Chapter 13
The Aquatic Lepidopterans: A Mysterious and Unknown Fauna

Iasmim De-Freitas, Julia De Agostini, and Vanessa Stefani

Abstract The order Lepidoptera is represented by the popular butterflies and moths, and is identified by the presence of scales on the wings with an extraordinary variety of colors and sizes. 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. Thus, we can find aquatic Lepidoptera that have tracheal breathing that can remain outside the water for a limited time, being considered semiaquatic larvae, while larvae with branchial respiration are aquatic while retaining all their submerged larval development. In this chapter, possible evolutionary paths are explored which aquatic lepidopteran larvae had to live in aquatic environments and we examine the incipient studies that address life aspects of these extraordinary animals.

Keywords Moths · Butterflies · Parapoynx · Petrophila · Crambidae · Caterpillar

When we talk about "the unknown tropical fauna," we often mean the animals of which little is known about their role in their habitat. This is considered true for some specimens of Lepidoptera, which spend a part of their lives on aquatic ecosystems.

Lepidoptera is one of the best known groups of insect, due to its exuberance, diversity, and economic importance. The lepidopterans are commonly known as moths and butterflies and can be mostly identified by the presence of scales on their wings and for their wide variety of colors and shape patterns. It is possible to find many studies about these insects in the literature, but most of them are focused on agriculture for their potential as herbivores in plantations or on taxonomic surveys of these holometabolous insects' adult forms. However, little is known about the biology and life history of this order, which leads to a gap in the

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scientific knowledge that mostly affects the species with part of their development in aquatic environments.

Currently, Lepidoptera has about 157,578 described species in the world (Zhang 2011) out of which approximately 740 species (representing 4.7% of the total) are believed to go through an aquatic larval stage (Mey and Speidel 2008). Nevertheless, the aquatic lepidopterans are relevant in aquatic ecosystems and can represent up to 32% of the macroinvertebrate community in a lotic system (Luiza-Andrade et al. 2017).

13.1 Evolution and Adaptation to the Aquatic Life

With the arising and radiation of the angiosperms in the Cretaceous Period, a new food resource became widely available promoting coevolutionary process and adaptive radiations in insect herbivorous including lepidopterans (Mey and Speidel 2008). During this coevolutive events, these insects were capable of exploiting all the parts of a plant and have possibly harnessed the resources of other ecosystems such as aquatic and semiaquatic environments. It is important to highlight that the transition from the aquatic to the semiaquatic life has independently occurred multiple times. Still, it has taken several adaptations to enable these forms of life to explore this new habitat, emphasizing changes in physiology and locomotion (Welch 1919).

As for terrestrial specimens, the respiratory system of the Lepidoptera larvae is formed by spiracles connecting with tracheas and a branched network of tubes that allows the air to flow throughout the body. However, in aquatic ecosystems, besides the tracheal breathing, it is also possible to find some individuals with bronchial breathing. The ones with a respiratory tracheal system are called semiaquatic and can survive out of the water for a certain period. These specimens have hydrophobic bristles throughout the body that cover the entire dorsal surface of the animal that when submerged allow the seizure of air, which is also stored around the respiratory spiracles that allows the animal to perform gas exchange. These characteristics can be observed in detail on the caterpillar of *Paracles klagesi* Rothschild 1910 (Erebidae: Arctiinae) as it has two kinds of bristles: one is thorn shaped (filiform) lying around the respiratory spiracles laterally along its body, and the other is drop shaped (pectiform), and it is located on the dorsal surface; both are hydrophobic (Fig. 13.1).

To feed, the caterpillar submerges. However, it must get back to the water surface periodically. This activity promotes the renewal of the air that is stocked between the tracheal spiracles at the base of the hydrophobic bristles. These spiracles open up in a cavity that has long chitin filaments until the lumen, directly connected to the connection trunk which leads to the trachea (Fig. 13.1). The number, anatomy, and histology of the spiracles vary among the species.

The aquatic species usually have filamentous gills (Fig. 13.2) that can show up at different larval instars varying with the species. Each gill filament has a cavity that connects directly to the hemocele. At the last instars, the gills become more ramified, and each filament will have a main trachea. At the axial position, the gill

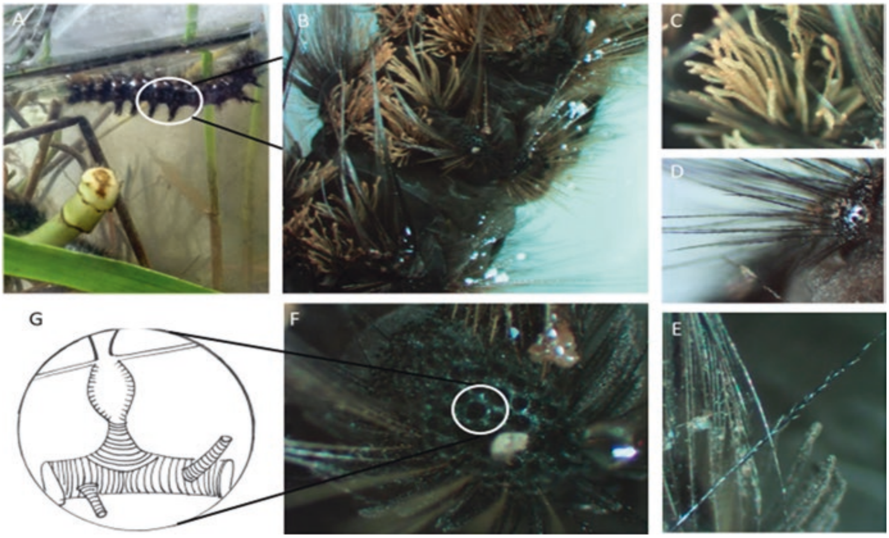

Fig. 13.1 Scheme of the tracheal respiratory system of *Paracles klagesi* based on Welch 1922. (**a**) The submerged larva—the arrow indicates the air bubbles between the bristles; (**b**) detail of the body segments showing the bristles; (**c**) orange drop-shaped bristles; (**d**) filiform bristles on the tracheal spiracle; (**e**) anatomic detail of the filiform bristle; (**f**) tracheal spiracles; (**g**) internal scheme of the tracheal bristle (photographs: **a**–**f** Iasmim De-Freitas)

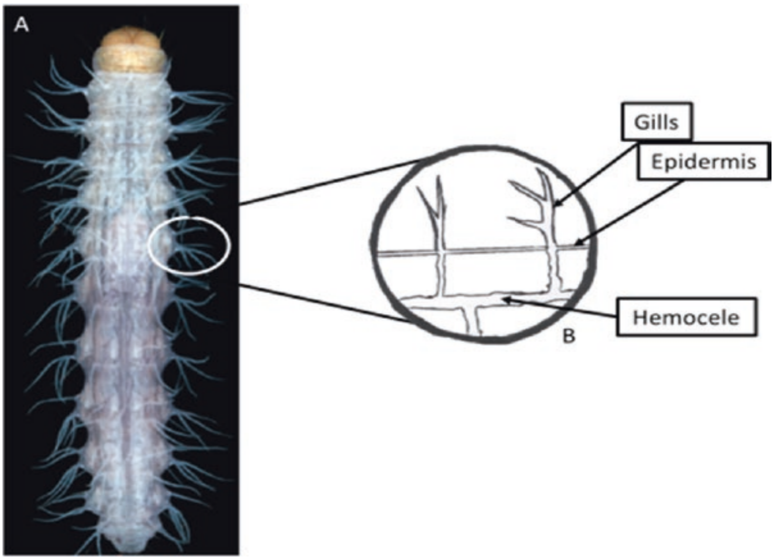

Fig. 13.2 Scheme of the *Usingeriessa onyxalis* branchial respiration based on Welch 1922. (**a**) *Usingeriessa onyxalis* caterpillar in dorsal view; (**b**) internal scheme of a gill (photograph of the aquatic larva: courtesy of M. Alma Solis, Nathan E. Harms, Eugenie Phillips-Rodríguez, Sonja J. Scheffer, Matthew L. Lewis, Daniel H. Janzen, Winnie Hallwachs, and Mark A. Metz; 2018. Aquatic Larvae of Two Acentropines, *Usingeriessa onyxalis* (Hampson) and *Oxyelophila callista* (Forbes) (Lepidoptera: Crambidae), Entomological Society of Washington, 120(1):180–195)

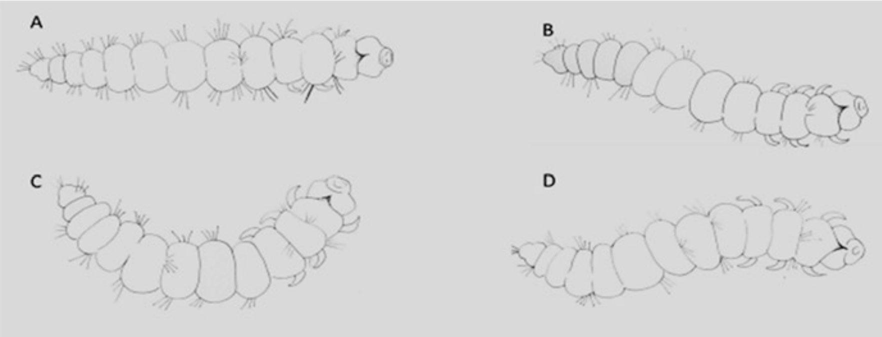

Fig. 13.3 Locomotion scheme. (**a**) Inert caterpillar; (**b**) the beginning of the bending; (**c**) the bending; (**d**) whip effect

filaments, along with the trachea, extend together in fine branches and form the tracheoles (Fig. 13.2).

The locomotion in terrestrial species can be typified mainly as "inchworm," while the aquatic ones developed a mechanism characterized by horizontal movements along the water column, like a whip in the posterior body parts where, initially, the anterior body part is flexed to one side horizontally and with a fast movement that provides the propulsion required to swim (Fig. 13.3).

13.2 Biology and Life History

Erebidae, Nepticulidae, Coleophoridae, Tortricidae, Pyralidae, Cosmopterigidae, Crambidae, and Noctuidae (Hamada et al. 2014; Mey and Speidel 2008; Mccafferty and Minno 1979) are the main families of Lepidoptera that are possible to find in literature with aquatic representatives. However, even though it is known that these species have aquatic larvae, there are not enough studies about their life histories and biological aspects. Having that in mind, some known neotropical exceptions will be presented in the following paragraphs.

The Arctiinae (Erebidae) subfamily has more than 3600 species; the *Paracles* genus has two aquatic representatives: the *Paracles klagesi* Rothschil 1910 and the *Paracles laboulbeni* Bar 1873 (Meneses et al. 2013; Mey and Speidel 2008). The *P. klagesi* aquatic larvae have tracheal breathing and were found in two distinct regions of aquatic environments in Brazilian territory—in lakes near the city of Timon (Maranhão State, 43°01′52.2″W, 05°03′03.3″S) and at "Vereda" lakes of the Neotropical Savanna near the city of Uberlândia (Minas Gerais State, 48°14′02″W, 18°54′52″S). Meneses et al. (2013) observed that the caterpillar eats two types of aquatic macrophytes: *Eichhornia* sp. (Pontederiaceae) and *Cabomba caroliniana* (Cabombaceae). The pupal stage consists of a fiber cocoon which allows buoyancy and is always adhered to a plant (Fig. 13.4). The *P. laboulbeni* caterpillar has tracheal

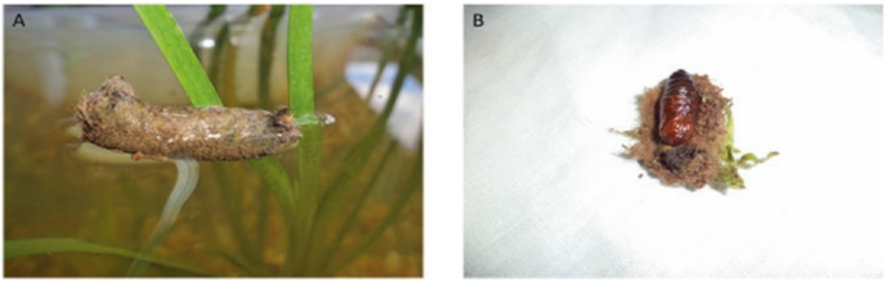

Fig. 13.4 (**a**) The *Paracles klagesi* pupa in its natural environment, with the cocoon made of hydrophobic fibers that allow buoyancy; (**b**) the fiber wrap was taken off so the cocoon cloud be visualized (photographs: **a** and **b** Iasmim De-Freitas)

breathing and eats macrophytes like *Echinochloa spectabilis*, *Hymenachne amplexicaulis*, *Oryza grandiglunis*, and algae of the *Oedogonium* genus (Adis 1983). The larval development varies from 30 to 35 days and the period of the greatest abundance was recorded from May to June, which precedes the rise in water level. However, its abundance is reduced when the water level is low (Adis 1983).

The Crambidae family has about 600 described species (Hamada et al. 2014). Among the species that have an aquatic larval stage, there is the *Niphograpta albiguttalis* Warren 1889, distributed between Argentina and Brazil. Its total development, since the egg to the adult form, lasts about 35 days; the adult females oviposit on the leaves of *Eichhornia crassipes* (Pontederiaceae), primarily in areas where the epidermis has been damaged, which will feed during the five larval instars (Julien 2001). However, despite the *N. albiguttalis* having been considered a biological control agent against the water hyacinth, currently it is considered a plague of *E. crassipes*, because when the oldest larvae eat the leaves, the plants become waterlogged and sink (Canavan et al. 2014).

Other species that have aquatic larvae are *Donacaula forficella* Thunberg 1794 (found in China, Europe, and South Africa); *Nymphula nitidulata* Hufnagel 1767 (found in Europe, Japan, Turkey, Armenia, Russia, and China); *Schoenobius gigantella* Denis and Schiffermüller 1775 (found in Europe and China); *Cataclysta lemnata* Linnaeus 1758 (found in Europe, Morocco, and Iran); and *Elophila nymphaeata* Linnaeus 1758 (found in Europe) (Vallenduuk and Cuppen 2004); however, little is known about their life histories and biology. It is important to highlight that the geographic extension of these species can be higher than it was described.

The eccentric species *Acentria ephemerella* Denis and Schiffermüller 1775 (Crambidae) draws attention for having females with paedomorphosis (the retention of the juvenile or even larval traits into later life), which means that even though they are adults they still live in the aquatic environments and do not develop wings. The most interesting aspect about the *A. ephemerella* happens during its mating because the females need to swim to the surface and put the abdomen above the water surface so that the male can copulate (Vallenduuk and Cuppen 2004). However, this species can only be found in Central Europe. No other species of aquatic lepidoptera with paedomorphosis has been found, even in tropical regions.

The Pyralidae family has about 5000 described species (Hamada et al. 2014). The aquatic larva of the *Parapoynx rugosalis* Moschler 1890 has gills and a study carried out in Costa Rica found that *P. rugosalis* uses a tent made of leaves that protects it from predators; as its development advances this tent is changed (Mueller and Dearing 1994). Another member of the Pyralidae family is the *Samea multiplicalis* Guenee 1854 (Knopf and Habeck 1976) that also has a wide distribution that extends from the Southwest of the United States to Argentina. The average development time for each stage of life of *S. multiplicalis* is 4 days to the eggs; 15.6 days to the larvae; and 5.2 days to the pupa; also, the number of eggs laid by a female in its natural environment was 94 eggs.

Among the most interesting aspects found among the representatives of the Pyralidae family, there is the Californian species *Parargyractis confusali* Walker, which has gills and the females of which go into the water to oviposit between 220 and 296 eggs on submerged rocks. The *P. confusali* larva builds silk chambers in depressions or cracks in the rocks and feeds on resources around them. When the cocoon is packed, it has an outer casing, which has openings for the water circulation (Tuskes 1977).

It is clear that studies on aquatic Lepidoptera are very scarce, being the great majority realized for species in temperate regions. Even though the studies about the biology and natural history of these specimens are almost unknown for tropical environments, it is important to emphasize morphological works (Solis et al. 2018), molecular studies (Park et al. 2014), and studies of biological controls (Hickel et al. 2017). These aspects mentioned above could be the gateway to new research with a focus on aquatic lepidoptera, not only for scientific knowledge but also for the ecological importance they exert as bioindicators (Stoops et al. 1998) and as herbivores (Habeck 1974), and the economic importance as food resources (Ramos-Elorduy 2006; Williams and Williams 2017) and agricultural pests (Mey and Speidel 2008; McGaha 1954). It is known that tropical aquatic environments are constantly polluted by anthropic interference, such as the discharge of urban sewage, the flow of agricultural nutrients, and the waste of confined animals that alter these sensitive environments and that compromise the survival of species that we will not even know.

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References

Adis J (1983) Eco-entomological observations from the Amazon. Occurrence and feeding habits of the aquatic caterpillar *Palustra laboulbeni* Bar, 1873 (Arctiidae: Lepidoptera) in the vicinity of Manaus, Brazil. Acta Amazon 13(1):31–36

Canavan K, Coetzee JA, Hill MP, Paterson ID (2014) Effect of water trophic level on the impact of the water hyacinth moth *Niphograpta albiguttalis* on *Eichhornia crassipes*. Afr J Aquat Sci 399(2):203–208

Habeck D H (1974) Parapoynx Caterpillars In Relation With Aquatic In Florida. Department of Entomology and Nematology 32611. p 15–18

Hamada N, Nessimian JL, Querino RB (2014) Insetos aquáticos na Amazônia brasileira: taxonomia, biologia e ecologia. Editora do INPA, Manaus, p 724

Hickel E, Prando FH, Domingos SE (2017) Lagartas nas lavouras catarinenses de arroz irrigado: Ocorrência, monitoramento e manejo integrado. Epagri, Itajaí, p 182

Julien MH (2001) Biological control of water hyacinth with arthropods: a review to 2000. ACIAR Proc 102:8–20

Knopf KW, Habeck DH (1976) Life history and biology of *Samea multiplicalis*. Environ Entomol 5(3):539–542

Luiza-andrade A, Montag ALF, Juen L (2017) Functional diversity in studies of aquatic macroinvertebrates community. Scientometrics 111(3):1643–1656

Mccafferty WP, Minno MC (1979) The aquatic and semi-aquatic Lepidoptera of Indiana and adjacent areas. Entomol Great Lakes 12:179–187

Mcgaha YJ (1954) Contribution to the biology of some Lepidoptera that feed on certain plants of aquatic flowers. Trans Am Microsc Soc 73(2):167–177

Meneses AR, Bevilaqua MVO, Hamada N, Querino RB (2013) The aquatic habit and host plants of Paracles klagesi (Rothschild) (Lepidoptera, Erebidae, Arctiinae) in Brazil. Rev Bras Entomol 57(3):350–352

Mey W, Speidel W (2008) Global diversity of butterflies (Lepidoptera) in freshwater. Hydrobiologia 595(1):521–528

Mueller UG, Dearing MD (1994) Predation and avoidance of tough leaves by aquatic larvae of the moth *Parapoynx rugosalis* (Lepidoptera: Pyralidae). Ecol Entomol 19(2):155–158

Park JS, Kim MJ, Kim SS, Kim I (2014) Complete mitochondrial genome of an aquatic moth, Elophila interruptalis (Lepidoptera: Crambidae). Mitochondrial DNA 25:275–277

Ramos-Elorduy J (2006) Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. J Ethnobiol Ethnomed 2(1):51

Solis MA, Harms NE, Phillips-Rodríguez E, Scheffer SJ, Lewis ML, Janzen DH, Hallwachs W, Metz MA (2018) Aquatic larvae of two Acentropines, *Usingeriessa onyxalis* (Hampson) and *Oxyelophila callista* (Forbes) (Lepidoptera: Crambidae). Ann Washington Entomol Soc 120(1):180–195

Stoops CA, Adler PH, Mccreadie JW (1998) Ecology of aquatic Lepidoptera (Crambidae: Nymphulinae) in South Carolina, USA. Hydrobiologia 379:33–40

Tuskes PM (1977) Observations on the biology of *Parargyractis confusalis*, an aquatic pyralid (Lepidoptera: Pyralidae). Can Entomol 109(5):695–699

Vallenduuk HJ, Cuppen HMJ (2004) Aquatic live caterpillars (Lepidoptera: Pyraloidea: Crambidae) from Central Europe. A key to larvae and autecology. Lauterbornia 49:1–17

Welch PS (1919) The aquatic adaptations of *Pyrausta penitalis* Grt. (Lepidoptera). Ann Entomol Soc Am 12(3):213–226

Welch PS (1922) The respiratory mechanism in certain aquatic Lepidoptera. Trans Am Microsc Soc 41(1):29–50

Williams DD, Williams SS (2017) Aquatic insects of Siân S. and its potential to contribute to the diet of the human population in global expansion. Insects 8(3):72

Zhang ZQ (2011) Animal biodiversity: an introduction to higher-level classification and taxonomic richness. Zootaxa 3148:212