

INSECT BIODIVERSITY

SCIENCE AND SOCIETY

Edited by Robert G. Foottit and Peter H. Adler

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Insects are the world's most diverse group of animals, making up more than 58% of the known global biodiversity. They inhabit all habitat types and play major roles in the function and stability of terrestrial and aquatic ecosystems. Insects are closely associated with our lives and affect the welfare of humanity in diverse ways. At the same time, large numbers of insect species, including those not known to science, continue to become extinct or extirpated from local habitats worldwide. Our knowledge of insect biodiversity is far from complete; for example, barely 65% of the North American insect fauna has been described. Only a relatively few species of insects have been studied in depth. We urgently need to explore and describe insect biodiversity and to better understand the biology and ecology of insects if ecosystems are to be managed sustainably and if the effect of global environment change is to be mitigated.

The scientific study of insect biodiversity is at a precarious point. Resources for the support of taxonomy are tenuous worldwide. The number of taxonomists is declining and the output of taxonomic research has slowed. Many taxonomists are reaching retirement age and will not be replaced with trained scientists, which will result in a lack of taxonomic expertise for many groups of insects. These trends contrast with an increasing need for taxonomic information and services in our society, particularly for biodiversity assessment, ecosystem management, conservation, sustainable development, management of climate-change effects, and pest management. In light of these contrasting trends, the scientific community and its leadership must increase their understanding of the science of insect biodiversity and taxonomy and ensure that policy makers are informed of the importance of biodiversity for a sustainable future for humanity.

We have attended and contributed to many scientific meetings and management and policy gatherings where the future, the resource needs, and importance of insect taxonomy and biodiversity have been debated.

In fact, discussion of the future of taxonomy is a favorite pastime of taxonomists; there is no shortage of 'taxonomic opinion.' Considerable discussion has focused on the daunting task of describing the diversity of insect life and how many undescribed species are out there. However, we felt that there was a need for a up-to-date, quantitative assessment of what insect biodiversity entails, and to connect what we know with what we do not know about insect biodiversity with its implications on human society.

Our approach was to ask authors to develop accounts of biodiversity in certain orders of insects and in certain geographic regions and along selected subject lines. In certain categories, we were limited by the availability of contributing contributors and their time and resources. Many insect groups, geographic regions, and scientific and societal issues could not be treated in a single volume. It also was apparent to us, sometimes painfully so, that many taxonomists are wildly over-committed. This situation can be seen as part of the so-called taxonomic impediment – the lack of available taxonomic expertise is compounded by an overburdened community of present-day taxonomists with too much work and perhaps too much unrealistic enthusiasm.

In Chapter 1, we introduce the ongoing challenge to document insect biodiversity and develop its service to society. Chapter 2 provides a comprehensive overview of the importance and value of insects to humans. The next two sections deal with regional treatments and order-level accounts of insect biodiversity. These approaches were a serious challenge to the contributors who had to compile information from a wide array of sources or, alternatively, deal with situations in which accurate information simply is insufficient. In Part III, we document some of the tools and approaches to the science of taxonomy and its applications. Perspective is provided on the past, present, and future of the science of insect taxonomy and the all-important influence of species concepts and their operational treatment on taxonomic science and insect biodiversity. Contributions

Insects are the most exuberant manifestation of Earth's many and varied life forms. To me, one of their greatest fascinations is how a rather simple basic unifying body plan has become modified and adapted to produce an enormous variety of species, able to exploit virtually all terrestrial and freshwater environments on the planet while, as a paradox debated extensively a few decades ago, not becoming equally predominant in the seas and oceans. Features such as possession of wings and the complete metamorphosis of many species have been cited frequently as fostering this massive diversity. However, the 'success' of insects can be measured by many parameters: their long-term persistence and stability of their basic patterns, the variety of higher groups (with almost 30 orders commonly recognized) and, as emphasized in this book, the wealth of species and similar entities. Each of these species has its individual biological peculiarities, ecological role, distribution, and interactions within the local community. And each may differ in habit and appearance both from its closest relatives and also across its range to reflect local influences and conditions. Every species is thus a mosaic of physical variety and genetic constitution that can lead to both taxonomic and ecological ambiguity in interpreting its integrity and the ways in which it may evolve and persist.

Entomologists will continue to debate the number of insect 'species' that exist and the levels of past and likely future extinctions. Documenting and cataloging insect biodiversity as a major component of Earth's life is a natural quest of human inquiry but is not an end in itself and, importantly, is not synonymous with conserving insects or a necessary prerequisite to assuring their well-being. Despite many ambiguities in projecting the actual numbers of insect species, no one would query that there are a lot and that the various ecological processes that sustain ecosystems depend heavily on insect activity. Indeed, 'ecological services' such as pollination, recycling of materials, and the economically important activities of predators

and parasitoids are signaled increasingly as part of the rationale for insect conservation because these values can be appreciated easily through direct economic impacts. All these themes are dealt with in this book centered on questions related to our ignorance of fundamental matters of 'how many are there?' 'how important are they?' to which the broad answers of 'millions' and 'massive' may incorporate considerable uncertainty; this uncertainty, however, is reduced in many of the chapters here.

In any investigations of insect biodiversity, the rote inventory tends to be emphasized. Documenting numbers of species (however they are delimited or defined) gives us foci for conservation advocacy and is pivotal in helping to elucidate patterns of evolution and distribution. Recognizing and naming species allow us to transfer information, but high proportions of undescribed or unrecognizable species necessitate the use of terms such as 'morphospecies' in much ecological interpretation of diversity. Nevertheless, other than in some temperate regions, particularly in the Northern Hemisphere, many estimates of insect species richness and naming the species present are highly incomplete. Much of the tropics, for example, harbors few resident entomologists other than those involved with pressing problems of human welfare, and more basic sustained documentation almost inevitably depends on assistance from elsewhere. Some insects, of course, have been explored much more comprehensively than others, so that selected taxonomic groups (such as butterflies, larger beetles, and dragonflies) and ecological groups ('pests') have received much more attention than many less charismatic or less economically important groups. Indeed, when collecting Psocoptera in parts of the tropics, I have occasionally been asked by local people why I am not collecting birdwing butterflies, stag beetles, or other 'popular' (or commercially desirable!) insects, and my responses have done little to change their opinions of my insanity! In spite of many gaps in knowledge of insect diversity per-

advocacy in helping to conserve areas with largely unheralded wealth of biodiversity. Presence of unusual lineages of insects, of narrow range endemics, as well as highly localized radiations and distributional idiosyncrasies (such as isolated populations beyond the main range of the taxon) are all commonplace scenarios and may in various ways help us to designate priorities for allocating the limited conservation resources available. Many such examples from selected insect groups are revealed in this book – but evaluating the richness and ecological importance of the so-called meek inheritors, that vast majority of insects that do not intrude notably on human intelligence and welfare, remains a major challenge. Many such taxa receive attention from only a handful of entomologists at any time, and some are essentially ‘orphaned’ for considerable periods. Progress with their documentation is inevitably slow and sporadic. In addition, some hyperdiverse orders and families of insects exhibit daunting complexity of form and biology, as ‘black hole groups’ whose elucidation is among the major challenges that face us.

Insect conservation has drawn heavily on issues relevant to biodiversity and appreciation of the vast richness of insects – not only of easily recognizable ‘species’ but also of the occurrence of subspecies and other infraspecific variants such as significant populations, collectively ‘evolutionarily significant units’. This more complex dimension of insect biodiversity is receiving considerable attention as new molecular tools (such as DNA analysis) enable us to probe characters in ways undreamed of only a decade or so ago to augment the perspectives provided by morphological interpretation. The vast arrays of cryptic

powers may determine the future of the system, which those insects participate. Education and communication, based on the soundest available information, are essential components of insect conservation. This book is a significant contribution to this endeavor through indicating how we may come to identify and understand insect biodiversity more effectively. In addition to providing a range of opinions and facts on insect richness in a variety of taxonomic, geographical, and methodological contexts, it helps to emphasize the importance of accurate species recognition. The failure to recognize adventive alien species may have dire economic or ecological consequences, for example, or confusion between biotypes or cryptic species may invalidate expensive management programs for pest suppression or conservation.

A new generation of skilled insect systematists whose visions encompass the wider ramifications of insect biodiversity, its importance in understanding the natural world and the accelerating impacts of human activity upon it – is an urgent need. They enter an exciting and challenging field of endeavor, and the perspectives included in this volume are essential background for their future contributions. This book is thus both a foundation and a stimulating working tool toward that end, and I expect many of the chapters to be cited with references as we progressively refine and enlarge the bases of our understanding of insects and their activity in the modern world.

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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

species, proposed by John Ray in 1691 (Berenyi in 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. Beetles are far in front, leading the next largest taxon, 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 an excellent tool for handling the taxonomic juggernaut of 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 is in the tropical areas of the globe. One hectare of Amazonian rainforest contains more than 100,000 species of arthropods (Erwin 2004), of which roughly 80% are insects (May 1998). This value is more than 100 times the total described species of insects in the entire Nearctic Region. Yet, this tropical skew is based primarily on a view of species as structurally distinct from one another. Morphologically similar, if not indistinguishable, species (i.e., sibling species) typically do not count in estimates of the number of insect species. If organisms as large as elephants and giraffes are composed of multiple species (Brown et al. 2007), a leap of imagination 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 many-fold, in the number of species (Hebert et al. 2004, Erwin et al. 2007). We do not yet have a clear indication

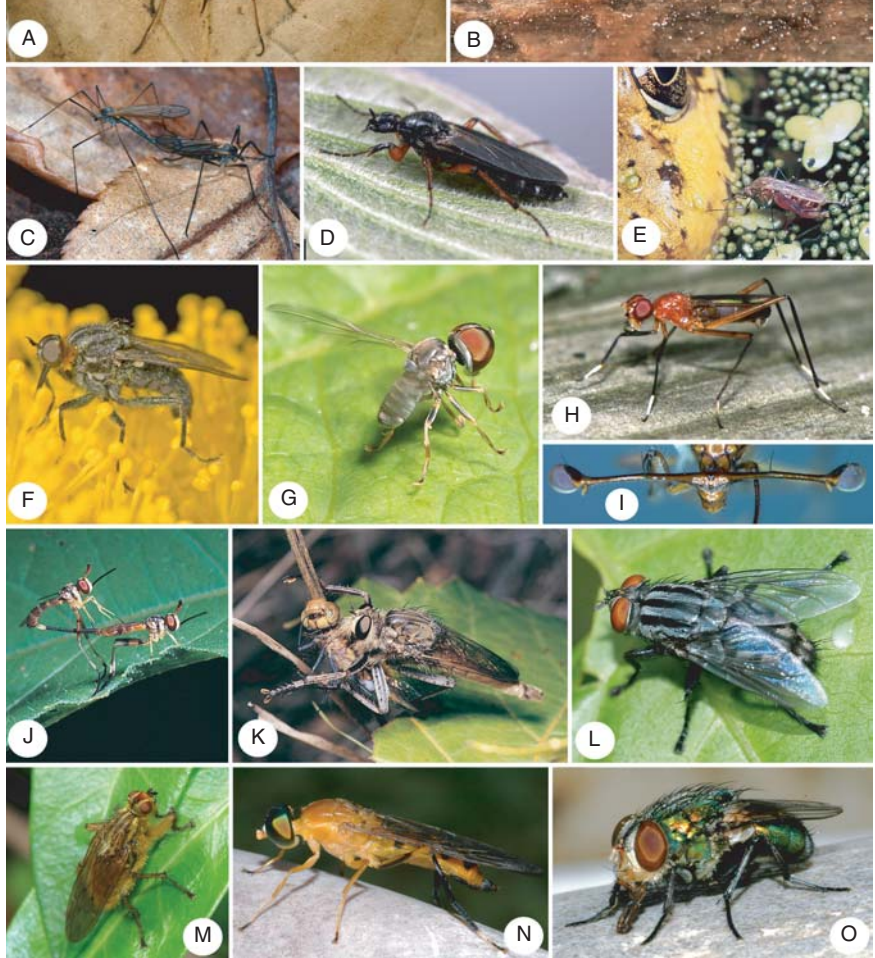


Plate 4

Adult Diptera. (a) Tipulidae (*Tanysipetra*) habitus, dorsal view. (b) Axymyiidae (*Axymyia*), lateral view. (c) Limoniidae (*Prionolabis*) mating pair, oblique-dorsal view. (d) Bibionidae (*Bibio*) habitus, oblique-lateral view. (e) Culicidae (*Culex*) feeding on ranid frog. (f) Empididae (*Empis*) habitus, lateral view. (g) Pipunculidae taking flight, oblique-lateral view. (h) Micropezidae (*Grallipeza*) habitus, lateral view. (i) Diopsidae (*Teleopsis*) head, frontal view.

(j) Conopidae (*Stylogaster*) mating pair, lateral view. (k) Asilidae (*Proctacanthus*) feeding on dragonfly, oblique-dorsal view. (l) Sarcophagidae (*Sarcophaga*) habitus, oblique-lateral view. (m) Scathophagidae (*Scathophaga*) habitus, oblique-lateral view. (n) Stratiomyidae habitus, lateral view. (o) Calliphoridae (*Hemipyrellia*) habitus, frontolateral view. (Images by E. Bernard [a], g. Courtney [b, c, h, i, m], S. Marshall [e, f, g, j, k], M. Rice [d] and I. Sivec [l, n, o].)

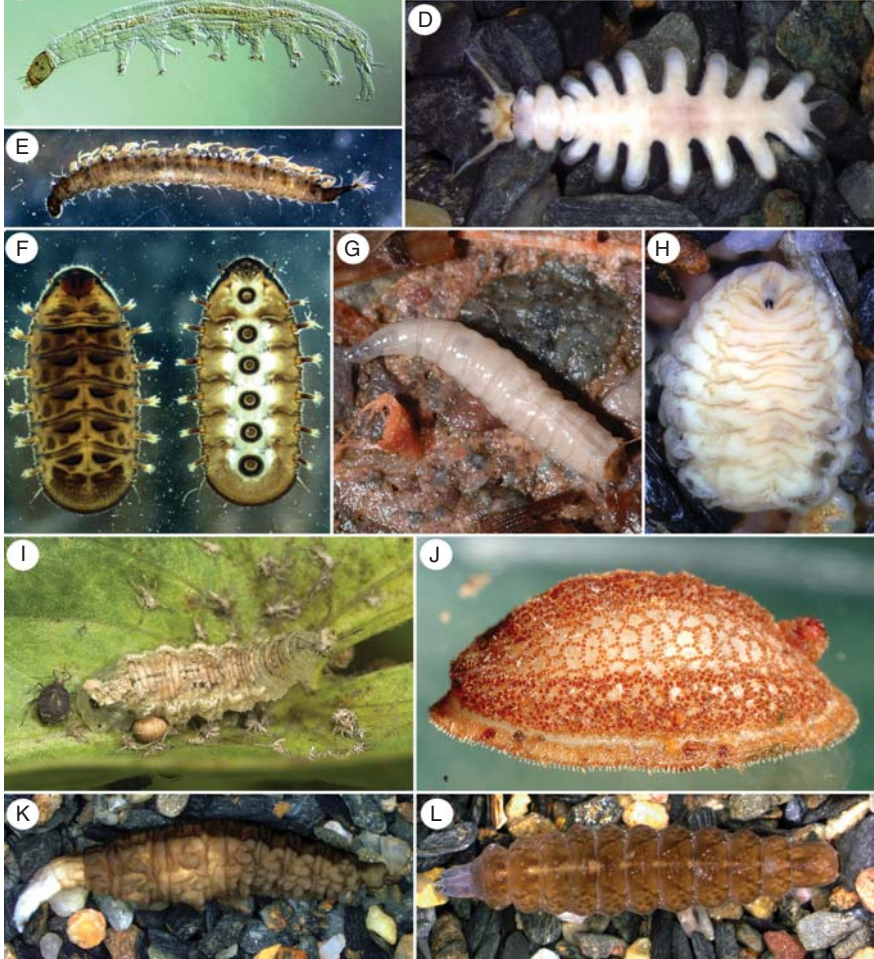


Plate 5

Larval Diptera. (a) Tipulidae (*Epiphragma*) habitus, dorsal (top) and ventral (bottom) views. (b) Ptychopteridae (*Bitacomorpha*) head, thorax and abdominal segments I–III, lateral view. (c) Nymphomyiidae (*Nymphomyia*) habitus lateral view. (d) Deuterophlebiidae (*Deuterophlebia*) habitus, dorsal view. (e) Psychodidae (*Pericoma*) habitus, lateral view. (f) Blephariceridae (*Horatia*) habitus, dorsal (left) and ventral

(right) views. (g) Calliphoridae (*Lucilia*) habitus, dorsal view. (h) Tephritidae (*Eurosta*) habitus, ventral view. (i) Syrphidae (*Syrphus*) feeding on aphids, dorsal view. (j) Syrphidae (*Microdon*) on glass, lateral view. (k) Sciomyzidae (*Tetanocera*) habitus, lateral view. (l) Stratiomyidae (*Caloparyphus*) habitus, dorsal view. (Images by G. Courtney [a–f, h, k, j], S. Marshall [g, i, l].)

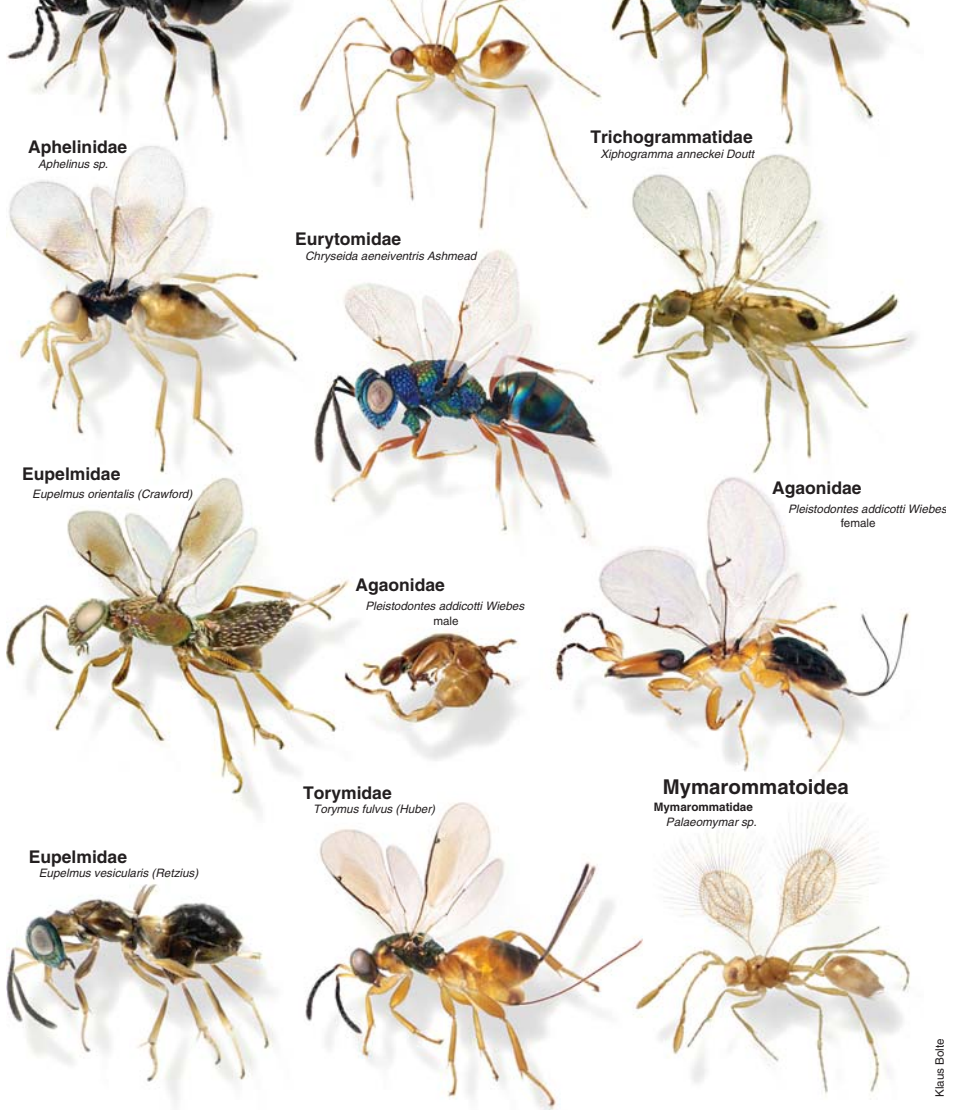


Plate 6

Lateral habitus views of representative genera of nine families of Chalcidoidea and Mymarommatodea (Hymenoptera).
by Klaus Bolte.



Plate 7

(caption on following page)