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 fav pastime of taxonomists; there is no shortage of ' onomic opinion.'' Considerable discussion has foc on the daunting task of describing the diversit insect life and how many undescribed species are there. However, we felt that there was a need fo up-to-date, quantitative assessment of what insect diversity entails, and to connect what we know do not know about insect biodiversity with its im on human society.

Our approach was to ask authors to develop acco of biodiversity in certain orders of insects and graphic regions and along selected subject lines. I categories, we were limited by the availability of ing contributors and their time and resources. M insect groups, geographic regions, and scientific societal issues could not be treated in a single volu It also was apparent to us, sometimes painfully so, many taxonomists are wildly over-committed. Thi uation can be seen as part of the so-called taxono impediment – the lack of available taxonomic ex tise is compounded by an overburdened commu of present-day taxonomists with too much work perhaps too much unrealistic enthusiasm.

In Chapter 1, we introduce the ongoing challeng document insect biodiversity and develop its serv Chapter 2 provides a comprehensive overview o importance and value of insects to humans. The two sections deal with regional treatments and ord level accounts of insect biodiversity. These approa were a serious challenge to the contributors who to compile information from a wide array of source alternatively, deal with situations in which accu information simply is insufficient. In Part III, we d ment some of the tools and approaches to the scien taxonomy and its applications. Perspective is prov on the past, present, and future of the science of in taxonomy and the all-important influence of sp concepts and their operational treatment on t nomic science and insect biodiversity. Contribut

tion of biodiversity. The book ends with an historical

Clemson, South Carolina

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 o rationale for insect conservation because these va can be appreciated easily through direct econ impacts. All these themes are dealt with in this b centered on questions related to our ignorance o fundamental matters of 'how many are there?' 'how important are they?' to which the broad ans of 'millions and 'massive' may incorporate consider uncertainty; this uncertainty, however, is reduce many of the chapters here.

In any investigations of insect biodiversity, the ro inventory tends to be emphasized. Documenting n bers of species (however they are delimited or defi gives us foci for conservation advocacy and is piv in helping to elucidate patterns of evolution and tribution. Recognizing and naming species allow to transfer information, but high proportions of u scribed or unrecognizable species necessitate the of terms such as 'morphospecies' in much ecolo interpretation of diversity. Nevertheless, other tha some temperate regions, particularly in the Nort Hemisphere, many estimates of insect species rich and naming the species present are highly incomp Much of the tropics, for example, harbors few resi entomologists other than those involved with p ing problems of human welfare, and more basic sustained documentation almost inevitably dep on assistance from elsewhere. Some insects, of cou have been explored much more comprehensively t others, so that selected taxonomic groups (suc butterflies, larger beetles, and dragonflies) and eco cal groups ('pests') have received much more atten than many less charismatic or less economically im tant groups. Indeed, when collecting Psocopter parts of the tropics, I have occasionally been aske local people why I am not collecting birdwing bu flies, stag beetles, or other 'popular' (or commerc desirable!) insects, and my responses have done tle to change their opinions of my insanity! In sh 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 syste
which those insects participate. Education and co
nication, based on the soundest available inform
are essential components of insect conservation
book is a significant contribution to this ende
through indicating how we may come to int
and understand insect biodiversity more effective
addition to providing a range of opinions and fa
insect richness in a variety of taxonomic, geogr
cal, and methodological contexts, it helps to empl
the importance of accurate species recognition
ure to recognize adventive alien species may
dire economic or ecological consequences, for exa
or confusion between biotypes or cryptic species
invalidate expensive management programs for
suppression or conservation.

A new generation of skilled insect systemati
whose visions encompass the wider ramificatio
insect biodiversity, its importance in understandi
natural world and the accelerating impacts of hu
upon it – is an urgent need. They enter an ex
and challenging field of endeavor, and the perspe
included in this volume are essential backgrou
their future contributions. This book is thus b
foundation and a stimulating working tool towar
end, and I expect many of the chapters to b
references as we progressively refine and enlarg
bases of our understanding of insects and their act
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 (Berent
this volume), to as many as 80 million (Erwin 2
Today's total of 1,004,898 described living sp
(Table 1.1) is more than 100 times the 1691 esti
Based on a figure of 1.50–1.74 million desc
eukaryotic species in the world (May 1998), in
represent 58–67% of the total.

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

The greatest concentration of insect species l
tropical areas of the globe. One hectare of Am
nian rainforest contains more than 100,000 sp
of arthropods (Erwin 2004), of which roughly
are insects (May 1998). This value is more than
of the total described species of insects in the
Nearctic Region. Yet, this tropical skew is based p
on a view of species as structurally distinct from
another. Morphologically similar, if not indistinga
able, species (i.e., sibling species) typically do not
in estimates of the number of insect species. If o
isms as large as elephants and giraffes are comp
of multiple species (Brown et al. 2007), a leap of
is not required to realize that smaller earthlings
consist of additional, reproductively isolated un
biodiversity. When long-recognized nominal spec
insects, from black flies to butterflies, are probed
deeply, the repetitive result is an increase, often m
fold, in the number of species (Hebert et al. 2004
et al. 2007). We do not yet have a clear indic

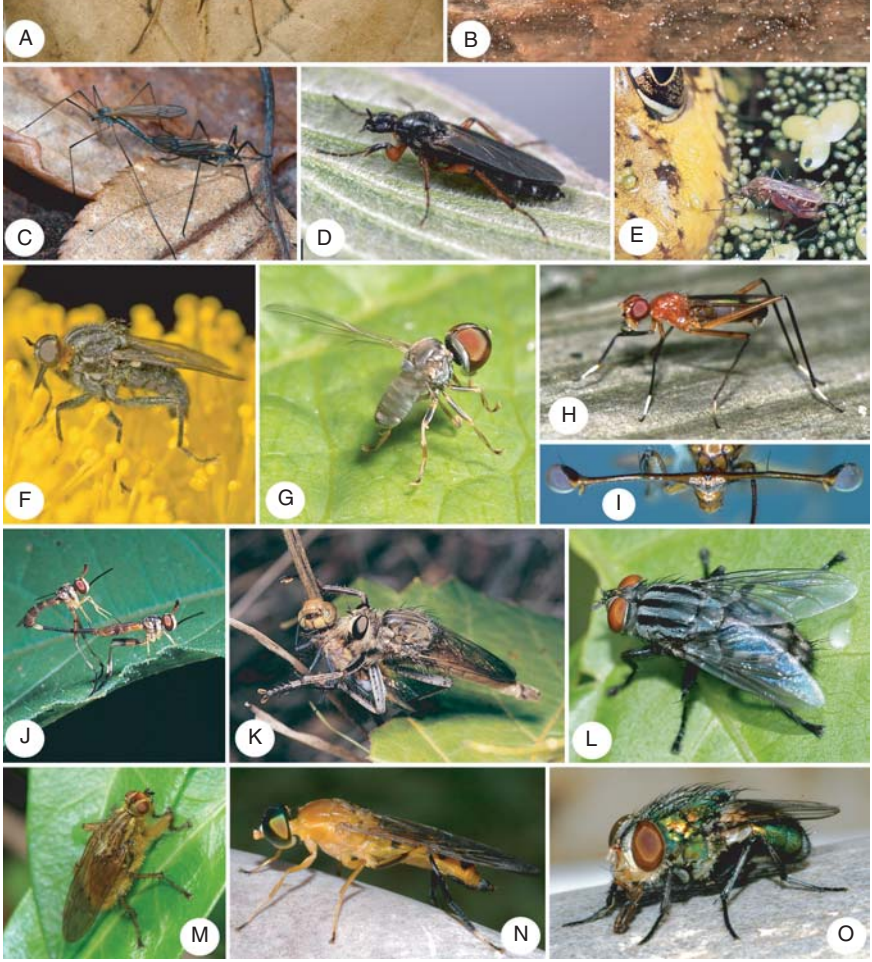

Plate 4

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

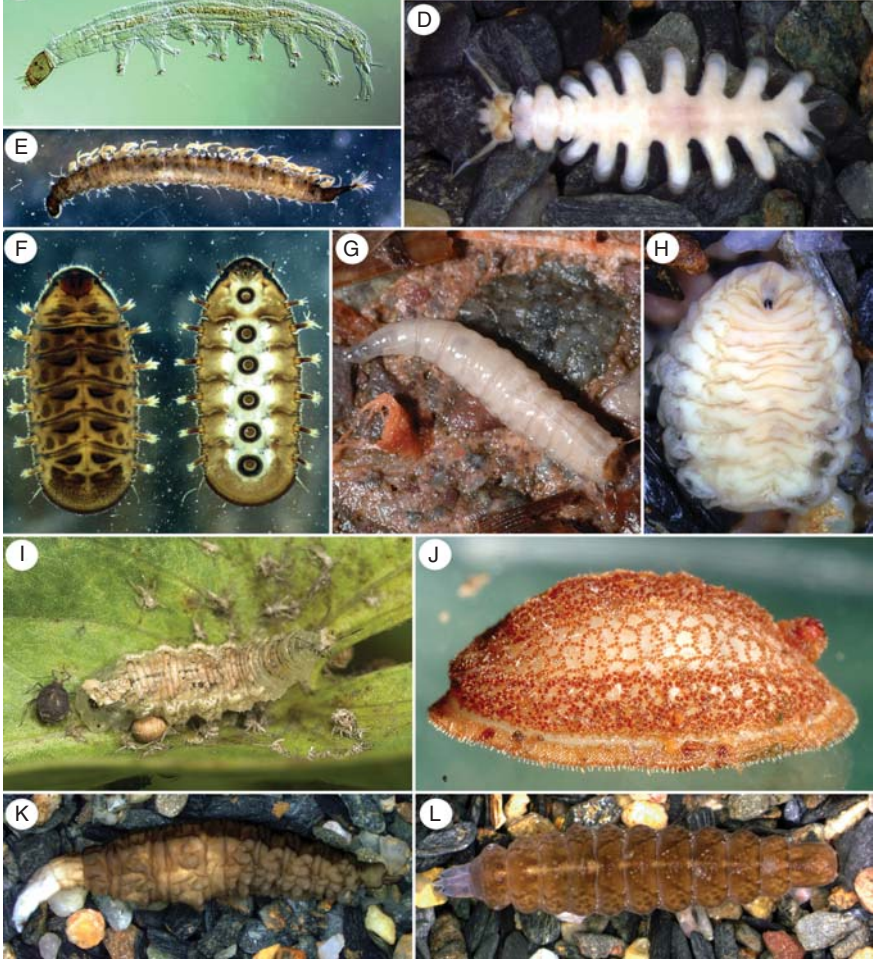

Plate 5

Larval Diptera. (a) Tipulidae (*Epiphragma*) habitus, dorsal (top) and ventral (bottom) views. (b) Ptychopteridae (*Bittacomorpha*) 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 (*Horaia*) habitus, dorsal (left) and ventral (right) views. (g) Calliphoridae (*Lucilia*) habitus, dorsal
(h) Tephritidae (*Eurosta*) habitus, ventral view. (i) Syrp
(*Syrphus*) feeding on aphids, dorsal view. (j) Syrp
(*Microdon*) on glass, lateral view. (k) Sciomyzidae (*Tetan*
habitus, lateral view. (l) Stratiomyidae (*Caloparyphus*)
tus, dorsal view. (Images by G. Courtney [a–f, h, k, j]
S. Marshall [g, i, l].)

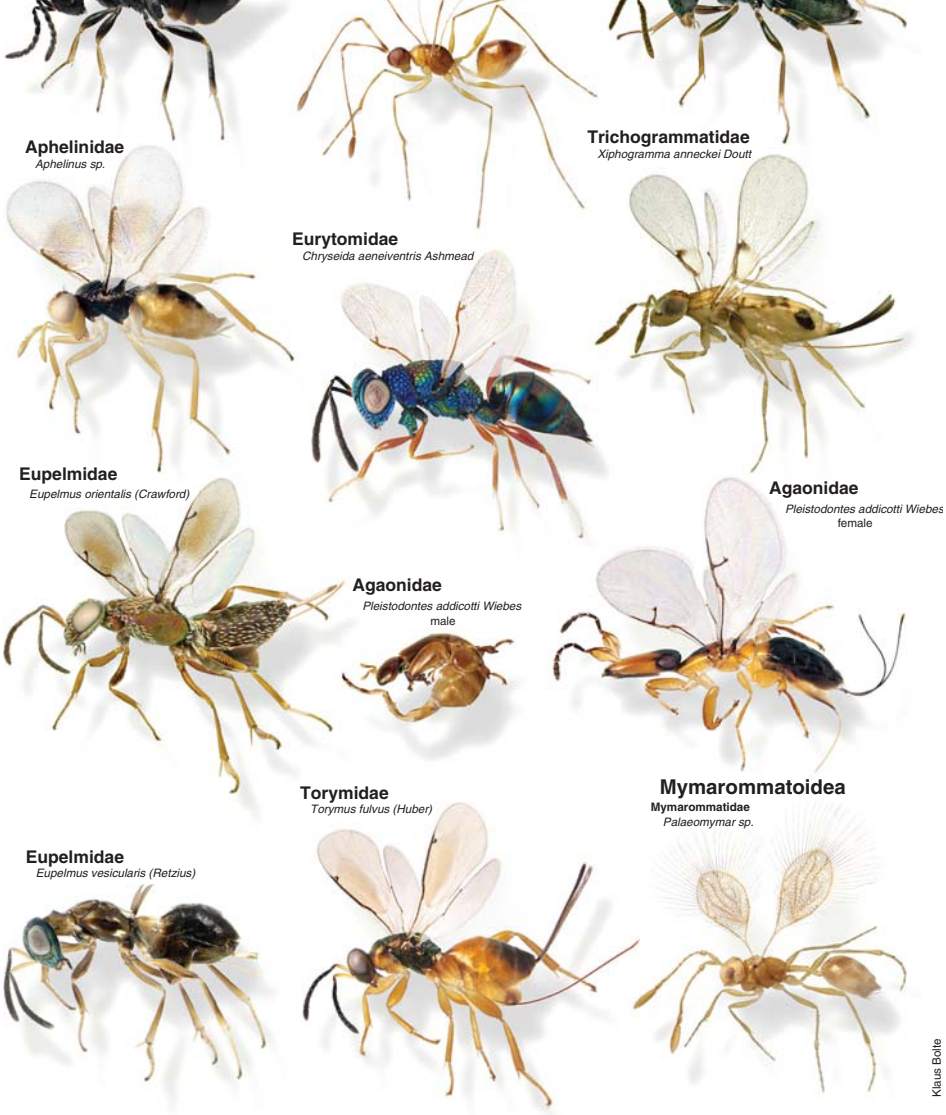

Plate 6

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

Plate 7

(caption on following page)