Chapter **1**

The science of ichthyology

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Fishes make up more than half of the 55,000 species of living vertebrates. Along with this remarkable taxonomic diversity comes an equally impressive habitat diversity. Today, and in the past, fishes have occupied nearly all major aquatic habitats, from lakes and polar oceans that are ice-covered through much of the year, to tropical swamps, temporary ponds, intertidal pools, ocean depths, and all the more benign environments that lie within these various extremes. Fishes have been ecological dominants in aquatic habitats through much of the history of complex life. To colonize and thrive in such a variety of environments, fishes have evolved obvious and striking anatomical, physiological, behavioral, and ecological adaptations. Students of evolution in general and of fish evolution in particular are aided by an extensive fossil record dating back more than 500 million years. All told, fishes are excellent showcases of the evolutionary process, exemplifying the intimate relationship between form and function, between habitat and adaptation. Adaptation and diversity are interwoven throughout the evolutionary history of fishes and are a recurring theme throughout this book.

What is a fish?

It may in fact be unrealistic to attempt to define a "fish", given the diversity of adaptation that characterizes the thousands of species alive today, each with a unique evolutionary history going back millions of years and including many more species. Recognizing this diversity, one can define a fish as "a poikilothermic, aquatic chordate with appendages (when present) developed as fins, whose chief respiratory organs are gills and whose body is usually covered with scales" (Berra 2001, p. xx), or more simply, a fish is an aquatic vertebrate with gills and with limbs in the shape of fins (Nelson 2006). To most biologists, the term "fish" is not so much a taxonomic ranking as a convenient description for aquatic organisms as diverse as hagfishes, lampreys, sharks, rays, lungfishes, sturgeons, gars, and advanced ray-finned fishes.

Definitions are dangerous, since exceptions are often viewed as falsifications of the statement (see, again, Berra 2001). Exceptions to the definitions above do not negate them but instead give clues to adaptations arising from particularly powerful selection pressures. Hence loss of scales and fins in many eel-shaped fishes tell us something about the normal function of these structures and their inappropriateness in benthic fishes with an elongate body. Similarly, homeothermy in tunas and lamnid sharks instructs us about the metabolic requirements of fast-moving predators in open sea environments, and lungs or other accessory breathing structures in lungfishes, gars, African catfishes, and gouramis indicate periodic environmental conditions where gills are inefficient for transferring water-dissolved oxygen to the blood. Deviation from "normal" in these and other exceptions are part of the lesson that fishes have to teach us about evolutionary processes.

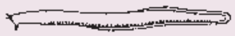
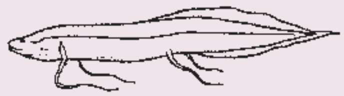
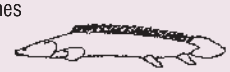
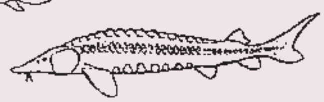
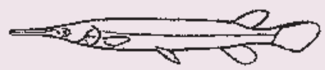
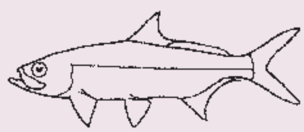
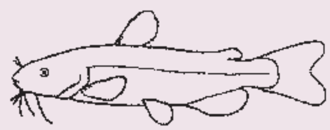
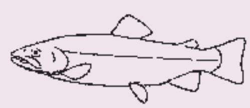
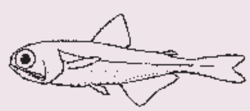
The diversity of fishes

Numerically, valid scientific descriptions exist for approximately 27,977 living species of fishes in 515 families and 62 orders (Nelson 2006; W. Eschmeyer pers. comm.; Table 1.1) (note: "**fish**" is singular and plural for a single species, "**fishes**" is singular and plural for more than one species; see Fig. 1.1). Of these, 108 are jawless fishes (70 hagfishes and 38 lampreys); 970 are cartilaginous sharks (403), skates

Table 1.1

The diversity of living fishes. Below is a brief listing of higher taxonomic categories of living fishes, in phylogenetic order. This list is meant as an introduction to major groups of living fishes as they will be discussed in the initial two sections of this book. Many intermediate taxonomic levels, such as infraclasses, subdivisions, and series, are not presented here; they will be detailed when the actual groups are discussed in Part III. Only a few representatives of interesting or diverse groups are listed. Taxa and illustrations from Nelson (2006).

Subphylum Cephalochordata – lancelets

- Subphylum Craniata
  - Superclass Myxinomorphi
    - Class Myxini – hagfishes 
  - Superclass Petromyzontomorphi
    - Class Petromyzontida – lampreys
  - Superclass Gnathostomata – jawed fishes
    - Class Chondrichthyes – cartilaginous fishes 
      - Subclass Elasmobranchii – sharklike fishes
      - Subclass Holocephali – chimaeras
    - Grade Teleostomi – bony fishes
      - Class Sarcopterygii – lobe-finned fishes 
        - Subclass Coelacanthimorpha – coelacanths
        - Subclass Dipnoi – lungfishes 
      - Class Actinopterygii – ray-finned fishes
        - Subclass Cladistia – bichirs 
        - Subclass Chondrostei – paddlefishes, sturgeons 
        - Subclass Neopterygii – modern bony fishes, including gars and bowfin[a] 
          - Division Teleostei
            - Subdivision Osteoglossomorpha – bonytongues
            - Subdivision Elopomorpha – tarpons, bonefishes, eels 
            - Subdivision Otocephala
              - Superorder Clupeomorpha – herrings
              - Superorder Ostariophysi – minnows, suckers, characins, loaches, catfishes 
            - Subdivision Euteleostei – advanced bony fishes
              - Superorder Protacanthopterygii – pickerels, smelts, salmons 
              - [Order Esociformes – pikes, mudminnows][b]
              - Superorder Stenopterygii – bristlemouths, marine hatchetfishes, dragonfishes 
              - Superorder Ateleopodomorpha – jellynose fishes
              - Superorder Cyclosquamata – greeneyes, lizardfishes 
              - Superorder Scopelomorpha – lanternfishes
              - Superorder Lampriomorpha – opahs, oarfishes
              - Superorder Polymixiomorpha – beardfishes
              - Superorder Paracanthopterygii – troutperches, cods, toadfishes, anglerfishes 
              - Superorder Acanthopterygii – spiny rayed fishes: mullets, silversides, killifishes, squirrelfishes, sticklebacks, scorpionfishes, basses, perches, tunas, flatfishes, pufferfishes, and many others  

[a] Gars and Bowfin are sometimes separated out as holosteans, a sister group to the teleosts (see Chapter 13).
[b] The esociform pikes and mudminnows are not as yet assigned to a superorder (see Chapter 14).

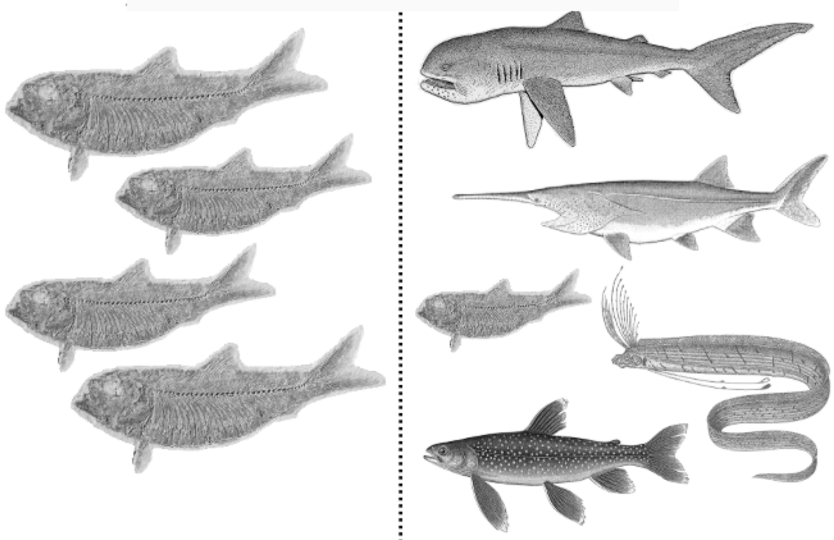


Figure 1.1
Fish versus fishes. By convention, "fish" refers to one or more individuals of a single species. "Fishes" is used when discussing more than one species, regardless of the number of individuals involved. Megamouth, paddlefish, and char drawings courtesy of P. Vecsei; oarfish drawing courtesy of T. Roberts.

and rays (534), and chimaeras (33); and the remaining 26,000+ species are bony fishes; many others remain to be formally described. When broken down by major habitats, 41% of species live in fresh water, 58% in sea water, and 1% move between fresh water and the sea during their life cycles (Cohen 1970). Geographically, the highest diversities are found in the tropics. The Indo-West Pacific area that includes the western Pacific and Indian oceans and the Red Sea has the highest diversity for a marine area, whereas South America, Africa, and Southeast Asia, in that order, contain the most freshwater fishes (Berra 2001; Lévêque et al. 2008). Fishes occupy essentially all aquatic habitats that have liquid water throughout the year, including thermal and alkaline springs, hypersaline lakes, sunless caves, anoxic swamps, temporary ponds, torrential rivers, wave-swept coasts, and high-altitude and high-latitude environments. The altitudinal record is set by some nemacheiline river loaches that inhabit Tibetan hot springs at elevations of 5200 m. The record for unheated waters is Lake Titicaca in northern South America, where pupfishes live at an altitude of 3812 m. The deepest living fishes are cusk-eels, which occur 8000 m down in the deep sea.

Variation in body length ranges more than 1000-fold. The world's smallest fishes – and vertebrates – mature at around 7–8 mm and include an Indonesian minnow, *Paedocypris progenetica*, and two gobioids, *Trimmatom nanus* from the Indian Ocean and *Schindleria brevipinguis* from Australia's Great Barrier Reef (parasitic males of a deepsea anglerfish *Photocorynus spiniceps* mature at 6.2 mm, although females are 10 times that length). The world's longest cartilaginous fish is the 12 m long (or longer) Whale Shark *Rhincodon typus*, whereas the longest bony fish is the 8 m long (or longer) Oarfish *Regalecus glesne*. Body masses top out at 34,000 kg for whale sharks and 2300 kg for the Ocean Sunfish *Mola mola*. Diversity in form includes relatively fishlike shapes such as minnows, trouts, perches, basses, and tunas, but also such unexpected shapes as boxlike trunkfishes, elongate eels and catfishes, globose lumpsuckers and frogfishes, rectangular ocean sunfishes, question-mark-shaped seahorses, and flattened and circular flatfishes and batfishes, ignoring the exceptionally bizarre fishes of the deep sea.

Superlative fishes

A large part of ichthyology's fascination is the spectacular and unusual nature of the subject matter (see Lundberg et al. 2000). As a few examples:

- Coelacanths, an offshoot of the lineage that gave rise to the amphibians, were thought to have died out with the dinosaurs at the end of the Cretaceous, 65 million years ago. However, in 1938, fishermen in South Africa trawled up a very live Coelacanth. This fortuitous capture of a living fossil not only rekindled debates about the evolution of higher vertebrates, but underscored the international and political nature of conservation efforts (see Chapter 13).
- Lungfishes can live in a state of dry "suspended animation" for up to 4 years, becoming dormant when their ponds dry up and reviving quickly when immersed in water (see Chapters 5, 13).
- Antarctic fishes live in water that is colder than the freezing point of their blood. The fishes keep from freezing by avoiding free ice and because their blood contains antifreeze proteins that depress their blood's

freezing point to –2°C. Some Antarctic fishes have no hemoglobin (see Chapter 18).

- Deepsea fishes include many forms that can swallow prey larger than themselves. Some deepsea anglerfishes are characterized by females that are 10 times larger than males, the males existing as small parasites permanently fused to the side of the female, living off her blood stream (see Chapter 18).
- Fishes grow throughout their lives, changing their ecological role several times. In some fishes, differences between larvae and adults are so pronounced that many larvae were originally described as entirely different taxa (see Chapter 9).
- Fishes have maximum life spans of as little as 10 weeks (African killifishes and Great Barrier Reef pygmy gobies) and as long as 150 years (sturgeons and scorpaenid rockfishes). Some short-lived species are annuals, surviving drought as eggs which hatch with the advent of rains. Longer lived species may not begin reproducing until they are 20 years old, and then only at 5+ year intervals (see Chapter 10).
- Gender change is common among fishes. Some species are simultaneously male and female, whereas others change from male to female, or from female to male (see Chapters 10, 21).
- Fishes engage in parental care that ranges from simple nest guarding to mouth brooding to the production of external or internal body substances upon which young feed. Many sharks have a placental structure as complex as any found in mammals. Egg-laying fishes may construct nests by themselves, whereas some species deposit eggs in the siphon of living clams, on the undersides of leaves of terrestrial plants, or in the nests of other fishes (see Chapters 12, 21).
- Fishes are unique among organisms with respect to the use of bioelectricity. Many fishes can detect biologically meaningful, minute quantities of electricity, which they use to find prey, competitors, or predators and for navigation. Some groups have converged on the ability to produce an electrical field and obtain information about their surroundings from disturbances to the field, whereas others produce large amounts of high-voltage electricity to deter predators or stun prey (see Chapters 6, 19, 20).
- Fishes are unique among vertebrates in their ability to produce light; this ability has evolved independently in different lineages and can be either autogenic (produced by the fish itself) or symbiotic (produced by bacteria living on or in the fish) (see Chapter 18).
- Although classically thought of as cold-blooded, some pelagic sharks and tunas maintain body temperatures warmer than their surroundings and have circulatory systems specifically designed for such temperature maintenance (see Chapter 7).
- Predatory tactics include attracting prey with modified body parts disguised as lures, or by feigning death. Fishes include specialists that feed on ectoparasites, feces, blood, fins, scales, young, and eyes of other fishes (see Chapters 19, 20).
- Fishes can significantly change the depth of their bodies by erecting their fins or by filling themselves with water, an effective technique for deterring many predators. In turn, the ligamentous and levering arrangement of mouth bones in some fishes allows them to increase mouth volume when open by as much as 40-fold (see Chapters 8, 20).
- Some of the most dramatic field and laboratory demonstrations of evolution as an ongoing process result from studies of fishes. Both natural and sexual selection have been experimentally manipulated in Guppies, swordtails, and sticklebacks, among others. These investigations show how competition, predation, and mate choice lead to adaptive alterations in body shape and armor, body color and color vision, and feeding habits and locales (see Chapters 17, 19, 20, 24). Fishing has also proven to be a powerful evolutionary force, affecting population structure and size, ages and sizes at which fish reproduce, body shape, and behavior (see Chapter 26).

Additionally, and although not covered in detail in this text, fishes have become increasingly important as laboratory and assay organisms. Because of small size, ease of care, rapid growth and short generation times, and larval anatomical features, such species as Medaka, *Oryzias latipes*, and Zebrafish, *Danio rerio*, are used increasingly in studies of toxicology, pharmacology, neurobiology, developmental biology, cancer and other medical research, aging, genomics, and recombinant DNA methodology (e.g., Geisler et al. 1999; Bolis et al. 2001; Tropepe & Sive 2003; Zbikowska 2003).

A brief history of ichthyology

Fishes would be just as diverse and successful without ichthyologists studying them, but what we know about their diversity is the product of the efforts of workers worldwide over several centuries. Students in an introductory course often have difficulty appreciating historical treatments of the subject; the names are strange, the people are dead (sometimes as a result of their scientific efforts), and the relevance is elusive. However, science is a human endeavor and knowing something about early ichthyologists, their activities, and their contributions to the storehouse of knowledge that we possess today should help give a sense of the dynamics and continuity of this long-established science.

Although natural historians in most cultures have studied fishes for millenia, modern science generally places its roots in the works of Carl Linne (Linnaeus). Linnaeus produced the first real attempt at an organized system of classification. Zoologists have agreed to use the 10th edition of his *Systema naturae* (1758) as the starting point for our formal nomenclature. The genius of Linnaeus' system is what we refer to as **binomial nomenclature**, naming every organism with a two-part name based on **genus** (plural **genera**) and **species** (singular and plural, abbreviated **sp.** or **spp.**, respectively). Linnaeus did not care much for fishes so his ichthyological classification, which put the diversity of fishes at less than 500 species, is actually based largely on the efforts of Peter Artedi, the acknowledged "father of ichthyology". Artedi reportedly drowned one night after falling into a canal in Amsterdam while drunk, albeit under suspicious circumstances implicating a jealous mentor.

In the mid-1800s, the great French anatomist Georges Cuvier joined forces with Achille Valenciennes to produce the first complete list of the fishes of the world. During those times, French explorers were active throughout much of the world and many of their expeditions included naturalists who collected and saved material. Thus, the *Histoire naturelle de poissons* (1829–1849) includes descriptions of many previously undescribed species of fishes in its 24 volumes. This major reference is still of great importance to systematic ichthyologists today, as are the specimens upon which it is based, many of which are housed in the Museum National d'Histoire Naturelle in Paris.

A few years later, Albert Günther produced a multivolume *Catalogue of fishes in the British Museum* (1859–1870). Although initially designed to simply list all the specimens in the British collections, Günther included all the species of which he was aware, making this catalog the second attempt at listing the known fishes of the world.

The efforts of Linnaeus, Artedi, Cuvier and Valenciennes, and Günther all placed species in genera and genera in families based on overall resemblance. A modern philosophical background to classification was first developed by Charles Darwin with the publication of his *On the origin of species* in 1859. His theory of evolution meant that species placed together in a genus were assumed to have had a common origin, a concept that underlies all important subsequent classifications of fishes and other organisms.

The major force in American ichthyology was David Starr Jordan. Jordan moved from Cornell University to the University of Indiana and then to the presidency of Stanford University. He and his students and colleagues were involved in describing the fishes collected during explorations of the United States and elsewhere in the late 1800s and early 1900s. In addition to a long list of papers, Jordan and his co-workers, including B. W. Evermann, produced several publications which form the basis of our present knowledge of North American fishes. This includes the four-volume *The fishes of North and Middle America* (1896–1990) which described all the freshwater and marine fishes known from the Americas north of the Isthmus of Panama. Jordan and Evermann in 1923 published a list of all the genera of fishes that had ever been described, which served as the standard reference until recently, when it was updated and replaced by Eschmeyer (1990).

Overlapping with Jordan was the distinguished British ichthyologist, C. Tate Regan, based at the British Museum of Natural History. Regan revised many groups and his work formed the basis of most recent classifications. Unfortunately, this classification was never published in one place and the best summary of it is in the individual sections on fishes in the 14th edition of the *Encyclopedia Britannica* (1929).

A Russian ichthyologist, Leo S. Berg, first integrated paleoichthylogy into the study of living fishes in his 1947 monograph *Classification of fishes, both recent and fossil*, published originally in Russian and English. He was also the first ichthyologist to apply the **-iformes** uniform endings to orders of fishes, replacing the classic and often confusing group names.

In 1966, three young ichthyologists, P. Humphry Greenwood at the British Museum, Donn Eric Rosen at the American Museum of Natural History, and Stanley H. Weitzman at the US National Museum of Natural History, joined with an old-school ichthyologist, George S. Myers of Stanford University, to produce the first modern classification of the majority of present-day fishes, the Teleostei. This classification was updated in Greenwood's 3rd edition of J. R. Norman's classic *A history of fishes* (Norman & Greenwood 1975), and is the framework, with modifications based on more recent findings, of the classification used by Nelson and followed in this book.

Details of the early history of ichthyology are available in D. S. Jordan's classic *A guide to the study of fishes*, Vol. I (1905). For a more thorough treatment of the history of North American ichthyology, we recommend Myers (1964) and Hubbs (1964). An excellent historical synopsis of European and North American ichthyologists can also be found in the introduction of Pietsch and Grobecker (1987); a compilation focusing on the contributions of women ichthyologists appears in Balon et al. (1994). Some recent and important discoveries are reviewed in Lundberg et al. (2000).

Additional sources of information

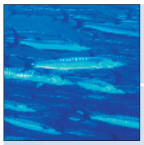
This book is one view of ichthyology, with an emphasis on diversity and adaptation (please read the preface). It is by no means the final word nor the only perspective available. As undergraduates, we learned about fishes from other textbooks, some of which are in updated editions from which we have taught our own classes. All of these books are valuable. We have read or reread them during the production of this book to check on topics deserving coverage, and we frequently turn to them for alternative approaches and additional information. Among the most useful are Lagler et al. (1977), Bone et al. (1995), Hart and Reynolds (2002a, 2002b), Moyle and Cech (2004), and Barton (2006). The 1997 edition of the present text was summarized by Helfman (2001). For laboratory purposes, Cailliet et al. (1986) is very helpful. From a historical perspective, books by Jordan (1905, 1922), Nikolsky (1961), and Norman and Greenwood (1975) are informative and enjoyable.

Three references have proven indispensable during the production of this book, and their ready access is recommended to anyone desiring additional information and particularly for anyone contemplating a career in ichthyology or fisheries science. Most valuable is Nelson's *Fishes of the world* (4th edn, 2006). For North American workers, the current edition of Nelson et al. *Common and scientific names of fishes from the United States, Canada, and Mexico* (6th edn, 2004) is especially useful. Finally, of a specialized but no less valuable nature, is Eschmeyer's *Catalog of the genera of recent fishes* (1990, updated in 2005 and available at www.calacademy.org). The first two books, although primarily taxonomic lists, are organized in such a way that they provide information on currently accepted phylogenies, characters, and nomenclature; Nelson (2006) is remarkably helpful with anatomical, ecological, evolutionary, and zoogeographic information on most families. Eschmeyer's volumes are invaluable when reading older or international literature because they give other names that have been used for a fish (**synonymies**) and indicate the family to which a genus belongs.

Of a less technical but useful nature are fish encyclopedias, such as Wheeler's (1975) *Fishes of the world*, also published as *The world encyclopedia of fishes* (1985), *McClane's new standard fishing encyclopedia* (McClane 1974), or Paxton and Eschmeyer's (1998) *Encyclopedia of fishes* (the latter is fact-filled and lavishly illustrated). Species guides exist for most states and provinces in North America, most countries in Europe (including current and former British Commonwealth nations), and some tropical nations and regions. These are too numerous and too variable in quality for listing here; a good source for titles is Berra (2001). Two of our favorite geographic treatments of fishes are as much anthropological as they are ichthyological, namely Johannes' (1981) *Words of the lagoon* and Goulding's (1980) *The fishes and the forest*. A stroll through the shelves of any decent public or academic library is potentially fascinating, with their collections of ichthyology texts dating back a century, geographic and taxonomic guides to fishes, specialty texts and edited volumes, and works in or translated from many languages. Among the better known, established journals that specialize in or often focus on fish research are *Copeia*, *Transactions of the American Fisheries Society*, *Environmental Biology of Fishes*, *North American Journal of Fisheries Management*, *US Fishery Bulletin*, *Canadian Journal of Fisheries and Aquatic Sciences*, *Canadian Journal of Zoology*, *Journal of Fish Biology*, *Journal of Ichthyology* (the translation of the Russian journal *Voprosy Ikhtiologii*), *Australian and New Zealand Journals of Marine and Freshwater Research*, *Bulletin of Marine Science*, and *Japanese Journal of Ichthyology*.

The world wide web has developed into an indispensable source for technical information, spectacular photographs, and updated conservation information concerning fishes. Although websites come and go – and although web information often suffers from a lack of critical peer review – many sites have proven themselves to be both dependable and reliable. For general, international taxonomic information, the Integrated Taxonomic Information System (ITIS, www.itis.usda.gov/index.html) and Global Biodiversity Information Facility (GBIF, www.gbif.org) are starting points. For user-friendliness and general information, FishBase (www.FishBase.org) is the unquestioned leader. Photographs and drawings are most easily accessed via Google and A9, which are cross-linked (http://images.google.com, www.A9.com). For conservation status and background details, www.redlist.org is the accepted authority on international issues, and NatureServe (www.natureserve.org) is the most useful clearinghouse for North American taxa. Several museums maintain updated information on fishes; our favorites are the Australian Museum (www.amonline.net.au/fishes), University of Michigan Museum of Zoology (http://animaldiversity.ummz.umich.edu), Florida Museum of Natural History (www.flmnh.ufl.edu/fish, which is especially good for sharks), and the California Academy of Sciences (www.calacademy.org/research/ichthyology); for North American freshwater fishes, see the Texas Memorial Museum (www.utexas.edu/tmm/tnhc/fish/na/naindex) and the North American Native Fishes Association website (http://nanfa.org/checklist.shtml). The best sites provide links to many additional sites that offer more localized or specific information.

Although **diving** does not in itself constitute a biological science any more than does casual bird watching, snorkeling and scuba diving are essential methods for acquiring detailed information on fish biology. Two of us (Helfman, Collette) credit the thousands of hours we have spent underwater as formative and essential to our understanding of fishes. A full appreciation for the wonders of adaptation in fishes requires that they be viewed in their natural habitat, as they would be seen by their conspecifics, competitors, predators, and neighbors (it is fun to try to think like a fish). We strongly urge anyone seriously interested in any aspect of fish biology to acquire basic diving skills, including the patience necessary to watch fishes going about their daily lives. **Public and commercial aquaria** are almost as valuable, particularly because they expose an interested person to a wide zoogeographic range of species, or to an intense selection of local fishes that are otherwise only seen dying in a bait bucket or at the end of a fishing line. Our complaint about such facilities is that, perhaps because of space constraints or an anticipated short attention span on the part of viewers, large aquaria seldom provide details about the fascinating lives of the animals they hold in captivity. Home aquaria are an additional source for inspiration and fascination, although we are deeply ambivalent about their value because so many tropical fishes are killed or habitats destroyed in the process of providing animals for the commercial aquarium trade, particularly for marine tropicals.



Summary

SUMMARY

1 Fishes account for more than half of all living vertebrates and are the most successful vertebrates in aquatic habitats worldwide. There are about 28,000 living species of fishes, of which approximately 1000 are cartilaginous (sharks, skates, ray), 108 are jawless (hagfishes, lampreys), and the remaining 26,000 are bony fishes.

2 A fish can be defined as an aquatic vertebrate with gills and with limbs in the shape of fins. Included in this definition is a tremendous diversity of sizes (from 8 mm gobies and minnows to 12+ m whale sharks), shapes, ecological functions, life history scenarios, anatomical specializations, and evolutionary histories.

3 Most (about 60%) of living fishes are primarily marine and the remainder live in fresh water; about 1% move between salt and fresh water as a normal part of their life cycle. The greatest diversity of fishes is found in the tropics, particularly the Indo-West Pacific region for marine fishes, and tropical South America, Africa, and Southeast Asia for freshwater species.

4 Unusual adaptations among fishes include African lungfishes that can live in dry mud for up to 4 years, supercooled Antarctic fishes that live in water colder than the freezing point of their blood, deepsea fishes that can swallow prey larger than themselves (some deepsea fishes exist as small males fused to and entirely parasitic on larger females), annual species that live less than a year and other species that may live 150 years, fishes that change sex from female to male or vice versa, sharks that provide nutrition for developing young via a complex placenta, fishes that create an electric field around themselves and detect biologically significant disturbances of the field, light-emitting fishes, warm-blooded fishes, and at least one taxon, the coelacanth, that was thought to have gone extinct with the dinosaurs.

5 Historically important contributions to ichthyology were made by Linnaeus, Peter Artedi, Georges Cuvier, Achille Valenciennes, Albert Günther, David Starr Jordan, B. W. Evermann, C. Tate Regan, and Leo S. Berg, among many others.

6 The literature on fishes is voluminous, including a diversity of college-level textbooks, popular and technical books, and websites that contain information on particular geographic regions, taxonomic groups, or species sought by anglers or best suited for aquarium keeping or aquaculture. Scientific journals with local, national, or international focus are produced in many countries. Another valuable source of knowledge is public aquaria. Observing fishes by snorkel or scuba diving will provide anyone interested in fishes with indispensable, first-hand knowledge and appreciation.