Introductory Fish Biology

Introductory Fish Biology:

An Ecophysiological Approach

By

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This Book is Dedicated to
My wife Cheryl
and
My Academic Mentors,
Dr. John Briggs
(1920 -2018)
Dr. Robert Shipp
and
Dr. Jose Torres

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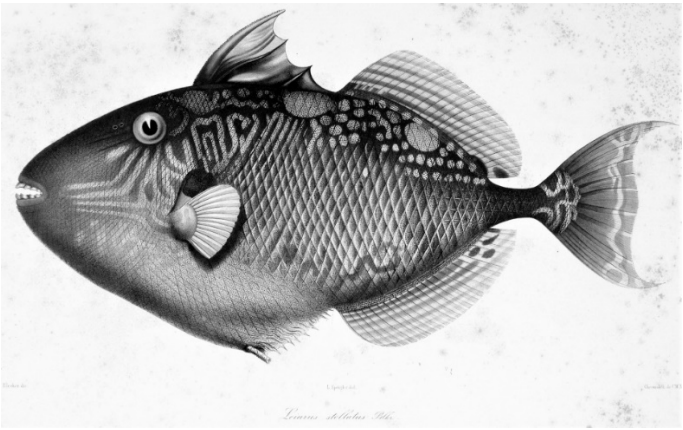
PREFACE

"Extinction of an organism is like discovering ancient texts written in a language that we cannot yet decipher and then destroying them all. Who knows what mysteries would have been solved or what inspiration might have been provided by the words written there!"
—Glenn R. Parsons, 2007. Sharks, Skates, and Rays of the Gulf of Mexico, University Press of Mississippi, Jackson, MS.



Abalistes stellatus, the starry triggerfish, is a member of the family Balistidae. This fish occurs in the Red Sea, the Persian Gulf, and the Indian and western Pacific Oceans. Image from M. P. Bleeker, Atlas ichthyologique des Indes Orientales, 1862-1879.

From the Author

Why would anyone saddle themselves with the herculean task of writing a textbook, years of literature research, agonizing over every sentence, producing graphics to illustrate important points, long hours of editing, worrying over what should be included and what should not? I

would venture to say that the authors of those textbooks that have an organismal focus, fishes, mammals, insects, birds, etc., are individuals that are truly excited by the group to which they have devoted many years and, in some cases, a lifetime of study. This level of excitement and fascination is the energy upon which they draw to take on this task with the hopes that their enthusiasm might inspire others. In fact, when I think back on my years in academia, invariably the most enthusiastic, animated, and exciting lecturers, were the professors of herpetology, botany, entomology, and ichthyology. Scientists of this caliber were likely inspired at an early age by some book, event, mentor, or activity that sparked a flame of curiosity, and this led them to pursue a career in biology. I can say without reservation that my interest in fish biology came about because of two things, my love of sport-fishing and "The Undersea World of Jacques Cousteau". Although I was not a very good fisherman, I loved being on the water, I never missed an episode of Jacques Cousteau, and I have been fascinated with fish ever since. In fact, I often wonder how my friends and colleagues could not share my interest. Some fascinating facts about fishes: they hold the record for the oldest vertebrate on earth (Greenland shark), the most numerous vertebrate on earth, (midwater bristlemouths), the deepest dwelling vertebrate, (the snailfish, 8000 meters), the largest vertebrate migration on earth (oceanic vertical migration), and the fastest moving body part of all animals (jaws of the anglerfish). The smallest brain-to-body ratio of all vertebrates is found in the bony-eared assfish, so one might argue that the "dumbest" vertebrate on earth is a fish. The point of these ramblings? In my estimation, the author of a scientific textbook must have a great love and appreciation for the beauty and unbelievable complexity of the world of biology to put themselves through the rigor of completing a textbook! Hopefully, that fascination will be evident in the pages of this book.

This book is an introductory fish biology textbook written for upper-level, undergraduate students that have a solid background in basic biology. However, I believe the book could likewise be useful for graduate students, particularly those that want to refresh their understanding of organismal level topics. After 35 years of teaching, at various times, 15 different biology courses that included freshman biology, introductory physiology, fish biology, ichthyology, ecophysiology, fishery biology,

conservation biology, and biological oceanography, I believe I have an effective approach and an appropriate "voice" by which this topic can be conveyed. For example, unlike students that attended my classes when I began my career in academia in 1987, there are greater numbers of students today that are more visual learners. For this reason, I have included hundreds of diagrams, figures, and photographs in the text. Additionally, by drawing on my many years of teaching freshman biology, I am aware of the topics that students typically have the greatest trouble understanding, and I have endeavored to put extra effort into explaining those topics. Knowing that there can be a great range in experience and preparedness in Junior and Senior level students, I have tried to provide greater details in my explanations and have likewise included over 450 references, so students would have additional source material to help in their understanding and to perhaps delve deeper into areas of interest. My research endeavors have been rather eclectic at times but some of my most interesting contributions have been in the physiology, ecology, and ecophysiology of sharks. For this reason, sharks are often used as examples in the book. While this book is written as an introductory fish biology text, I have nevertheless emphasized those areas of biology that I find most interesting, and hopefully, students will as well.

Some scientists believe we may be entering a period of human-caused extinction that will result in significant losses in biodiversity of the earth. Issues such as habitat degradation, fragmentation, and destruction urgently need to be addressed. Aquatic and marine ecosystems are no exception and in reality, are under greater threat than terrestrial ecosystems. According to the International Union on the Conservation of Nature (IUCN), nine of the top ten most threatened ecosystems on the planet are marine or aquatic. To draw attention to conservation issues that are specific to fishes, I have included "Conservation Alert" boxes in various chapters. In addition, I have included "Focus On" boxes that describe in greater detail items of interest relevant to fish biology.

Over the past few decades, across college and university campuses, the trend in education has been to eliminate from the curriculum courses that focused on groups of organisms or "natural history" courses. Courses of this kind include the "ologies" such as ichthyology, herpetology, and

mammology. Further exacerbating this *"natural history knowledge gap"* is the fact that those professors trained to teach those courses are retiring and those disciplines are not being replaced in the curriculum. This movement away from organismal level biology at many colleges and universities has occurred over the past few decades. According to Lyman (2017):

> *In the 1960s and '70s, biology went through a reductionist revolution. Biochemistry and molecular biology were emphasized because of the discovery of the structure of DNA.*

The reductionist approach to biology has been ongoing across countless institutions of higher learning for several decades. Fortunately, natural history and organismal level instruction has recently taken on renewed importance in major universities such as Harvard and U.C. Berkeley, and courses offered in ichthyology, herpetology, and entomology are very popular among students. This welcomed change to more balanced coverage in university curricula and research emphases is critically important if we are to meet the conservation challenges that we will surely face. My wish for this book is to assist instructors in inspiring students to further their interests in fish biology and perhaps contribute to a continued revival of interest in organismal level biology.

The Ecophysiological Perspective

Fish biology as a discipline includes all of the classic areas of study typically associated with the biological sciences: genetics, taxonomy, physiology, ecology, etc. However, the emphasis in designing this textbook is to examine the interface between the environment and the physiology of the organism. This **ecophysiological emphasis** may include, for example, the effects of temperature, salinity, dissolved oxygen, photoperiod, nutrients, competition, and a host of other parameters, on physiological processes in fishes. For example, the ecophysiologist might examine, in the laboratory, the physiological response to temperature fluctuations that an organism would normally experience in nature, and then make predictions about how those fluctuations might alter the competitive ability of that organism in the wild. Ecophysiology has also focused on how physiological processes change as the size of the organism changes. This approach

requires an understanding of the organisms' environment, both biological and physical, the ecological role of the organism, but also an understanding of its physiology. Ecophysiology encompasses numerous disciplines. For this reason, I have included the required basic biological information to assist the student in understanding the ecophysiological topics.

A significant amount of new information concerning the biology of fishes is published each year, and there is no end in sight. This book will address this rapid increase by identifying and reviewing the most vigorous areas of fish ecophysiological research, by pointing out the areas where research is most sorely needed, and by providing recommendations on future research/study direction.

Acknowledgments

Many fine people contributed to this textbook and their assistance was invaluable. First of all, I would like to thank the many thousands of undergraduate students that I've taught at the University of Mississippi. I would also like to thank the many undergraduate and graduate students that have worked in my laboratory. The research projects we completed together have been a great source of information for this textbook. Those students include Dr. Steven Reed Adams, James Bartlett, Dr. Rachel Beecham, Will V. Bet-Sayad, Dr. Bryan Cage, Dr. John Carlson, Dr. Linda Lombardi-Carlson, Matthew Chan, Jill Frank, Dr. Lauren Fuller, Caleb Gaston, Matthew Gaylord, Dr. Eric Hoffmayer, Alan Katzenmeyer, Josh Rangel, Kyle Rice, Angeline Rodgers, Melissa Sandrene, Dr. Peter Smiley, Ehlana Stell, Dr. Larry Sylvester, and Dr. Dalma Martinovic-Weigelt (note that I have used their current titles and not all doctoral degrees were earned in my lab). Lecturing and interacting with undergraduate and graduate students required me to remain current regarding the most recent discoveries in fish biology and provided a forum, over my many years of teaching, whereby I was able to better explain difficult topics. I know that helped me to be a better communicator and I hope that is evident in this textbook. Kudos to Helen Edwards of Cambridge Scholars who kept me aware of approaching deadlines and assisted in the preparation of the text. I would also like to recognize my friends and colleagues for their assistance, discussions, encouragement, reprints, and advice: Dr. Paul Lago, Dan Foster, Dr.

Richard Buchholz, Dr. Jan Hoover, Dr. Phil Motta, and Dr. Greg Tolley. Finally, I am very grateful for the many people that contributed to Wikimedia Commons, Public Domain, and whose illustrations and photographs appear in this text.

Literature Cited

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CHAPTER ONE

INTRODUCTION

"When they go fishing, it is not really fish they are after."
—E. T. Brown, Not Without Prejudice: Essays on Assorted Subjects

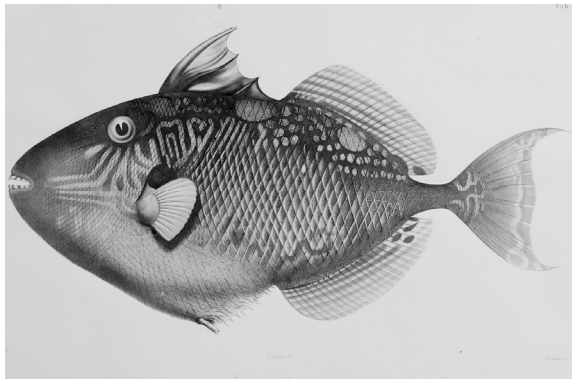


Figure 1.10. The triggerfish, *Leiurus stellatus.* (Artwork from Bleeker, *Atlas Ichthyologique*.)

An argument could be made that fishes have provided humankind with the greatest abundance and variety of benefits than any other animal group. Fishes have provided us with sport, food, scientific inquiry, and artistic inspiration. Fishes have helped improve human health since various pharmaceuticals have been derived from fish. Additionally, they have helped safeguard the environment as they are used in toxicological testing. Fish provide the majority of the protein that is consumed by the worlds' populations and various fish byproducts are used in manufacturing. As suggested by the quote above from E. T. Brown, the pursuit of fish via sport fishing has given more than a few fishers the opportunity for personal growth, to reflect on the human condition, and to consider the

machinations of the universe. Fishes have figured prominently in the religions of various cultures of the world. In rural areas of India, various species of fish are held in pools associated with religious temples. These revered fishes are protected and are considered symbols of divine power. The Buddhist golden fish symbol represents living in a state of fearlessness, happiness, and fertility (Lynch 2014) (Fig. 1.11). In Judaism, fish are associated with good luck and fertility. The *ichthys,* from which the word *ichthyology* is derived, is a Greek symbol consisting of two intersecting arcs that resemble a fish. The symbol was used in early Christianity to mark meeting places and to recognize friends from foes (Fig. 1.11). Finally, many sport fishers readily admit the need for an almost spiritual reconnection with the natural world that fishing provides. For a beautifully crafted description of nature, fishing and spirituality, the reader should refer to the story and resulting movie *A River Runs Through It* by Norman McLean.

It is noteworthy that among the vertebrates, fishes occupy a special place on the planet for the following reasons. They are the most diverse group of vertebrates on the planet with over 35,000 species known. The bristlemouth fishes are believed to be the most numerous of all vertebrates with their numbers estimated in the quadrillions! Recently, the deepest living vertebrate was described, a snailfish that is found at 27,000 feet below sea level. Finally, the Greenland shark was discovered to be the oldest vertebrate on earth. These slow-moving, cold-water species were found to be 400 years old and some individuals may be 500 years old!

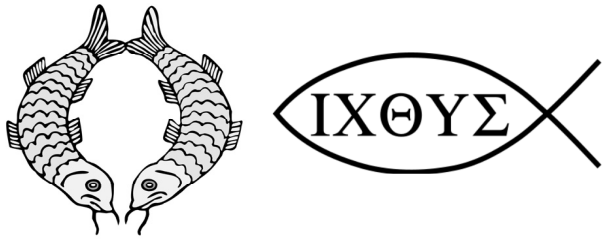


Figure 1.11. (A.) The Buddhist golden fish (left) and the Christian *ichthys* (right). (Image credits: left: Wikimedia commons; right: Christopher J. Fynn / CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0)

Aesthetics

The aesthetic qualities of fishes have been recognized ever since people put pen to paper, brush to canvas, and image to film. For example, one of the oldest depictions of a fish is found in the **Abri du Poisson Cave** in France that dates to about 23,000 BC. Inside this Paleolithic cave can be seen a stone relief sculpture with detail enough to be identified as a salmon. The **Native American Mogollon culture** (ca 1500 to 200 BC) located in the Southwestern United States and Northern Mexico produced a distinctive style of pottery that prominently included fishes (Fig. 1.12). It is estimated that about 8% of all the pottery this culture produced included fish imagery.

Figure 1.12. A fishbowl from the Mimbres tradition of the Mogollon culture from 1050 to 1150 BC. (Photo by Sharon Mollerus - Ceramic Bowl Fish, Mimbres, c. 1050-1150, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=64105136)

Fish have not often been the subject of poetic flights of fancy but perhaps the most famous piscatorial poem was by Elizabeth Bishop, aptly entitled *The Fish*. The poem uses wonderful imagery, in the first lines of the poem, to describe a venerable fish captured and then released in the final line. Perhaps the most famous piece of literature produced by the novelist Ernest Hemingway is *The Old Man and The Sea*. Set in Cuba in the 1950s, the story tells of an elderly fisherman and his struggle to capture a

marlin of epic proportions (Fig. 1.13). The novel was important in garnering Hemingway the Nobel Prize for Literature in 1954. Certainly, any list of literature of a "fishy" nature must include the novel *Jaws* by Peter Benchley. While not likely to be prominent in Nobel Prize discussions, the novel and resulting movie were wildly popular with sales of 20 million copies of the book worldwide. The movie was the highest-grossing film of all time in 1975 and spawned the Hollywood term "blockbuster".

Figure 1.13. A movie poster from Ernest Hemingway's *The Old Man and the Sea. (1958, public domain).*

Figure 1.14. In the painting *Watson and the Shark* (1778) by John Singleton Copley, rescue is close at hand.

Figure 1.15. Winslow Homer's oil painting *The Gulf Stream* (1899). Surrounded by sharks, a lone sailor on a battered boat ponders his fate.

Fish have been the subjects of some of the masters of painting. Goldfish are a reoccurring theme in the paintings of Henri Matisse. Sharks, in particular, have been portrayed in various paintings. For example, John Singleton Copley's *Watson and the Shark* (Fig. 1.14) depicts a hopeful rescue scene as a hapless person is apparently being plucked from the jaws of a closing shark. Winslow Homer's *The Gulf Stream* depicts a more dire situation with a lone sailor caught between a water spout and advancing sharks, (Fig. 1.15**)**. *The Gulf Stream* is believed by some to be Homers' greatest painting. Fish have even been used as instruments of art themselves. **Gyotaku** is the Japanese art of fish printing wherein ink is brushed onto a fishes' body and rice paper is applied to transfer an image to the paper. This form of art dating back to the 1800s is thought to have been used by Samurai warriors to document fish size during fishing competitions. On several occasions, the author of this text has used gyotaku as a teaching tool in the laboratory portion of fish biology classes (Fig. 1.16).

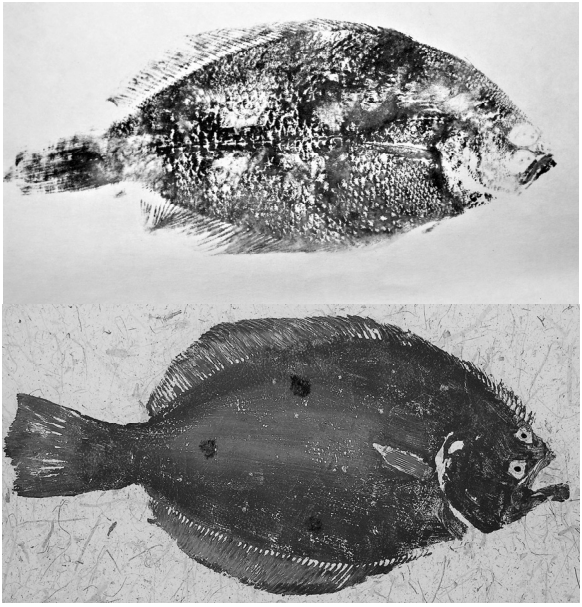


Figure 1.16. Gyotaku, the Japanese art of fish printing used to reproduce a whiff, *Etropus sp.* (top) and a flounder, *Paralichthys* sp. (bottom). This simple technique can provide a detailed fish image and can be used in fish biology labs to teach external anatomy.

Commercial and Recreational Fishing

Fishes play an important role in the lives of millions of people as an important food source. Fish are a crucial source of protein for many people around the globe, particularly in developing countries (see Box 1.1). Tilapia, for example, has become a widely aqua-cultured species that provides nourishment for protein starved populations. Ocean harvest of fish and other seafood from 1990 to 2015 has remained stable at approximately 90 million tons annually (Fig. 1.17). However, production of species via aquaculture has increased steadily over the same period and in 2013 exceeded wild-caught production. The value of the world's commercial fisheries, excluding aquacultured species, was estimated to be $80 billion in 2010, but when all associated industries were factored in,

boat building, fishing equipment manufacturing, etc., the value increased to $240 billion (**Pew Environment Group**).

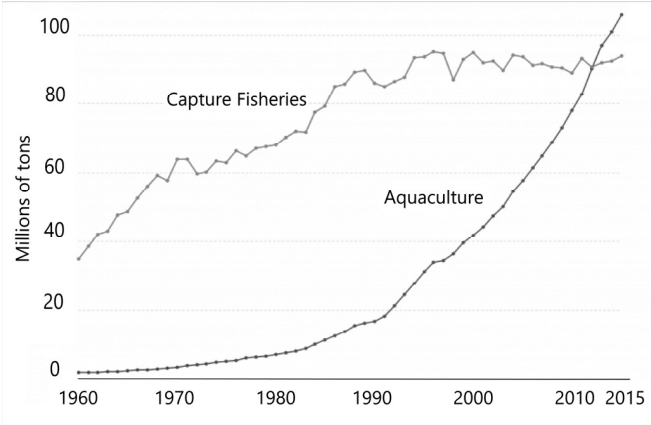


Figure 1.17. World wild-caught and farmed seafood production, 1960-2015. (Food and Agricultural Organization of the United Nations)

According to a report by the Food and Agriculture Organization of the United Nations, 60% of fisheries worldwide are fully fished. However, 33% of fisheries are **overfished** meaning the number of fish that were not harvested was below the level necessary to sustain the populations. Additionally, as much as 30% of the global catch is unreported which means that some fisheries that appear to be fully fished may indeed be overfished (Fig. 1.18). Consistent under-reporting by some nations, notably China, the world leader in ocean harvest, (Pauly 2014) makes management of fisheries difficult.

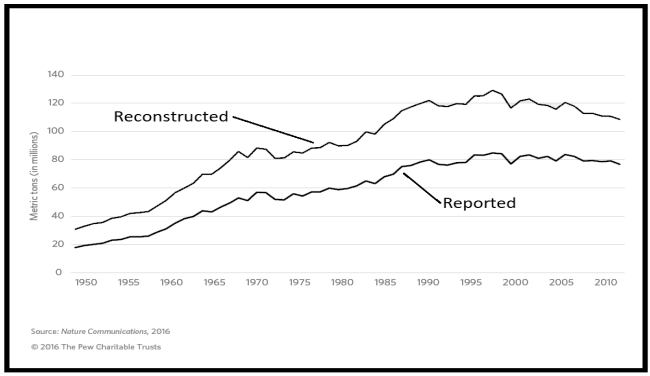
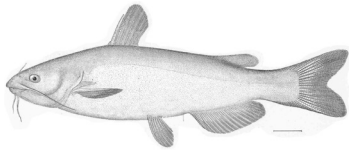


Figure 1.18. A 2016 study found that 30% of fisheries catch is unreported and that global fisheries landings have been declining since the 1990s. From Pauly and Zeller (2016).



THE CHANNEL CATFISH, *Ictalurus punctatus*

Box 1.1. Focus on Aquaculture. Fishes are aquacultured in many parts of the world. In the southern U.S., the channel catfish, *Ictalurus punctatus* is cultured in freshwater ponds particularly in the states of Mississippi, Arkansas, Alabama and Louisiana where 94% of all U.S. catfish acreage can be found. In other parts of the world, fast-growing species of tilapia are cultured. According to the Food and Agriculture Organization of the United Nations, 1.5 million tons of tilapia, primarily species of *Tilapia, Orechromis, and Sarotherodon,* are harvested each year. Sea cage culture, in Australian waters has seen significant development where Atlantic salmon, *Salmo salar* and southern bluefin tuna, *Thunnus maccoyii,* are cultured. Farmed fish production has soared over the past 30 years with about 67 million tons of fish aquacultured in 2012 (Figure 1.16). While aquaculture has been touted by some as the 'silver bullet" for a protein hungry world, problems with water table depletion (catfish culture), introductions of invasive, non-native species (tilapia culture) and pollution of ocean environments (cage culture) have yet to be over-come.

For many people, some of their most meaningful and enjoyable experiences in the outdoors have come from recreational, sport-fishing. Although fishing as an individual endeavor dates back about 40,000 years, sport-fishing using a rod similar to modern techniques was practiced by the Egyptians more than 2000 years ago. However, fish hooks made of bone have been found in Czechoslovakia and are believed to be 20,000 years old. Recreational fishers are important to the economies of many areas and there are an estimated 220 to 700 million anglers worldwide. Those anglers are estimated to spend $190 billion annually and that is likely an underestimate since it does not include money spent on fishing tackle (FAO). Recreational fishing in the U. S. is the fourth most popular sport and, from humble beginnings in the 1960s, competitive sport fishing has grown to be a multi-million-dollar industry (Fig. 1.19). Saltwater tarpon, tuna, and billfish tournaments may have prizes for first place in the millions of dollars.

Figure 1.19. Largemouth bass, *Micropterus salmoides*, is the most popular sport fish in the U. S. with some bass fishing tournaments offering prize money of $100,000 for first place. (Photograph courtesy of Erin and Hunter Garrett).

Drug Development and Discovery

Various fish species have been important in new drug discovery and/or for their contribution to pharmaceutical development. The zebrafish, *Dania rerio* has replaced the white mouse in many labs where drug screening is conducted (Strange 2016). Zebrafish have also been used recently in opioid addiction research. In a study designed by Lam and Petersen (2019), zebrafish were able to self-administer opioids, became addicted to the drugs, and displayed behavioral characteristics similar to those observed in humans. This research provides a more thorough means for measuring motivation in drug-seeking.

Consuming fish is a healthy means of obtaining protein and a portion of those health benefits are attributed to a particular kind of fats that are found in certain kinds of fish. The health benefits of **omega-3 fatty acids** derived from fish oils are well known and several prescription drugs derived from fish oil are being used to fight cardiovascular disease (Herper 2018). Various drugs derived from shark cartilage have been shown to have **antiangiogenic** (blood vessel formation inhibition) properties and have been touted as possible anti-cancer drugs since tumor formation is dependent upon the recruitment of blood vessels to the growing cancerous tissue. However, in laboratory trials, patient life expectancy was not increased when shark cartilage was administered alongside traditional chemo and radiation therapy (Ostrander, et al. 2004). A more promising recent development in the war on cancer and other diseases involves the discovery of **variable new antigen receptor (VNAR) proteins** in sharks (Koveleva et al. 2014). These proteins, similar to antibodies, are important in the proper functioning of the shark immune system and are being researched for application in human disease treatment (see Box 1.2).