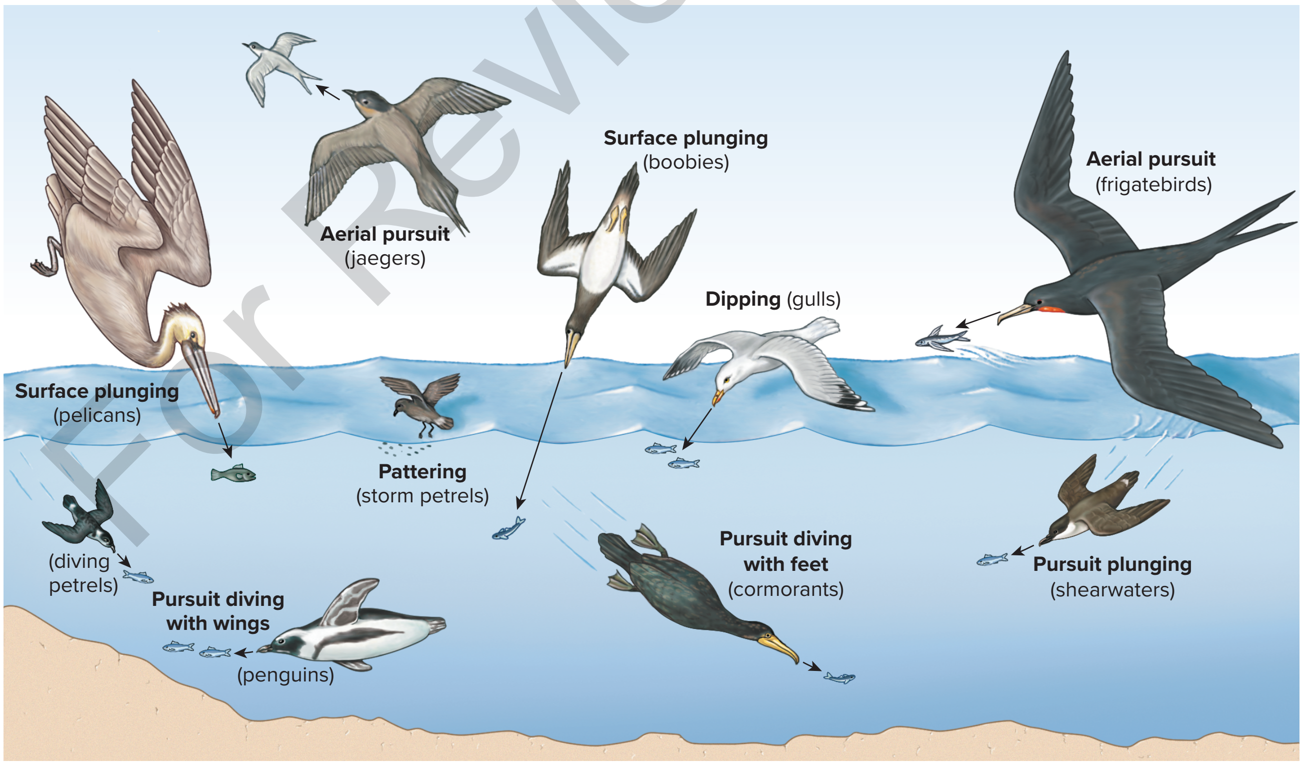
Most species of albatrosses are threatened or endangered as a consequence of increased mortality resulting from longline fishing coupled with their slow reproductive rate. Pairs breed every two years because it takes almost a year to rear a single chick.

Pelicans and Related Seabirds Pelicans (*Pelecanus*) have a unique pouch below their large beaks that are used as nets for fishing. Some species, like the brown pelican, feed by plunging into the water and catching fish in the pouch. The brown pelican was once common along the coasts of the United States but was decimated by pesticide pollution. It has made a comeback as a result of restrictions on the manufacture and use of the pesticide DDT.

Cormorants (*Phalacrocorax*; Fig. 11.8) are long-necked, usually black, seabirds that dive and pursue their prey. About 40 species are recognized, some known as shags. Cormorants can be easily identified by their low flights over water and the fact that they float low in the water, with only the neck above the surface. The Galápagos cormorant (P. *harrisi*), however, is flightless. Cormorants are generally seen ashore in a spread-wing resting position; scientists believe this posture allows them to dry their feathers.

Frigatebirds have narrow wings and a long, forked tail. They soar majestically along the coast, forcing other seabirds to regurgitate fish in midair or catching prey from the surface, such as fish chased out of the water by other predators (Fig. 11.8). These agile pirates rarely, if ever, enter the water, not even to rest, because their feathers are not very waterproof. They can fly for days, once recorded as long as 63 days, without rest! They soar with the air that rises under cumulus clouds and glide downwards to feed, hardly moving their wings. They do manage to sleep while flying, with one or both sides of their brains asleep for short intervals.

Gulls and Related Seabirds Gulls (*Larus*) and their relatives make up the largest variety of seabirds. Common and widespread, gulls are predators and scavengers happy to eat just about anything (Fig. 11.8). They are very successful in the company of humans and congregate near piers and garbage dumps. Jaegers and skuas are gull-like predators that steal fish from other birds (Fig. 11.8). They nest near the rookeries of penguins and other seabirds and eat their eggs and young.



Source: Bill Ober

Figure 11.8 Feeding strategies vary widely among seabirds. Pelicans (*Pelecanus*) and boobies (*Sula*) plunge from the air into the water, jaegers (*Stercorarius*) pursue other seabirds and force them to regurgitate food, and frigatebirds (*Fregata*) take fish from the surface and steal fish from other seabirds. Gulls (*Larus*) rarely plunge from the air, and storm petrels (*Oceanodroma*) simply flutter over the waves. Divers like cormorants (*Phalacrocorax*) pursue prey under water.

Terns (*Sterna*; see Fig. 11.7c) are graceful flyers that hover over their prey before plunging. Their slender beaks are specialized to catch small fish, which they swallow whole. The Arctic tern is another amazing wanderer. It breeds in the Arctic during the northern summer and can travel an average of 70,800 km, to Antarctica for the southern summer, and then returns to the Arctic.

Also related to gulls are several cold-water diving seabirds. Puffins (*Fratercula*, see Fig. 11.6e) have heavy beaks similar to those of parrots. The related razorbill (*Alca*) is a black and white bird reminiscent of penguins (see Fig. 11.7b). Like penguins, they use their wings to swim under water. Their extinct cousin, the great auk (*Pinguinus impennis*), looked and acted like a penguin. Great auks once lived in great numbers in the North Atlantic but were slaughtered for their eggs, meat, and feathers. The last great auk died in 1844.

Shorebirds Many species of wading shorebirds, most of which do not have webbed feet and do not swim much, are not seabirds in the strict sense. Some are common in estuaries and coastal marshes. Plovers, sandpipers, and similar birds are related to gulls (see Fig. 11.15). Many other shorebirds live on the coast: rails, coots, herons, egrets, and ducks.

Biology of Seabirds

Seabirds have several key adaptations that allow them to thrive in the marine environment, such as maintaining a stable internal temperature, the presence of feathers, and flight.

Thermoregulation Birds are homeotherms, commonly referred to as “warm-blooded.” They are also endotherms. This has allowed seabirds, in contrast to marine reptiles, to swim and dive in a wide variety of marine environments, mostly along coasts. Seabirds have a variety of adaptations to maintain their body temperature. For example, Antarctic penguins do not freeze when out of the water. Water within the feathers is squeezed out rather than staying in and freezing. Oil from the oil glands also helps to repel the water and keep it away from the bird’s body.

Swimming and Diving Penguins are spectacular swimmers, propelling their streamlined bodies with powerful strokes of the wings (see Fig. 11.8). Like all true seabirds, penguins have webbed feet for swimming. Their bones are denser than those of other birds to reduce buoyancy and to make diving easier. They exhibit countershading and have a layer of fat under the skin and closely packed feathers. The dense, waterproof feathers trap air that, warmed by body heat, protects against the cold like a down coat. They can also jump out of the water and sometimes cover long distances by alternately swimming and jumping. They breathe air while jumping out of the water, with the efficiency of oxygen intake increased by air continuously flowing, in addition to the lungs, through air sacs characteristic of all birds.

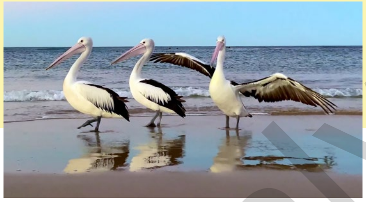
InContext

Homeotherms Organisms able to keep their body temperature more or less constant regardless of the temperature of the environment.

Emperor penguins have been known to dive over 200 m deep. As in marine mammals, penguins have a high number of **erythrocytes**, or red blood cells, which have a high concentration of hemoglobin, their muscles contain high amounts of myoglobin to store additional oxygen, and their heart rate is reduced to cut down oxygen consumption while diving. On land it is another story: they are clumsy and awkward. They are nearsighted, having eyes that are adapted for underwater vision.

Get It?

Describe some adaptations found in seabirds.



Reproduction Seabirds typically mate for life. Courtship, partner selection, and recognition by the mated pairs involve elaborate display behaviors, which include calls.

The male emperor penguin incubates a single large egg during the dark Antarctic winter. The female leaves to feed as soon as she lays the egg. The male, standing on ice, must keep the egg warm by holding it on top of his feet and against his body for 64 days. Males huddle together in huge groups to protect themselves from the cold and winter storms. Emperor penguins lay their eggs at the coldest time of the year so that the egg hatches during the productive Antarctic summer, when food is most plentiful. When the single egg hatches, the female finally returns and regurgitates food for the fuzzy chick. After that, both parents take turns feeding the chick. While the parents feed, the fast-growing young are herded into groups guarded by a few adult "babysitters." Returning parents identify their chick among thousands by its voice and appearance. The parents continue to feed the chick for five-and-a-half months, until it is strong enough to feed itself at sea (Fig. 11.6a). In contrast, Adélies and other Antarctic penguins lay their eggs, typically two, during summer.

A threat to penguins is the reduction of Antarctic sea ice, a result of global climate change. Populations have been declining since 1986, correlated with a decline in their food, krill, which depend on algae that grow under ice. Emperor penguins depend on the ice to breed and escape from predators. There has also been a drop in the populations of some species of penguins correlated with a decline in their food, krill, which depend in part on minute algae that grow under ice. Satellite images, however, have revealed previously unknown colonies of emperor penguins.

Albatrosses and other tubenoses take a long time to reach sexual maturity, but also live for many decades, 50 year or more in albatrosses. Most return to nest on the same wind-swept, remote islands that are inaccessible to predators. Male and female remain faithful to each other and perform particularly elaborate courtship and greeting behaviors. Incubation in the albatrosses lasts from 70 to 80 days, even longer in the large-size species. They feed the young regurgitated food. The overall investment in reproduction is great so they typically do not lay eggs in successive years.

Pelicans nest in large colonies along the coast, where space can be limited. As in many other seabirds, they typically lay fewer eggs than land birds do, and their broods are reduced when less food is available. The messy nests are made of twigs and anything else they can find. The excrement of millions of pelicans, boobies (see Fig. 11.6b), cormorants, and other seabirds accumulates as **guano**. Guano deposits are particularly thick in dry coastal regions and islands near very productive waters like the coasts of Perú and southwest Africa. These deposits are mined for fertilizer.

Section Review

1. **Identify** What are the different groups of seabirds and what characterizes each group?
2. **Describe** What are the general characteristics of reproduction in seabirds?

Use the Practices

Solve Problems Before the advent of modern navigational technology, people sailing across the ocean used stars and the progress of the Sun for general directions. These long-range signs were good for long-distance travel but not useful for finding small, isolated islands, like Hawai'i. Using what you have learned about seabirds, suggest a way ancient explorers could use birds to find land.

11.3 Marine Mammals

Key Questions

1. What are the main characteristics of mammals?
2. How does current legislation protect marine mammals?

Study Strategy

Sequence and Order Using your notes, work with a partner to review the history of whaling. Then practice retelling the sequence without your notes. Ask questions of one another for deeper learning.

What Are Marine Mammals?

About 200 million years ago another major group of air-breathing vertebrates, the mammals (class Mammalia), evolved from now-extinct reptiles. For a long time, the mammals were overshadowed by the dinosaurs, which were reptiles. About 65 million years ago, however, the dinosaurs became extinct. It was then that mammals thrived, taking the place of the dinosaurs. There are now roughly 4,600 species of mammals, including humans. Fishes, reptiles, and birds each outnumber mammals in number of species.

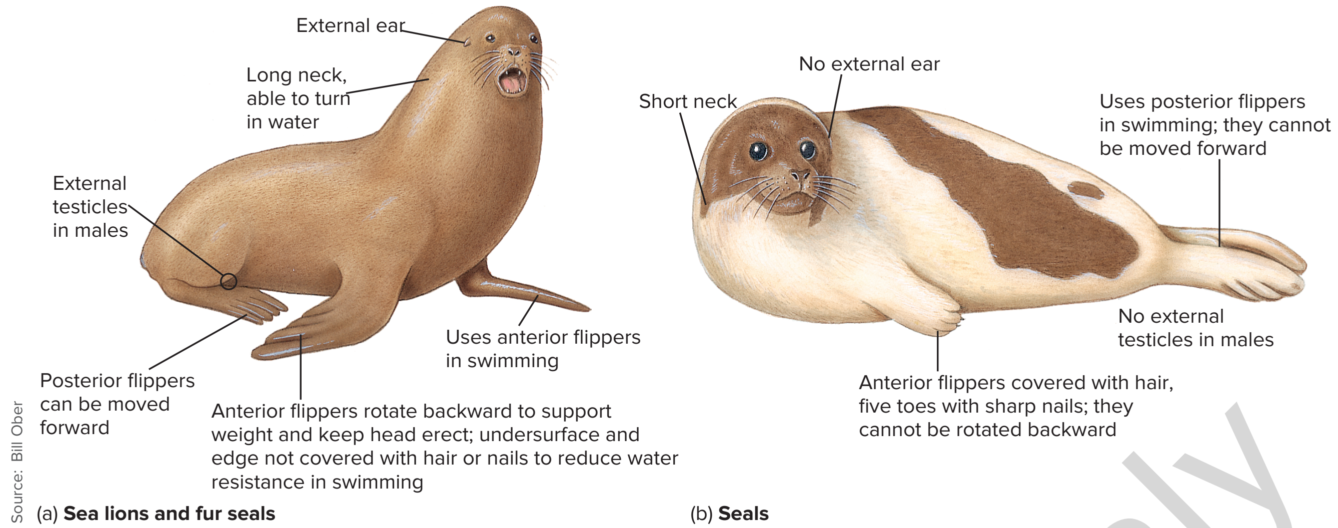
Like birds, mammals have the advantage of being endotherms and homeotherms. The skin of mammals, however, has hair instead of feathers to retain body heat. With few exceptions, mammals are viviparous. The embryo receives nutrients and oxygen through the **placenta**, or afterbirth, a membrane that connects it to the womb, thus an instance of placental viviparity. The newborn is fed by milk secreted by the mother's **mammary glands**. Instead of releasing millions of eggs, mammals produce few—but well-cared-for—young.

And then there is the brain. It is larger in relation to body size and more complex than that of other vertebrates, allowing the storage and processing of more information. This accounts in part for the adaptability of mammals. They live anywhere there is air to breathe and food to eat, including the ocean.

At least five different groups of land mammals succeeded in invading the oceans. They have followed different paths in adapting to the marine environment. Some are so fish-like that we have to remind ourselves that they have hair and bear live young nourished by their mother's milk.

Seals, Sea Lions, and Walrus

Seals, sea lions, and walrus are marine mammals that have paddle-shaped flippers for swimming but still need to rest and breed on land. They make up one of the 19 or 20 major groups, or orders, of mammals, the pinnipeds (order Pinnipedia; see Fig. 11.1). Pinnipeds evolved from an early form of terrestrial carnivore (order Carnivora), which includes cats, dogs and bears, The similarities are so close that many biologists classify them with the carnivores. Pinnipeds are predators and their streamlined bodies are adapted for swimming (see Fig. 11.9).



(a) **Sea lions and fur seals** (b) **Seals**

Figure 11.9 Though they differ in some structural features and the ways in which they swim and move on land, (a) sea lions and fur seals and (b) seals are now thought to have evolved from the same group of land carnivores.

Most pinnipeds live in cold water. To keep warm they have a thick layer of fat, called **blubber**, under their skin. Besides acting as insulation, it serves as a food reserve and helps provide buoyancy. Some pinnipeds also have bristly hair for added protection against the cold. Many of them are quite large, which also helps conserve body heat because large animals have less surface area for their size than small animals and therefore lose less body heat.

Get It?

How do pinnipeds keep warm in cold water?

Seals The largest group of pinnipeds, some 19 species, is the seals. Seals are distinguished by having rear flippers that cannot be moved forward (Fig. 11.9b). On land they must move by pulling themselves along with their front flippers. They swim with powerful strokes of the rear flippers.

Harbor seals (*Phoca vitulina*; Fig. 11.9b) are common in both the North Atlantic and North Pacific. They feed mostly on fishes, using their whiskers to detect the currents produced by fish gills. Elephant seals (*Mirounga*; Fig.11.10a) are the largest pinnipeds. Males, or bulls, reach 6 m in length and can weigh as much as 3,600 kg. One unusual seal is the crabeater seal (*Lobodon carcinophagus*), which feeds on Antarctic krill. These seals strain krill from the water with their intricately cusped, sieve-like teeth. Unlike most seals, monk seals live in warm regions. The Mediterranean (*Monachus monachus*) and Hawaiian (*M. schauinslandi*) monk seals are now endangered. A third species, the Caribbean monk seal (*M. tropicalis*), was last seen in 1952.

Seals are hunted for their skin and meat and for the oil extracted from their blubber. The Marine Mammal Protection Act of 1972 extends protection to all marine mammals and restricts the sale of their products in the United States. For some seals, however, this protection has not been enough.

Sea Lions Sea lions, or eared seals, and the related fur have external ears and can move their rear flippers forward, so they can use all four limbs to walk or run on land. The front flippers can be rotated backward to support the body, so the animal can sit on land with its neck and head raised (Fig. 11.10a). Sea lions are graceful and agile swimmers, relying mostly on their broad front flippers. Adult males are much bigger than females, or cows, and have a massive head with a hairy mane.

There are six species of sea lions and nine of fur seals. The most familiar of all is the California sea lion (*Zalophus californianus*) of the Pacific coast of North America. These sea lions are the trained barking circus "seals" that do tricks for a fish or two. Fur seals like the northern fur seal (*Callorhinus ursinus*; Fig. 11.10b) were once almost exterminated for their thick fur. Now most are protected around the world, though some species are still hunted. Sea lions lack this underfur. Still, both sea lions and fur seals can run afoul of fishers. They sometimes drown in nets or are shot because of their notorious ability to steal fish. Populations of the Steller sea lion (*Eumetopias jubatus*) in Alaska have decreased by 80% since the 1970s, probably because of a decline in the fishes they eat as a result of an increase in commercial fishing.

(a)

(b)

(c)

Figure 11.10 Seals. (a) The northern elephant seal (*Mirounga angustirostris*), is named because of the huge proboscis of the male. (b) The New Zealand fur seal (*Arctocephalus forsteri*), like the other fur seals, has a thick underfur. (c) Female harp seals (*Phoca groenlandica*), are threatened by hunting and decreased ice cover.

Walruses The walrus (*Odobenus rosmarus*; Fig. 11.11) is a large pinniped with a pair of distinctive tusks protruding down from the mouth. It feeds mostly on bottom invertebrates, particularly clams. It was once thought that the walrus used its tusks to dig up food, but there is no evidence for this. Instead, these pinnipeds apparently suck up their food as they move along the bottom. The stiff whiskers of the snout probably act as feelers. The tusks are used for defense and to hold or anchor to ice.

Figure 11.11 The walrus (*Odobenus rosmarus*) lives at the edge of pack ice in the Arctic. They also crowd onto beaches on isolated islands and coasts, but a reduction of coastal sea ice has limited these resting areas. The walrus is still hunted legally by native Alaskans and Siberians.

The walrus is restricted to the Arctic Ocean and adjacent waters. Two populations isolated from each other can be identified; one along the Arctic coasts of Russia and Alaska extending to the North Pacific, and a second in northern Canada, Greenland, and the North Atlantic. Each population is considered to belong to a geographically isolated group or **subspecies**.

Sea Otter, Marine Otter, and Polar Bear

The sea otter (*Enhydra lutris*; Fig. 11.12) is a member of the order Carnivora. The sea otter is the smallest truly marine mammal; an average male weighs 25 to 35 kg. Unlike other marine mammals, sea otters lack a layer of blubber. Insulation from the cold is provided by air trapped in its dense fur. This splendid, dark brown fur, unfortunately, attracted hunters. Sea otters were hunted to near extinction until they became protected by an international agreement in 1911. Sea otters in California then slowly expanded from the few individuals that had managed to survive in remote locations. Their numbers, however, have been declining in recent years. They have slightly declined in California since peaking in 2004, mostly as a result of disease. The sea otter is still a threatened species.

There are three subspecies of sea otters. The Asian sea otter is found from northern Japan to Siberia, the Alaskan sea otter from the Aleutian Islands to the northwestern United States, and the California, or southern, sea otter in central California. They differ from one another in having slightly different sizes, in the amount of time they spend on land, and a few other characters.

Figure 11.12 California sea otters (*Enhydra lutris*) live in and around kelp forests and play an important role in ecosystem help by controlling grazers such as urchins.

Sea otters are playful and intelligent animals. They spend most or all of their time in the water, including breeding and giving birth. The furry pup is constantly groomed and nursed by its mother.

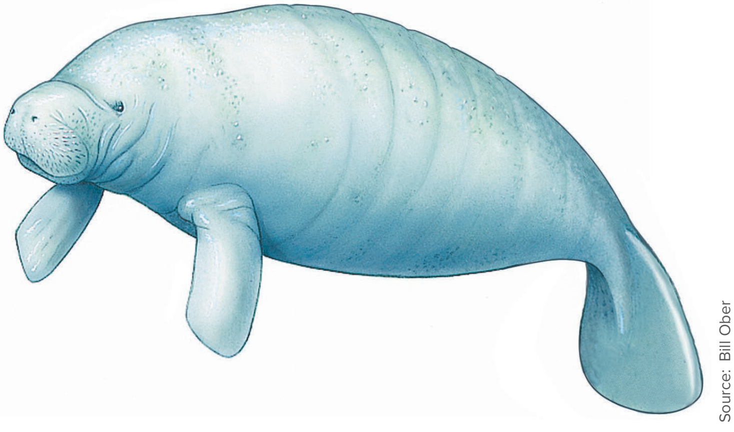
Sea otters need to eat 25 to 30% of their body weight per day, so they spend a lot of time looking for food. Sea otters satisfy their ravenous appetites with sea urchins, abalone, mussels, crabs, other invertebrates, and even fishes. Sea otters help protect kelp beds from sea urchins. They are remarkable for their use of a tool—a rock for crushing sea urchins and molluscs. They carry a flat rock in side "pockets" of loose skin and fur. The sea otter floats on its back at the surface, places the rock on its chest, and crushes its toughest prey against it. Some have been observed carrying and using beer bottles as tools!

The rare marine otter, or sea cat (*Lontra felina*), is a small (up to 6 kg) otter that inhabits the Pacific coast of temperate South America. It feeds mostly on small invertebrates, but, unlike the sea otter, it spends most of the time on rocky shores. The marine otter is endangered because of hunting and habitat loss.

The polar bear (*Ursus maritimus*; Fig. 11.13) is the second member of the order Carnivora that inhabits the marine environment. Polar bears are semiaquatic animals that spend a good part of their lives on drifting ice in the Arctic. They are threatened by the decrease in Arctic ice. They feed primarily on seals, which they stalk and capture as the seals surface to breathe or rest. As the ice retreats, however, polar bears are venturing inland in search of alternative land-based food. Attacks on humans have also increased.

Figure 11.13 The polar bear (*Ursus maritimus*) is beautifully adapted to live in the Arctic drifting ice, a habitat that is rapidly shrinking.

Manatees and Dugong Relatives of the elephant, manatees and the dugong, also live at sea. They are also known as sea cows, or sirenians (order Sirenia). Both have a pair of front flippers but no rear limbs (Fig. 11.14). They swim with up-and-down strokes of their paddle-shaped, horizontal tail. The round, tapered body is well padded with blubber. They have wrinkled skin with a few scattered hairs. The group is named after the mythical mermaids or sirens whose songs lured lonely sailors. Sirenians are gentle creatures usually living in groups. They are the only strict vegetarians among marine mammals. Their large and prehensile lips are used to feed on seagrasses and other aquatic vegetation. All sirenians are large. Dugongs can reach 3 m and 420 kg, manatees 4.5 m and 600 kg. The largest sirenian of all was the Steller's sea cow, which supposedly grew to 7.5 m long. It was hunted to extinction.



Source: Bill Ober

Figure 11.14 An estimated 7,000 West Indian manatees (*Trichechus manatus*) remain along the coasts and rivers of Florida. Manatees have been considered as a possible way to control weeds that sometimes block waterways.

Humans have exploited sirenians for their meat (which supposedly tastes like veal), skin, and oil-rich blubber. Like elephants and other large mammals, they reproduce slowly, typically one calf every three years. Seagrass beds, their main source of food, are being destroyed at an alarming rate by anchor and boat damage and by excess silt and nutrients from land, which often results from deforestation and intensive farming. All four species of sirenians are in danger of extinction. Three species of manatee live in the Atlantic Ocean; one is restricted to the Amazon and the other two inhabit shallow coastal waters and rivers from Florida to West Africa. The dugong (*Dugong dugon*) is strictly marine and survives from East Africa to some of the western Pacific islands. Its numbers are critically low throughout most of its range.

Whales, Dolphins, And Porpoises

The largest group of marine mammals is the cetaceans (order Cetacea)—the whales, dolphins, and porpoises. There are some 90 living species of cetaceans. They are all marine except for five species of river dolphins in Asia and South America. Cetaceans are divided into two groups: the toothless, filter-feeding whales and the toothed, carnivorous whales, a group that includes the dolphins and porpoises. No group of marine animals has captured our imaginations like the dolphins and whales, perhaps because they are mammals like us.

Of all marine mammals, the cetaceans, together with the sirenians, have made the most complete transition to aquatic life. Whereas most other marine mammals return to land at least part of the time, these two groups spend their entire lives in the water. The bodies of cetaceans are streamlined and look remarkably fish-like (Fig. 11.15). This is a dramatic example of **convergent evolution**, in which different species develop similar structures because they have similar lifestyles. Though they superficially resemble fishes, cetaceans breathe air and will drown if trapped below the surface. They are endotherms, have hair (though scanty), and produce milk for their young.

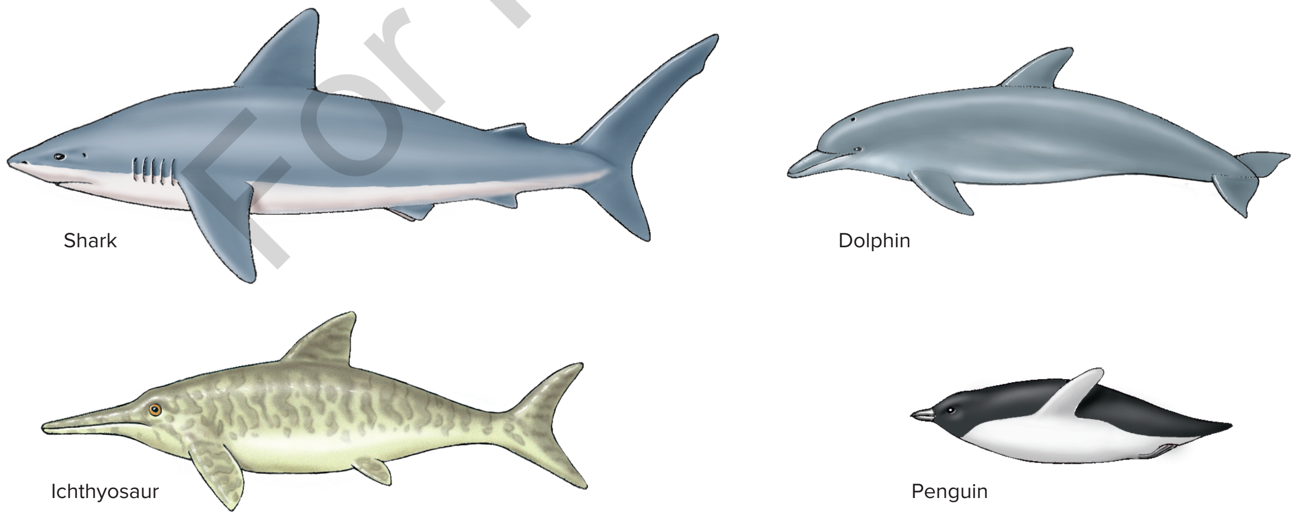


Figure 11.15 Streamlining to reduce water resistance evolved independently in different groups of fast-swimming marine animals: sharks, ichthyosaurs (extinct reptiles), dolphins, and penguins. Notice that dolphins lack posterior fins and that their flukes are horizontal, not vertical like the caudal fin of fishes.

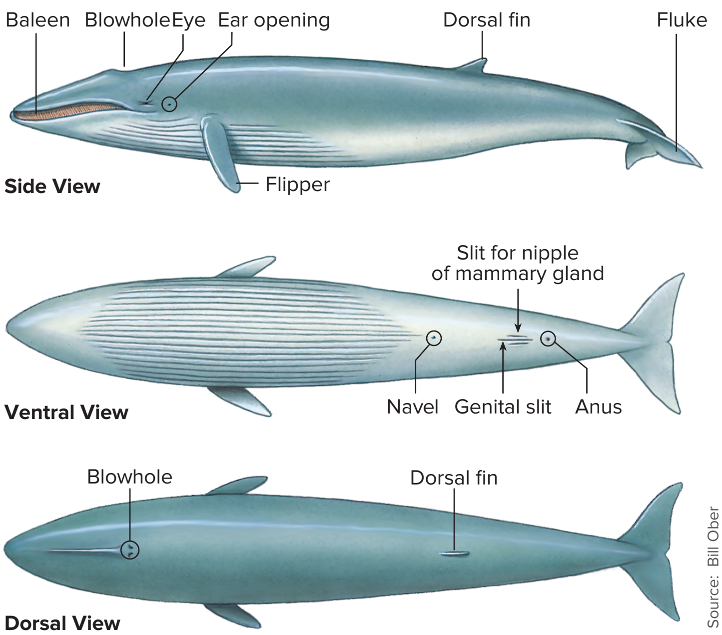


Figure 11.16 External morphology of a female blue whale (*Balaenoptera musculus*). Males have a genital slit halfway between the anus and navel, and they lack mammary slits.

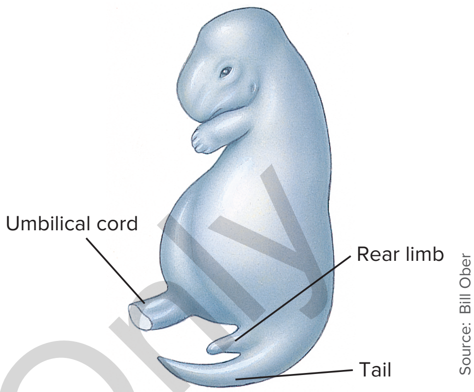


Figure 11.17 The fetus of a white-sided dolphin (*Lagenorhynchus*) shows two distinct pairs of limbs; the rear pair will eventually disappear.

Cetaceans have a pair of front flippers, but the rear pair of limbs has disappeared (Fig. 11.16). The rear limbs are actually present in the embryo but fail to develop (Fig. 11.17). In adults they remain only as small, useless bones. Like fishes, many cetaceans have a dorsal fin, another example of convergent evolution. The muscular tail ends in a pair of fin-like, horizontal **flukes**. Blubber provides insulation and buoyancy; body hair is practically absent. Cetacean nostrils differ from those of other mammals. Rather than being on the front of the head, they are on top, forming a single or double opening called the **blowhole** (Fig. 11.16). Barnacles, attached crustaceans, are often found living on the tough skin of whales.

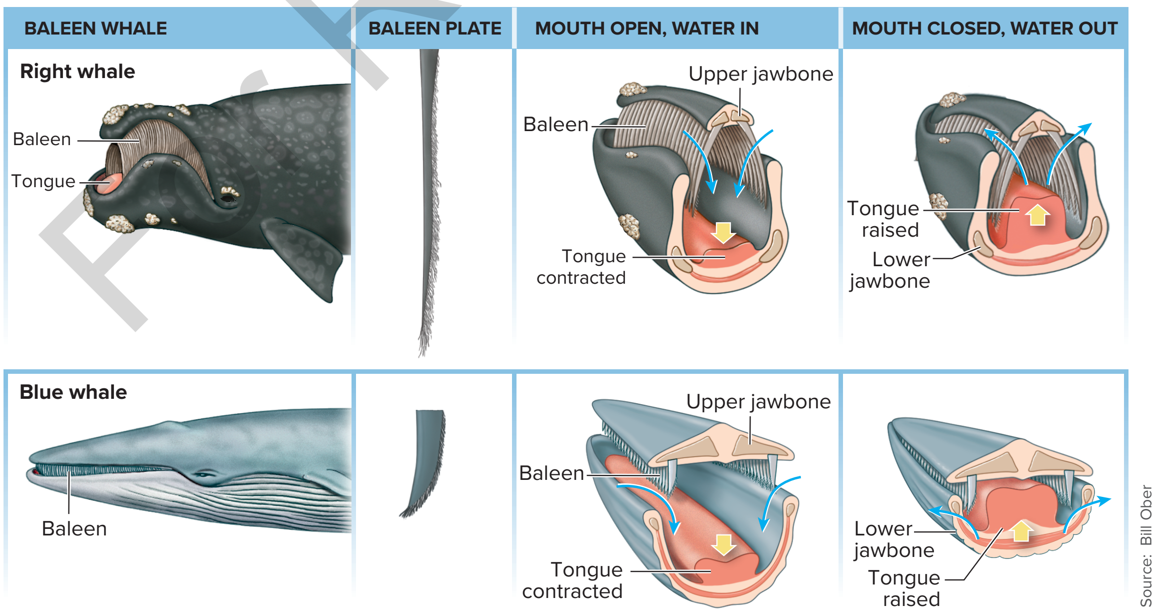
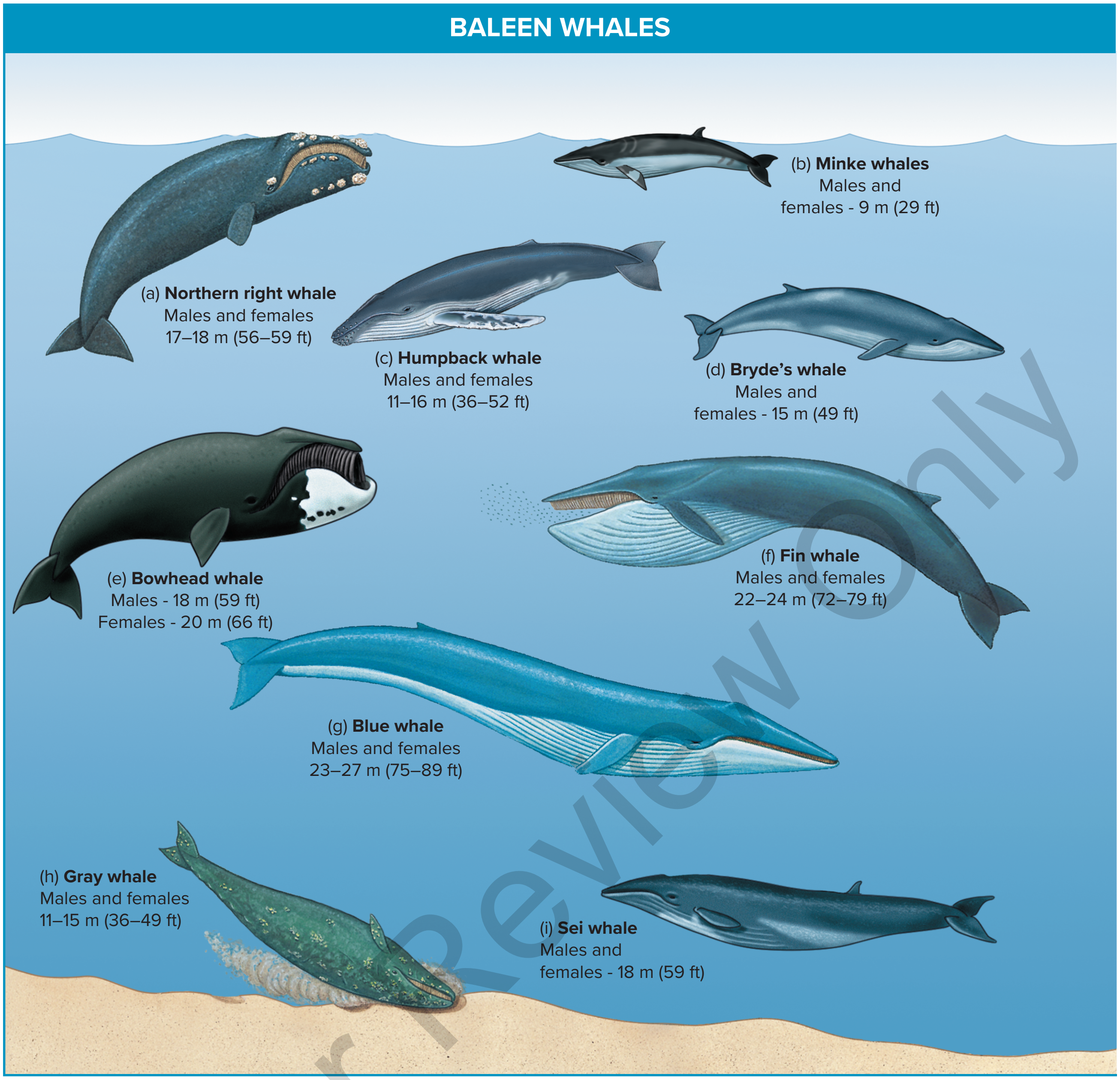


Figure 11.18 Filtering in whales involves vertical baleen plates. The plates are up to 3 m in the northern right whale (*Eubalaena glacialis*) but only 1 m in the blue whale (*Balaenoptera musculus*). Water is filtered as the mouth closes and the tongue (yellow arrow) pushes up, forcing the water out through the baleen.

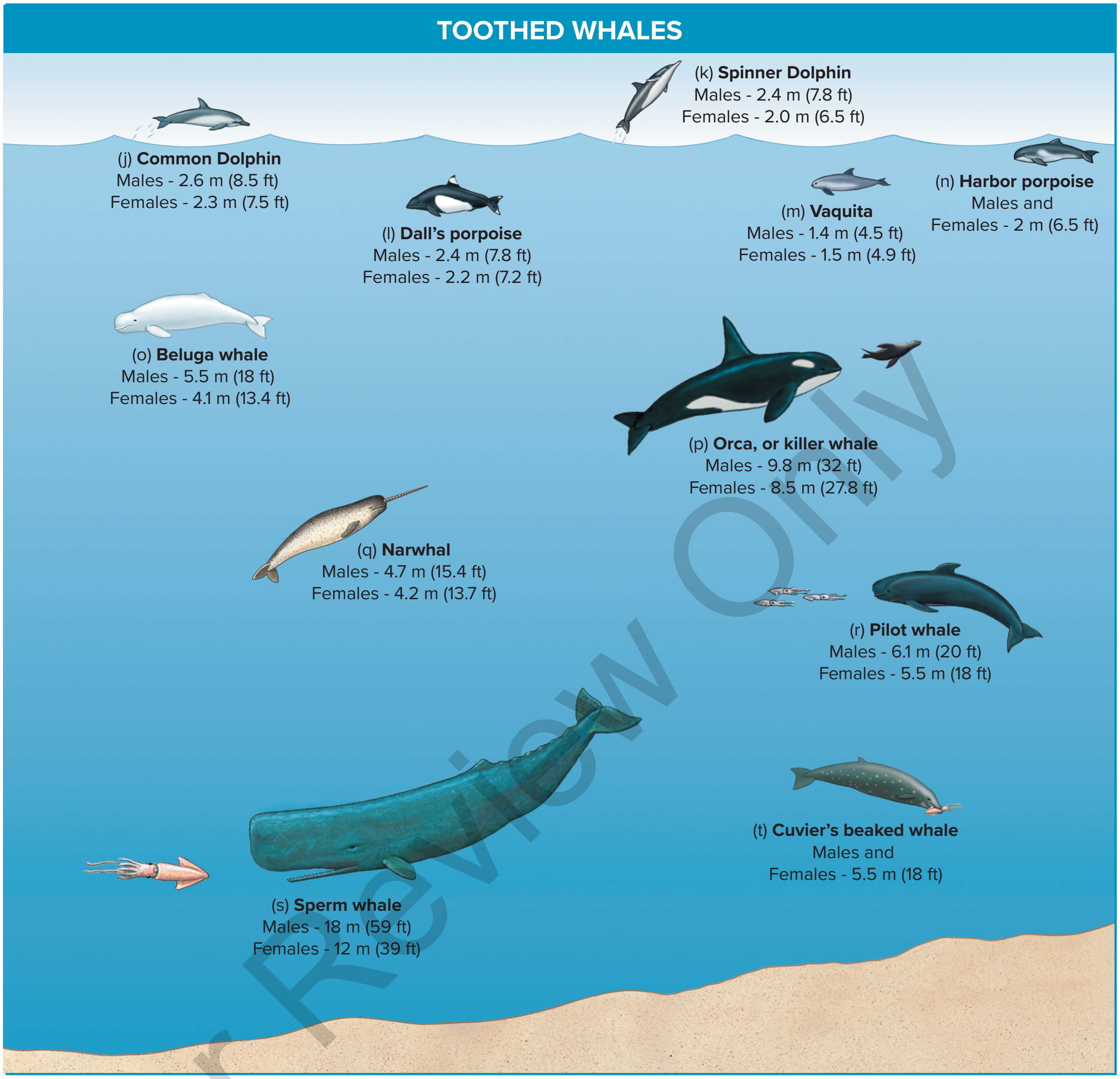


Source: Bill Ober

Figure 11.19 Representative baleen and toothed whales.

Baleen Whales The toothless whales are better known as the baleen whales. Instead of teeth, they have rows of flexible plates, named baleen, which hang from the upper jaws (see Fig. 11.18). Baleen is made of keratin, the same material as our hair and nails. The inner edge of each plate consists of hair-like bristles that overlap and form a dense mat in the roof of the mouth. The whale filter-feeds by taking a big mouthful of water and squeezing it out through the bristles by pushing up the tongue.

Baleen whales are not only the largest whales but also are among the largest animals that have ever lived on Earth. There are 14 recognized species of tbaleen whales. They were once common in all the oceans, but overhunting has brought many species to the brink of extinction. The blue whale (Balaenoptera musculus), which is actually blue gray, is the largest of all (Fig. 11.19g). Males average 25 m, and there is a record of a female 33.5 m. How do you weigh a blue whale? Very carefully—they average 80,000 to 130,000 kg, but the record is an estimated 178,000 kg.



The blue whale, the fin whale (*Balaenoptera physalus*; Fig. 11.19f), and the minke whale (now recognized as two different species, the common minke, *Balaenoptera acutorostrata*, and the Antarctic minke, *B. bonarensis*; Fig. 11.19b)—together with four other related species—are known as the rorquals.

The rorquals and the humpback whale (*Megaptera novaeangliae*; Fig. 11.19c), which is often included among the rorquals, feed by gulping up schools of fish and swarms of krill. The lower part of the anterior half of the body expands when feeding, hence the distinctive, accordion-like grooves on the underside of these whales (see Fig. 11.16). Krill is the most important part of the rorqual diet, especially in the Southern Hemisphere. Humpback whales often herd fishes like herring and mackerel by blowing curtains of bubbles around them and then surfacing after feeding with their mouth wide open (see Fig. 11.20).

The right whales (*Eubalaena, Caperaea*; Fig. 11.19a) and the bowhead whale (*Balaena mysticetus*; Fig. 11.19e) feed by swimming along the surface with their huge mouths open. They have the largest baleen plates of the whales but the finest bristles (see Fig. 11.18). This allows them to filter small plankton like copepods and some krill (see Table 11.1).

Gray whales (*Eschrichtius robustus*) are primarily bottom feeders. They feed mostly on amphipods that inhabit soft bottoms (see Table 11.1). Grays stir up the bottom with their pointed snouts and then filter the sediment, leaving characteristic pits on the bottom (see Fig. 11.19h). Most appear to feed on their right side because the baleen on this side is more worn. Some, however, are "left-handed" and feed on the left side. A 10-week-old female kept in captivity in San Diego, California, was fed 815 kg of squid every day, gaining weight at the rate of 1 kg an hour.

Figure 11.20 Humpback whales (*Megaptera novaeangliae*) often hunt in groups by surrounding schools of small fish with bubbles before lunging to the surface with open mouths and swallowing hundreds of fish in one gulp. Some of the whales help others by diving below the school to force the fish to the surface; others are known to flap the surface to herd the fish with their flukes before forming the bubbles.

The Rice's whale (*Balaenoptera ricei*), which is restricted to the northeastern Gulf of Mexico, was officially established as a new species of baleen whale in 2021. It is estimated that there are less than 100 individuals, and as such one of the most endangered cetaceans in the world.

Toothed Whales The roughly 80 remaining species of cetaceans are toothed whales. Their teeth are adapted for a diet of fish, squid, and other prey. They use the teeth only to catch and hold prey, not to chew it, so food is swallowed whole.

Table 11.1 Diet of Whales

Whale Species	Bottom Invertebrates (%)	Large Zooplankton (%)	Small Squids (%)	Large Squids (%)	Small Pelagic Fishes (%)	Mesopelagic Fishes* (%)	Miscellaneous Fishes (%)
Blue	—	100	—	—	—	—	—
Bowhead	20	80	—	—	—	—	—
Bryde's	—	40	—	—	20	20	20
Fin	—	80	5	—	5	5	5
Gray	90	5	—	—	—	5	—
Humpback	—	55	—	—	15	—	30
Common and Antarctic minkes	—	65	—	—	30	—	5
Northern and Southern rights	—	100	—	—	—	—	—
Sei	—	80	5	—	5	5	5
Sperm	5	—	10	60	5	5	15

**Fishes found at depths of around 200 to 1,000 m*

Table 11.2 Status and Estimated Numbers of Great Whales

Whale Species	Status (Red List[1])	Estimated Pre-exploitation Number	Current Estimated Numbers
Blue	Endangered	160,000–240,000	5,000–15,000
Bowhead	Least concern but some populations endangered; Japanese and aboriginal whaling	52,000–60,000	24,000
Bryde's	Least concern; Japanese and aboriginal whaling	100,000	21,000–90,000
Fin	Vulnerable; hunted	300,000	100,000
Gray (eastern Pacific)	Least concern	15,000–22,000	22,000–26,000
Gray (western Pacific)	Endangered	1,500–10,000	140
Gray (Atlantic)	Extinct	Unknown	0
Humpback	Recovering population; aboriginal whaling	150,000	90,000
Common minke	Hunted, including aboriginal whaling	265,000	205,000
Antarctic minke	Hunted	670,000	460,000–690,000
North Pacific right	Endangered	Unknown	430–450
North Atlantic right	Facing extinction; aboriginal whaling	Unknown	400–450
Southern right	Recovering populations	100,000	16,000
Sei	Endangered; Japanese whaling	100,000	8,000
Sperm	Recovering population	>2,000,000	300,000–500,000

[1] Compiled by the International Union for Conservation of Nature and Natural Resources (IUCN). Classified as "Least Concern," "Near Threatened," "Vulnerable," "Endangered," and "Critically Endangered."

As in all cetaceans, food is ground up in one of the three compartments of the stomach. The blowhole has one opening, as opposed to two in the baleen whales.

The largest toothed whale is the sperm whale (*Physeter catodon*), the blunt-nosed giant of *Moby Dick* fame (see Fig. 11.19s). Together, the sperm and baleen whales are often called the great whales. There is growing evidence that sperm whales, though toothed, are more closely related to baleen whales than to other toothed whales. The sperm whale is now the most numerous of the great whales, even though it was the mainstay of the whaling industry for centuries (Table 11.2). The largest on record weighed 38,000 kg.

Sperm whales are fond of squid, including the giant deep-sea ones. Undigested squid beaks and other debris accumulate in the gut as large globs of sticky material known as **ambergris**, an ingredient in fine perfumes. Sperm whales also eat a wide variety of fishes, lobsters, and other animals (see Table 11.1).

Evidence of the high value of ambergris is the finding by Yemeni fishers of $1.5 million worth of the material in the belly of the carcass of a sperm whale in 2021. Sperm whales also eat a wide variety of fishes (including sharks) and other marine animals (see Table 11.1).

The other toothed whales are much smaller than the great whales. One is the orca, or killer whale (*Orcinus orca*; see Fig. 11.19p), a predator of seals, penguins, fishes, sea otters, and even other whales. They appear to use their white bellies to flash and frighten herring schools and their flukes to stun the fish. Orcas are most common in cold water but are found around the world. They have a nasty reputation, but there are very few confirmed cases of their attacking humans in the wild, although there have been cases of individuals aggressively ramming boats. DNA analysis has confirmed that there are several types, perhaps different species, of orcas, each with a distinct appearance, hunting habit, and diet. Orcas are quick to learn new tricks to catch their prey, and these behaviors are communicated to other members of the same population. Orcas in Antarctica have learned to make waves to knock seals off floating ice and others in Patagonia climb ashore on beaches to catch resting sea lions. Orcas of other pods work as teams to herd and ambush dolphins; others herd schools of herring into tight balls and push them to the surface to feast on them.

One of the most enigmatic of whales is the narwhal (*Monodon monoceros*; see Fig. 11.19q), a small Arctic whale having a long, spiral tusk that can be as long as 2.7 m. Narwhal tusks washed ashore apparently gave rise to the legend of the unicorn. The tusk, a modified tooth found only in males, appears to be related to the establishment of a hierarchy of dominance. Narwhals have been recorded with drones using the tusk to hit and stun fish.

Though they are all whales, most of the small-toothed whales are called dolphins or porpoises. Technically, the six species of porpoises are blunt-nosed whales (see Fig. 11.19m and Fig. 11.19n) having flattened teeth in contrast to the conical teeth of dolphins. In some places, however, the name "porpoise" is given to some of the dolphins.

The many species of dolphins typically possess a distinctive snout, or beak, and a perpetual "smile." Playful, highly social, and easily trained, dolphins win people's hearts. They often travel in large groups called **pods**, herds, or schools. They like to catch rides along the bows of boats (Fig. 11.21) or around great whales. The bottlenose dolphin (*Tursiops truncatus*) is the dolphin seen in marine parks around the world.

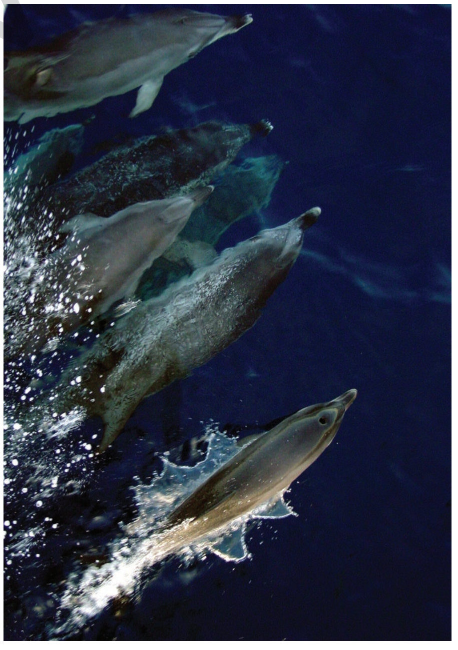


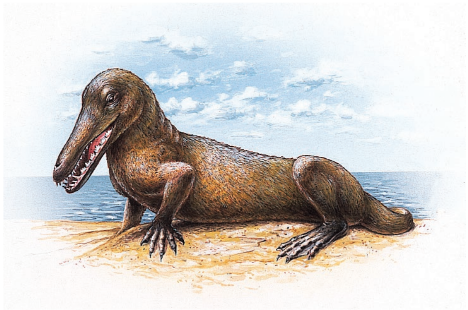
Figure 11.21 Dolphins like the Atlantic sotted dolphin (*Stenella frontalis*) often ride the bow wave of boats or even that of whales. They ride without beating their tails, obtaining thrust from the pressure wave in front of the ship.

Conservation of Cetaceans Whale hunting, or **whaling**, is an old tradition with a rich history. Stone Age people hunted whales as early as 6000 BCE. Native Americans hunted gray whales in prehistoric times; the aboriginal peoples of the Arctic still legally hunt them.

MARINE SCIENCE IN ACTION

The Whales That Walked to Sea

What did the first whales look like, and how did they evolve from land-dwelling mammals into modern cetaceans? Transitional fossils help tell the story of how cetaceans became fully marine.


Source: Bill Ober

Ambulocetus natans, the walking whale that swam.

Pakicetus In 1979 scientists found a fossilized whale embedded in rocks that were dated to be 52 million years old in Pakistan. The fossil, named *Pakicetus*, is a complete skull of an archeocyte, an extinct group of ancestors to modern cetaceans, and provides precious details on the origin of cetaceans. The skull is cetacean-like but its jawbones lack the enlarged space that is filled with fat or oil for receiving underwater sound in modern whales and lacks a blowhole. *Pakicetus* probably detected sound through the ear opening like land mammals. *Pakicetus* is a transitional form between a group of extinct flesh-eating mammals, the mesonychids, and cetaceans. *Pakicetus* likely fed on fish in shallow water and was not yet adapted for life in the open ocean.

Basilosaurus Several skeletons of another early whale, *Basilosaurus*, were found in 1989 in what was the Tethys Sea, now the Sahara in Egypt. This whale lived around 40 million years ago, 12 million years after *Pakicetus*. A complete hind leg was found that features feet with three tiny toes. The legs are too small to have supported the 15-meter-long *Basilosaurus* on land. *Basilosaurus* was undoubtedly a fully marine whale, possibly with non-functional, or vestigial, hind legs.

Ambulocetus* and *Mystacodon In 1994, also in Pakistan, the fossil *Ambulocetus natans* was discovered. This early whale lived 49 million years ago, 3 million years after *Pakicetus* but 9 million years before *Basilosaurus*. The fossilized hind leg indicates they were functional both on land and sea. The whale still retained a tail and lacked a fluke. The structure of the backbone suggests that *Ambulocetus* could swim as modern whales do. The large hind legs were used for propulsion in water. On land, *Ambulocetus* may have moved like sea lions. It undoubtedly linked life on land with life at sea.

The oldest known baleen whale is the skeleton of a 36-million-year-old whale from Perú, *Mystacodon*. It shows the first steps in the transition from a toothed to a baleen whale through its pointed skull which has teeth that are flattened as in the modern baleen whales. There is no evidence of baleen, however, which is difficult to fossilize. It has been hypothesized that *Mystacodon* was a suction feeder, a possible first step in the evolution of filter feeding.

Think Critically

1. Why is *Pakicetus* considered a transitional fossil?
2. Which ancient sea were most of the whale fossils from?

GO ONLINE to access the inquiry activity to investigate the evolution of whales.

Basques may have hunted them off Newfoundland before Columbus. It was not until the 1600s, however, that Europeans started to substantially exploit the great whales in the North Atlantic. Whales were harpooned from small, open boats (Fig. 11.22), a technique whalers learned from the Native Americans. It was a rewarding fishery, though not one exploited primarily for food. Blubber provided “train oil,” which was used to make soap and lamp oil. Baleen, meat and other valuable products were also obtained. Whaling efforts rapidly increased after fast steamships and the devastating explosive harpoon were introduced in the 1800s. The largest and fastest whales, like the blue and fin whales, were then at the mercy of whalers.

Figure 11.22 Long-boat crew harpooning a right whale in the 1800s.

Impacts of whaling Whales are long-lived mammals with a low reproductive rate. The great whales generally give birth to one well-developed calf that has been carried by the mother for a year or more. Females usually don’t become pregnant for one or two years after giving birth. As a result of this low reproductive potential, whale populations could not stand the intense whaling pressure, and many of the fisheries collapsed.

The first to be seriously depleted was the slow-swimming North Atlantic right whale (*Eubalaena glacialis*; see Fig. 11.19a), the “right” species to be killed, according to whalers, because it floated after being harpooned. By the early 1900s whaling had moved to the rich feeding grounds around Antarctica, where other species of whales could be hunted. This location proved to be a bonanza. Whaling nations developed factory ships able to process whole carcasses. The Antarctic fishery reached its peak in the 1930s where more than a million wales were taken. The whales received a reprieve during World War II, but it was too late.

Blue whales, the largest of them all, were especially sought. A large specimen yielded more than 9,000 gallons of oil. It has been estimated that more than 200,000 blue whales were taken worldwide between 1924 and 1971, close to 30,000 during the 1930–1931 whaling season alone. Catches climbed way above the sustainable yield level. Catch per whaler-day’s effort declined every year after 1936. As many as 80% of all blue whales caught by 1963 were sexually immature, so that there were even fewer individuals able to perpetuate the species.

Fin whales, the second largest of all whales, became the next major target as blue whales became scarce. The 1950s and early 1960s saw annual catches of 20,000 to 32,000 fin whales per year, mostly from Antarctica. As catches dwindled, whalers shifted their target again in the mid-1960s to the smaller sei whale (*Balaenoptera borealis*; see Fig. 11.19i). The sei whale averages a length of around 13 m, whereas the fin whale averages 20 m.

Get It?

Why is it important to implement whaling policies?

Whaling policy The disappearance of the more commercially valuable whales meant lower profits for the whaling industry. Twenty whaling nations established the International Whaling Commission (IWC) in 1946 in an attempt to regulate whale hunting to stop overfishing. It collected data on the number of whales and set annual quotas for the number of whales to be caught each year; however, these quotas were non-binding and could not be enforced.

Furthermore, some whaling nations did not belong to the IWC. The blue whale was not completely protected by the IWC until the 1965–1966 season, long after its numbers had been drastically reduced. By then blue whales were so hard to find that the fishery for them was no longer profitable. Even under the protection of the IWC, blue whales were hunted at least until 1971 by countries that did not belong to the IWC.

Under mounting pressure from conservationists, the IWC gradually banned the hunting of other whales. Demand for whale products, mostly oil used in the manufacture of margarine and lubricants, was reduced because substitutes had been found for most of them. Whale meat, however, continued to be used as pet food and is still valued as human food, mostly in Japan. The lower quotas of the IWC were, unfortunately, not always accepted by all nations.

The United States Congress passed the Marine Mammal Protection Act of 1972, which bans the hunting of all marine mammals in U.S. waters (except in the traditional fisheries of the indigenous people of Alaska) and the importation of marine mammal products. By 1974 the IWC had protected the blue, gray, humpback, and right whales worldwide, but only after their catches were no longer economically viable. Sperm, minke, fin, and sei whales were still hunted, but catches began to dwindle. Catches of these whales fell from 64,418 in 1965 to 38,892 in 1975 and 6,623 in 1985.

A moratorium on all commercial whaling was declared by the IWC in 1985. The former Soviet Union halted all whaling in 1987. Japan, Iceland, and Norway, however, opted in 1988 to continue catching minke, fin, and sei whales, as allowed by the IWC under the controversial title of "scientific whaling."

In 1994 the IWC created a vast sanctuary for all whales in the waters around Antarctica, the main feeding ground for 80% of the surviving great whales. Japan, however, decided to continue hunting whales in Antarctica.

Starting with the 1997–1998 season, Japan took 440 minkes from Antarctica and 100 from the North Pacific each season until 2002, when it expanded its North Pacific catch to include 150 minke, 50 Bryde's (*Balaenoptera edeni*; see Fig. 11.19d), 10 sperm, and, for the first time since 1987, 50 sei whales. Disruptions from anti-whaling activists and low demand were responsible for the low Japanese catches, almost all minkes, in Antarctica.

In 2006, the 70-nation IWC abandoned its conservationist policies on the belief that the populations of many of the whale species were large enough to support sustainable whaling. Norway had already resumed commercial whaling in 2005 by setting itself an annual quota of 796 North Sea minkes (Fig. 11.23). Iceland, which had not hunted whales since 1989, joined Norway in 2006 to further break the 1985 ban. Since 2005 and under the provisions of "scientific" whaling, about 3,600 minkes were taken in Antarctica, a high of 680 during the 2005–2006 season to 251 in 2013–2014. The IWC approved stricter criteria for nations applying to undertake whaling for research purposes. Japan nevertheless restarted whaling under a new "scientific" program during the 2015–2016 season, when 333 minkes were caught. The same number was taken during the 2016–2017 season before Japan withdrew from IWC and abandoned Antarctic whaling in 2018. It nevertheless resumed, after a 31-year absence, commercial whaling in its own coastal waters in the northwestern Pacific, catching 187 Bryde's, 91 minke, and 25 sei whales, an endangered species in 2021.

Figure 11.23 A harpooned common minke whale (*Balaenoptera acutorostrata*) being hauled on board a Norwegian whaling ship in the North Sea.

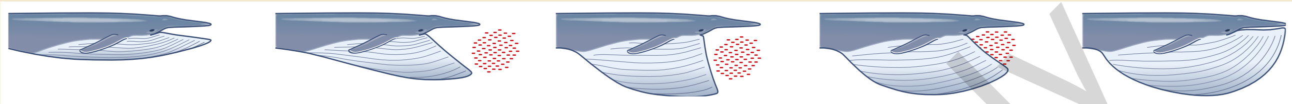
Small-scale whaling, or aboriginal subsistence whaling, remains part of the traditional fisheries of the indigenous inhabitants of the Arctic region from Greenland to Siberia and in the Lesser Antilles in the Caribbean. One of the whales hunted in the Arctic, the bowhead, and another in the Lesser Antilles, the humpback, are endangered. Other smaller whales—the orca, narwhal, and beluga (*Delphinapterus leucas*; see Fig. 11.19o)—are also hunted in the Arctic and North Altantic.

Current status of whaling The current status of the great whale species according to population estimates varies from "vulnerable" to "critically endangered" depending on the classification of particular agencies or countries. The status may also vary among different populations of the same species. Collision with ships, entanglement with fishing nets, noise pollution, and illegal hunting remain as threats now that pressure from commercial whaling has almost disappeared. The North Atlantic right whale, which is facing extinction, has been hit by entanglement in ropes connecting lobster traps with buoys. Eighteen of them died in 2017, a tragedy considering that only 100 breeding females are left and that no calves were born during the 2017–2018 breeding season. Nobody knows when the great whales will again roam the oceans in numbers approaching those before the start of large-scale whaling.

MARINE SCIENCE IN ACTION

Feeding in the Blue Whale

How do blue whales (*Balaenoptera musculus*), the largest animals that have ever lived, maintain such a large size while diving for food, migrating long distances, maintaining body temperature, and reproducing all on a diet of krill? Blue whales and other rorquals have longitudinal grooves along a much of the lower surface of their body. The blubber along this area consists of tough ridges divided by deep channels of elastic tissue, which allow the whales to expand their massive oral cavities to feed on large amounts of krill.



Source: Bill Ober

Energy balance Whales expend energy to perform basic functions as well as accelerate their huge bodies to lunge and feed. Figuring out how blue whales balance these requirements involves estimating the energetic efficiency, or cost, of feeding. In other words, how much energy do they obtain after subtracting the energy they burn while feeding? A team from the University of British Columbia, Canada, investigated this question by tracking 265 blue whales along the Pacific coast with several types of electronic sensors.

Energy out The researchers found that whales lunge to feed as many as six times during a dive, with each dive lasting from 3.1 to 15.2 minutes. The speed of whales as they lunged was calculated by correlating speed with the noise of water rushing by the animal, as measured by hydrophones attached to individual whales. Since the oral cavity inflates much like a parachute, a parachute aerodynamics expert helped develop a mathematical model to calculate the energy needed in each lunge. The team found that whales expend 3,226 to 8,071 kilojoules of energy per lunge.

Energy in Scientists then estimated the volume of the oral cavity from the size of jaw bones in museums, and the density of krill in the water from the scientific literature. They calculated that each mouthful of krill contained from 34,726 to 1,912,680 kilojoules, which is 240 times as much energy spent in each lunge! Even including the cost of diving, each dive could provide 90 times as much energy as whales use while diving. Blue whales certainly obtain more than enough energy from their food, and such extraordinary feeding efficiency helps explain their ability to survive despite their gigantic size.

Think Critically

1. What do blue whales feed on?
2. How many times more energy does a blue whale gain per dive versus spend diving?

GO ONLINE to access the inquiry activity to investigate blue whale migrations.

Some experts worry that a few endangered species will never recover completely. Though, recovery is underway in some species. The California gray whale, protected since 1947, has made a sweeping comeback. It was removed from the endangered species list in 1994. It is estimated that 78,000 to 117,000 grays lived before exploitation, much higher than most estimates (see Table 11.2). In 1997 the IWC allowed the catching of 600 gray whales by indigenous hunters in Siberia and 20 by the Makah Native Americans in Washington State. The Makah only took a single gray whale, in 1999. The Makah only took a single whale, in 1999. Hundreds of dead grays have nevertheless been washing up along North American beaches since 2019. These unusual mortality events appear to be caused by malnutrition resulting from the lack of prey, perhaps the consequence of warming Arctic waters. Some of the whales, however, were probably struck by ships or entangled by fishing gear.

Figure 11.24 The blue whale (*Balaenoptera musculus*) has made a remarkable and unexpected comeback along the Pacific coast of North America. It is estimated that 2,200 individuals now live in the northeastern Pacific. These two individuals were photographed in the Gulf of California, Mexico.

Even the blue whale, whose reproduction is severely limited by its restriction to small populations scattered around the world, is making a comeback. It has returned to the Arctic Ocean north of Norway, a region where they flourished before their near extermination by whalers. Sightings off the Pacific coast of North America have increased sharply (Fig. 11.24) and they were recently seen off Sydney Harbor, Australia for the first time in 100 years. Their numbers in Antarctica, however, are even lower than first estimates: around 500 individuals, or only about 1% of those feeding there before whaling began. Increased sightings of blue and other baleen whales in Arctic waters appear to be an unexpected benefit of the rapid melting of Arctic sea ice. Increased penetration of light could be triggering increases in the amount of the plankton used as food.

A decrease in Arctic sea ice, however, is negatively impacting cetaceans such as the narwhal, beluga, and bowhead whales, all of which are closely associated with sea ice. Decreasing ice is also allowing orcas, an important predator to these cetaceans, to enter areas otherwise not accessed by the orcas. The noise of increased shipping traffic has also been reported as affecting whales. Dolphins are also at great risk (see Table 11.2). Small cetaceans are not under IWC regulation, and as many as 28 species are in immediate danger of extinction.

The vaquita, or "little cow" (*Phocoena sinus*; see Fig. 11.19m), is Earth's most endangered marine cetacean. As of 2023, it is estimated that only 10 to 13 specimens remain. This small, shovel-nosed porpoise is found only in a small area in the Gulf of California, Mexico, where it remained unknown to science until 1958. Their numbers have undergone a catastrophic decline in recent years with half of the surviving vaquitas vanishing between 2015 and 2016. The culprit is legal and illegal gill-net fishing, mostly for totoaba (*Totoaba macdonald*), another threatened and endemic species. The fish are targeted because their swim bladders are believed to have medicinal powers. Although vaquitas are now protected by the Mexican government, some drastic measures must be taken to save them. One proposed, but risky, scheme is to use dolphins to herd the remaining vaquitas to a marine sanctuary.

Everywhere, fishers are depleting stocks of fishes and squid on which dolphins feed. Dolphins themselves are being hunted for human food. Most of the 5 species of river dolphins are critically endangered. China's Yangtze River dolphin, or baiji (*Lipotes vexillifer*), a freshwater dolphin found only in that Chinese river, was declared extinct in 2006, the first cetacean to become extinct as a result of human activity. A second freshwater cetacean, the Yangtze finless porpoise (*Neophocaena phocaenenoides asiaorientalis*), is in danger of also becoming extinct.

Tuna fishers using giant purse seine nets sometimes trap and drown dolphins that often swim above schools of tuna, mostly yellowfin tuna in the eastern Pacific. Public outrage in the early 1970s resulted in a quota for the number of dolphins that could be killed by American fishing fleets. The use of special nets was enforced, and observers were placed on board vessels to verify compliance. By 1990 it was estimated that the number of dolphins killed by the American tuna had reached zero. The same year the three biggest tuna packers in the United States pledged not to buy or sell fish that was caught using methods that injure or kill dolphins. Tuna cans began to display "dolphin-safe" labels, and imported tuna caught without the use of dolphin-safe methods were banned from sale in the United States.

Dolphins have also been entangled and killed by the thousands in drift nets, which also threaten other marine life. The huge nets deplete valuable commercial fisheries as well as noncommercial species. Hundreds of fishing boats outfitted for drift netting were used to catch tuna in the South Pacific. The United Nations called for a moratorium on drift-net fishing in 1992, and most countries ended the practice in 1993. Still drift-net fishing, some of it illegal, continues in some areas.

Section Review

1. **Summarize** Make a table that summarizes the adaptations that the different groups of marine mammals have evolved to live in the marine environment and provide an example of each.
2. **Compare and contrast** baleen whales and toothed whales.

Use the Practices

Obtain, Evaluate, and Communicate Information Design a matrix chart which showcases eight different marine mammals of your choice and compares their different characteristics in the following categories: Feeding Patterns, Habitat, Size of Mammal, Locomotion Strategies, and Threats/Predators.

11.4 Biology of Marine Mammals

Key Questions

1. How are cetaceans adapted for swimming?
2. Why do pinnipeds and cetaceans migrate?

Study Strategy

Background Knowledge Check Based on what you know, predict the meaning of each new vocabulary term found in the Chapter Summary before reading the section. As you read, check the actual meaning compared to your prediction.

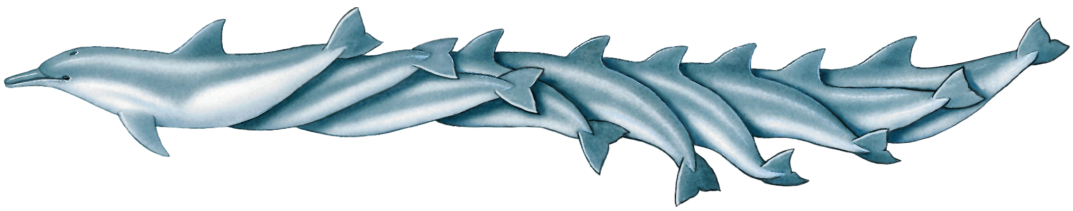
What Do We Know About Marine Mammals?

It is surprising how little we know about marine mammals. Most are difficult or impossible to keep in captivity or even to observe for long periods at sea. Some whales and dolphins are rarely seen, so what little we know about them comes from captive or stranded individuals and information gathered over the years by whalers.

Swimming

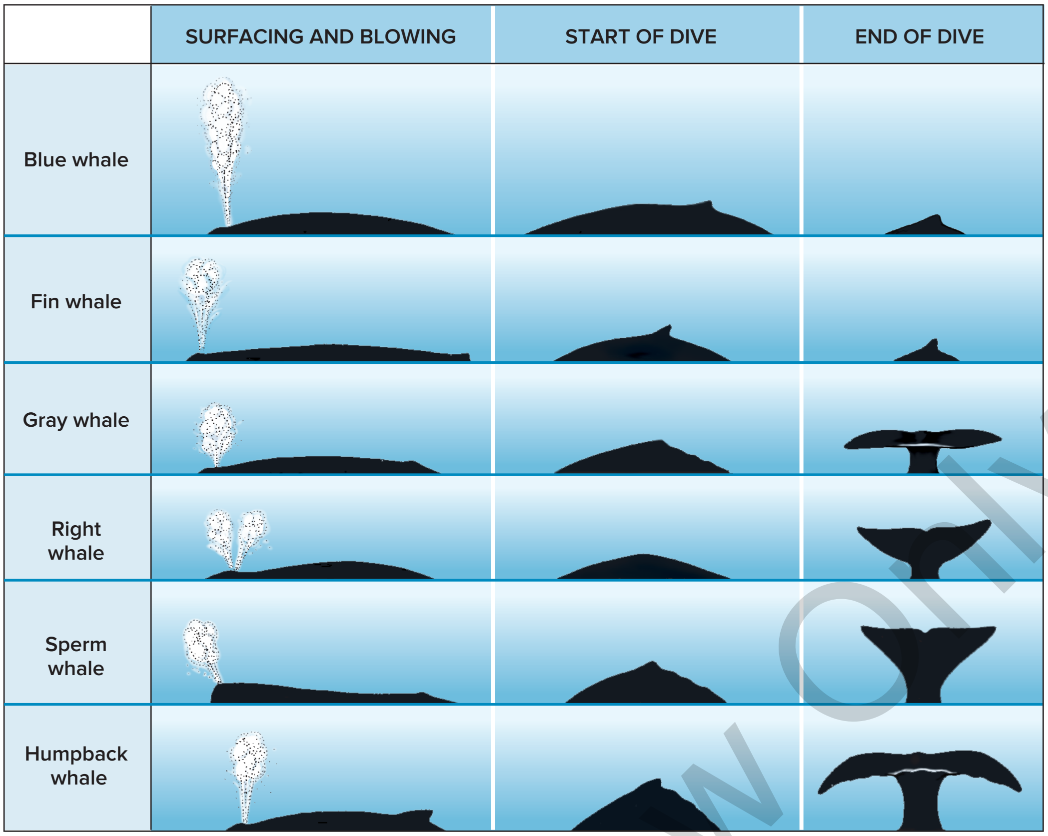
Streamlining of the body for swimming is a hallmark of marine mammals. Seals, sea lions, and the walrus swim mostly by moving their flippers. Sea otters swim by using their hind feet, which are broad and webbed. Polar bears are strong swimmers and can cover long distances using all four legs for swimming, very much like a dog. Sirenians and cetaceans, in contrast, move their tails and flukes up and down (Fig. 11.25), in contrast to fishes who move their tails from side to side. Sea lions have been timed at speeds of 35 kph, orcas and blue whales at 50 kph. A group of common dolphins (*Delphinus delphis*; see Fig. 11.19j) was recorded bow-riding at a speed of 64 kph.

Cetaceans have the advantage of having the blowhole on top of the head. This allows them to breathe even though most of the body is under water, although many pinnipeds and dolphins jump clear out of the water to take a breath when they are swimming fast. It also means that cetaceans can eat and swallow without drowning. The blowhole is absent in all other marine mammals and therefore must use their frontally located nostrils to breathe air just like us. To avoid inhaling water, all marine mammals take very quick breaths. A fin whale can empty and refill its lungs in less than two seconds, half the time we take, even though the whale breathes in 3,000 times more air!



Source: Bill Ober

Figure 11.25 Cetaceans swim with strong up-and-down movements of the tail and flukes.



Source: Bill Ober

Figure 11.26 Great whales can be identified from a distance by their blowing pattern, their outline on the surface, and the way they dive.

In the large whales, the moisture in their warm breath condenses when it hits the air. Together with a little mucus and seawater, this water vapor forms the characteristic **spout**, or blow. The spout can be seen at great distances, and its height and angle can be used to identify the whale (Fig. 11.26). The blue whale, for instance, has a spout some 6 to 12 m high.

To keep warm in cold water, the great whales depend on a thick layer of blubber. Feeding, however, leaves their huge mouths exposed to low temperatures, a major problem in the very cold polar waters where they normally feed. A network of blood vessels in their tongues reduces heat loss by transferring heat from warm blood into vessels that carry it back to the body core.

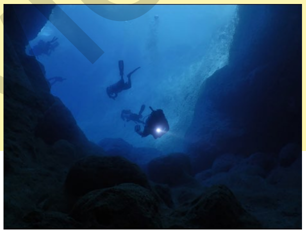
Diving Marine mammals have mastered the art of diving, and most make prolonged dives to considerable depths for food. There is a wide range in diving ability. Sea otters can dive for only 4 or 5 minutes, to depths of perhaps 55 m. Pinnipeds normally dive for up to 30 minutes at maximum depths of 150 to 250 m. Female northern elephant seals (*Mirounga angustirostris*), however, are capable of continuous deep dives of up to 400 m. One individual was recorded diving to a depth of 1,500 m. The Weddell seal (*Leptonychotes weddelli*) has been recorded diving for as long as 1 hour 13 minutes and as deep as 575 m. Sirenians spend most of their time in relatively shallow water, but a dugong was recorded diving to 20 m. Polar bears have been estimated capable of diving as deep as 6 m. Different species of toothed whales have evolved different hunting strategies. Short-finned pilot whales (*Globicephala*; see Fig. 11.19r), for instance, sprint as fast as 9 m per second after single or several prey as deep as 1,000 m, very much like large wildcats do.

The plankton-feeding habits of baleen whales do not require them to dive too deeply for their food, and they seldom venture below 100 m. Toothed whales, however, are excellent divers. Dolphins are known to dive as deep as 300 m. Though sperm whales are known to dive to 2,250 m for at least an hour, beaked whales are the champion divers. The Cuvier's beaked whale (*Ziphius cavirostris*; see Fig. 11.19t) regularly dives to more than 1,000 m to catch the deep-water squids that make up most of its diet. The deepest recorded dive of a beaked whale was close to 3,000 m; another was recorded diving for 3 hours, 42 minutes without surfacing for air.

The Bends A potential problem faced by air-breathing, diving animals (including human divers) results from the presence of large amounts of nitrogen (70% of total volume) in the air. Nitrogen dissolves much better at high pressures, like those experienced at depth. The blood of scuba divers picks up nitrogen while they are below the surface. If the pressure is suddenly released, some of the nitrogen will not stay dissolved and forms tiny bubbles in the bloodstream. A similar phenomenon can be observed when someone opens a bottle of soda pop. As long as the top is on, the contents are under pressure. The carbonation, actually carbon dioxide gas (CO_2), remains dissolved. When you open the bottle, the pressure is released and bubbles form. When nitrogen bubbles form in the blood after diving, they can lodge in the joints or block the flow of blood to the brain and other organs. This produces a painful condition known as the **bends**, or decompression sickness. To avoid the bends, human divers must be very careful about how deep they go, how long they stay under water, and how fast they come up.

Get It?

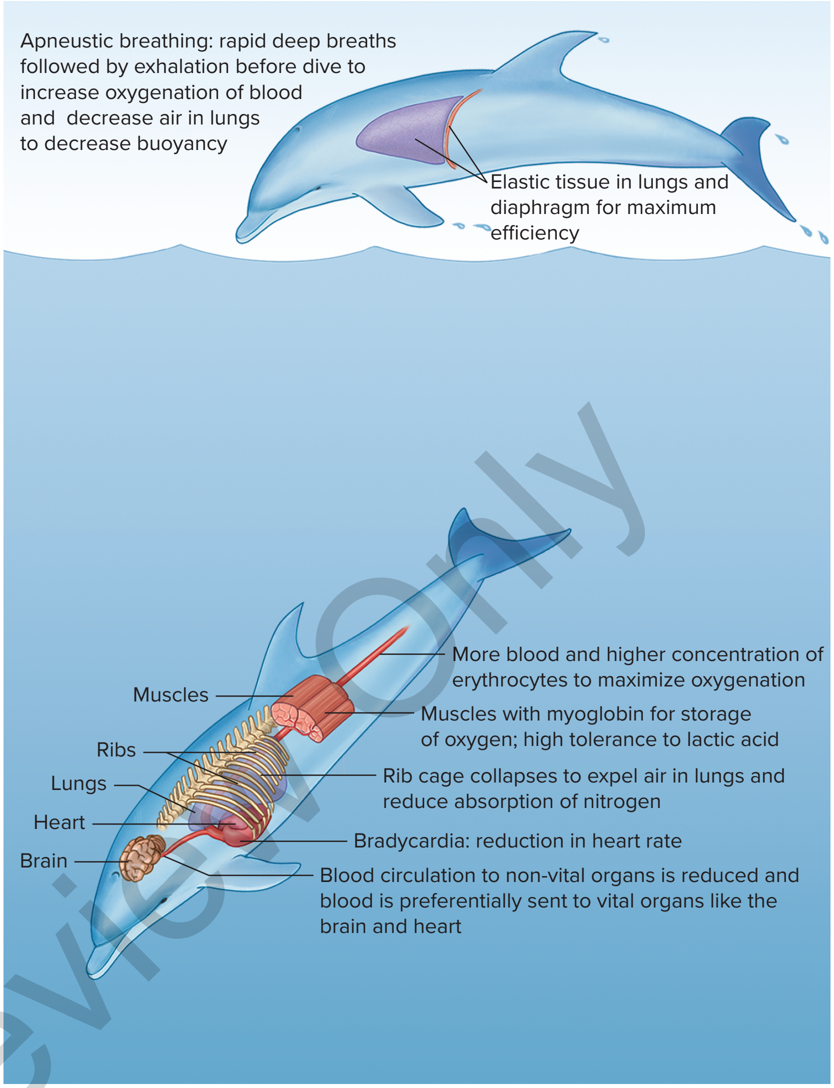
What problems do humans run into when making prolonged scuba dives?



Marine mammals dive deeper and stay down longer than human divers, so do they get the bends? Marine mammals do have adaptations that prevent nitrogen from dissolving in the blood. Human lungs work pretty much the same while scuba diving under water as on land. When marine mammals dive, their lungs actually collapse. They have a flexible rib cage that gets pushed in by the pressure of the water (see Fig. 11.27). This, and increased water pressure with the increased depth, squeezes the air out of peripheral areas of the lungs where it readily dissolves into the blood. Air is moved instead into the central spaces of the lungs, where little nitrogen is absorbed. High concentrations of hemoglobin and myoglobin store the oxygen that marine mammals need in the blood and muscles during dives. Less air is needed in the lungs, which reduces the amount of nitrogen that can be absorbed. Apneustic breathing, exhaling before a dive, further reduces the amount of air—and therefore nitrogen—in the lungs. A reduction in the amount of air in the lungs has the additional advantage of decreasing buoyancy, which makes descents to deep water easier.

The long-held view that marine mammals don't get the bends may not be accurate after all. It has been suggested that deep-diving whales suffer from some of the effects of the bends, as evidenced by the degeneration of bone and cartilage in sperm whales, possibly caused by nitrogen bubbles.

Breathing without Gills The long, deep dives of marine mammals require several crucial adaptations. For one thing, they must be able to go a long time without breathing. This involves more than just holding their breath, for they must keep their vital organs supplied with oxygen. Being homeotherms means that marine mammals must use energy to keep their temperature constant—and the release of energy by aerobic respiration requires oxygen. To get as much oxygen as possible before dives, most marine mammals and some seabirds take several deep breaths, then rapidly exhale, a behavior known as **apneustic breathing** (Fig. 11.27). As much as 90% of the oxygen contained in the lungs is exchanged during each breath, in contrast to 20% in humans. Many marine mammals have elastic tissues in their lungs and diaphragms, which help lungs fill and empty rapidly and efficiently.



Source: Bill Ober

Figure 11.27 Marine mammals have evolved a series of adaptations that allow them to undertake long, deep dives.

Marine mammals are also better than other mammals at absorbing the oxygen from the air and storing it in their blood. To start with, they have relatively more blood than non-diving mammals. As in seabirds, their blood also contains a higher concentration of erythrocytes, and these cells carry more hemoglobin. Furthermore, their muscles are extra-rich in myoglobin, which means that the muscles themselves can store a lot of oxygen.

Marine mammals have adaptations that reduce oxygen consumption in addition to increasing supply. When they dive, the heart rate slows dramatically, an automatic reflex known as **bradycardia**. Diving bradycardia has been recorded in many diving vertebrates, including humans.

InContext

Aerobic Respiration in all cells: organic matter (glucose) + $O_2 \rightarrow CO_2 + H_2O$ + energy

Anaerobic Respiration in muscles: organic matter (glucose) → energy + lactic acid

- Introduced in Section 6.1, The Ingredients of Life

It is thought to have evolved as an oxygen-conserving mechanism. In the northern elephant seal, for example, the heart rate decreases from about 85 beats per minute to about 12. Blood flow to non-essential parts of the body, like the extremities and the intestine, is reduced, but it is maintained to vital organs like the brain and heart. Thus, oxygen is made available where it is needed most when oxygen supply is cut off during a dive.

The reduction or absence of oxygen triggers the muscle cells of many animals (including humans during exercise) to carry out anaerobic respiration, an "emergency" respiration that releases, though inefficiently, some energy without the need of oxygen. A product of anaerobic respiration is lactic acid, a chemical that produces cramps and is detrimental to muscular function. The tissues of marine mammals, however, have evolved a high tolerance to the accumulation of lactic acid, another adaptation to increase diving efficiency.

Echolocation

Marine mammals depend little on the sense of smell, which is so important to land mammals. Their vision is excellent, but some have developed **echolocation**, another sensory system based on hearing. Echolocation is nature's version of sonar. Most if not all toothed whales, including dolphins and porpoises, and some pinnipeds are known to echolocate. At least some baleen whales could also use echolocation. There is no evidence of echolocation among sirenians, who use their sensitive whiskers when grazing. Echolocation is not exclusive to marine mammals. Bats, for example, use it to find insects and other prey while flying at night. Marine mammals echolocate by emitting sound waves, which travel about five times faster in water than in air and listening for the echoes reflected back from surrounding objects (Fig. 11.28). The brain then analyzes the echoes. The time it takes the echoes to return tells the animals how far away the object is.

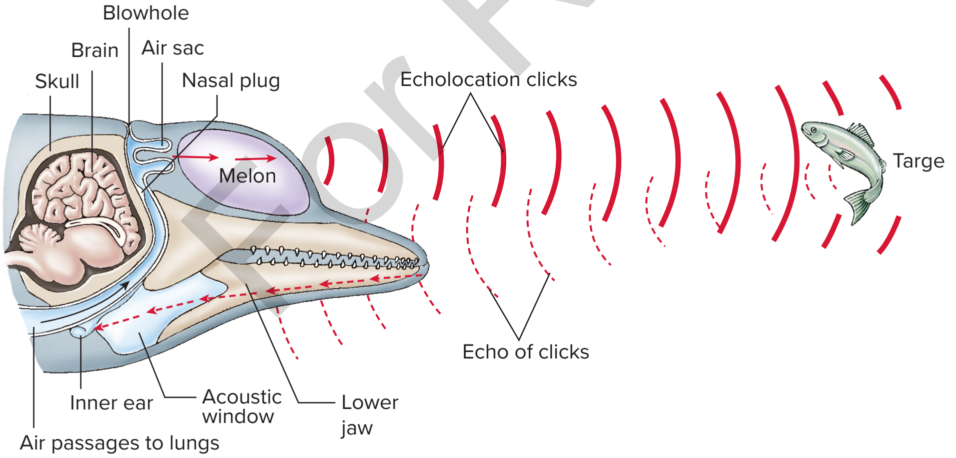


Figure 11.28 Dolphins echolocate by emitting bursts of sound waves, or clicks, as air is pushed through internal air passages. Two muscular nasal plugs act as valves, closing and opening the passages. Flaps of tissue on the plugs also produce sound by vibrating in the moving air. The clicks are focused into a beam by the melon. To cover a wider area, the dolphin moves its head from side to side. The melon is also receives the echoes and transmits them to the ears, but most are received by the lower jaw.

The sounds used in echolocation consist of short bursts of sharp clicks that are repeated at different frequencies. Low-frequency clicks have a high penetrating power and can travel long distances. They reflect from large features and are used to obtain information on the surrounding topography. Low-frequency sound waves can also be used by some toothed whales to stun their prey. It seems that sperm whales catch squids, including giant squids, without using their teeth, even if the teeth are actually of little help because they are present only in the lower jaw. Live squids have been known to come out alive from the stomachs of freshly caught whales! To discriminate more detail and locate nearby prey, high-frequency clicks that are inaudible to humans are used. Experiments have shown that blindfolded bottlenose dolphins can discriminate between objects of slightly different size or made of different types of materials and can even detect wires.

Cetaceans produce clicks, squeaks, and whistles as air is forced through the air passages and several associated air sacs while the blowhole is closed (see Fig. 11.28). The frequency of the clicks is changed, or modulated, by contracting and relaxing muscles along the air passages and sacs. A fatty structure on the forehead of toothed whales, the **melon**, appears to focus and direct the outgoing sound waves.

The melon gives these whales their characteristic rounded foreheads. To accommodate the melon, the skull is modified to form a pointed, dish-shaped face. The skull is also asymmetric, the right side being slightly different from the left side. Belugas (Fig. 11.29a) have a bulging forehead, which changes shape as the melon, moved by muscles, focuses the sound. The huge forehead of the sperm whale is filled in part with a massive melon called the **spermaceti organ**. Whalers originally thought this was the sperm sac of the whale, hence the peculiar name. This organ is filled with a waxy oil, **spermaceti**, once much sought after for making candles and still used as a lubricant for precision instruments. The actual function of the spermaceti organ is a controversial issue. It has been suggested that the deep-diving sperm whale might also use the spermaceti organ to regulate buoyancy or to absorb excess nitrogen, keeping it out of the bloodstream.

(a) (b)

Figure 11.29 (a) The beluga (*Delphinapterus leucas*) is a white Arctic whale with a conspicuous melon. This individual was photographed under the ice in the White Sea, Russia. (b) In their natural environment belugas live in small groups.

Incoming sound waves are received primarily by the lower jaw in toothed whales (see Fig. 11.28). The ear canal that connects the outside with the inner ear is reduced or blocked in most cetaceans. The jawbones, filled with fat or oil, transmit sound to the two, very sensitive inner ears. Each ear receives sound independently. The ears are protected by a bony case and embedded in an oily mixture that insulates the ear but allows sound waves to pass from the jaws. Sound information is sent to the brain, which forms a mental "picture" of the target or surroundings. In fact, sight and sound information seems to be handled similarly by the brain. Captive dolphins can recognize by echolocation objects they have seen and recognize by sight those they have previously echolocated.

Behavior

The mammalian brain has evolved as an association center for complex behaviors in which learning, not instinct, dominates. In contrast to fishes, birds, and other vertebrates, mammals rely mostly on past experience, stored and processed by the brain, to respond to changes in the environment. Cetacean brains are as complex as those of humans as far as their anatomy is concerned. Their brains even have the same type of brain cell that is associated with abstract reasoning in humans.

Most marine mammals are highly social, living in groups at least part of the time. The polar bear is a notable exception. Many pinnipeds live in huge colonies during the breeding season. Most cetaceans spend their entire lives in highly organized pods of a few to thousands of individuals (see Fig. 11.29b). Some pods include smaller subgroups organized by age and sex. To keep in contact, many of their highly complex and sophisticated behaviors are directed toward members of their own species. It has been said that cetaceans, like humans, have complex cultures that vary from group to group.

Vocalizations Sounds, or vocalizations, play a prominent role in communication. Sea lions and fur seals communicate by loud barks and whimpers; seals use more sedate grunts, whistles, and chirps. The vocalizations of pinnipeds are especially important in maintaining territories during reproduction (see "Reproduction," below). Females and their pups or calves recognize each other partly by their sounds, partly by smell. Sea otters use body contact and several vocalizations to communicate with each other. Sirenians similarly use "chirps" and "squeaks" for communication.

Cetaceans produce a rich variety of vocalizations that are different from the sounds used for echolocation. Both types of sounds can be produced simultaneously, providing further evidence of the complexity of sound production in marine mammals. Social vocalizations are low-frequency sounds that humans can hear. The variety of sounds is amazing and includes grunts, barks, squeaks, chirps, and even "moos." Different sounds are associated with various moods and are used in social and sexual signaling. Whistles, emitted in many variations and tones, are characteristic of each species. Some of these sounds serve as a "signature," allowing individuals of the same species to recognize one another. Bottlenose dolphins use signature sounds to address each other. Male fin whales use high-intensity songs to attract females. Among the more than 70 calls that have been identified among orcas, some are present in all individuals, whereas others are "dialects" that identify certain pods.

Sounds are also used to maintain the distance between individuals and have an important role in the structure of the pod. Particular sounds are emitted during breeding, feeding, alarms, and birth. Mother gray whales grunt to stay in contact with their calves. Fin whales make a low-pitched sound thought to be involved in long-distance communication. Right whales have at least six distinct calls, each related to a specific function, and they can even call louder as background noise gets louder.

The humpback whale is renowned for its soulful songs. They are sung by breeding males to attract females by advertising their readiness to mate. The songs consist of phrases and themes repeated in a regular pattern for a half hour or longer. They may be repeated over and over for days. The songs change over time. Males also start each breeding season with the song they were singing at the end of the previous breeding season. New songs learned from immigrants have been shown to gain instant popularity among native whales. Researchers record and catalog songs to help track whales in their annual migrations.

Communication among cetaceans is not restricted to vocalizations. Researchers have described a variety of postures and movements that can also indicate the animal's mood. Dolphins clap their jaws or turn around with their mouths open as a threat. The loud cracking sound made when some marine mammals slap their flukes or flippers on the surface is thought to be a way of communicating with other individuals.

Play Behavior Cetaceans are noted for their play behavior, seemingly pleasurable activities with no serious goal. Dolphins and orcas play with food or floating objects like kelp leaves, and feathers, throwing them up in the air or holding and pushing them with their snouts. Individuals can swim head down or on their backs apparently just for the fun of it. Captive dolphins and belugas play with rings of air bubbles they create. Dolphins also like to surf, and pilot and right whales go "sailing" with their flukes out of the water to catch the wind. Sex play, the rubbing and touching of the genital opening, is also common.

The sight of a great whale **breaching**, leaping up in the air and loudly crashing on the surface, is breathtaking (Fig. 11.30). Breaching has been variously interpreted as a warning signal, for scanning the surface or the shoreline, for getting rid of external parasites or an ardent lover, and simply for fun. Humpbacks may use breaching as a way of signaling distant groups of whales.

Source: Bill Ober

Figure 11.30 A humpback whale (*Megaptera novaeangliae*) performing a full spinning breach.

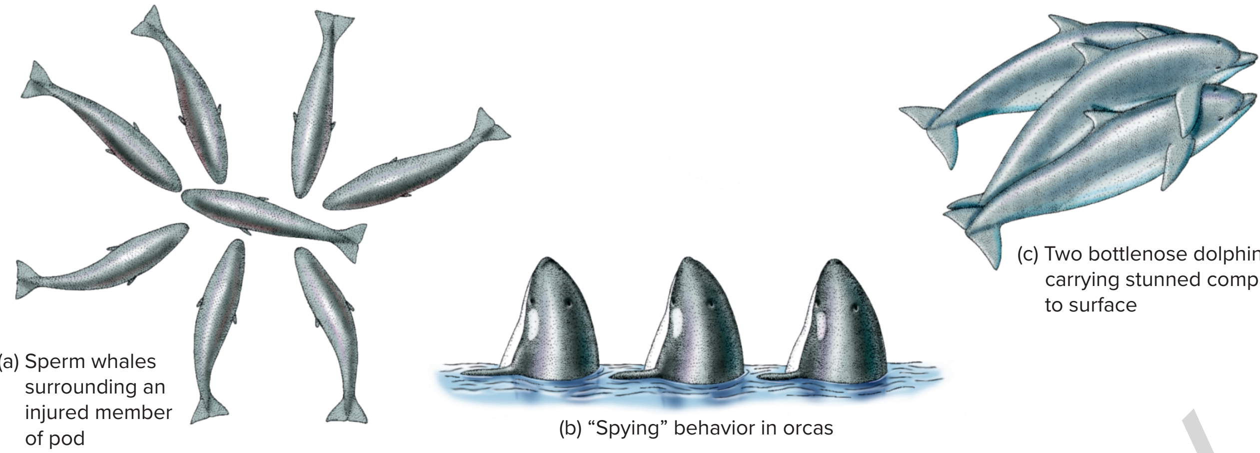


Figure 11.31 Whale watchers can be rewarded with examples of the complex behavior of whales like in (a) sperm whales (*Physeter macrocephalus*) (b) orcas (*Orcinus orca*) and (c) bottlenose dolphins (*Tursiops truncatus*).

After a deep dive, sperm whales can breach, fall on their backs, and make a splash that can be heard 4 km and seen 28 km away. Many whales stick their heads out of the water to spy on their surroundings (Fig. 11.31b).

Social Behavior The complex behavior of cetaceans is evident in other ways. When one individual is in trouble, others can come to assist (Fig. 11.31a). Members of a pod refuse to leave a wounded or dying comrade. Whalers knew that a harpooned whale was a lure for others, which are drawn from miles around. Dolphins will carry injured individuals to the surface to breathe (Fig. 11.31c). Interaction between dolphins even crosses the species barrier. Bottlenose and spotted dolphins have been reported playing and hunting together, and seemingly guarding each others' calves.

Many toothed whales work together when they hunt, some in coordinated pairs or groups. Sometimes whales take turns feeding while their partners herd a school of fish. An individual may investigate something strange lying ahead while the rest of the group waits for the "report" of the scout. Some humpback whales work in groups by producing bubbles to heard fish (see Fig. 11.20). Studies of dolphins in the wild have shown that they belong to a complex society, one in which long-term partnerships of members of the same sex play an important role in sexual behavior, parental care, and other aspects of daily life. Social behavior in cetaceans could ultimately show many parallels with social behavior in large-brained mammals like apes and humans.

Beaching One of the mysteries of the behavior of cetaceans is the stranding, or **beaching**, of individuals, sometimes dozens, on beaches (see Fig. 11.32). The animals refuse to move, and efforts to move them into deeper water usually fail. Even if they are pulled out to sea, they often beach themselves again. The whales die because their internal organs collapse without the support of the water. Stranding has been described in many species, but some, like pilot and sperm whales, strand themselves more often than others. It appears that whales become stranded when they follow one or more members of their group that have become disoriented by a storm, illness, or injury. This indicates the strong cohesiveness and herd instinct of the group.

Stranding of whales has been linked to high-intensity sonar that uses bursts of intense sound waves used by the navies of the United States and other nations to detect enemy submarines. Whales stranding after naval exercises where the sonar was used showed hemorrhages in the brain and inner ears, which cause disorientation and death. Tissue injury can also be caused by the formation of nitrogen bubbles, or the bends. The United States Navy limited the use of sonar in specified areas of the Pacific. Noise from ship propellers, depth sounders, and sonar used for scientific purposes has also been suggested as disturbing to whales. Dolphins spend more time on the surface and restless, and orcas calls last longer, when whale-watching boats are close by. There was a noticeable increase in the sightings of cetaceans (and other marine mammals) in coastal waters worldwide as a result of the sharp decrease in shipping and other maritime traffic during the COVID-19 pandemic.

Figure 11.32 These pilot whales (*Globicephala melas*) stranded themselves on a beach in Western Australia in 2009. About 80 pilot whales and bottlenose dolphins (*Tursiops truncates*) were stranded. Most perished, but 17 whales were saved by volunteer rescue workers.

Dolphins and humans The relationship between dolphins and humans is a controversial one. Though exaggerations abound, there are authenticated cases of dolphins approaching human swimmers who appeared to be in trouble. For more than a century, fishers in southern Brazil have established a unique partnership with dolphins. The dolphins detect fish and deliver them to fishers waiting with nets. Fishers have learned to interpret cues given by the dolphins about the location and abundance of fish. Generations of dolphins have learned that a row of fishers holding a net in shallow water means an easy catch for themselves, even if it has to be shared with funny-looking, two-legged mammals. Some people swear of experiencing “spiritual inspiration” while swimming among dolphins during the “dolphin encounters” offered by some resorts. Some even advocate “dolphin-assisted” deliveries of babies. Dolphins trained for military purposes by the former Soviet navy are being used to treat children suffering from behavioral disorders. Other people perceive this as outright exploitation of the captive animals, and interactions with humans could after all be harmful to dolphins.

Migrations

Many pinnipeds make seasonal migrations, often traveling thousands of miles from feeding grounds to breeding areas. Male southern elephant seals (*Mirounga leonine*) are known to travel as far as 8,000 km to mate. The walrus migrates following the coastal pack ice. Some migrate long distances to group in large numbers on isolated rocky beaches when the ice melts in the summer. The polar bear similarly follows the edge of the coastal pack ice, and some migrate long distances to group in large numbers on isolated rocky beaches when the ice melts in the summer. Most toothed whales, the sea otter, and sirenians, on the other hand, do not migrate at all, though they can move about in search of food.

The migrations of the great whales are by far the most remarkable. Many baleen whales congregate to feed during the summer in the productive waters of the polar regions of both hemispheres, where huge concentrations of diatoms and krill thrive in the long days. During the winter they migrate to warmer waters to breed.

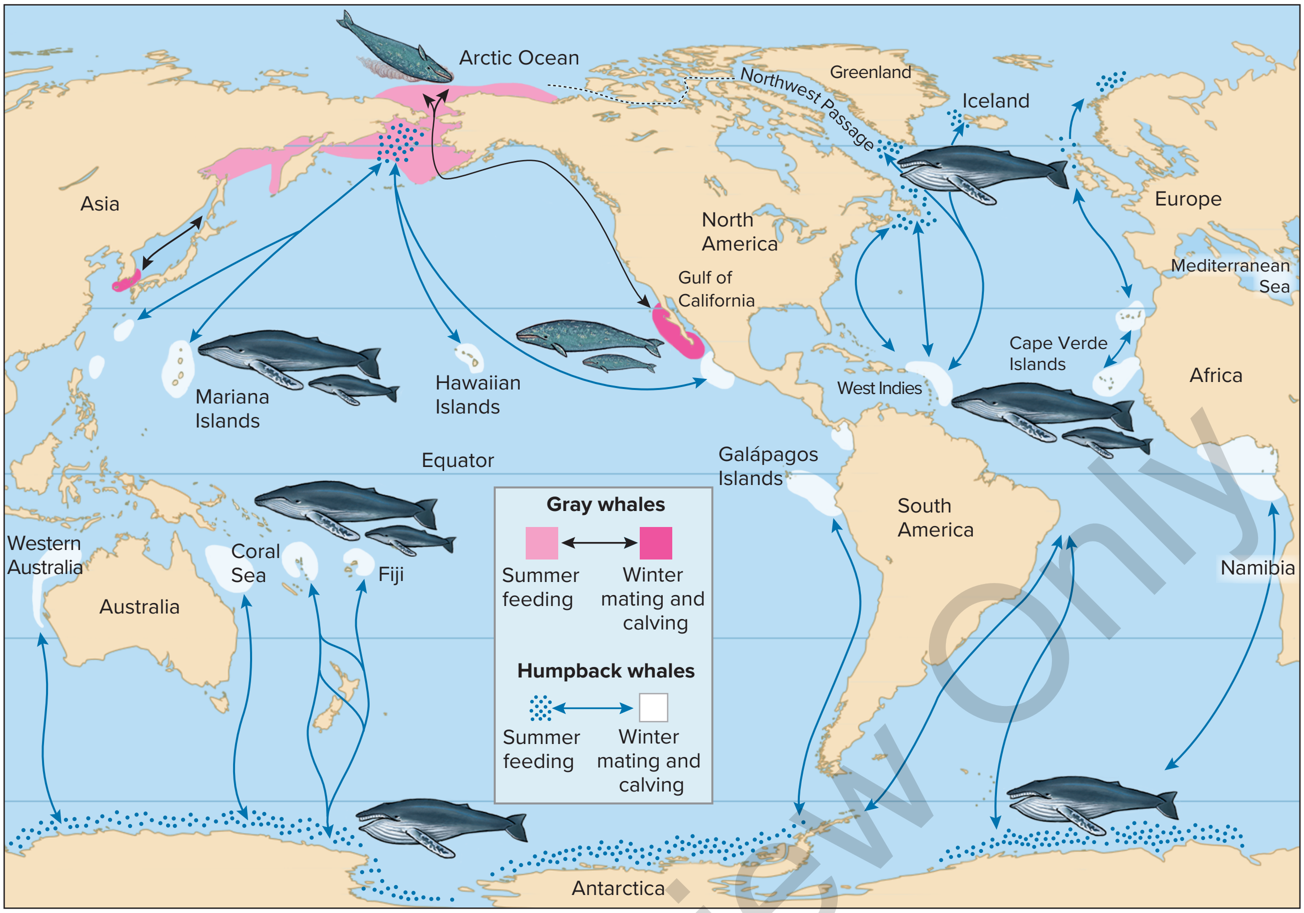


Figure 11.33 Migration routes of humpback (*Megaptera novaeangliae*) and gray whales (*Eschrichtius robustus*). Both species tend to migrate and breed close to shore, where they were easily hunted. Gray whales used to live in the North Atlantic until exterminated in the nineteenth century. Gray whales were spotted in the Mediterranean Sea in 2010 and 2021, apparently swimming along the ice-free Northwest Passage in northern Canada. Another individual was spotted off the coast of Namibia, southern Africa, in 2013.

The seasons are reversed in the Northern and Southern Hemispheres, so, when some humpback whales are wintering in the Hawaiian Islands or the West Indies, other humpbacks living in the Southern Hemisphere are feeding around Antarctica during the southern summer (Fig. 11.33). The migratory route of the gray whale is the best known of any of the great whales (Fig. 11.33). From the end of May to late September, the whales feed in shallow water in the northern Bering, Beaufort, and East Siberian seas. They move south in late September when ice begins to form. In November they begin crossing through the eastern Aleutian Islands. They eat less while on the move, burning off close to a quarter of their body weight. The whales cover about 185 km per day. They travel alone or in small groups along the coast of the Gulf of Alaska and down the western coast of North America en route to the Baja California Peninsula in Mexico.

Migrating individuals often push their heads out of the water, raising the possibility that they navigate using landmarks. They reach Oregon around late November or early December and San Francisco by mid-December. Females generally migrate earlier. In late February pregnant females appear in the shallow, quiet lagoons in southern Baja California and the southern mainland coast of the Gulf of California. Here, females give birth and males mate with non-pregnant females.

How Intelligent Are Cetaceans?

Cetaceans are among the most intelligent animals. Like us, cetaceans have large brains with a distinctively folded cortex—the location where memory and sensory perception are centered—and are capable of astonishing intellectual feats.

Bottlenose dolphins (*Tursiops truncatus*) are used in research to test acoustic communication in cetaceans.

Learning Conditioning is a type of learning that occurs when an animal performs a particular behavior and receives a reward (for cetaceans this is usually a fish). Like many animals, captive dolphins can be conditioned to perform tricks. Unlike most other animals, however, dolphins also through observation. Studies on discrimination and problem-solving skills in the bottle-nose dolphin show that its intelligence lies "somewhere between that of a dog and a chimpanzee," but it is important to realize that intelligence is a human concept. After all, not many people would consider themselves unintelligent because they couldn't locate and identify a fish by its echo. Why should we judge cetaceans by their ability to solve human problems? Instead of "intelligence," some people prefer to speak of cetacean "awareness." Cetaceans probably have a very different awareness and perception of their environment than do humans. Maybe one day we will come to understand cetaceans on their terms instead of ours, and perhaps we will discover a mental sophistication rivaling our own.

Tool Use Observations of cetaceans in the wild have provided additional insights into their learning abilities. Several bottlenose dolphins off Western Australia, for instance, have been observed carrying large, cone-shaped sponges over their beaks to supposedly protect themselves against stingrays and other hazards as they search for fish to eat. The use of sponges as tools appears to be passed down by mothers to offspring.

Can dolphins talk? While dolphins produce a rich repertoire of complex sounds, they lack vocal cords so there are no true "talking" dolphins. Bottlenose dolphins have been trained to make sounds through their blowhole, and some captive bottlenose dolphins have learned to communicate with trainers who use American Sign Language to ask simple questions. Dolphins answer back by pushing a "yes" or "no" paddle. These dolphins can also distinguish among commands that differ only in their word order, a truly remarkable achievement.

Think Critically

1. What is conditioning?
2. What tools have dolphins learned to use?

GO ONLINE to access the inquiry to further research cetacean intelligence.

The northbound migration begins by March, after the birth of the 700 to 1,400 kg calves. Females mate every two years, and the first to migrate north are the newly pregnant females that did not give birth. They will return 12 months later to give birth. Mothers with calves leave last. On the way north the whales tend to stay farther from the coast and move slower than on their southward migration, an average of 80 km per day because of the unfavorable currents and the newborn calves. The last whales leave the coast off Washington State by early May. They start reaching their feeding areas by late May, completing an amazing eight-month trip of up to 18,000 km, the longest migration of any mammal.

There is still much to be learned about the migrations of the gray and other whales. One vexing question is how whales navigate. It has been suggested that they use Earth's magnetic field, a possibility that implies that they carry some type of internal compass to orient themselves. To investigate, scientists have attached small radio transmitters to whales and tracked their movements by satellite. This has uncovered some intriguing details. Some isolated groups of gray whales along the migratory route do not migrate at all. One group only resides in the Queen Charlotte Islands off the coast of British Columbia. Analysis of the DNA of humpback whale populations in the Hawaiian Islands suggests that, as in the green turtle, individuals always return to the feeding grounds of their mothers.

Reproduction

The reproductive system of marine mammals, though similar to land mammals, as have some unique adaptations to life in the water. To keep the body streamlined, male cetaceans and most other marine mammals have an internal penis and testes. The penis, which in blue whales can be over 3 m long, is kept rigid by a bone called the baculum. It is extruded just before copulation through the genital slit, an opening anterior to the anus (see Fig. 11.16).

Reproduction in Pinnipeds Pinnipeds breed on land or ice, some migrating long distances to isolated islands to do so. In most species of seals each adult male breeds with only one female. Camcorders attached to animals have shown that male harbor seals make rumbling noises, quiver their necks, and release a stream of air bubbles, perhaps a display to attract females. In sea lions, fur seals, and elephant seals, however, a male breeds with many females. During the breeding season the males of these species, which are much bigger and heavier than females, come ashore and establish breeding territories. They stop eating and defend their territories by constant, violent fighting. They herd **harems** of as many as 50 females onto their territories and keep other males away (see Fig. 11.34). Only the strongest males can hold territories and breed.

The others gather into **bachelor groups** and spend much of their time trying to sneak into harems for a quick copulation. Defending the harem is exhausting work, and dominant males "burn out" after a year or two, making way for newcomers. It nevertheless pays off in the huge number of offspring they leave, compared with the males that never reach dominance, even though the subordinate males live longer.

Female pinnipeds give birth to pups on shore. They seem to be indifferent to the birth process but soon establish a close relationship with the pup (see Fig. 11.35).

(a) (b)

Figure 11.34 (a) A male Steller sea lion (*Eumetopias jubatus*) guarding his harem on a rocky island off the coast of Alaska. (b) A harem of female California sea lions (*Zalophus californianus*) on Santa Barbara Island, Southern California. The harem (center) is being guarded by a large, darker bull (top left).

Since females continue to go to sea to feed, they must learn to recognize their own pups out of all the others by sound and smell. The pups generally cannot swim at birth. They are nursed for periods of four days to two years, depending on the species. Most pinnipeds have two pairs of mammary glands that produce a fat-rich milk ideal for the rapid development of the pup's blubber.

A female pinniped can become pregnant only during a brief period after **ovulation**, the release of an egg by her ovaries. This occurs just days or weeks after the birth of her pup. Females of most species return to the breeding grounds only once a year. By contrast, **gestation**, the length of time it takes the embryo to develop, is less than a year. This difference would cause the pup to be born too early, before the mother returns to the breeding ground. To prevent this, the newly formed embryo stops developing and remains dormant in the female's womb, the uterus. After a delay of as long as four months, the embryo finally attaches to the inner wall of the uterus and continues its normal development. This phenomenon, known as **delayed implantation**, allows pinnipeds to prolong the embryo's development so that the timing of birth coincides with the female's arrival at the safety of shore.

The walrus also shows delayed implantation as in other pinnipeds. Females give birth to one pup during the summer migration after a long gestation period of 15 to 16 months. They give birth every two years, the lowest reproductive rate among pinnipeds. Walruses mate both on land and in the water; nursing takes place in the water.

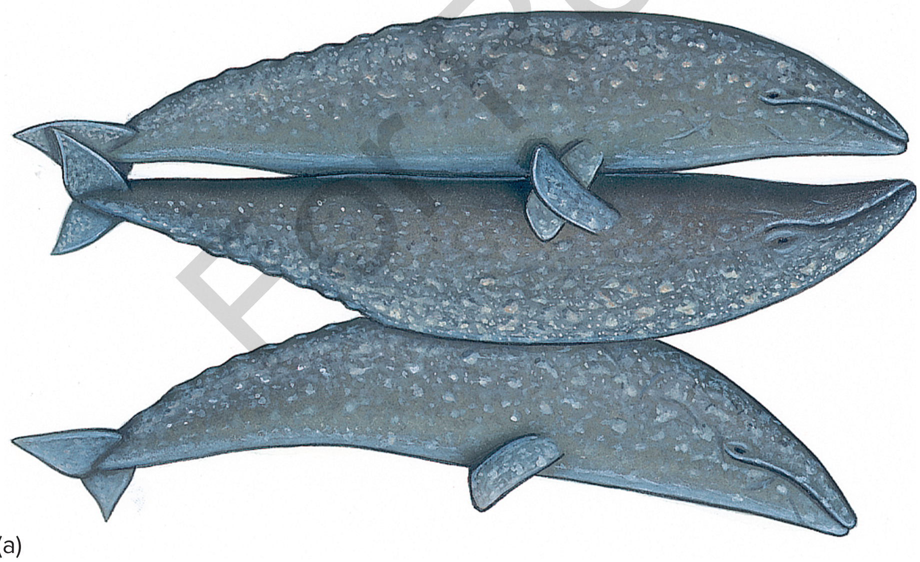
Reproduction in Sea Otters Sea otters reproduce year round, and males mate with multiple females. Mating takes place in the water, with males violently biting females on the nose. The gestation period, which includes delayed implantation, is of four to six months. Birth takes place in the water. Females are notoriously devoted to their pups, carrying and nursing them on their chests.

Figure 11.35 A California sea lion (*Zalophus californianus*) with pup.

Reproduction in Polar Bears Polar bears are solitary except during the mating season in late spring or early summer. Mating induces females to ovulate so successive copulations are necessary to guarantee fertilization. Males can mate with several females, and DNA tests have shown that twins can be fathered by different males. Pregnant females build a den in the snow or ice in the fall and hibernate, giving birth to one or two cubs after a gestation period of around eight months. Delayed implantation guarantees that the cub is born at the ideal time after winter. Cubs typically nurse for approximately two years.

Reproduction in Sirenians Manatees reproduce slowly, becoming mature after about five years and giving birth to a single calf every two to five years after a gestation period of about a year. Dugong females mature after at least six years and give birth to a calf every 2.5 to six years; gestation is from 13 to 15 months. Female sirenians, however, can mate any time of the year, typically with several males. They nurse their calves for a year or more from two mammary glands, each located behind a flipper.

Reproduction in Cetaceans We know relatively little about cetacean reproductive behavior. Like humans, they appear to use sex not only for procreation but for pleasure as well. Cetaceans reach sexual maturity relatively early, at age 5 to 10 in great whales. Sexual behavior appears to have a role in the establishment and maintenance of bonds among all individuals, not just potential mates. The sexes are typically segregated within the pod, and males perform elaborate courtship displays to catch the attention of potentially receptive females. Fights among rival males are common, but cooperation also occurs. Gray whales are known to copulate with the help of a third party, another male that helps support the female (Fig. 11.36b). Group matings have been observed in humpbacks and belugas. Considerable touching and rubbing precedes copulation (Fig. 11.36a). Actual copulation lasts less than a minute but is commonly repeated frequently.



(a)

(b)

Figure 11.36 Mating behavior in great whales. (a) Gray whales (*Eschrichtius robustus*) often mate with the help of a third party, another male that props the female against the mating male. Actual copulation is reported to last for just 30 to 60 seconds. (b) Courtship in humpback whales (*Megaptera novaeangliae*) includes rolling, slapping of the flukes, and pairs surfacing vertically face to face.

The vaginas of bottlenose dolphin and harbor porpoise have folds that appear to block penis entry, probably giving females the ability to control paternity.

Figure 11.37 A bottlenose dolphin (*Tursiops truncatus*) giving birth in captivity. The gestation period lasted for about a year.

Gestation lasts for 11 or 12 months in most cetaceans. An exception is the sperm whale, which has a gestation period of 16 months. Development in most species of large baleen whales is relatively fast for a mammal of their size. It is synchronized with the annual migration to warm waters. It is remarkable that it takes 9 months for a 3-kg human baby to develop, but a 2,700-kg blue whale calf needs only about 11 months.

Cetacean calves are born tail-first (Fig. 11.37). This allows them to remain attached to the placenta, which provides oxygenated blood from the mother, for as long as possible to prevent oxygen deprivation. The calf immediately swims to the surface. In captive dolphins, the mother or an attending female can help the calf to the surface. Fat-rich milk is responsible for the rapid growth of calves, particularly in the great whales. They are born without their full complement of blubber and must gain weight before migrating with their mothers to feeding grounds in polar waters. It has been estimated that a blue whale calf gains 90 kg in weight and 4 cm in length every day for the first seven months of its life.

The mother's milk is produced by two mammary glands with nipples located on both sides of the genital slit (see Fig. 11.16). The milk is squirted into the calf's mouth, which allows the calf to drink under water. In at least some of the great whales, females do not seem to feed much while they are nursing. The calves are not weaned until they arrive at the feeding grounds. In some species they continue to nurse for more than a year after birth.

The relationship between mother and calf during the nursing period is close. Frequent contact and vocalizations are used in communication. Dolphin mothers modify their swimming behavior to allow calves to glide alongside. Mothers are known to defend their calves when there is danger. Sperm whale calves are watched by "babysitting" adults when mothers deep-dive for food. There is a report of a female gray whale lifting her calf onto her flipper to save it from the attacks of orcas. The bond between mother and calf probably lasts for several years. Captive young dolphins are known to return to their mothers for comfort in times of danger or stress.

Average estimated life expectancy in the wild is about 15–20 years in the polar bear, 40–45 years in the bottlenose dolphin, 40–50 years in manatees, and 20–30 years in male orcas, 30–90 in females. Female orcas living beyond their reproductive years may indicate their role as providers of information about food, predators, and other aspects important for the survival of the pod. Great whales live at least 30 to 40 years, humpbacks at least 50 years, bowheads 150 years or more.

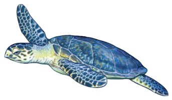
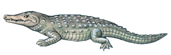
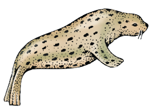
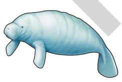
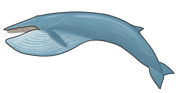
Section Review

1. **Describe** What adaptations do marine mammals have for diving?
2. **Explain** What is echolocation? How does it work?
3. **Explain** What is the role of vocalization in communication among marine mammals?

Use the Practices

Interpret Data If you were going on a whale watching off the coast during winter months, what types of whales could you expect to see? Review this section to suggest the types of whales and behaviors of the whales you might encounter. Would the whales produce vocalizations you could detect? Would they be traveling with other whales and, if so, what kinds and/or ages? Finally, what characteristics of the whale would help you identify if it is the kind you expect?

Table 11.3 Most Important Characteristics of the Marine Reptiles, Seabirds, and Marine Mammals

Group	Distinguishing Features	Temperature Regulation	Feeding	Reproduction	Ecology
Sea Turtles 	Body covered by shell, scales on exposed parts of body, legs modified as flippers, found mostly in tropical seas	Poikilotherms, ectotherms	Toothless jaws adapted for crushing hard invertebrates or picking up soft invertebrates	Oviparious, laying eggs on sandy beaches	Predators of jellyfishes and bottom invertebrates, grazers of seagrasses and seaweeds
Sea Snakes 	Skin with scales, no legs, laterally flattened for swimming, venomous, found only in tropical Indian and Pacific oceans	Pokilothermic, ectotherms	Small teeth adapted for capturing small prey	Ovoviviparous, giving birth at sea, or oviparous, laying eggs on land	Predators of bottom fishes; some feed mostly on fish eggs
Marine Iguane 	Skin with scales, tail laterally flattened for swimming, found only in the Galápagos Islands	Pokilothermic, ectotherms	Three-cusped teeth adapted for grazing	Oviparous, laying eggs in nest on land	Grazer of seaweeds
Saltwater crocodile 	Skin with scales, massive jaws and tail, found in coastal regions in Australia, Southeast Asia, and some western Pacific Islands	Pokilothermic, ectotherms	Heavily toothed jaws for capturing wide range of prey	Oviparous, laying eggs in nest of mud and vegetation on land	Predator of wide variety of coastal animals, including fishes, seabirds, sea turtles, and crabs
Seabirds 	Feathers for insulation, webbed feet, light bones as adaptation for flight, found in all coastal regions	Homeotherms, ectotherms	Beachs adapted for capturing wide range of prey, including filtering	Oviparous, laying eggs in nest on land	Predators of fishes and many groups of surface-dwelling and shallow-water invertebrates, including plankton
Pinnipeds 	Seals, sea lions, walrus: blubber, flippers, reduced hair (fur in some), found mostly in temperate and polar waters	Homeotherms, endotherms	Teeth for capturing and eating prey	Viviparous, giving birth on land	Predators of mostly fishes, crab-eater seal filters water for krill, leopard seal hunts mostly seabirds, walrus feeds on clams and bottom invertebrates
Sea Otter 	Dense, dark fur, dorsoventrally flattened tail, flattened hind feet, found only in northern and northeastern Pacific Ocean	Homeotherms, endotherms	Flattened teeth for capturing and crushing prey	Viviparous, giving birth at sea or on land	Predator of sea urchins and wide range of bottom invertebrates and fishes in kelp forest
Poler Bear 	Dense, white fur, proportionally short legs, tail, and ears; found in Arctic mostly on drifting ice	Homeotherms, endotherms	Powerful jaws and teeth for capturing and eating prey	Viviparous, giving birth on land	Primary predator of ring seals, other prey (birds, caribou) if available
Sirenians 	Manatees, dugong: blubber, reduced hair, front flippers, paddle-shaped tail, tropical seas (one species only in fresh water)	Homeotherms, endotherms	Teeth as thick ridge pads for crushing vegetation	Viviparous, giving birth at sea	Grazers of seagrasses and other coastal vegetation
Baleen Whales 	Blubber, streamlined body, reduced hair, front flippers, tail fluke, blowhole, found in all seas	Homeotherms, endotherms	Baleen on upper jaw for filtering small plankton	Viviparous, giving birth at sea in warm waters	Filter feeders of plankton and small fishes, mostly in polar water; greys feed on small animals (mostly amphipods) in soft bottoms
Toothed whales 	Blubber, streamlined body, reduced hair, front flippers, blowhole, found in all seas (some dolphins live in fresh water)	Homeotherms, endotherms	Conical teeth for capturing prey	Viviparous, giving birth at sea	Predators of fishes, squids, other marine mammals, and some large bottom invertebrates like lobsters

Source: Bill Ober

CHAPTER 11 Summary

11.1 Marine Reptiles

With the exception of the leatherback turtle, marine reptiles are poikilotherms and ectotherms, generally limiting their distribution to warm water.

Key Questions

1. What are the main characteristics of reptiles?
2. Differentiate between the terms *ectotherm*, *endotherm*, and *poikilotherm*.

Vocabulary

tetrapod
temperature-dependent sex determination

11.2 Seabirds

Seabirds are widely distributed around the globe, breeding on land, but feeding at sea.

Key Questions

1. What is the definition of "seabird"?
2. What are the main characteristics of seabirds?

Vocabulary

salt gland
erythrocyte
guano

11.3 Marine Mammals

Marine mammals comprise a diverse group of animals with hair and mammary glands.

Key Questions

1. What are the main characteristics of mammals?
2. How does current legislation protect marine mammals?

Vocabulary

placenta
mammary gland
blubber
subspecies
convergent evolution
fluke
blowhole
ambergris
pod
whaling

11.4 Biology of Marine Mammals

Marine mammals have adaptations and complex behaviors (particularly communication) that allow them to survive in the marine environment.

Key Questions

1. How are cetaceans adapted for swimming?
2. Why do pinnipeds and cetaceans migrate?

Vocabulary

spout
bends
apneustic breathing
bradycardia
echolocation
melon
spermaceti organ
spermaceti
breaching
beaching
harem
bachelor group
ovulation
gestation
delayed implantation

CER Revisit the Ripple Effect

Recall the claim you made concerning the Ripple Effect before reading the chapter. What evidence did you gather along the way? Does your evidence support the initial claim you made? If not, revise your claim. Summarize your reasoning.

CHAPTER 11 Assessment

Review Questions

Multiple Choice

1. Which of the following groups of animals are homeotherms?
   - **a.** reptiles and birds
   - **b.** birds and mammals
   - **c.** mammals and reptiles
   - **d.** reptiles, birds, and mammals
2. Which describes reproduction in seabirds?
   - **a.** ovoviviparous, giving birth at sea
   - **b.** oviparous, laying eggs in nests on land
   - **c.** viviparous, giving birth on land
   - **d.** viviparous, giving birth at sea
3. Which of the following best describes the evolutionary order of each group of vertebrates?
   - **a.** Fishes → Marine Reptiles and Mammals → Tetrapods → Land Reptiles and Mammals
   - **b.** Fishes → Tetrapods → Land Reptiles and Mammals → Marine Reptiles and Mammals
   - **c.** Fishes → Land Reptiles and Mammals → Tetrapods → Marine Reptiles and Mammals
   - **d.** Fishes → Tetrapods → Marine Reptiles and Mammals → Land Reptiles and Mammals
4. Surface plunging, pattering, dipping, and pursuit diving with feet are all examples of
   - **a.** thermoregulation strategies.
   - **b.** reproductive strategies.
   - **c.** courtship behaviors.
   - **d.** feeding strategies.
5. The following are all adaptations of seabirds for swimming and diving except
   - **a.** relatively dense bones to reduce buoyancy.
   - **b.** air sacs increasing oxygen intake.
   - **c.** low numbers of erythrocytes.
   - **d.** webbed feet.
6. The only strict vegetarians among marine mammals are the
   - **a.** sirenians.
   - **b.** pinnipeds.
   - **c.** cetaceans
   - **d.** sea otters.

Short Answer

7. How are penguins adapted for swimming and diving?
8. What has been done to try to curtail whaling? Have efforts been successful?
9. What is delayed implantation? What advantage does it give pinnipeds?
10. Describe the adaptations of marine mammals that aid in avoiding decompression sickness.

Critical Thinking

11. One way to bolster sea turtle populations is to reintroduce them to areas where they have been wiped out. This is done by reburying eggs or by releasing newborn turtles on beaches. Why do this instead of releasing fully grown individuals?

12. Cetaceans give birth to few well-developed calves at well-spaced intervals. They also feed and protect the calves for long periods. This is in sharp contrast to most fishes, in which many eggs are spawned, and the parents spend no time feeding and protecting the offspring. What do you think is the best strategy? Has this strategy paid off in the great whales?

13. Sea snakes are found in the Indian and Pacific Oceans, but not in the Atlantic. Using information from Chapters 2 and 10, explain this in the context of Earth's geologic history.

DATA ANALYSIS LAB

Is plastic ingestion a threat to endangered albatross species?

Albatrosses are large seabirds that spend the majority of their lives migrating between breeding and non-breeding areas. Albatrosses feed on fish, zooplankton, or scavenge on dead birds or whales. They have a slow reproductive rate, and many species of albatross are threatened with extinction. A known threat to albatross species is interaction with commercial fishing boats and/or nets. Another known threat is invasive species on islands where albatross breed. These threats, however, do not account for all the decreases in population numbers for albatross species.

Data and Observations

Scientists wondered if plastic ingestion was a viable threat to albatross. They examined records of albatross deaths from wildlife centers to determine if the dead birds had eaten plastic and, if they had, was ingestion of plastic the cause of death. They compared the probabilities of death due to interactions with fishing operations and those due to plastic ingestion. The graphs below show data for two areas in the Southern Hemisphere.

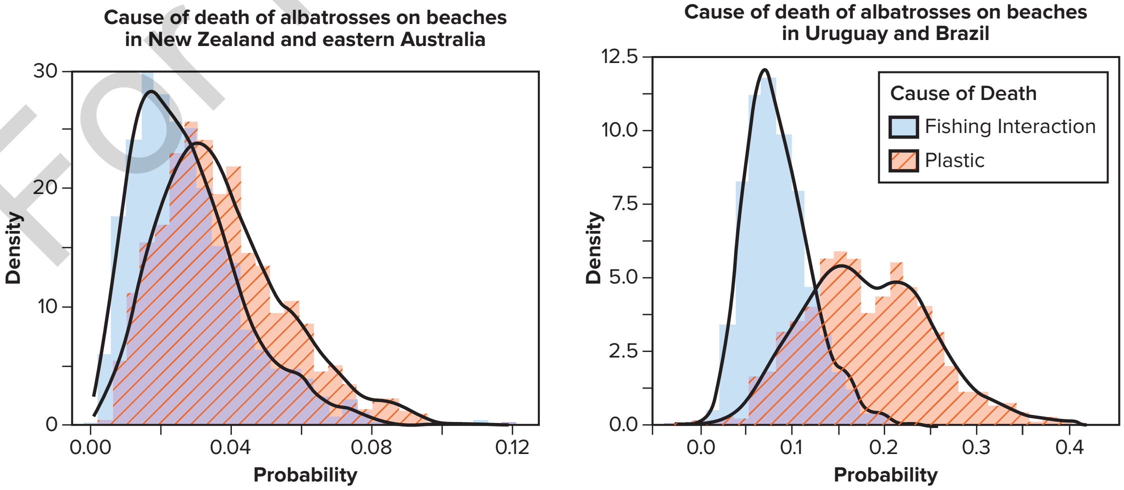


Figure A The first graph shows the cause of death of albatroses in New Zealand and Australia, the second shows cause of death of albatroses in Urugauy and Brazil.
*Data obtained from: Roman, L., Butcher, R. G., Stewart, D., Hunter, S., Jolly, M., Kowalski, P., ... & Lenting, B. (2021). Plastic ingestion is an underestimated cause of death for southern hemisphere albatrosses. Conservation Letters, *14(3)*, e12785.

Analysis

1. Based on these data, the scientists concluded that ingestion of plastic was a viable threat to albatrosses and should be recognized as such by the international community and policy makers. What data from the graphs support the scientists' conclusions?

2. As a result of their study, the scientists recommended that countries take more actions to reduce land-based plastic pollution. Recall that much of the plastic pollution in the ocean originates as plastic pollution on land. Design a plan to get different countries to reduce plastic use and/or prevent plastic from reaching oceans. Include details about how to coordinate an international effort to reduce plastic in the ocean.

CHAPTER PROJECT

Chapter 11 Project: "Are You A Dolphin Trainer?"

Everyone at some point has had one or more "dream jobs." It is often easy to imagine the most visible and exciting part of a career when there is so much more involved in the day-to-day tasks. Marine biologists can be found in a variety of fields, making an impact in the arts, education, policy, and of course, science. What are some career pathways you might take, with your unique set of skills, in-terests, and abilities?

You will:

- Develop an understanding of how marine biologists can work in a variety of capacities with a variety of skill sets.
- Determine what skills and knowledge you would need for a career in marine biology that interests you.

GO ONLINE to access your chapter project and begin your research.