Chapter 1
INTRODUCTION

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This book, the third edition of *Invertebrate Medicine*, represents a determined effort by a group of dedicated authors on the broad topic of invertebrate animal medicine. It has been substantially expanded from the second edition to reflect the tremendous growth of the pertinent evidence-based literature and work that is being accomplished in the fields of invertebrate animal medicine, disease investigation, diagnostic imaging, conservation, taxonomy, husbandry, public health, and animal welfare. With the continued merging of animal and human medicine ("one health" or "one medicine"), the expanding importance of invertebrates in biomedical research, and the many ongoing efforts to preserve habitat, protect at-risk species, and learn more about how invertebrates help define and connect ecosystems, this new edition is warranted, timely, and state-of-the-science.

Five new chapters ("Actinaria [Anemones]," "Ctenophora and Scyphozoa [Jellies]," "Corals," "Chitons," and "Formulary") have been added and one chapter from the last edition (Coelenterates) was dropped and split into the three aforementioned coelenterate chapters. The reader should find the comprehensive formulary especially helpful for both clinical and research endeavors.

This is not an invertebrate zoology textbook and is not close to being comprehensive with regard to the anatomy, physiology, natural history, and taxonomy of the myriad of invertebrate taxa. This is a veterinary text about invertebrate animals. It includes pertinent biologic information as well as current information pertaining to medicine and the clinical condition.

What sort of topic is invertebrate medicine? And what exactly are invertebrates? Many text books address this topic (Hyman 1940–1967; Fretter and Graham 1976; Sherman and Sherman 1976; Barrington 1979; Kinne 1980–1990; Cohen 1985; Pearse et al. 1987; Kozloff 1990; Conn 1991; Harrison 1991–1999; Meglitsch and Schram 1991; Frye 1992; Stachowitsch 1992; New 1995; Stolen et al. 1995; Mothersill and Austin 2000; Barnes et al. 2001; Mitsuhashi 2002; Young et al. 2002; Brusca and Brusca 2003; Ruppert et al. 2004; Lewbart 2017; Kane and Faux 2021; LaDouceur 2021). Ruppert and Barnes (1994) have said that the invertebrates are a group of unrelated taxa that share no universal "positive" traits. Undergraduate and graduate courses are dedicated to invertebrate zoology or even to specific parts of this topic, such as entomology, malacology, or protozoology. Simply put, the invertebrates are a collection of animals, comprising more than 95% of the earth's animal species, unified by a single negative trait, the lack of a vertebral column (Ruppert et al. 2004).

Interesting genetic research has produced some intriguing ideas about intertaxonomic relationships regarding invertebrates and vertebrates. With the complete genetic sequencing for a number of species, including the fruit fly (*Drosophila melanogaster*), an important biomedical research nematode (*Caenorhabditis elegans*), humans (*Homo sapiens*), and, more recently, an annelid worm (*Platynereis dumerlii*), some theories on animal evolution and phylogenetic relationships are being revisited and revised (Telford 2004; Wolf et al. 2004; Federov and Federova 2006). The more traditional "Coelomata hypothesis," linking animals (many invertebrates and all vertebrates) possessing a coelom, may be giving way to the "Ecdysozoa hypothesis," which places molting invertebrates, such as arthropods and introvertans (nematodes and other pseudocoelomates), in the same broad taxonomic group (Telford 2004). Based largely on the comparison of small nonprotein-coding DNA segments called introns, researchers have learned that annelid worms may be more closely related to humans than they are to either insects or nematodes (Raible et al. 2005).

Taxonomy has always been a dynamic discipline. With the rapid improvement and efficiency of molecular techniques, the taxonomic landscape of all animals, and especially invertebrates, has experienced some major foundational changes over the past decade. At one time, the echiurans (spoon worms) and sipunculans (peanut worms) were considered separate phyla. Now both groups have been included with the annelids, and all indications are they belong in the class Polychaeta (Pechenik 2010; Goto 2016; Boyle and Rice 2018; Goto et al. 2020). An even more stirring taxonomic shift has been the combining of the insects and crustaceans as sister groups in the vast phylum known as Pancrustacea (Ahyong 2020). The names Crustaceomorpha and Tetraconata have also been proposed for this immense phylum (Ahyong 2020). Laumer et al. (2019) have reviewed metazoan phylogeny using a wealth of genomic data. While the authors acknowledge that there is work to be done, Figure 1.1 illustrates

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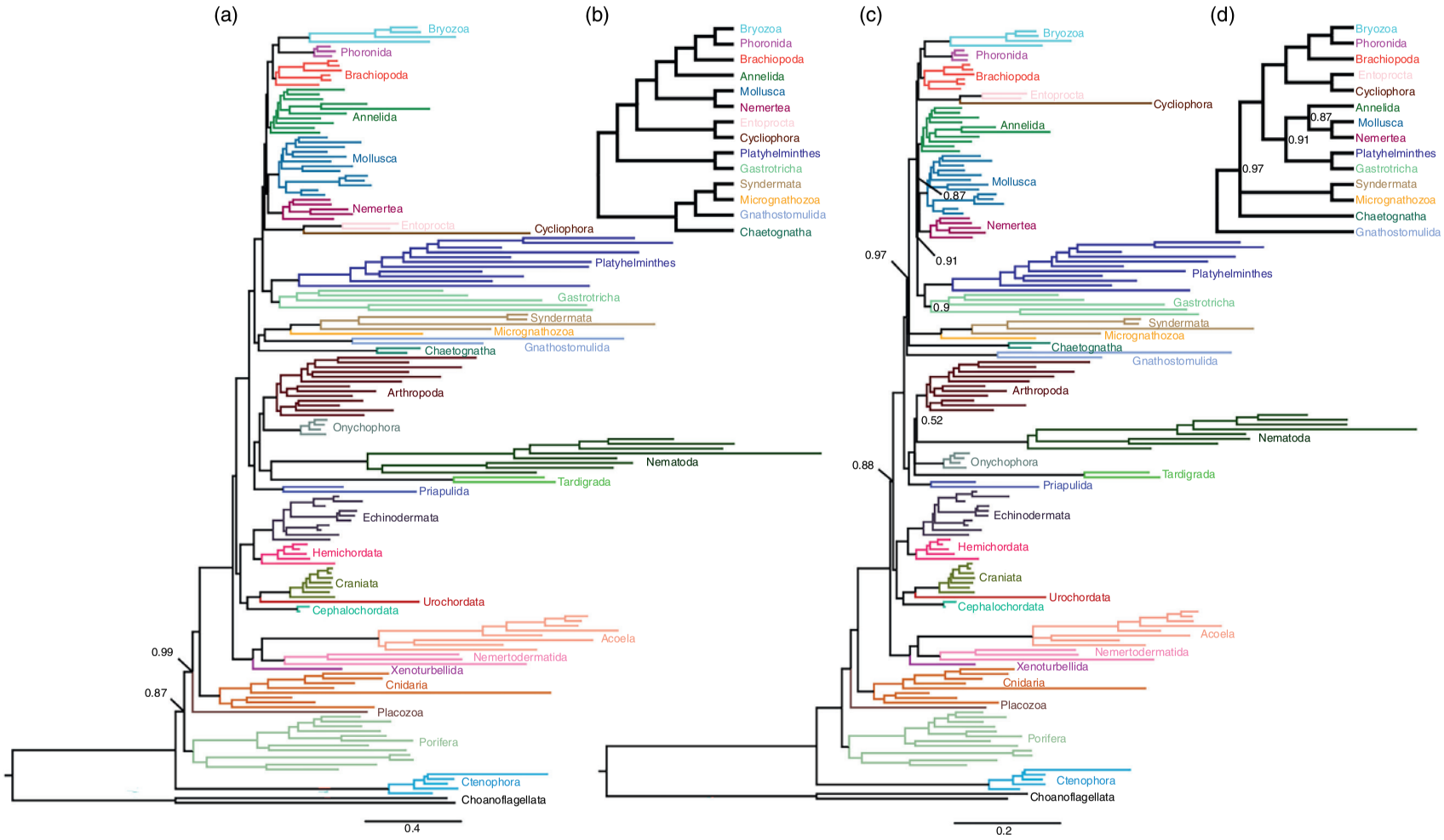

Figure 1.1. This is a complex four-part figure showing genetic consensus summaries and cladograms based on RNA and DNA genetic data along with amino acid sequencing. To help illustrate the vast diversity and evolutionary complexity of invertebrates, the reader is encouraged to find the *Craniata* (a clade that includes fishes, amphibians, reptiles, birds, and mammals) in the diagrams. (a) Posterior consensus summary of CAT þ GTR þ G4 analysis of reduced, BMGE-trimmed pan-Metazoa matrix in amino acid space, trimmed of four rogue taxa prior to summary. (b) Cladogram depiction of relationships and support within Spiralia recovered in the previous analysis, shown to improve readability. The *Spiralia* are a large group of invertebrate taxa that display spiral cleavage in their development and include the platyhelminthes, nemerteans, rotifers, annelids, mollusks, and bryozoans among other groups. (c) Posterior consensus summary of CAT þ GTR þ G4 analysis of the same matrix, recoded into Dayhoff-6 groups and trimmed of six rogue taxa prior to summary. (d) Cladogram depiction of relationships and support within Spiralia recovered in the previous analysis. Nodal support values are posterior probability; unlabeled nodes received full support. Relationships within labeled clades (phyla) are not annotated with support values to improve visualization, except in the case that the monophyly of the clade in question received less than full posterior probability. *Source*: Laumer et al. (2019). The Royal Society/CC BY 4.0.

Table 1.1. Invertebrate phyla and major classes not reviewed in this book.

Placozoa: A small phylum that only recently was changed from monotypic status to containing at least three genera (Eitel et al. 2017). This primitive amoeboid metazoan, believed to share common ancestry with cnidarians, is flattened, less than 3 mm in diameter, and exhibits extracellular digestion of detritus and algae.

Orthonectida: A small phylum (about 20 species) of minute (no larger than 1 mm) internal parasites of other invertebrates such as bivalves, polychaetes, tunicates, turbellarians, and nemerteans.

Dicyemida: This phylum contains about 75 species of very thin renal parasites of cephalopods. The group is also known as Rhombozoa. Ongoing research may one day move this phylum with the orthonectids or even nematodes (Lu et al. 2017).

Xenoturbella: This flatworm-like group of benthic, ciliated, marine organisms was first discovered in the early years of the twenty-first century but initially and incorrectly considered a free-living turbellarian. Later, it was erroneously linked to other taxonomic groups, including hemichordates and echinoderms. In the 1990s, based on *Xenoturbella bocki* samples that were "contaminated" by food the animal was consuming, the group was reclassified as a bivalve mollusk. Molecular work elevated this cryptic and small group of animals into their own phylum of deuterostomes (bilaterally symmetrical animals like the echinoderms, hemichordates, and chordates, which possess radial cleavage, an ectodermal mouth, and anal opening originating from the blastopore). Unique and unusual traits include lack of a gut or defined coelomic cavity, absence of gonads or excretory organs, and a nerve net system without a cephalic or central ganglionic region. There are just a handful of described species (Nakano et al. 2017).

Nemertea: This diverse phylum contains approximately 1150 species of *ribbon worms,* which tend to be much larger and longer than flatworms. Unlike flatworms, nemerteans have a true coelomic circulatory system. Most are marine, but there are a few freshwater and terrestrial forms. Nemerteans are predators and use a long, eversible proboscis to capture and retain prey. The longest animal in the world may be the bootlace worm, *Lineus longissimus*, which has been reported to reach a length of over 50 m.

Aplacophora: This molluscan class consists of about 320 species of small, vermiform, marine animals that live at depths of between 200 and 7000 m.

Scaphopoda: Known as the "tusk" or "tooth" mollusks because of their shell shape. The approximately 500 species are all marine, and most are burrowers with the head facing down within the substrate.

Echiura: Commonly known as the *spoon worms,* most of the 230 species, now classified as annelids, either live in U-shaped burrows or between rocks closely associated with the marine environment. Most are deposit feeders, and some are an important food source for fishes. The name comes from the large and flared prostomium that resembles a spoon or small scoop.

Sipuncula: The sipunculids, or *peanut worms,* are a group of about 160 marine burrowing species in the phylum Annelida. Most are smaller than 10 cm, but some can reach 70 cm in length. They possess an interesting feeding structure termed the *introvert* that can be expelled from or retracted into the main body or trunk.

Onychophora: This group of tropical, terrestrial animals (200 known species) is commonly referred to as *velvet worms* or *walking worms*. They are segmented and aligned with arthropods. In fact, some workers include the phyla Onychophora, Tardigrada, and Arthropoda in the superphylum Panarthropoda. Velvet worms prey on smaller arthropods by capturing them with slime ejected from paired glands near the mouth.

Tardigrada: If the *water bears,* or *moss piglets* as they are commonly known, grew larger (most are less than 1 mm long), they would surely be common and popular pets and display animals. There are marine, freshwater, and terrestrial representatives among the 1300-plus species in this group of taxonomically mysterious animals (Degma et al. 2019). They have features in common with the arthropods but are different enough to warrant their own phylum. Perhaps their most interesting attribute is their ability to undergo cryptobiosis and form desiccated *tuns*, which can withstand adverse environmental conditions. Some tardigrades may live as long as 100 years with the aid of cryptobiosis, and they are the only animals known to have the ability to survive the vacuum and cosmic radiation of space (Weronika and Lukasz 2017). In fact, it is likely that some survived or survive on the moon following the crash of Israeli spacecraft Beresheet in 2019 (Gibney 2019).

Gastrotricha: Many of the 800 species belonging to this microscopic phylum are interstitial. Most look like miniature bowling pins atop two small pegs and are commonly referred to as *hairybellies* or *hairybacks*. There are freshwater and marine forms.

Nematomorpha: The *horsehair worms* or *Gordian worms* superficially resemble nematodes but are very long and free living as aquatic adults. The larvae usually parasitize either crustaceans or insects. Approximately 350 species have been described.

Priapulida: This small phylum containing just 22 species is all marine and benthic. They are cylindrical and resemble a small cactus.

Loricifera: This interesting and microscopic marine phylum (all appear to be interstitial) was not known to science until 1983. Many of the 100 or so known species have not yet been described due to the difficulty of examining fresh, living specimens. Thirty-six species have been described (Neves et al. 2016). These little creatures are so dogged in their attachment to sand grains that only freshwater will dislodge them, causing osmotic damage and distortion of their anatomy.

Kinorhyncha: The *mud dragons* somewhat resemble the Gastrotricha in general shape but have an oral feeding structure called the *oral styles* at the end of a movable introvert. Most are microscopic and are either interstitial or benthic on mud and sand. There are approximately 270 species and all are marine.

Gnathostomulida: Virtually all 100 known species of *jaw worms* are marine, interstitial, and less than 1 mm long. They are vermiform and were not known to science until 1956.

Rotifera: Most occur in freshwater, but there are marine and terrestrial (primarily in water films) species. They are defined and frequently identified by the ciliated corona or *wheel organ* near the head. Some rotifers are extremely important in freshwater and marine food chains (in some cases, hundreds may be found in a liter of water) and are also commonly reared to support invertebrate and finfish aquaculture. There are approximately 2200 described species.

Acanthocephala: A totally parasitic group containing 1420 species. They are commonly known as *thorny-headed worms*, or *spiny-headed worms*, and some are important parasites of wild and domestic vertebrates. Most use other invertebrates as intermediate hosts.

Kamptozoa: Also known as Entoprocta, the 150 species are nearly all marine. Most are stalked, and some people refer to them as *nodders* because of the zooid's tendency to nod or rock at the end of the stalk. Although some zoologists still classify them as bryozoans, these animals differ in their complete lack of a coelomic cavity. Some zoologists feel that the morphological similarities between the groups are convergent.

Cycliophora: This small (in size and species number) phylum was not introduced to science until 1995 (Funch and Kristensen 1995). The three described species in the genus *Symbion* exhibit a commensal lifestyle with lobsters. They are suspension feeders and have a complex reproductive cycle with both asexual and sexual life stages. None of the life stages is over 0.5 mm long.

Phoronida: There are less than 20 species in two genera of these sessile marine creatures known as *horsehair worms*. These vermiform animals live in chitinous tubes that they secrete. Although externally they are bilaterally symmetrical, internally the

(*continued*)

Table 1.1. (continued)

left side is dominant. They feed by means of a lophophore and are grouped into the superphylum Lophophorata along with the bryozoans and brachiopods.

Brachiopoda: The brachiopods, or *lamp shells*, are an interesting group of 330 extant marine species in over 100 genera that grossly resemble bivalve mollusks. Thousands of species are known from the fossil record, in part due to their mineralized valves that are preserved well. They are not related to mollusks, and the hard valves that protect the soft body are oriented opposite that of the bivalve's. They feed with the aid of a lophophore, placing them in the superphylum Lophophorata. Most are the size of small *cherrystone* clams and frequently turn up in shops specializing in fossils. Most species occur in colder waters.

Bryozoa: Known as the *moss animals,* these are common animals that can be found on many marine substrates (there are a few freshwater species), including rocks, algae, pilings, and even living animals such as sea turtles. With nearly 6000 species, this phylum is the best known of the Lophophorata and is studied as part of nearly all basic invertebrate zoology courses. The vast majority are colonial, although there is one solitary genus. From a distance, they may look more like plants than animals to casual observers. Some colonies are polymorphic, whereas other species are monomorphic. They are filter feeders, using the lophophore to trap and retain small food items.

Pycnogonida: Known commonly as the *sea spiders*, this class of arthropods contains about 1300 known species. They are all marine and widely distributed, with most occurring in benthic habitats. Very few species are larger than 1 cm, and although they resemble a true spider, they are not close relatives.

Table 1.2. Habitats and approximate metazoan species numbers.

Phylum	Benthic marine	Pelagic marine	Benthic freshwater	Pelagic freshwater	Terrestrial	Ectosymbiotic	Endosymbiotic
Porifera	###	—	#	—	—	#	—
Placozoa	#	—	—	—	—	—	—
Orthonectida	—	—	—	—	—	—	#
Dicyemida	—	—	—	—	—	—	#
Cnidaria	###	##	#	#	—	#	—
Ctenophora	#	#	—	—	—	—	—
Platyhelminthes	###	#	###	—	##	#	####
Xenoturbella	#	—	—	—	—	—	—
Nemertea	##	#	#	—	#	#	—
Mollusca	#####	#	###	—	###	#	#
Annelida	####	#	##	—	###	##	—
Onychophora		—	—	—	##	—	—
Tardigrada	#	—	##	—	#	—	—
Arthropoda	####	###	####	###	#####	###	###
Gastrotricha	##	—	##	—	—	—	—
Nematoda	###	#	###	#	###	###	###
Nematomorpha	—	—	—	—	—	—	##
Priapulida	#	—	—	—	—	—	—
Loricifera	#	—	—	—	—	—	—
Kinorhyncha	##	—	—	—	—	—	—
Gnathostomulida	#	—	—	—	—	—	—
Rotifera	#	#	##	##	#	#	#
Acanthocephala	—	—	—	—	—	—	###
Kamptozoa	##	—	#	—	—	#	—
Cycliophora	—	—	—	—	—	#	—
Phoronida	#	—	—	—	—	—	—
Brachiopoda	##	—	—	—	—	—	—
Bryozoa	###	—	#	—	—	—	—
Chaetognatha	#	#		—	—	—	—
Hemichordata	#			—	—	—	—
Echinodermata	###	#		—	—	—	—
Chordata (Cephalochordata and Urochordata)	###	#	—	—	—	—	—
Chordata (Vertebrata)	###	###	##	###	####	#	#

#, 1–100; ##, 100–1000; ###, 1000–10 000; ####, 10 000–100 000; and #####, over 100 000. *Source*: Modified from Pearse et al. (1987).

the complex but linear genetic links between the various metazoan clades.

While each chapter of this book, where appropriate, reviews taxonomy, detailed accounts and discussion of invertebrate taxonomy and phylogeny in general are beyond the scope of this medical text. Still, this is an active area of sophisticated research, the results and subsequent deliberations of which are worth being aware of for the clinician or caregiver charged with invertebrate animal health, welfare, and husbandry.

Depending on the text or investigator, there are currently over 30 recognized phyla of invertebrates (not including the protozoans). Many of these might be considered obscure, but for no better reason than they may contain few species, microscopic representatives, or lack obvious economic value to humans. In reality, each phylum and its members are important to the diversity and survival of the planet, even if the group is studied only by a small number of investigators. Unfortunately, very little is known about the veterinary aspects of many of these taxa, and writing a comprehensive text for all invertebrate phyla would currently be a daunting and somewhat inefficient task. Consequently, I have elected to include the most economically important and "visible" metazoan taxonomic groups. Exclusively parasitic taxa (e.g., trematodes, cestodes, and acanthocephalans) are only touched upon. Still, in recent years, invertebrate parasites and their place within global ecosystems have been viewed in a new and sometimes positive light. In fact, there are efforts to conserve many species of parasites, as when their hosts go extinct, so do they (Carlson et al. 2020).

Table 1.1, which lists the major taxonomic groups (along with brief descriptions) that do not have their own chapter, has been included in an effort to remind readers of the diversity of the invertebrate animal sphere. Table 1.2 provides a cursory picture of animal diversity with regard to the number of described species and habitat. I encourage interested readers to obtain one or more of the general invertebrate zoology texts listed under the section "General Invertebrate Zoology Resources," where detailed descriptions of the various groups in Table 1.1 and throughout this book can be found.

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