Chapter 1
Aquatic Insects: Why It Is Important to Dedicate Our Time on Their Study?

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Abstract Evolution begets diversity, and insects are the most diverse organisms in the history of life, so insects should provide profound insight into evolution. Insects are considered keystone species because loss of their critical ecological functions (e.g., pollinators; seed dispersers; predators; and parasitoids) could lead to collapse of the wider ecosystem. Indeed, insects dominate freshwater aquatic systems, but in general we know very few about the biology and natural history of these organisms. Here, we present a good set of basic data and knowledge in ecology, natural history, and behavior of this unknown fauna. Our hope is that it encourages young researchers to investigate basic aspects of the life history of aquatic insects, mainly in tropical systems.

Keywords Biology · Behavior · Behavioral ecology · Ecological networks · Wetlands

The diversity of life is one of the most astonishing aspects of our planet. Organisms are spread from the highest mountains to the deepest oceans of the Earth. They are under the bark of trees and inside flowers, in deep soil, in air, and even in frozen lakes. How many are they? How long will they stay as they are, or will evolve? Or disappear like so many others?

In a more recent and conservative perspective we suspect that there are more than 8.7 million (±1.3 million SE) eukaryotic species globally (Mora et al. 2011). But these numbers can be higher, as some researchers suggest that only to arthropods we could have between 5 and 10 million species (Ødegarrd 2000), perhaps 30 million (Erwin 1991). Regarding insects, the estimations vary from a minimum of 1 to possibly more than 5 million species (Scheffers et al. 2012), in a conservative approach. The unique real consensus is that we do not know the majority of species; 86% of existing organisms on continental environments and 91% of species in the ocean

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still await description (Mora et al. 2011). If they need description and basic taxonomic studies, then what we know about their behavior, ecology, and natural history? Indeed, very little.

I was a naturalist for my whole life, roaming around tropical forests, savannas, high mountains, and margins of rivers and lakes. When asked by a student about "what that insect does for a living?" my most common answer, after some general comment, is "but … indeed, in this specific case, it is a very interesting question! Why you do not study it?" This is particularly real in relation to aquatic insects, mainly in the tropics, where their diversity is absurdly high and most species are unknown. A book like this has as objective to stimulate young biologists to go deep in the water exploring these amazing creatures' life histories.

Evolution begets diversity, and insects are the most diverse organisms in the history of life, so insects should provide profound insight into evolution (Grimaldi and Engel 2005). The vast majority of known insects are among the most conspicuous creatures, like the flying butterflies, beetles, wasps, and bees, that call our attention for beauty and also for agronomic, economic, or sanitary reasons. Insects may dominate food chains and food webs in a wide aspect being essentials in (a) nutrient recycling and soil turnover, like ecosystem engineers; (b) plant propagation, including pollination and seed dispersal; (c) control of plant community composition and structure, via herbivory; (d) base of food chain, serving as food for insectivorous animals; and (e) regulation of animal community structure, via predation, parasitism, or like a vector of several diseases (Fig. 1.1). Thus "Some insects are considered *keystone species* because loss of their critical ecological functions (e.g. pollinators; seed dispersers; predators and parasitoids) could lead to collapse of the wider ecosystem" (Gullan and Cranston 2014). Despite this clear importance of insects, even in the twenty-first century we still need to harp on the same string: the vast majority of our knowledge on insects is based on the most visible, beautiful, or important animals to man's health, economy, or their ecological services. What can we say about the immense hidden insect fauna? The "Darwin's entangled bank" was buried in the ground or dipped in lakes, ponds, streams, and rivers.

All inland water bodies (rivers, streams, or lakes) support a biological community. Invertebrates (insects, crustaceans, and nematodes) provide the highest levels of biomass, production, and number of individuals in freshwater communities. Indeed, insects dominate freshwater aquatic systems. However, in general we know more about the biology and natural history of the few vertebrate species (mainly fishes and birds) in any inland aquatic system than of the whole community of invertebrates that structure all the bottom-up process in these complex ecological networks. We cannot neglect the immense and extremely important set of knowledge we have produced on aquatic insects' biology, physiology, taxonomy, environmental monitoring, and general zoology (e.g., Grimaldi and Engel 2005; Gullan and Cranston 2014). But to the major orders of insects that are almost exclusively aquatic in their immature stages, the Ephemeroptera (mayflies), Odonata (damselflies and dragonflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), we know in fact little about their life histories, ecology, and behavior. It is surprising

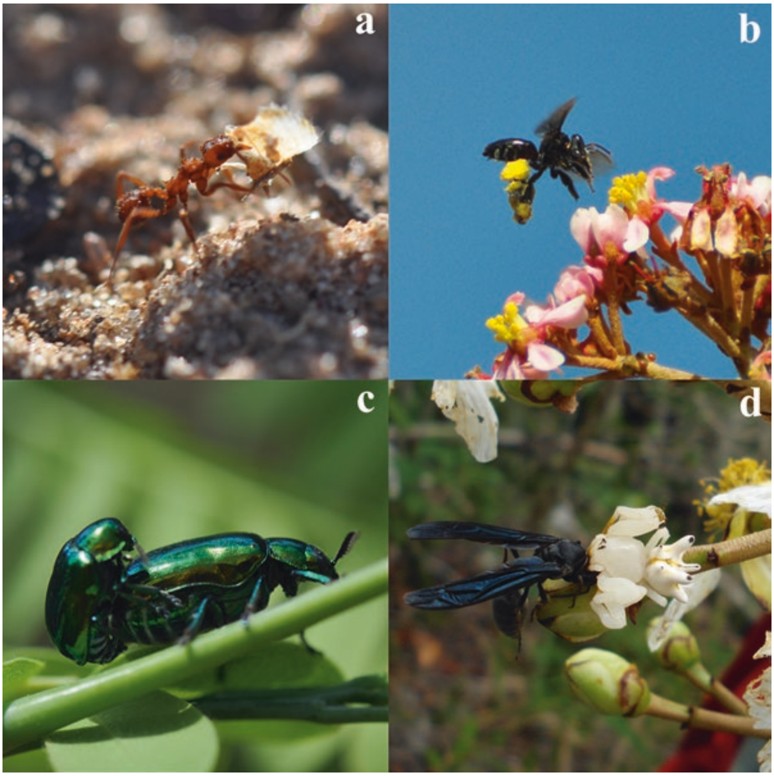

Fig. 1.1 Insects are the most diverse organisms in the history of life, so insects can act as ecosystem engineers (**a**) modifying the environment like the ants *Pogonomyrmex naegeli* that revolve soil and also prey on or disperse seeds. Their activities, like pollination by bees (**b**) and herbivory by beetles (**c**), shape plant community composition and structure. Serving as food for insectivorous animals, like *Epicadus heterogaster* (**d**), a crab spider that prey on pollinators while hidden in flowers, insects also interfere in the whole animal community directly or indirectly

that it also occurs to adults of the most species of Odonata, animals commonly conspicuous, very attractive for their beauty (Fig. 1.2).

I am an ethologist, and to me it is incomprehensible to how to think about the preservation of these amazing species, without thinking about how they relate each other, and how each behavioral decision of one impacts reproduction, life, and death of others. We need to know details of life histories and behavior, to understand the ecological interactions and the network behind the Darwin's entangled bank.

The study of ecological networks is derived from graph theory to investigate the structure and shape of ecological interactions around the world. Nowadays, it is incontestable that graph theory brings enormous advances to the knowledge of ecological interactions modifying the manner we look to the tree of life (Del-Claro et al. 2018). Thus, to indeed understand the dynamic of aquatic ecological networks, we need to know deeply the set of interconnected biotic interactions. The sum of

Fig. 1.2 *Argia angelae* (Odonata: Coenagrionidae), example of a very flashy group of aquatic insects on which we have relatively little knowledge

this knowledge, that conducts us to understand like conserve and/or recover the severely endangered freshwater systems, has its basis in basic biology, natural history, and behavior.

Thus, the aim of our book is to present a good set of basic data and knowledge in ecology, natural history, and behavior of this unknown fauna. Our hope is that it encourages young researchers to investigate basic aspects of the life history of these insects, mainly in tropical systems. It is imperative, especially in endangered biomes like the tropical savanna of South America and Africa, where species are quickly disappearing due to the expansion of human activities on natural areas. See what WWF says about Cerrado, the Brazilian savanna, in a recent publication titled "The Big Five of the Cerrado":

"*Imagine a place where there are over 11,000 species of plants and the fauna is as diverse as the flora. The Cerrado harbours 837 species of birds, 120 reptiles, 150 amphibians, 1,200 fish, 90,000 insects and 199 mammals. Together, they account for 5% of the world's species and 30% of Brazil's biodiversity. … Less than 10% of the Cerrado is covered by protected areas, and less than 3% of its area is strictly protected, putting various animals at risk of extinction.*"

(https://www.wwf.org.br/informacoes/english/?50242/The-Big-Five-of-the-Cerrado).

This text is about the five big mammals of Cerrado, the maned wolf, the giant anteater, the jaguar, the tapir, and the giant armadillo. Nevertheless, in just one small pound in central Brazil, a Vereda (palm swamp communities, Fig. 1.3) surrounded by tropical savanna, only 5 km far from the borders of a big city (population of ~750,000), we recorded at least 31 damselflies and dragonflies species of 5 different

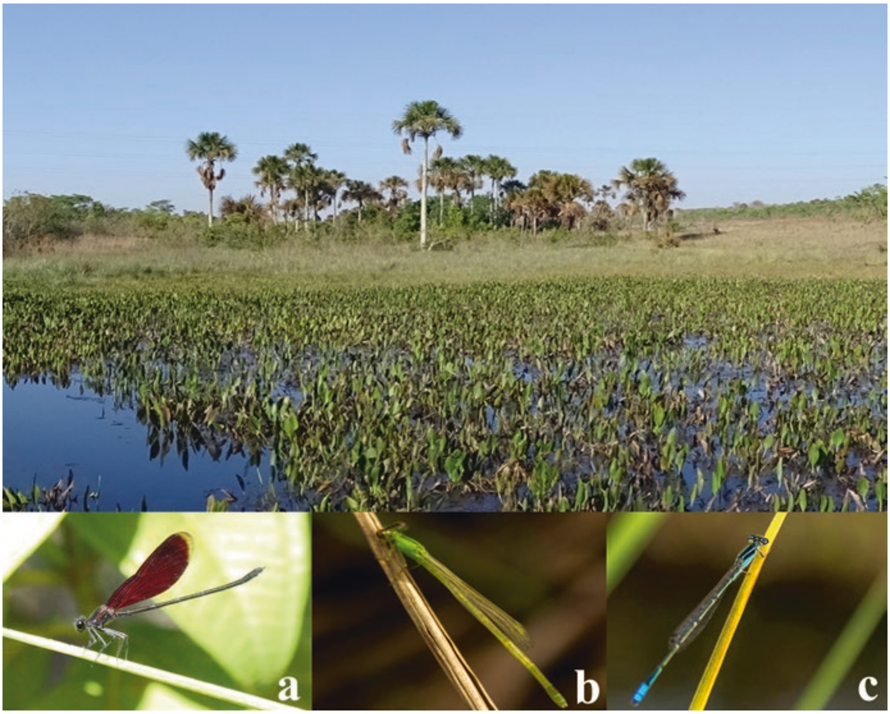

Fig. 1.3 In a single Vereda, a palm swamp environment, in central Brazil we can find an enormous and unknown diversity of aquatic insects. Of damselflies, like *Mnesarete pudica* (**a**), *Ischnura capreolus* (**b**), and *Acanthagrion truncatum* (**c**), we do not know anything about the life underwater and know very little about their adult life

families and 21 genera (Vilela et al. 2016), some possibly endemic, and some new species. Our knowledge on this fauna is still poor, and areas like that are in general located in private country clubs and small farms. Being so, these areas are subject to real estate speculation, or risk being used for agricultural purposes; in any case they are in evident risk of extinction.

The study of behavior, or in simple words “what an animal does or does not do” (Del-Claro 2010), is not only a basic tool to better explore and know the ecology and the outcomes of interactions involving animals, like aquatic insects. It is also a tool to present amazing and surprising strategies of animals in their constant fight for survival and reproduction, in a captivating manner to the general public. Behavior is not only a source of knowledge; it’s also a way to make people fall in love with nature. For example, Vilela et al. (2017) studying the tropical tiger damselfly, *Tigriagrion aurantinigrum*, combining techniques of computer sciences with basic observations of animal behavior and behavioral ecology, showed that the species replaced direct and physical conflict with the use of visual signals to solve territorial contests. The authors demonstrated that winner males have more orange-yellow patches in their frontal head than the losers, and that threat displays are more efficient to win contests than physical conflict. This study confirms the importance of coloration patters in Odonata and the importance of these insects as models in the study of animal visual communication. There are several other studies, just as much or even more interesting to the general public, that need better scientific divulgation.

Then, in our search of a way to stimulate more people, mainly young biologists, to dedicate their time on the study of aquatic insects, we edited this book that presents in few chapters a general vision of ecology and behavior of aquatic insects, beginning with basic knowledge and finishing with possible future applications. Thus, after this introduction, the second chapter, headed by Ricardo Koroiva and Mateus Pepinelli, will show how aquatic insects have successfully achieved a global distribution, with an extraordinary capacity of survival in the most distinct conditions. Considering the breadth of the subject, this chapter aims to show some of the factors related to the distribution of aquatic insects, illustrating the main habitats used by the main orders. But not only distribution, but also dispersal, is one of the fundamental processes that influence the ability of organisms to reach suitable habitats, to find mates, and to avoid potentially disastrous disturbances. In the third chapter, Michael L. May brightly discusses fascinating questions related to aquatic insects' dispersal capabilities and its implications. In the two following chapters, headed by Rhainer Guillermo and an enthusiastic group of young researchers, the abiotic (Vinicius Marques Lopez, Aurélio Fajar Tonetto) and biotic factors (Gabriela C. Mendes, Guilherme Gonzaga da Silva, Leonardo Samuel Ricioli) that influence the interactions and success of aquatic insects, depending on its biology and behavior, are explored. These chapters shape an interesting background for beginners in this research field.

Communication is imperative to the evolutionary success of any organism. In the sixth chapter, J. Manuel Tierno de Figueroa, Julio M. Luzón-Ortega, and Manuel Jesús López-Rodríguez use the mating behavior of stoneflies to show us how vibrational signals can be produced by drumming, rubbing, tremulation, or a combination of these methods, and are species specific; therefore, they can be used as a method to confirm/infer phylogenies or define species. Following the line of communication and visual perception, our colleagues Manuela Rebora, Gianandrea Salerno, and Silvana Piersanti give us an excellent contribution. In their chapter titled "Aquatic Insect Sensilla: Morphology and Function," they teach us how insect success is directly related to their ability to respond quickly to external and internal cues, thanks to a great variety of sensory systems, able to evolve over a relatively short time.

The sensory and communication abilities open a new window to aquatic insects, the habitat contestation, and the defense of territories. Gregory F. Grether after providing a brief introduction to territoriality in general in his chapter reviewed the taxonomic distribution and types of territoriality reported in aquatic insects, before delving into more theoretical topics. This was extremely well done, offering some general advice for studying territoriality and concluding by identifying areas where more research is needed. For example, what is the importance of communication to the sex of aquatic insects? Bright colors associated to face-to-face displays exhibited by males can communicate strong, ability, dominance to females and result in success? Our colleagues, Diogo Silva Vilela and Iago Sanmartín-Villar, revised the communication aspects involved in the reproductive behavior and sexual selection among aquatic insects. In one of the best illustrated chapters, the authors lecture about it in a so clear manner that any college student will be able to comprehend the text completely. This presentation opens space for a deeper analysis, which was done in sequence by Adolfo Cordero-Rivera and Anais Rivas-Torres. According to them, "the field of sexual selection has been historically dominated by a stereotyped view of the sexual roles, with competing males and selective females, but in recent decades there has been a paradigm switch, with the emergence and dominance of the concept of sexual conflict." In an amazing chapter these colleagues stressed the hypothesis that "the dimensional structure of the habitat will affect the intensity of sexual conflict over mating rate, copulation duration and postcopulatory guarding." To achieve their objective, authors illustrate the text with wonderful examples in which behavior, basic biology, and ecology are fundamental to our understanding of what is going on.

Animals live to survive, grow up, and reproduce; they evolved distinct mechanisms and features to have success in this process, which in the endgame may also be needed to protect their best chance for eternity: the progeny. In the book sequence, parental care is discussed among aquatic insects, having as model the giant water bugs (Belostomatidae). Our colleagues Shin-ya Ohba, José Ricardo I. Ribeiro, and Melania Santer revel how behavioral ecology may be important providing basic tools to enable us to study parental care as it deserves, with experimentation. This chapter is finalized in a very stimulating manner, presenting plausible directions that must be followed. One of these directions calls attention to unknown fauna underwater, unexpected life forms that we can find especially in tropical systems. Vanessa Stefani and her scientific initiation students Iasmim De-Freitas and Julia De Agostini presented us an amazing case. Although most Lepidoptera are exclusively terrestrial there are some lineages associated with the aquatic environment. Little is known about aspects of the biology and life history of its representatives, leading to a gap in scientific knowledge. In this chapter, possible evolutionary paths explored which aquatic lepidopteran larvae had to live in aquatic environments, and the authors examine the incipient studies that address life aspects of these extraordinary animals.

The three final chapters of the book are more applied and point to us future directions. Not only the very preserved and untouched natural areas are under our sights and deserve our attention, but also study and preservation of aquatic insects. In the urban environment, our colleagues Javier Muzón, Lía S. Ramos, and Alejandro del Palacio show that "aquatic insects, as key components of urban wetlands, are critically impacted by human environmental changes and practices. The main threats are those derived from the loss, replacement or fragmentation of natural habitats, ecosystem homogenization, and the modification of hydrological, sedimentological and thermal wetland characteristics, due to the surrounding urban matrix." Therefore, this chapter will focus on the importance of insect knowledge as indicators of environmental health in urban wetlands, and the promotion of the citizen science to improve their conservation. Thinking in the same direction, Drielly da Silveira Queiroga, Renan Fernandes Moura, and Jessica Ware bring us an excellent new look over aquatic environments in their chapter "Genetic Connectivity in Conservation of Freshwater Insects." The authors will show us in this amazing chapter that "rich biodiversity is fundamental for the balance and stability of ecosystems, providing vital ecosystem services such as climate regulation. Although aquatic environments are essential to human health, they are often the most exploited environments. Many aquatic insects may increase or decrease their abundance in response to environmental disturbances; these species are known bioindicators and may be used to evaluate environmental quality of an aquatic ecosystem. Thus, it is imperative to preserve bioindicators as they can alert us before degradation becomes large enough to extinguish ecologically important species. To best determine which species require the most attention, many scientists have turned to genetic tools to identify genetically diverse populations and their relative genetic connectivity: the exchange of genetic material among populations of the same species, enabling the maintenance of genetic diversity."

We decided to close the book, with a futuristic chapter that very competently Stanislav N. Gorb and Elena V. Gorb produced to us. In this awesome chapter the authors demonstrate how the knowledge of basic biology, morphology, and behavior can help humans solve contemporary problems. "Aquatic insects, due to their aquatic or amphibiotic habit, evolved many particularly interesting functional solutions, which are of special interest for biomimetics. Understanding functional principles of insect materials, structures, sensors, actuators, locomotion patterns, control systems, and behavior is of major scientific interest, since we can learn about their functional principles and biological role. On the other hand, this knowledge is also highly relevant for technical applications. One of the greatest challenges for today's engineering science is miniaturization." I am sure that this chapter will call attention of a broad and diverse audience.

I am a beginner in the study of aquatic insects and this book was a challenge to me: to produce a piece of art supported in the shoulders of others, lovers of aquatic insects: people devoted to give part of their time in this wonderful planet to protect, to preserve, and to recover the unknown fauna that can maintain our survival as a species.

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