

## Editorial

## An Overview of “Insect Biodiversity”

Giorgia Sollai \*  and Paolo Solari \* 

Department of Biomedical Sciences, Section of Physiology, University of Cagliari, University Campus, S.P. 8, 09042 Monserrato, Italy

\* Correspondence: gsollai@unica.it (G.S.); solari@unica.it (P.S.)

Insects comprise more than half of all described species in the animal kingdom and account for a considerable proportion of all biodiversity on the planet [1,2]. This great variability is due to the specificity of the genetic, morphological, and functional aspects that different insect species have developed to successfully cope with the complex and dynamic habitats in which they live.

Insects are referred to as pests or disease carriers that influence agriculture, human health, and natural resources. Many of them are also beneficial for humans, as they pollinate plants, produce useful substances, control pest insects, act as scavengers, and serve as food for other animals and, in the near future, possibly for humans too [3]. Furthermore, given their great biodiversity, insects are valuable objects of study in biology, evolution, and ecology. In fact, a large amount of scientific knowledge in genetics has been obtained from fruit fly experiments, as well as population biology in flour beetle studies. Insects are often used in investigations regarding hormonal action, nerve and sense organ functions, and many other physiological processes, and also as environmental quality indicators. Even if the causes of their remarkable diversity remain poorly understood, it has been suggested that herbivory may have accelerated diversification in many insect clades [4,5].

In this respect, this Special Issue aims to highlight new research and significant advances in order to better understand, from different perspectives and methodological approaches, the genetic and the morpho-functional aspects characterizing the great level of biodiversity in insects.

One key but controversial aspect in assessing insect biodiversity is that taxonomy sometimes appears inadequate and/or incomplete, and in a case where a species falls outside of the intraspecific variability range of closely related species, many taxonomists tend to list it as a new species [6]. An article by Deng et al. [7] in this Special Issue deals with this concern. These authors collected 1261 articles containing 4811 new insect species between 2009 and 2017 and reported that, despite the increased taxonomic efforts for the discovery of more species and their geographical distribution information, more than 21% of these new species were described from only one specimen and/or one locality, and half of all new species were reported based on fewer than five specimens. On the other hand, these authors encourage taxonomists to adopt better practices, such as increasing the number of specimens and geographical coverage of sampling, including DNA data, and improving international collaboration in the description of new species.

Alternatively, the possibility exists that global species numbers might be underestimated because of cryptic diversity [2,8]. Therefore, the use of good morphological methods and intensive studies with large specimen numbers from many localities would help separate most species previously found to be cryptic. Advances in revealing cryptic diversity may also come from the use of DNA methods. This topic is supported in this Special Issue by de Moya et al. [9], who explored the *Bemisia tabaci* complex of whiteflies, which are considered pests worldwide and are thought to contain cryptic species corresponding to geographically structured phylogenetic clades. Based on their automatic barcode gap discovery (ABGD) analyses, these authors reported the existence of at least five species from both the analyses of nuclear orthologs and cytochrome oxidase I.



**Citation:** Sollai, G.; Solari, P. An Overview of “Insect Biodiversity”. *Diversity* **2022**, *14*, 134. <https://doi.org/10.3390/d14020134>

Received: 7 February 2022

Accepted: 10 February 2022

Published: 14 February 2022

**Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

In a different paper of this Special Issue, Han et al. [10] revisited the phylogenetic position of the genus *Yaeprimus* within Chironomini on the basis of both morphological and molecular evidence. Their molecular results strongly support *Yaeprimus* as a sister to *Imparipecten* Freeman, 1961, rather than to the *Microtendipes* group, thus countering a previously reported systematical position exclusively based on morphological analyses.

An important, emerging threat for insect biodiversity is posed by the widespread contamination of ecosystems with plant protection chemicals, such as fertilizers, pesticides, and herbicides, which ultimately cause a rapid decline in both insect biomass and diversity [11,12]. In this Special Issue, an article by Giglio et al. [13] examined this aspect. By way of combined field and laboratory trials, these authors tested the effects of exposure to realistic doses of pendimethalin-based herbicides on the constitutive immunity of *Harpalus* (*Pseudophonus*) *rufipes*, a beneficial carabid species that inhabits croplands. They reported that exposure to herbicides can have sublethal effects, as herbicides interfere with some key components of the immune response in insects. These effects depend on both the different field conditions from which the insect population comes and on the cumulative effects of repeated applications over time and suggest that this highly lipophilic herbicide, applied in early spring when adults start foraging in the field, may be quickly absorbed through the cuticle or ingested through the direct consumption of contaminated food.

Insect biodiversity is associated with the quantity and type of host plants available, environmental factors, and their physiological state [14–17]. The availability of host plants and an insect's ability to find them are key factors for the survival of a species because they represent both suitable oviposition sites for adult females and potential food sources for the offspring [18–20]. An important role in the choice and recognition of a host plant is played by the information that the olfactory and gustatory systems send to the central nervous system (CNS) on the chemical composition of the plant [21–23]. In particular, insects show a great peripheral plasticity that allows them to adapt to the environment in which they live [24]. In this Special Issue, Sollai et al. [25] show that sex, physiological state, and experience can modulate the olfactory sensitivity of the medfly *Ceratitis capitata*, a highly invasive species of economic interest. The results show that: (a) lab-reared mated males are more sensitive to host plant headspace than females, while the opposite is true for wild insects; (b) wild virgin males are more sensitive than mated ones, while no difference was observed among lab-reared medflies; (c) lab-reared virgin females are more sensitive than mated ones, while few differences were found within wild medflies; (d) lab-reared mated males are more sensitive to host plant extracts than wild ones, while the opposite was found for females. Taken together, these findings highlight that the physiological state and habitat contribute to the peripheral plasticity of insects of both sexes, modulating their olfactory sensitivity to ensure the most appropriate adaptations for the survival of the species.

Remaining in the context of environmental conditions, in this Special Issue, Viterbi et al. [26] published an interesting study on the effects of temperature and its changes on the biodiversity of insects in mountains. In particular, the authors observed significant differences between groups of species and along the altitudinal gradient, although only small changes emerged in the overall biodiversity patterns. The effects of temperature increase could be more pronounced for spiders and butterflies and could be particularly detrimental for high-altitude species. They observed significant changes in community composition and species richness, especially in the alpine belt, but a clear separation between vegetation levels was also retained in the warming scenarios. This conservative approach suggests that even a moderate temperature increase (of about 1 °C) could influence animal biodiversity in mountain ecosystems.

Insects' biodiversity may represent a threat for rare plant species, which are reliable indicators of environmental changes but also are a resource in various economic sectors, such as pollination and human health. The loss of biodiversity is related to several key factors, such as human activity (fragmentation and loss of habitat, pollution, etc.), climatic events, and geological processes [27]. This course can be reversed through a reduction in

the use of environmental pollutants and pesticides and the increase in favorable habitats for the species [28]. To this end, it could be of particular importance to learn the factors that regulate the relationships between plants, the environment, and herbivores [29]. For example, the effects of herbivorous species capable of influencing the viability of a host plant and the development of its reproductive structures should be considered [30]. In this Special Issue, Bonsignore et al. [31] showed the effects that several species of herbivorous insects have on a rare plant species, *Salvia ceratophylloides*, endemic of southern Italy. They found bottom-up and top-down effects on plant health and reproduction associated with herbivorous action. Among the herbivores, mainly *Squamapion elongatum* affected this rare species of sage: the acquired data indicate that the density of the herbivore in the area of diffusion of sage does not represent a quantitative regulating factor of flowering, but it can rather condition the survival of the species.

In this Special Issue, Enkhtur et al. [32] showed that moths are creatures with an important role in the ecosystem and have the potential to serve as environmental indicators. In particular, Geometrid moths (Geometridae), constituting one of the biggest families of Lepidoptera, are a species-rich and easily recognizable family and have served as indicators for environmental changes [33]. By analyzing the distribution pattern, species richness, and biodiversity in the Mongolian ecoregions and correlating them with environmental variables, the authors concluded that annual precipitation and the maximum temperature of the warmest month were the most important environmental variables that correlated in an analysis of geometrid assemblages of different ecoregions in Mongolia.

Finally, Hristov et al. [34] published an interesting review describing how the reduction in honey bee populations affects various economic sectors, as well as human health. Despite the important role played by these insects, a progressive decline in bee colonies is being observed due to the effect of the excessive use of pesticides in agricultural production, genetically modified plants, electromagnetic radiation, inadequate honey bee nutrition, crops growing in monoculture, and biodiversity loss. Honey bees are the most economically valuable pollinator in the world: 9.5% of the total economic value of agricultural production comes from insect pollination, which totals an amount of just under USD 200 billion globally. They pollinate not only a large number of commercial crops (cereals, vegetables, fruits, edible oil crops, stimulants, and nuts and spices), but also many wild plants, some of which are threatened with extinction, playing a significant role in every aspect of ecosystem, facilitating the growth of trees, flowers, and other plants that serve as food and shelter for many creatures large and small. Honey bee products, such as honey, pollen, royal jelly, propolis, bee venom, wax, and bee bread, are important resources with regard to human nutrition and the production of pharmaceuticals and food additives.

In conclusion, even if this Special Issue does not entirely cover the vast range of the possible topics related to insect biodiversity, it provides insight into the multiple directions with which biodiversity intersects. Unfortunately, we are currently experiencing a biodiversity crisis: many species, among which are insects, are becoming extinct, probably before we can even detect their existence and describe them. This loss in insect biodiversity, which is mainly a consequence of anthropogenic pressure, will ultimately lead to a subsequent decline in ecosystem stability and functioning. In this respect, better knowledge of the genetic, morphological, and functional aspects characterizing the great level of biodiversity in insects will be decisive for the safeguarding of ecosystems.

**Author Contributions:** G.S. and P.S., writing—original draft preparation, review and editing. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** We would like to thank all the authors and referees for their remarkable contribution to this SI. We are also grateful to the staff members at the MDPI editorial office (in particular, Annabelle Wang, Emma Li, and Caitlin Sheng, managing editors) for their support during the editorial process.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Tihelka, E.; Cai, C.; Giacomelli, M.; Lozano-Fernandez, J.; Rota-Stabelli, O.; Huang, D.; Engel, M.S.; Donoghue, P.C.J.; Pisani, D. The evolution of insect biodiversity. *Curr. Biol.* **2021**, *31*, R1299–R1311. [[CrossRef](#)] [[PubMed](#)]
2. Stork, N.E. How Many Species of Insects and Other Terrestrial Arthropods Are There on Earth? *Ann. Rev. Entomol.* **2018**, *63*, 31–45. [[CrossRef](#)] [[PubMed](#)]
3. Manno, N.; Estraver, W.Z.; Tafur, C.M.; Torres, C.L.; Schwarzing, C.; List, M.; Schoefberger, W.; Coico, F.R.M.; Leon, J.M.; Battisti, A.; et al. Edible Insects and Other Chitin-Bearing Foods in Ethnic Peru: Accessibility, Nutritional Acceptance, and Food-Security Implications. *J. Ethnobiol.* **2018**, *38*, 424–447. [[CrossRef](#)]
4. Sollai, G.; Tomassini Barbarossa, I.; Masala, C.; Solari, P.; Crnjar, R. Gustatory sensitivity and food acceptance in two phylogenetically closely related papilionid species: *Papilio hospiton* and *Papilio machaon*. *PLoS ONE* **2014**, *9*, e100675. [[CrossRef](#)]
5. Wiens, J.J.; Lapoint, R.T.; Whiteman, N.K. Herbivory increases diversification across insect clades. *Nat. Comm.* **2015**, *6*, 8370. [[CrossRef](#)]
6. Lim, G.S.; Balke, M.; Meier, R. Determining species boundaries in a world full of rarity: Singletons, species delimitation methods. *Syst. Biol.* **2012**, *61*, 165–169. [[CrossRef](#)]
7. Deng, J.; Guo, Y.; Cheng, Z.; Lu, C.; Huang, X. The Prevalence of Single-Specimen/Locality Species in Insect Taxonomy: An Empirical Analysis. *Diversity* **2019**, *11*, 106. [[CrossRef](#)]
8. Adis, J. Thirty Million Arthropod Species—too Many or too Few? *J. Trop. Ecol.* **1990**, *6*, 115–118. [[CrossRef](#)]
9. De Moya, R.S.; Brown, J.K.; Sweet, A.D.; Walden, K.K.O.; Paredes-Montero, J.R.; Waterhouse, R.M.; Johnson, K.P. Nuclear Orthologs Derived from Whole Genome Sequencing Indicate Cryptic Diversity in the *Bemisia tabaci* (Insecta: Aleyrodidae) Complex of Whiteflies. *Diversity* **2019**, *11*, 151. [[CrossRef](#)]
10. Han, W.; Wei, J.; Lin, X.; Tang, H. The Afro–Oriental Genus *Yaeprimus* Sasa et Suzuki (Diptera: Chironomidae: Chironomini): Phylogeny, New Species and Expanded Diagnoses. *Diversity* **2020**, *12*, 31. [[CrossRef](#)]
11. Brühl, C.A.; Zaller, J.G. Biodiversity Decline as a Consequence of an Inappropriate Environmental Risk Assessment of Pesticides. *Front. Environ. Sci.* **2019**, *7*, 177. [[CrossRef](#)]
12. Raven, P.H.; Wagner, D.L. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proc. Natl. Acad. Sci. USA* **2021**, *118*. [[CrossRef](#)] [[PubMed](#)]
13. Giglio, A.; Cavaliere, F.; Giulianini, P.G.; Kurtz, J.; Vommaro, M.L.; Brandmayr, P. Continuous Agrochemical Treatments in Agroecosystems Can Modify the Effects of Pendimethalin-Based Herbicide Exposure on Immunocompetence of a Beneficial Ground Beetle. *Diversity* **2019**, *11*, 241. [[CrossRef](#)]
14. Dangles, O.; Irschick, D.; Chittka, L.; Casas, J. Variability in Sensory Ecology: Expanding the Bridge Between Physiology and Evolutionary Biology. *Q. Rev. Biol.* **2009**, *84*, 51–74. [[CrossRef](#)] [[PubMed](#)]
15. Reside, A.E.; Butt, N.; Adams, V.M. Adapting systematic conservation planning for climate change. *Biodivers. Conserv.* **2018**, *27*, 1–29. [[CrossRef](#)]
16. Sollai, G.; Biolchini, M.; Solari, P.; Crnjar, R. Chemosensory basis of larval performance of *Papilio hospiton* on different host plants. *J. Insect Physiol.* **2017**, *99*, 47–57. [[CrossRef](#)]
17. Thompson, J.N.; Pellmyr, O. Evolution of Oviposition Behavior and Host Preference in Lepidoptera. *Ann. Rev. Entomol.* **1991**, *36*, 65–89. [[CrossRef](#)]
18. Sollai, G.; Biolchini, M.; Crnjar, R. Taste sensitivity and divergence in host plant acceptance between adult females and larvae of *Papilio hospiton*. *Insect Sci.* **2018**, *25*, 809–822. [[CrossRef](#)]
19. Sollai, G.; Biolchini, M.; Loy, F.; Solari, P.; Crnjar, R. Taste input from tarsal sensilla is related to egg-laying behavior in *Papilio hospiton*. *Entomol. Exp. Appl.* **2017**, *165*, 38–49. [[CrossRef](#)]
20. Sollai, G.; Solari, P.; Crnjar, R. Olfactory sensitivity to major, intermediate and trace components of sex pheromone in *Ceratitis capitata* is related to mating and circadian rhythm. *J. Insect Physiol.* **2018**, *110*, 23–33. [[CrossRef](#)]
21. Feeny, P.; Städler, E.; Åhman, I.; Carter, M. Effects of plant odor on oviposition by the black swallowtail butterfly, *Papilio polyxenes* (Lepidoptera: Papilionidae). *J. Insect Behav.* **1989**, *2*, 803–827. [[CrossRef](#)]
22. Nishida, R. Chemosensory basis of host recognition in butterflies—multi-component system of oviposition stimulants and deterrents. *Chem. Sens.* **2005**, *30* (Suppl. 1), i293–i294. [[CrossRef](#)] [[PubMed](#)]
23. Solari, P.; Corda, V.; Sollai, G.; Kreissl, S.; Galizia, C.G.; Crnjar, R. Morphological characterization of the antennal lobes in the Mediterranean fruit fly *Ceratitis capitata*. *J. Comp. Physiol. A Neuroethol. Sens. Neur. Behav. Physiol.* **2016**, *202*, 131–146. [[CrossRef](#)] [[PubMed](#)]
24. Sollai, G.; Biolchini, M.; Crnjar, R. Taste receptor plasticity in relation to feeding history in two congeneric species of Papilionidae (Lepidoptera). *J. Insect Physiol.* **2018**, *107*, 41–56. [[CrossRef](#)] [[PubMed](#)]
25. Sollai, G.; Solari, P.; Crnjar, R. Differences in the Olfactory Sensitivity of *Ceratitis capitata* to Headspace of Some Host Plants in Relation to Sex, Mating Condition and Population. *Diversity* **2020**, *12*, 207. [[CrossRef](#)]
26. Viterbi, R.; Cerrato, C.; Bionda, R.; Provenza, A. Effects of Temperature Rise on Multi-Taxa Distributions in Mountain Ecosystems. *Diversity* **2020**, *12*, 210. [[CrossRef](#)]
27. Corlett, R.T. Plant diversity in a changing world: Status, trends, and conservation needs. *Plant Divers.* **2016**, *38*, 10–16. [[CrossRef](#)]
28. Wagner, D.L.; Van Driesche, R.G. Threats posed to rare or endangered insects by invasions of nonnative species. *Ann. Rev. Entomol.* **2010**, *55*, 547–568. [[CrossRef](#)]

29. Souza, L.; Zelikova, T.J.; Sanders, N.J. Bottom-up and top-down effects on plant communities: Nutrients limit productivity, but insects determine diversity and composition. *Oikos* **2016**, *125*, 566–575. [[CrossRef](#)]
30. Ancheta, J.; Heard, S.B. Impacts of insect herbivores on rare plant populations. *Biol. Conserv.* **2011**, *144*, 2395–2402. [[CrossRef](#)]
31. Bonsignore, C.P.; Laface, V.L.A.; Vono, G.; Marullo, R.; Musarella, C.M.; Spampinato, G. Threats Posed to the Rediscovered and Rare *Salvia ceratophylloides* Ard. (*Lamiaceae*) by Borer and Seed Feeder Insect Species. *Diversity* **2021**, *13*, 33.
32. Enkhtur, K.; Boldgiv, B.; Pfeiffer, M. Diversity and Distribution Patterns of Geometrid Moths (Geometridae, Lepidoptera) in Mongolia. *Diversity* **2020**, *12*, 186. [[CrossRef](#)]
33. Ashton, L.; Maunsell, S.; Bito, D.; Putland, D. Macrolepidopteran assemblages along an altitudinal gradient in subtropical rainforest—Exploring indicators of climate change. *Mem. Queensl. Mus.* **2011**, *55*, 375–389.
34. Hristov, P.; Neov, B.; Shumkova, R.; Palova, N. Significance of Apoidea as Main Pollinators. *Ecol. Econ. Impact Implic. Hum. Nutrition. Divers.* **2020**, *12*, 280.