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BOOK REVIEW

MARQUIS R.J. & KOPTUR S. (eds) 2022: CATERPILLARS IN THE MIDDLE. TRITROPHIC INTERACTIONS IN A CHANGING WORLD. Springer Nature Switzerland AG, xx + 642 pp. ISBN 978-3-030-86687-7. Hardcover. Price EUR 42.79.

Robert J. Marquis is Professor Emeritus at the University of Missouri – St. Louis (USA). He is the author of more than 150 scientific publications and his research focuses primarily on tritrophic interactions between host plants, herbivorous insects, and their natural enemies. Suzanne Koptur is Professor Emerita at Florida International University (USA). She is the author of more than 120 scientific publications. Her research focuses mainly on plant biology, including the protection of plants against herbivores and the relationships between plants and pollinators.

Caterpillars in the Middle (Fig. 1) is part of a book series entitled *Fascinating Life Sciences*, which has been published by Springer Nature since 2016. The book is organised thematically and provides an up-to-date overview of the role of caterpillars in the field of insect-plant biology. Following the book *Caterpillars: Ecological and Evolutionary Constraints on Foraging* (ISBN 0-412-02681-3) by Nancy E. Stamp and Timothy M. Casey, *Caterpillars in the Middle* is a second work that addresses the fundamental importance of the lepidopteran caterpillars in ecosystems. The book is divided into six parts consisting of 20 chapters compiled by 55 authors, most of whom are leading authorities on insect-plant interactions in both temperate and tropical habitats, and ends with subject and taxonomic indexes.

The *Introduction* forms the first part of the book and consists of two chapters: "*Introduction – Caterpillars as Focal Study Organisms*" and "*On Being a Caterpillar: Structure, Function, Ecology, and Behavior*", which not only provide the reader with some background knowledge on the life of lepidopteran caterpillars, but also on the history of the caterpillar becoming recognised as a developmental stage in the Lepidoptera. The second chapter serves as a guide to basic knowledge of Lepidoptera and covers important topics such as "*Basic Anatomy*", "*Ontogeny, Life Cycles, and Diapause*", "*Larval Diets*", "*Caterpillar Enemies: Predators and Parasitoids*" and "*Silk*".

The second part *Impacts of the First Trophic Level on Caterpillar Ecology and Evolution* consists of four chapters ("*Surface Warfare: Plant Structural Defenses Challenge Caterpillar Feeding*", "*Impacts of Plant Defenses on Host Choice by Lepidoptera in Neotropical Rainforests*", "*Ecology and Evolution of Secondary Compound Detoxification Systems in Caterpillars*", "*Sequestered Caterpillar Chemical Defenses: From 'Disgusting Morsels' to Model Systems*") and is devoted to the host plants, their chemical and physical defence mechanisms and the adaptations that caterpillars had to develop in order to overcome them. In this part, the authors also explain how climate change affects insect herbivores via their host plants.

The third part of the book, *Impacts of the Third Trophic Level on Caterpillar Ecology and Evolution*, comprises five chapters ("*Acoustic Defence Strategies in Caterpillars*", "*Natural History and Ecology of Caterpillar Parasitoids*", "*Predators and Caterpillar Diet Breadth: Appraising the Enemy-Free Space Hypothesis*", "*Caterpillar Responses to Ant Protectors of Plants*"), in which the influence of the third trophic level, represented by predators and parasitoids (Fig. 2), and their influence on the biology and evolution of caterpillars is analysed. In addition, the last chapter "*The Natural History of Caterpillar-Ant Associations*" describes the phenomenon of myrmecophily in Lepidoptera, its origin, mechanisms, and the most famous examples of its occurrence in nature. That chapter was updated to open access after publication of the book and is now available on the publisher's website (https://doi.org/10.1007/978-3-030-86688-4_11).

The next part *Multiple Interactive Effects Among All Three Trophic Levels* consists of five chapters ("*Caterpillars, Plant Chemistry, and Parasitoids in Natural vs. Agroecosystems*",

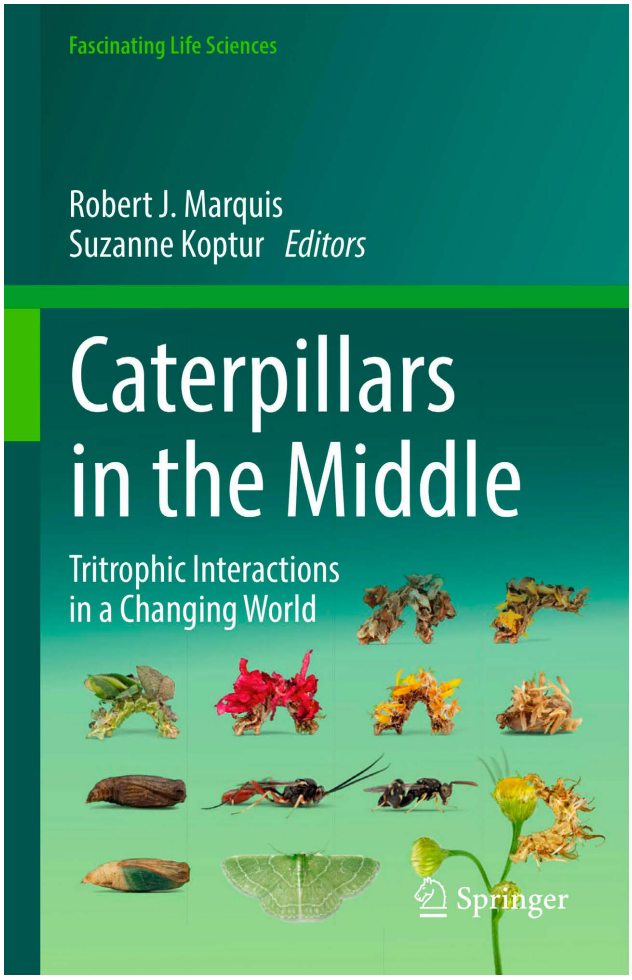

Fig. 1. The book cover (from Marquis & Koptur, 2022).

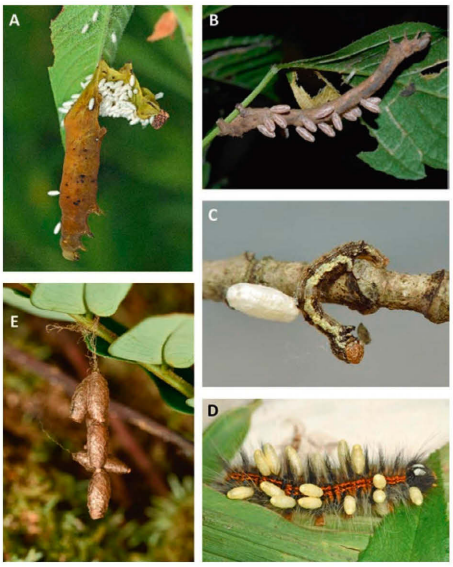

Fig. 1 Examples of cocoons of braconid parasitoids of caterpillars. (**a**) *Cotesia* sp. cocoons on a sphingid carcass (FL: SA Marshall). (**b**) Microgastrine braconid cocoons on *Prochoerodes lineola* (Geometridae) (OH: JOS). (**c**) A microgastrine cocoon on an unidentified geometrid (MO: SA Marshall). (**d**) Microgastrine braconid cocoons on an unidentified erebid (Ecuador: SA Marshall). (**e**) Gregarious meteorine braconid cocoons suspended from a twig (Brazil: SA Marshall)

a vast tropical forest, searching for a mate and for caterpillars to parasitize, and the tiny males out there searching for females. In a large complex world, it may be much more difficult for a male and female wasp to find each other and mate, than for a female to locate (more numerous) caterpillars. With other insects, such as parasitic flies, an unmated female might lay her eggs as they develop, but they are infertile and die. However, a parasitoid wasp can develop and lay eggs at times when male wasps cannot be found and those eggs can develop into male wasps. Thereby, an unmated female wasp has the capacity to flood the local environment with male wasps at precisely the time when males are scarce. Therefore, haplodiploidy, one of the most basic characteristics of the order Hymenoptera, gives these insects a key advantage over other groups of insect parasitoids: they can exist and survive locally at lower population densities.

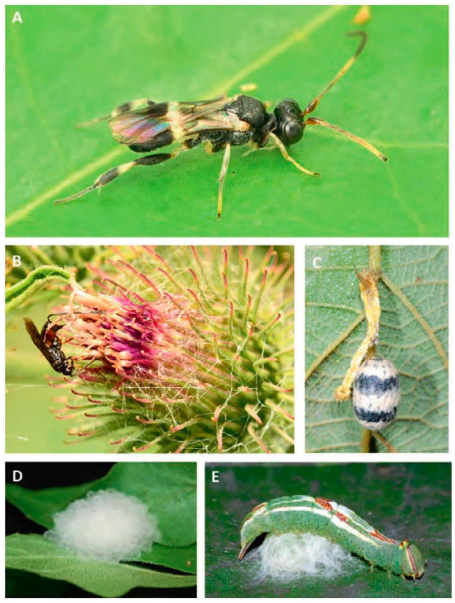

Fig. 2 Adults and pupae of Ichneumonoidea. (**a**) An adult of the chelonine braconid *Chelonus* (Brazil: SA Marshall). (**b**) An agathidine braconid (*Agathis malvacearum* Latreille) ovipositing into a *Metzneria lappella* (L.) caterpillar (Gelechiidae) concealed inside a cocklebur inflorescence (*Xanthium strumarium* L.) (ONT Canada: SA Marshall). (**c**) A campoplegine ichneumonid cocoon attached to the carcass of a sphingid caterpillar (OH: JOS). (**d**) A fluffy mass of microgastrine braconid cocoons concealing the noctuid host carcass from which they emerged (OH: JOS). (**e**) A notodontid caterpillar (*Heterocampa guttivitta* (Walker)) "guarding" the microgastrine braconid parasitoids that emerged from it (OH: JOS)

In parasitoid species that utilize sparsely distributed and difficult to locate hosts, inbreeding is common due to "local mate competition" (Godfray 1994). Many eggs might be oviposited into one host caterpillar, increasing the chances that emerging wasps will mate with their own siblings. Haplodiploid sex determination and control of egg fertilization allows female wasps to determine the sex of their offspring as eggs are laid, allowing them to skew sex ratios such that just barely sufficient numbers of males are produced. Female wasps can also assess the quality of

Fig. 2. Examples of lepidopteran caterpillar parasitoids (from Marquis & Koptur, 2022).

"*Host Plants as Mediators of Caterpillar-Natural Enemy Interactions*", "*Host Plant Effects on the Caterpillar Immune Response*", "*Trophic Interactions of Caterpillars in the Seasonal Environment of the Brazilian Cerrado and Their Importance in the Face of Climate Change*", "*The Impact of Construct Building by Caterpillars on Arthropod Colonists in a World of Climate Change*") and discusses how plant traits and habitat type influence the diversity, behaviour and physiology of caterpillars. They also address the interesting topic of host-plant-derived effects on lepidopteran immunity to natural enemies. The final chapter of this part of the book deals with how the constructs (shelters, leaf mines, etc.) built by caterpillars affect the abundance, diversity and community structure of other arthropods associated with the plants on which the constructs are built, as well as the impact of climate change on these ecosystem engineers.

The fifth part of the book, "*Caterpillar Foodwebs in a World of Rapidly Changing Climate*", contains three, thematically unrelated chapters. In the first chapter, "*Caterpillar Patterns in Space and Time: Insights From and Contrasts Between Two Citizen Science Datasets*", the authors debate the importance of two important citizen science programmes (*iNaturalist* – https://inaturalist.org and *Caterpillars Count!* – https://caterpillarscount.unc.edu) in detecting large-scale caterpillar patterns (taxonomic representation, occurrence and phenology) across North America. The second chapter, "*Impacts of Climatic Variability and Hurricanes on Caterpillar Diet Breadth and Plant-Herbivore Interaction Networks*", gives the reader an insight into how climate fluctuations and extreme weather events influence the diet, diversity, and composition of insect communities in western Mexico. In the final chapter, "*Plant-Caterpillar-Parasitoid Natural History Studies Over Decades and Across Large Geographic Gradients Provide Insight Into Specialization, Interaction Diversity, and Global Change*", the authors provide an overview of the changes in caterpillar networks based on long-term data and discuss the probable causes of the observed decline in caterpillars and parasitoids, and the impact on local ecosystems.

The book ends with a "*Synthesis*", which officially contains only one chapter: "*Synopsis and the Future of Caterpillar Research*", written by the editors. Three subchapters ("*Caterpillars Biology and Ecology in a Tritrophic World*", "*Development of Caterpillars in a Tritrophic World*" and "*Caterpillars in a Changing World*") briefly summarise the main topics covered in this book.

Overall, this is an excellent work that not only emphasises the general importance of studying tritrophic systems, the world of lepidopteran caterpillars, their parasitoids and predators, but also all sorts of ideas for future research. However, I am personally somewhat disappointed with the quality of the printed book, especially for the original price of 85.59 euros. Whilst this price has dropped by a half after a year in both soft and hard cover, the paper and print quality used for the book still feels quite thin and cheap, and the cracking sound and glue bubbles in the binding of

the book also do not seem worthy of the price. Despite this unfortunate detail, the scientific contribution of this publication to the biology, ecology and conservation of Lepidoptera is undeniable and the book should therefore be a part of every entomological library.

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