## Chapter 1

# INTRODUCTION

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Every so often, a technical term born in the biological community enters the popular vocabulary, usually because of its timeliness, political implications, media hype, and euphonious ability to capture the essence of an issue. 'Biotechnology', 'human genome', and 'stem cells' are terms as common in public discourse as they are in scientific circles. 'Biodiversity' is another recent example. Introduced in its portmanteau form in the mid-1980s by Warren G. Rosen (Wilson 1988), the term has grown steadily in popularity. By March 2008, the keyword 'biodiversity' generated 12 million hits on Google Search. Three months later, the number of hits, using the same keyword search, had shot to more than 17 million.

Although the word 'biodiversity' might be familiar to many, its definition is often subject to individual interpretation. Abraham Lincoln grappled with a similar concern over the word 'liberty'. In an 1864 speech, Lincoln opined, 'The world has never had a good definition of the word liberty, and the American people, just now, are much in want of one . . . but in using the same *word* we do not all mean the same *thing*' (Simpson 1998). To the layperson, 'biodiversity' might conjure a forest, a box of beetles, or perhaps the entire fabric of life. Among scientists, the word has been defined, explicitly and implicitly, *ad nauseum*, producing a range of variants (e.g., Gaston 1996). In its original context, the term 'biodiversity' encompassed a broad range of topics (Wilson 1988), and we embrace that perspective. Biodiversity, then, is big biology, describing a holistic view of life. It is 'the variety of all forms of life, from genes to species, through to the broad scale of ecosystems' (Faith 2007). The fundamental units of biodiversity – species – serve as focal points for studying the full panoply of life, allowing workers to zoom in and out along a scale from molecule to ecosystem. The species-centered view also provides a vital focus for conserving life forms and understanding the causes of declining biodiversity.

Despite disagreements over issues ranging from definitions of biodiversity to phylogenetic approaches, biologists can agree on four major points. (1) The world supports a great number of insects. (2) We do not know how many species of insects occupy our planet. (3) The value of insects to humanity is enormous. (4) Too few specialists exist to inventory the world's entomofauna.

By virtue of the sheer numbers of individuals and species, insects, more than any other life form, command the attention of biologists. The number of individual insects on earth at any given moment has been calculated at one quintillion ($10^{18}$) (Williams 1964), an unimaginably large number on par with the number of copepods in the ocean (Schubel and Butman 1998) and roughly equivalent to the number of sand grains along a few kilometers of beach (Ray 1996). The total number of insect species similarly bankrupts the mind. Estimates offered over the past four centuries have increased steadily from 10,000 species, proposed by John Ray in 1691 (Berenbaum, this volume), to as many as 80 million (Erwin 2004). Today's total of 1,004,898 described living species (Table 1.1) is more than 100 times the 1691 estimate. Based on a figure of 1.50–1.74 million described eukaryotic species in the world (May 1998), insects represent 58–67% of the total.

The members of the class Insecta are arranged in 29 orders (Grimaldi and Engel 2005, Arillo and Engel 2006). Four of these orders – the Coleoptera, Diptera, Hymenoptera, and Lepidoptera – account for 81% of all the described species of living insects. The beetles are far in front, leading the next largest order, the Lepidoptera, by a factor of about 2.3 (Table 1.1). A growing number of world checklists and catalogs are available online for various families and orders. Outfitted with search functions, they provide another tool for handling the taxonomic juggernaut of new species and nomenclatural changes. We can foresee a global registry of species in the near future that is updated with each new species or synonym, allowing real-time counts for any taxon.

The greatest concentration of insect species lies in tropical areas of the globe. One hectare of Amazonian rainforest contains more than 100,000 species of arthropods (Erwin 2004), of which roughly 85% are insects (May 1998). This value is more than 90% of the total described species of insects in the entire Nearctic Region. Yet, this tropical skew is based partly on a view of species as structurally distinct from one another. Morphologically similar, if not indistinguishable, species (i.e., sibling species) typically do not figure in estimates of the number of insect species. If organisms as large as elephants and giraffes are composites of multiple species (Brown et al. 2007), a leap of faith is not required to realize that smaller earthlings also consist of additional, reproductively isolated units of biodiversity. When long-recognized nominal species of insects, from black flies to butterflies, are probed more deeply, the repetitive result is an increase, often manyfold, in the number of species (Hebert et al. 2004, Post et al. 2007). We do not yet have a clear indication

**Table 1.1** World totals of described, living species in the 29 orders of the class Insecta.

| Order[1] | Described Species[2] | References |
|---|---:|---|
| Archaeognatha | 504 | Mendes 2002, Zoological Record 2002–2008 |
| Zygentoma | 527 | Mendes 2002, Zoological Record 2002–2008 |
| Ephemeroptera | 3046 | Barber-James et al. 2008 |
| Odonata | 5680 | Kalkman et al. 2008 |
| Dermaptera | 1967 | Steinmann 1989, Zoological Record 1989–2008 |
| Notoptera | 39 | Vrsansky et al. 2001, Engel and Grimaldi 2004 |
| Plecoptera | 3497 | Fochetti and de Figueroa 2008 |
| Embiodea | 458 | Ross 2001, Zoological Record 2002–2008 |
| Zoraptera | 34 | Hubbard 2004, Zoological Record 2004–2008 |
| Phasmatodea | 2853 | Brock 2008 |
| Orthoptera | 23,616 | Eades and Otte 2008 |
| Mantodea | 2384 | Ehrmann 2002, Zoological Record 2002–2008 |
| Blattaria | 4565 | Beccaloni 2007 |
| Isoptera | 2864 | Constantino 2008 |
| Psocoptera | 5574 | New and Lienhard 2007, Zoological Record 2008 |
| Phthiraptera | 5024 | Durden and Musser 1994, Price et al. 2003, L. Durden personal communication |
| Thysanoptera | 5749 | Mound 2005, personal communication |
| Hemiptera | 100,428 | Duffels and van der Laan 1985, Zoological Record 1981–2008 (Cicadidae); Remaudière and Remaudière 1997, G. L. Miller personal communication (Aphidoidea); McKamey 1998, 2007, personal communication (Cercopidae, Cicadellidae, Membracidae); Hollis 2002 (Psylloidea); Ben-Dov et al. 2006 (Coccoidea); Bourgoin 2005, McKamey personal communication (Fulgoroidea); Martin and Mound 2007 (Aleyrodidae); Henry, this volume (Heteroptera) |
| Coleoptera | 359,891 | Bouchard et al., this volume |
| Raphidioptera | 225 | Aspöck 2002, Oswald 2007, J. D. Oswald personal communication |
| Megaloptera | 337 | Cover and Resh 2008, J. D. Oswald personal communication |
| Neuroptera | 5704 | Oswald 2007, J. D. Oswald personal communication |
| Hymenoptera | 144,695 | Huber, this volume |
| Mecoptera | 681 | Penny 1997, Zoological Record 1998–2008 |
| Siphonaptera | 2048 | Lewis 1998, Zoological Record 1998–2008 |
| Strepsiptera | 603 | Proffitt 2005, Zoological Record 2005–2008 |
| Diptera | 152,244 | Courtney et al., this volume |
| Trichoptera | 12,868 | Morse 2008 |
| Lepidoptera | 156,793 | Pogue, this volume; Zoological Record 2007–2008 |
| **TOTAL** | **1,004,898** | |

[1] We follow the ordinal classification of Grimaldi and Engel (2005) for the class Insecta, updated to recognize Notoptera (i.e., Grylloblattodea + Mantophasmatodea; Arillo and Engel 2006). Thus, the three orders of the class Entognatha – the Collembola, Diplura, and Protura – are not included. These three orders would add roughly another 11,000 species to the total number in Table 1.1.

[2] Species were tallied in spring 2008, with the exception of Hymenoptera (Huber, this volume), which were counted primarily in 2006–2007, with earlier counts for some families, and Coleoptera (Bouchard et al., this volume), which were counted, with few exceptions, within the past decade.

across sufficient taxa to know whether a regional bias in sibling species of insects might exist or even vary among taxonomic groups.

The precise number of species, however, is not what we, as a global society, desperately need. Rather, we require a comprehensive, fully accessible library of all volumes (i.e., species) – a colossal compendium of names, descriptions, distributions, and biological information that ultimately can be transformed into a yellow pages of services. Insects hold a vast wealth of behavior, chemistry, form, and function that conservatively translates into an estimated $57 billion per annum in ecological services to the United States (Losey and Vaughan 2006), a value that does not include services provided by domesticated insects (e.g., honey bees) or their products (e.g., honey and shellac) or mass-reared biological control agents. To harvest the full range of benefits from insects, taxonomists and systematists must first reveal the earth's species and organize them with collateral information that can be retrieved with ease.

Biodiversity science must keep pace with the changing face of the planet, particularly species extinctions and reshufflings driven largely by human activities such as commerce, land conversion, and pollution. By 2007, for example, 1321 introduced species had been documented on the Galapagos Islands, of which at least 37% are insects (Anonymous 2007). As species of insects are being redistributed, others are disappearing, particularly in the tropics, though the data are murky. We are forced into an intractable bind, for we cannot know all that we are losing if we do not know all that we have. We do know, however, that extinction is an inevitable consequence of planetary abuse. The Brazilian government, for instance, announced that deforestation rates had increased in its portion of the Amazon, with a loss of 3235 sq km in the last 5 months of 2007. Using Erwin's (2004) figure of $3 \times 10^{10}$ individual terrestrial arthropods per hectare of tropical rainforest, we lost habitat for more than 30 trillion arthropods in that one point in space and time.

The urgency to inventory the world's insect fauna is gaining some balance through the current revolution in technology. Coupled with powerful electronic capabilities, the explosion of biodiversity information, much of it now derived from the genomic level, can be networked worldwide to facilitate not only communication and information storage and retrieval but also taxonomy itself – cybertaxonomy (*sensu* Wheeler 2007). Efforts to apply new approaches and bioinformatics on a global scale are now underway (e.g., Barcode of Life Data Systems 2008, Encyclopedia of Life 2008). We can imagine that in our lifetimes, automated complete-genome sequencing will be available to identify specimens as routinely as biologists today use identification keys. The futuristic handheld gadget that can read a specimen's genome and provide immediate identification, with access to all that is known about the organism (Janzen 2004), is no longer strictly science fiction. Yet, each new technique for revealing and organizing the elements of biodiversity comes with its own set of limitations, some of which we do not yet know. DNA-sequence readers, for instance, will do little to identify fossil organisms. An integrated methodology, mustering information from molecules to morphology, will continue to prove its merit, although it is the most difficult approach for the individual worker to master. Given the vast number of insect species, however, today's themes are likely to remain the same well beyond the advent of handheld, reveal-all devices: an unknown number of species, too few specialists, and too little appreciation of the value of insect biodiversity.

Those who study insect biodiversity do so largely out of a fascination for insects; no economic incentive is needed. But for most people, from a land developer to a hardscrabble farmer, a personal, typically economic reason is required to appreciate the value of insect biodiversity. This value, therefore, must be translated into economic gain. Today's biologists place a great deal of emphasis on discovering species, cataloging them, and inferring their evolutionary relationships. Rightly so. But these activities will not, in themselves, curry favor with the majority. We believe that, now, equal emphasis must be placed on developing the services of insects. We envision a new era, one of entrepreneurial biodiversity that crosses disciplinary boundaries and links the expertise of insect systematists with that of biotechnologists, chemists, economists, engineers, marketers, pharmacologists, and others. Only then can we expect to tap the magic well of benefits derivable from insects and broadly applicable to society, while ensuring a sustainable environment and conserving its biodiversity. And, this enterprise just might reinvigorate interest in biodiversity among the youth and aspiring professionals.

The chapters in this volume are written by biologists who share a passion for insect biodiversity. The text moves from a scene-setting overview of the value of insects through examples of regional biodiversity, taxon biodiversity, tools and approaches, and management and conservation to a historical view of the quest for the true number of insect species. The case is made throughout these pages that real progress has been achieved in discovering and organizing insect biodiversity and revealing the myriad ways, positive and negative, that insects influence human welfare. While the job remains unfinished, we can be assured that the number of insect-derived benefits yet to be realized is far greater than the number of species yet to be discovered.

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