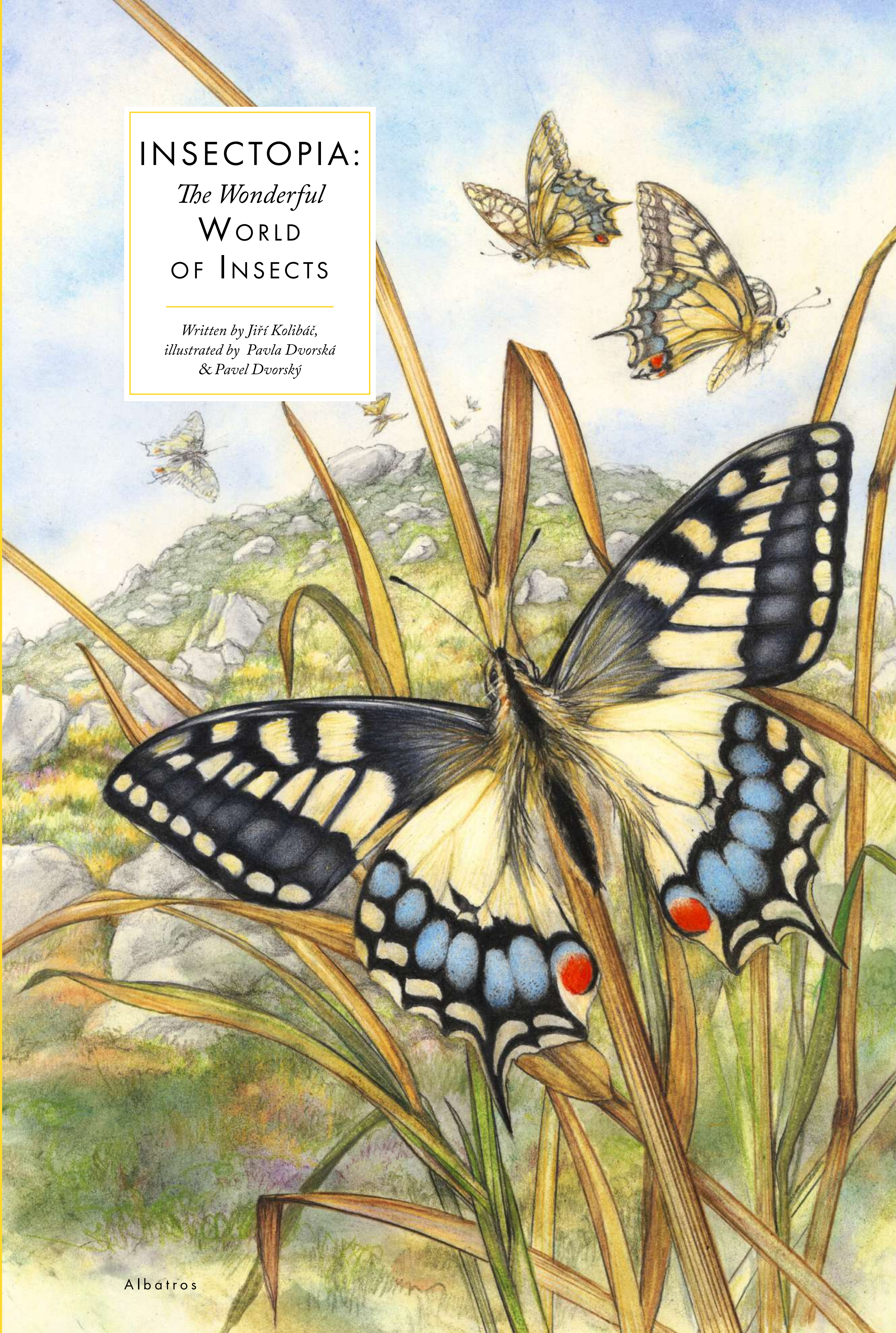
INSECTOPIA: *The Wonderful* World of Insects

Written by Jiří Kolibáč,
illustrated by Pavla Dvorská
& Pavel Dvorský



Albatros

Jiří Kolibáč • Pavla Dvorská • Pavel Dvorský
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The Wonderful World of Insects

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INTRODUCTION

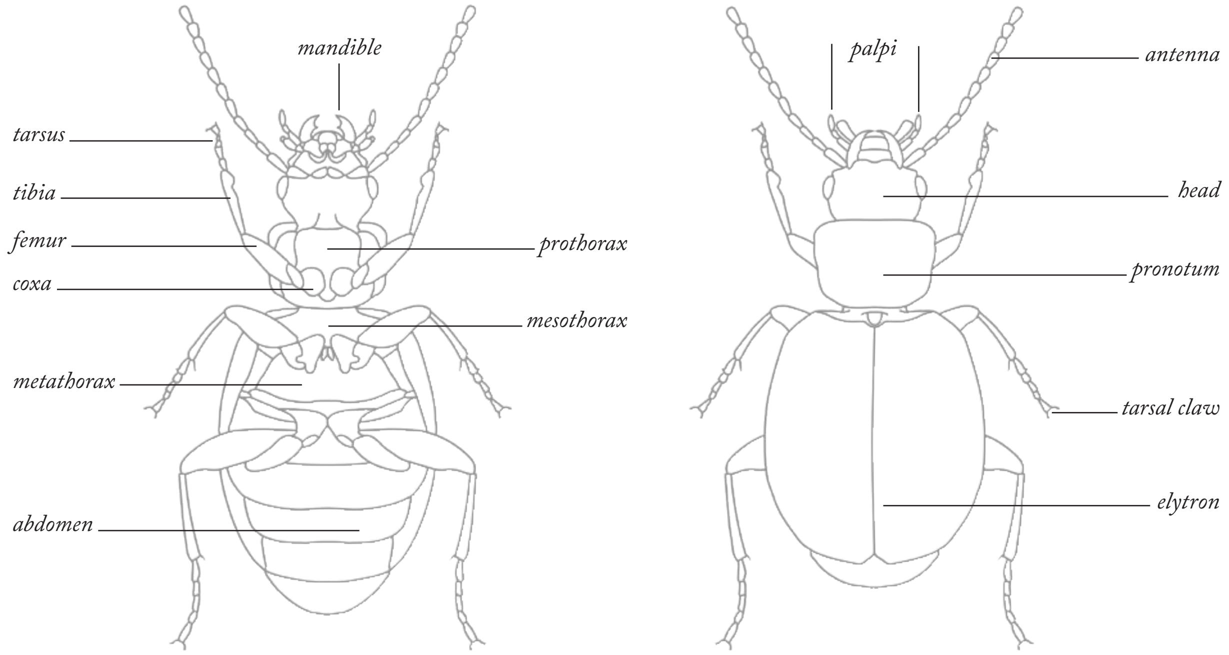
Insects are, by far, Earth's largest group of multicellular organisms. Currently, we know of over 1 million insect species, meaning they account for over half of the living organisms (animals and plants) we know about. Although we have not yet studied most small insects, some scientists estimate that over 90 percent of all animals are insects. Many entomologists (scientists who study insects) believe that there could be between 6 and 10 million insect species! So in terms of their impact on nature, insects can be considered the most important animal group of all. Insects have settled most of Earth's environments: meadows, forests, streams, steppes, and deserts, to name just a few. They are a rarity only in polar regions and at the tops of the highest mountains. Although they do not live in the sea, they inhabit its surface (think of water striders), while beetle larvae are found in coastal saltwater pools.

Beetles form the largest order of insects and also the largest group of animals on Earth: beetles account for about one-quarter of known species in the kingdom Animalia. There are over 400,000 known beetle species, to which hundreds more—especially in the world's tropical regions—are added each year. The orders Lepidoptera, Hymenoptera, and Diptera all comprise hundreds of thousands of species. All these, plus another 23 insect orders, have a tremendous impact on the terrestrial and freshwater natural environments—the ecosystems of planet Earth. We believe that about 150 million years ago, in the Mesozoic era, insect pollinators sparked the evolution of the flowering plants to which most of today's plant species belong. The existence of many plants is entirely dependent on insects. In the natural world, insects are part of a complex relationship of which pollinating flowers are only one part. They are of crucial importance for the decomposition of organisms and their excrement. The food chains of fish and birds contain billions of individual insects. The insect world has predators and parasites that help nature maintain balance among herbivorous insect species. If we were to go on in this strain, before long we would conclude that most of Earth's ecosystems are directly reliant on insects and that their disappearance would result in the collapse of entire communities of plants and animals.

Insects may be small, but in their relationships between the sexes, their care for their young, their abilities as mimics, and the division of labor in their communities, they have the power to astound us. This book attempts to show all of this. Plus, it seeks to present at least a fraction of the vast miscellany of colors and shapes that makes the insect world not only an exceptionally important part of nature but a beautiful and fascinating one too. We have been entranced by butterfly wings and the metallic elytra (forewing) of beetles for centuries. In the human imagination, however, insects also mean million-strong swarms of locusts and other pests of the field, the calamitous effect wrought by bark beetles on woodland, and serious diseases in humans and animals such as malaria, sleeping sickness, and the Zika virus. On the other hand, we associate summer by the sea with the chirping of cicadas, the flutter of bright-colored butterfly wings, and the buzzing of bees amid fragrant flowers. The reeds of rivers and lakes are vibrant with dragonflies in graceful flight, while twinkling fireflies light up warm summer nights. As well as being both useful and harmful, insects have an effect on human emotions. They are part of our culture, and they are central to our experience of nature.

Some scientists term the epoch we live in today the Anthropocene—the Age of Man. The influence of humans is now present in every place on Earth. Regrettably, the endless growth of civilization is not good for nature, including insects. Although we continue to think of insects as being abundant and ubiquitous, recent scientific findings give cause for concern. Up to 40 percent of insect species face extinction in the next few decades. And that's not all: long-term studies conducted in relatively unspoiled nature reserves in Europe have revealed catastrophic losses of total insect life, in some cases of over 75 percent. The exact cause of this insect apocalypse is unclear, but it is most likely a combination of things including changes in temperature and rainfall, intensive farming using artificial fertilizers and pesticides, the management of extensive forest and field monocultures, and light pollution from public lighting. One reason for the writing of this book was to inspire interest in insects—this marvelous, vital, beautiful, and wide-ranging animal group without which life on our planet would be impossible.

ANATOMY AND BODY STRUCTURE OF INSECTS



Morphology of a beetle from below (left) and from above (right)

Like other arthropods, insects have a visibly segmented body and a hard exoskeleton. The head is formed by the fusion of three original segments, the thorax from three segments, and the abdomen from eleven original segments, some of which fused during evolution. An insect's head has conspicuously segmented antennae containing sensory organs (for smell, taste, and touch, plus temperature and location) and sometimes other functions too. The organs of the mouth develop in accordance with how food is ingested, and they may not be the same in larvae and adults. The large mandibles in the mouthparts of beetles and grasshoppers, for instance, evolved into the piercing/sucking mouthparts of flies, mosquitoes, the sucking mouthparts of butterflies, and the lapping mouthparts of bees.

An insect's eye is a compound of numerous little eyes called ommatidia; in addition, the insect may have the remnants of up to three simple eyes (ocelli). An insect's thorax comprises the prothorax, the mesothorax, and the metathorax, of which each segment has a pair of jointed legs (making a total of six; the subphylum Hexapoda—the largest such insect division—means "six legs" in Greek). Hexapods are easily distinguished from spiders (which have eight legs), centipedes, millipedes, crayfish, and other multi-limbed arthropods. (Each body segment of a primitive arthropod had a pair of limbs that evolved into antennae, mandibles, and palps, or whose growth was stunted.) The mesothorax and the metathorax each have a pair of membranous veined wings, as seen most clearly in the dragonfly. The wings may be interconnected (as in butterflies and hymenopterans), they may be transformed (e.g., the beetle's hard elytra transformed from the first pair of wings), they may have disappeared altogether (as have the wings of the parasitic lice and fleas), or they did not evolve in individuals (as in worker ants and termites). The rear pair of wings of the order Diptera transformed into small club-shaped organs called halteres, which are used to maintain equilibrium during flight; this explains why flies are such excellent fliers. Insects have no lungs for oxygenating the blood. An insect distributes air through the body via tracheas (tubes that lead through small spiracles in the thorax and abdomen segments), breathing by inflating and deflating the abdomen and thorax. Water beetles do not have gills: they breathe by maintaining an air bubble in the body. As for other aquatic insects, the larvae of mayflies have gills, while those of chironomids take in oxygen with the whole body.

Insect blood is called haemolymph. It isn't red, and it transports only nutrients through the body. Instead of veins, insects have a dorsal vessel, through which, driven by the heart, haemolymph washes through the organs of the body. The abdomen contains a fatty corpuscle that principally serves as a store for energy. An insect's brain is formed by the fusion of several nerve clusters (ganglia), and it resides in the head—although individual ganglia are present in other body segments too, including the abdomen. One of the most immediately interesting things about an insect is its hard exoskeleton, to which muscles and tendons are attached from the inside. This tough shell, known as the cuticle, is composed of a complex glucose known as chitin; in chemical terms, it is close to cellulose in plants. Not only are all body segments, antennae, palps, and limbs reinforced with chitin, but so, too, are reproductive organs (male and female) and insect larvae—although in many cases larvae are softer, their segments less clearly defined, and their antennae very short. This is because larvae are still growing, while adult insects are not. The larvae of some insect orders (notably Diptera) are legless. Butterflies have several pairs of prolegs at the end of the abdomen. The end of a larva's abdomen has several protrusions of various lengths and shapes.

ORDERS OF INSECTS: A SURVEY

In this chapter, we will familiarize ourselves with the best-known groups of winged insects (Pterygota) and their common and scientific names.

Dragonflies (Odonata) are excellent fliers with veined, transparent wings that, when at rest, stand out from the body. They can hover in the air and even fly backwards. Dragonflies are predators. Their enormous eyes almost touch across their faces. Dragonfly larvae catch prey in water, although mostly they do not swim; instead, they lie on the bottom of the water or on plants. They hunt by means of a prehensile organ for grasping prey.

Stoneflies (Plecoptera) and **mayflies** (Ephemeroptera) are orders of simple, short-lived insects that live near water; their larvae are aquatic. Adults have long antennae and long paired appendages called cerci at the end of the abdomen. As the wings of the stonefly fold flat over the abdomen, as with most insects, and those of the mayfly fold together over the thorax, it is easy to distinguish the two groups: Palaeoptera (dragonflies and mayflies) and Neoptera (all other orders of winged insects). Neoptera are divided into two groups according to the evolution of their wings as a result of transformation: Exopterygota (which include stoneflies, which undergo an incomplete metamorphosis) and Endopterygota (which undergo a complete metamorphosis).

EXOPTERYGOTA

insects that undergo incomplete metamorphosis

Earwigs (Dermaptera) are like rove beetles in that their fan-like wings are hidden under short forewings. Most earwigs do not fly. They have pincers on the abdomen.

Cockroaches and **termites** (Blattodea) have a front pair of hardened wings and long antennae. Their long, bristly legs enable them to run fast.

Mantises (Mantodea) have small, rotating, triangular heads, folded wings on the back, and bristly forelegs for hunting their prey. An ability to change their color (mimetic coloring) is common.

Stick insects (Phasmodea) look like dry twigs or pieces of spined vegetation. They are herbivorous.

Orthoptera are divided into two large groups: Ensifera (largely carnivorous crickets with long antennae, as well as herbivorous groups such as mole crickets), and Caelifera (herbivorous grasshoppers with short antennae). Orthoptera fold their wings behind them. They have long legs for jumping. The sound they produce comes from them rubbing together the front pair of wings or the hind femurs. Young Orthoptera look like wingless adults.

True bugs (Heteroptera), along with aphids and cicadas, are of the order of Hemiptera. They have piercing-sucking mouthparts, forewings modified to form hemelytra ("half-elytra"), and antennae with only 5 segments. The young are similar to the adults.

The **lice** known as **Psocodea** are small winged or wingless insects with soft bodies. They include parasitic lice.

ENDOPTERYGOTA (AKA HOLOMETABOLA)

insects that undergo complete metamorphosis

The forewings of **beetles** (Coleoptera) are hardened into elytra, under which is a second pair of membranous wings that serve for flight. In exceptional cases (e.g., the rove beetle) the elytra are shortened or the membranous wings are incapable of flight (e.g., larger ground beetles). Hard mandibles allow for carnivorous and herbivorous feeding. Due to the huge number of species, beetles vary greatly in shape, coloring, size, and way of life. The smallest featherwing beetle is only 1 millimeter in length, while the largest longhorn and rhinoceros beetles measure almost 8 inches!

Snakeflies (Raphidioptera), **alderflies** (Megaloptera), and **net-winged insects** (Neuroptera) are small orders. Their veined, transparent wings fold roof-like over the body. Many of them have an elongated prothorax. The antlion is a well-known representative of this group.

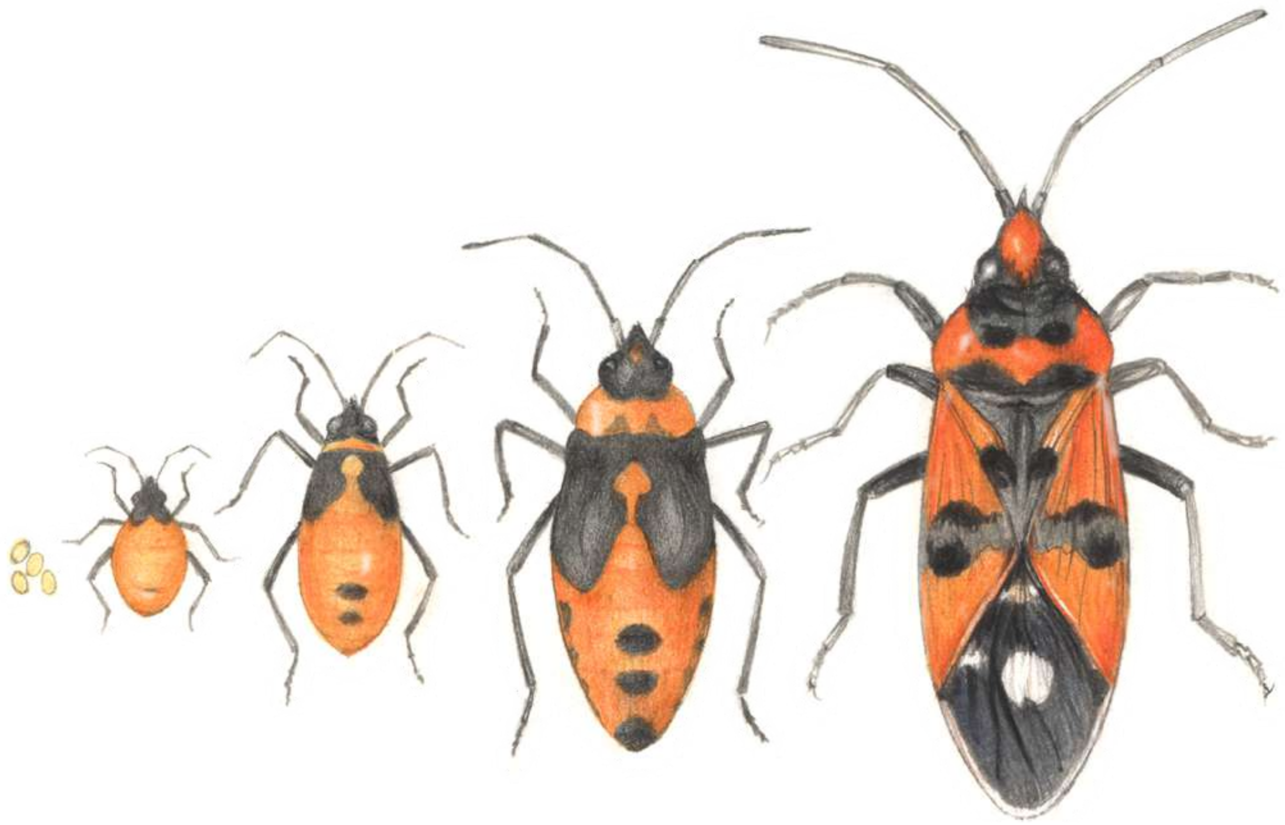
Caddisflies (Trichoptera) are similar to certain moths; however, their wings are folded roof-like. Their larvae live in water and form a protective case.

Butterflies (Lepidoptera) are noticeable by their two pairs of wings covered with small scales (in Greek, *lepis* means "scale" and *pteron* means "wing"); the forewings partially cover the hindwings. They suck up nectar from flowers using their long mouthpart, called a proboscis. Butterfly larvae, known as caterpillars, vary in the number of prolegs on the abdomen segment.

Diptera (meaning "two wings") have very short antennae and hindwings modified as halteres, which keep them stable in flight. Between the claws, they have spongelike pads that allow them to climb (e.g., on glass). Larvae are legless. Diptera include flies, mosquitoes, and horseflies.

Hymenoptera have membranous wings that they fold across the abdomen. The forewings are longer than the hindwings. The hindwings are connected to the forewings by hooks at the edges. Ants have no wings. Some hymenopterans live in communities in which only the queen (e.g., bees, wasps, ants) reproduces, and many of them are parasitic (e.g., sabre wasps). Their larvae are similar to those of the butterflies or are legless.

BIOLOGY AND DEVELOPMENT OF INSECTS



Incomplete metamorphosis: development from egg to growing nymph to adult true bug

As it is with most animals, so it is with insects: the female lays the eggs. The eggs hatch to produce larvae that are not at all similar to adults. Well-known insect larvae include those of the butterfly (caterpillars), the cockchafer, and the aquatic larvae of mosquitos. Larvae pupate, meaning they turn into pupa, which are the immature forms of insects before they become adults. With most orders of insects—including beetles, butterflies, Hymenoptera, and Diptera—a great transformation of tissue, known as complete metamorphosis, occurs in the pupa; what emerges from the pupa is an adult insect fully prepared for the life to come. A few orders develop by incomplete metamorphosis; this means that what hatches from the egg is an adult-like larva, known as a nymph.

Often, this nymph can be distinguished from the adult only by its lack of adult wings and its inability to fly. Nymphs do not end up with a pupa, although they grow and shed one several times. True bugs, grasshoppers, and cockroaches all achieve incomplete metamorphosis, as do mayflies and dragonflies, whose nymphs are adapted for aquatic surroundings, making them very different from adults. There are many exceptions within such a large group of animals, of course. For instance, some insect species do not lay eggs but give birth to larvae or even pupae (e.g., certain flies). Others have no males and their larvae hatch from unfertilized eggs. With social insects such as ants and bees, only the queen reproduces, by laying unfertilized eggs from which, once a season, males emerge capable of fertilizing a new queen during swarming. The new queen saves the male's sperm before laying fertilized eggs that develop into workers. The queen produces a secretion of her own that prevents the workers from reproducing; infertile their whole lives, they remain in the nest. A termite nest has a chamber that contains only the king and queen, whose sole task is to mate. As they develop, termite nymphs become workers or soldiers, as required by the nest. The decisive factor concerning which caste the nymph will assume as an adult remains a mystery. This is probably determined by a combination of food availability and perceptions of smell and touch.

Some insect groups are parasitic. Adult or larval parasites live on (e.g., the adult flea) or inside of (e.g., larval sabre wasp) a host. Common parasites feed on the blood or tissue of the host (e.g., lice in hair or fur). Others develop directly within the host's body. Parasites that eventually kill the host are known as parasitoids. Among insects, notable common parasitoids include larval sabre wasps and various

Complete metamorphosis: development from egg to larva (caterpillar), pupa, and adult butterfly

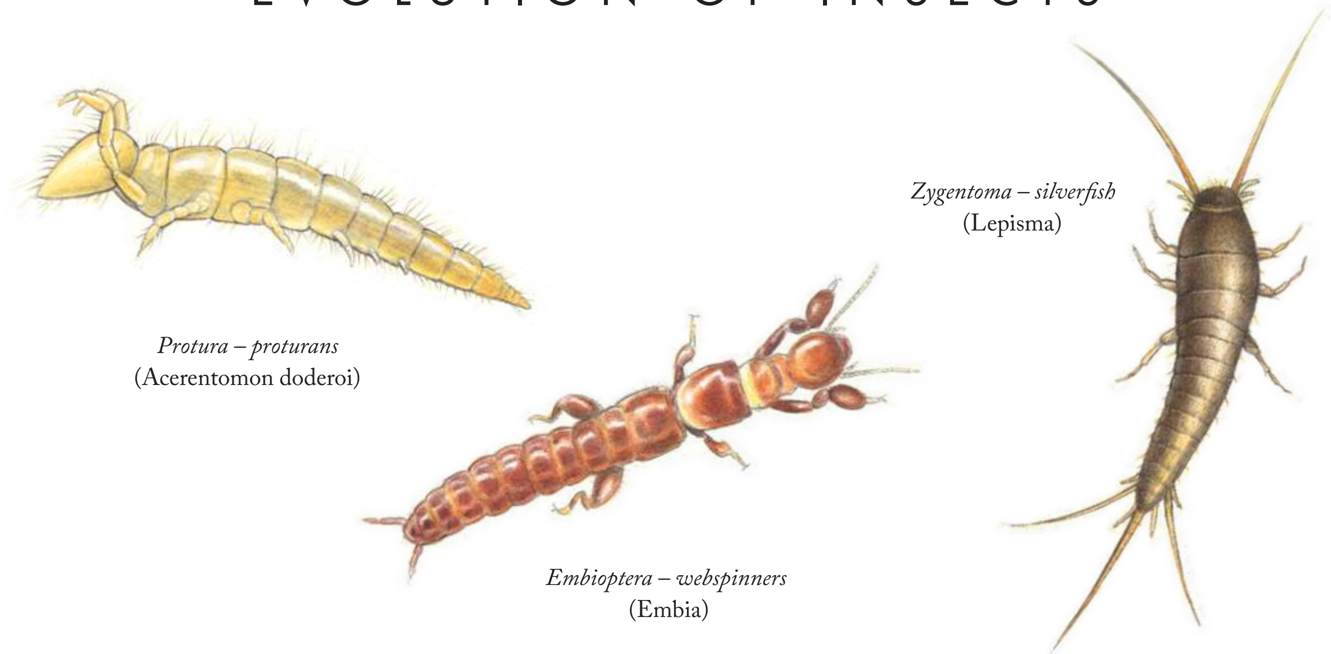
Caterpillar with pupae of hymenopteran parasite on its body

other wasps—some of which lay eggs on caterpillars, some of which place their ovipositor inside the victim's body. (The sabre wasp, for instance, lays eggs on larvae living deep in timber.) A larval parasite develops within the body of a caterpillar before drilling itself out through the host's cuticle or pupating in a dead caterpillar. Similarly, larval Diptera (flies and botflies) may develop in the nostrils or under the skin of frogs, ungulates, and other vertebrates, including humans. Nor are so-called hyperparasites (parasites whose hosts are also parasites) uncommon among insects. Notable among hymenopterous insects that engage in multiple parasitism are Braconidae and tiny wasps Chalcidoidea. Wasps of the family Sphecidae hunt spiders and other insects for their larvae, paralyzing them with their sting before carrying them to the nest, where they lay an egg on their paralyzed prey.

Insects living at higher latitudes of the northern and southern hemispheres, and also in the mountains, must be adapted for both cold and warm seasons. Insects reproduce only in the warm season, when but for a few exceptions, all plants grow and flower. Since most insects are short-lived (adults live for a few days, at most a month), the egg or the larvae tend to hibernate. In spring and summer, between one and three generations come into being, the last of which lays eggs (which will hatch in spring) in a concealed place. The cells of species whose larvae live for several years (long-horned beetles can develop in wood for several decades) contain a kind of antifreeze to enable them to survive. Less common, but all the more remarkable for it, is the hibernation of adults (e.g., butterflies) in the attics of houses and crevices in trees. A better-known form of hibernation is practiced by ladybirds, which hatch in the last warm days of autumn before creeping en masse under fallen trees, rocks, and piles of twigs, to be woken there by the spring sun.

The insects best known for their short lives are mayflies, most of which live for only a few days. Many predatory beetles, notably large ground and darkling beetles, live for several years. Larvae or nymphae of insects, including mayflies, often need many years to take on food, shed their old cuticle, and grow. Adults may have stunted mouthparts or take on food in limited amounts, and where this is the case, the main purpose of the male's short life is to find a female with whom to mate. To achieve this, he relies on his excellent sense of smell, whose organ is the antennae, and on many chemical substances—pheromones secreted by females. Insects communicate by a variety of means. Think of fireflies flickering, ants passing information by touching antennae, locusts and crickets chirping, etc.

EVOLUTION OF INSECTS

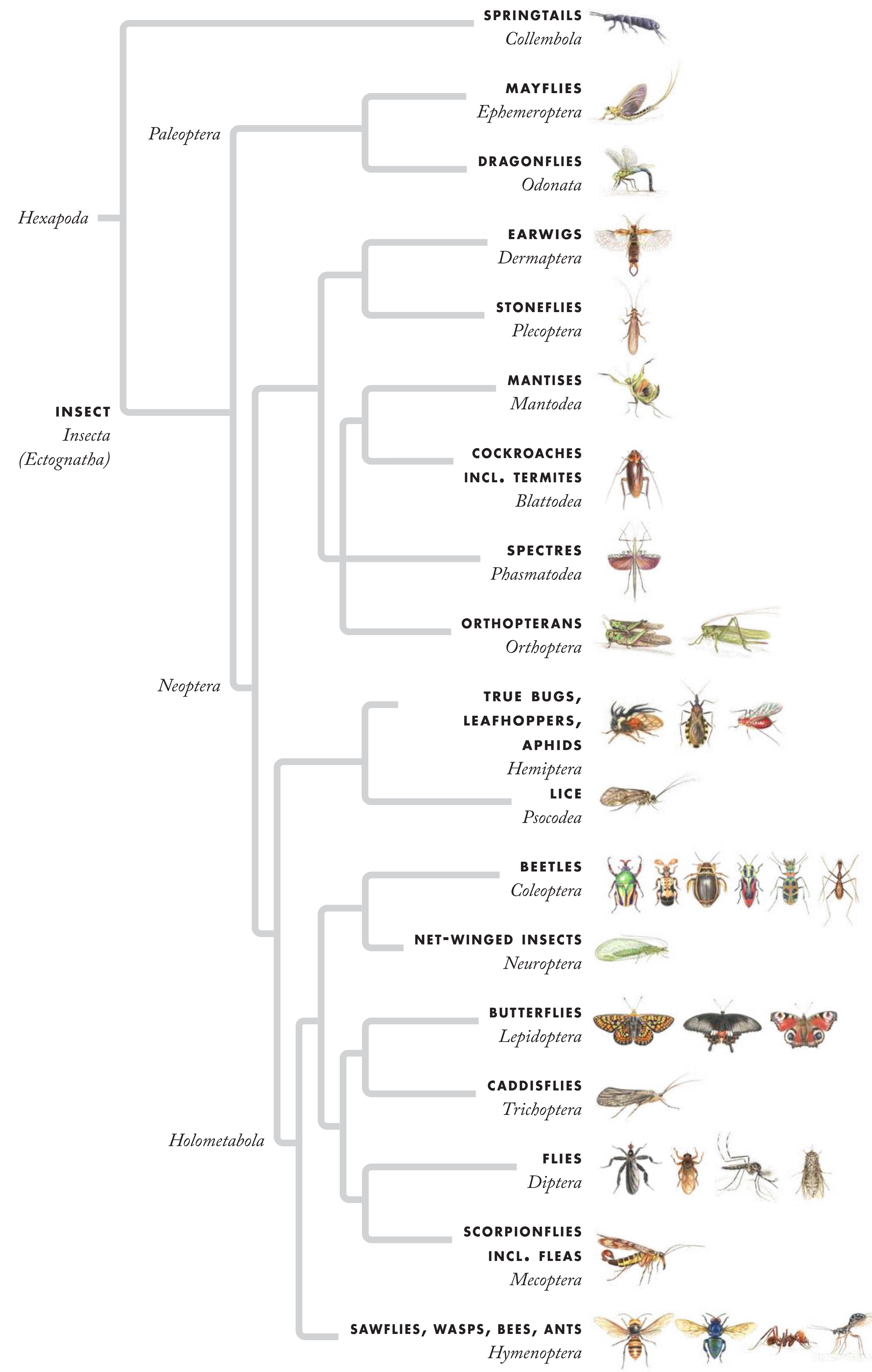


Insects are arthropods, members of the largest group in the animal kingdom in terms of absolute number and number of species. They are immensely important for the nature of our planet. The latest studies in anatomy, morphology (meaning "body structure"), and genetics show us that insects form the largest and (in terms of evolution) most advanced class of crustaceans, a group that also includes crayfish and crabs. The evolutionary success of insects and the wealth of forms they take can probably be put down to their conquest of the air 300 million years ago, in the early Carboniferous Period, when insects were the only life forms with the ability to fly. This ability has been further developed by different orders of insects over millions of years; as a result, they have succeeded in settling in various environments as many different species.

The relationships between individual insect groups remain a subject of research. In the chapter above on Orders of Insects, we learned about the best-known orders and how to recognize them. Here we will discuss the phylogeny of insects—or the evolutionary relationships between them. To do this, scientists use the so-called phylogenetic tree, formerly known as the evolutionary tree, or simply the tree of life. This is shown on the facing page. The end of each branch of the tree shows one order of insects. The number of pictures behind each branch roughly represents the present number of species of this order (this may have been different in the past). Our tree of life includes only orders of insects that appear in this book (27 in total), none of which are extinct. In the chapters on Paleontology below, we will show many fossils. It is often better to use the scientific names for orders of insects rather than those in common use, since the latter are often confusing or incorrect. Sometimes, we will use both names. For example, Diptera is a scientific name for insects whose most common representatives are flies and mosquitoes. We probably know of Hymenoptera through wasps, bees, and ants; because of their similarity with these, we would be right to assume that bumblebees, sabre wasps, woodwasps, and other small wasps belong in this order. Entomologists begin with such assumptions as they work out phylogenetic relationships, looking for similarities in body-build and small details on wings and limbs. In recent years, they have been able to identify genetic similarities between objects of study. In the final analysis, they can turn to fossilized traces in rock or ancient amber. From this jigsaw of various pieces of evidence, scientists form hypotheses on insect evolution.

The very term "insect" has two distinct meanings for entomologists. The first is as a broader term to describe the subphylum Hexapoda (Greek for "six legs"), which includes smaller groups of wingless proturans (Protura), "two-pronged bristletails" (Diplura), and springtails (Collembola), which live in terrestrial environments and are rarely longer than 5 mm. On the other hand, the class Insecta (otherwise known as Ectognatha) also has wingless representatives, the best known of which include the silverfish in our bathroom (they are of the order Zygentoma). Some insects have wings, while others have lost them secondarily. The most primitive insects are Palaeoptera (dragonflies and mayflies), whose wings fold over the thorax or are held away from the body. Other insects (Neoptera) can fold the wings over the abdomen, either roof-like or flat. Members of the same order do not always look alike, as they may have adapted to extreme living conditions in the course of evolution. Termites are of the same order as cockroaches, although they are adapted for social life in dark nests, divided into castes. Fleas are wingless creatures adapted for life in the extreme conditions of animal fur; they are very unlike scorpionflies, from which they evolved. In evolutionary terms, the most advanced superorder of insects is Holometabola (also known as Endopterygota), which undergoes a complete metamorphosis. Also the largest insect phylogenetic lineage, it includes beetles, butterflies, Hymenoptera, Diptera, and several less numerous orders. They are distinguished from other insects by their larval form (which does not resemble the adult) and the pupa, the stage at which the larva transforms into the adult.

EVOLUTIONARY TREE OF INSECTS



DAWN OF THE INSECTS

The Devonian, the Carboniferous, the Permian

Giant Carboniferous dragonfly Meganeura *(reconstruction)*

Cupes mucidus, *a present-day representative of the ancient family Cupedidae, related to beetles of the Permian*

Fossil of the oldest known beetle Moravocoleus permianus, *found in Permian strata in Czechia*

The oldest known animal fossil of insect-like creature originates from the Devonian Period of the Palaeozoic Era. We estimate its age at 410 million years. It was discovered in 1919, in a field of chert (a type of quartz rock) near the small Scottish village of Rhynie—hence the name *Rhyniella praecursor* (a precursor is a forerunner or ancestor). Paleontologists believe it to be a springtail (Collembola), which is a member of Hexapoda. It is very closely related to the insects of today. Some scientists believe that the mouthparts of *Rhyniella praecursor* are in fact those of another fossil, which was later given the name *Rhyniognatha hirsti.* Opinions differ as to how Rhyniognatha should be classified. Some paleontologists believe that it had wings and was related to the mayfly; others believe it was related to the centipede, which has little in common with insects. As the case may be, we know for sure that it was in the Devonian Period that terrestrial animal and plant life forms came into being, and these include arthropods.

The fossils we have from the Carboniferous Period (from 359 million to 299 million years ago) have far clearer features. In this period, Earth was first covered with plants—mainly tree-like club mosses (lycophytes) up to 100 feet tall, horsetails, and ferns. Later, seedless plants, including conifers, appeared. With their warm climate, the vast primeval forests of the Carboniferous Period provided a perfect environment for insects to develop in. This time period saw the origination of many insect orders that are with us to this day. Insects became planet Earth's first flyers. The oldest flying insects are mayflies and dragonflies, whose nymphs lived aquatically in vast swamps. Predatory dragonflies ruled the skies, and they grew to incredible proportions—the best known of them, Meganeura, had a wingspan of up to two and a half feet! Insects of the Carboniferous were probably so large because conditions favored them; they had no competitors in the skies.

One order of insects that has not survived to the present day is Palaeodictyoptera. It became extinct at the end of the Permian Period. Palaeodictyoptera, too, grew to estimable proportions; Mazothairos, for instance, had a wingspan of nearly two feet, as well as a mighty body and long appendages on the trunk. The *Dunbaria fasciipennis* fossil, discovered in Kansas, features beautifully speckled wings. Palaeodictyoptera probably had aquatic nymphs, and the adults fed by sucking on plants. More interesting still, they are the only animal in history to have six wings—a pair on each segment of the thorax. The wings of the prothorax were small and rounded, and we don't know what they were used for.

Other insect orders, too, originated in the Carboniferous and Permian Periods. The Carboniferous gave us fossils of cockroaches and the ancestors of crickets, grasshoppers, and stoneflies. Diversification of insects occurred in the Permian, 250 to 300 million years ago. From this period, we have the beautiful fossils of many insect orders that underwent incomplete metamorphosis, as well as the earliest examples of orders that underwent complete metamorphosis. These include Permian beetles, which have remained practically unchanged to the present day. The suborder Archostemata occurred all over the world in the Permian Period; that it exists today is remarkable. In the past, its larvae probably developed as they do today, in the wood of conifers. As the Permian gave way to the Triassic Period, 252 million years ago, huge volcanic eruptions resulted in a mass extinction event known as the Great Dying, in which 90 percent of the world's animal species perished. Insects were affected by this disaster, but they survived.

« *The palaeodictyoptera* Stenodictya *(foreground) and the dragonfly* Meganeura *(above). The cockroach on the horsetail stalk resembles today's species.*

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at the Moravian Museum in Brno.
This work is based on his lifelong research
and observations.

For more info, check out the following websites:

www.insectidentification.org
www.inaturalist.org
bugguide.net
www.si.edu/spotlight/buginfo

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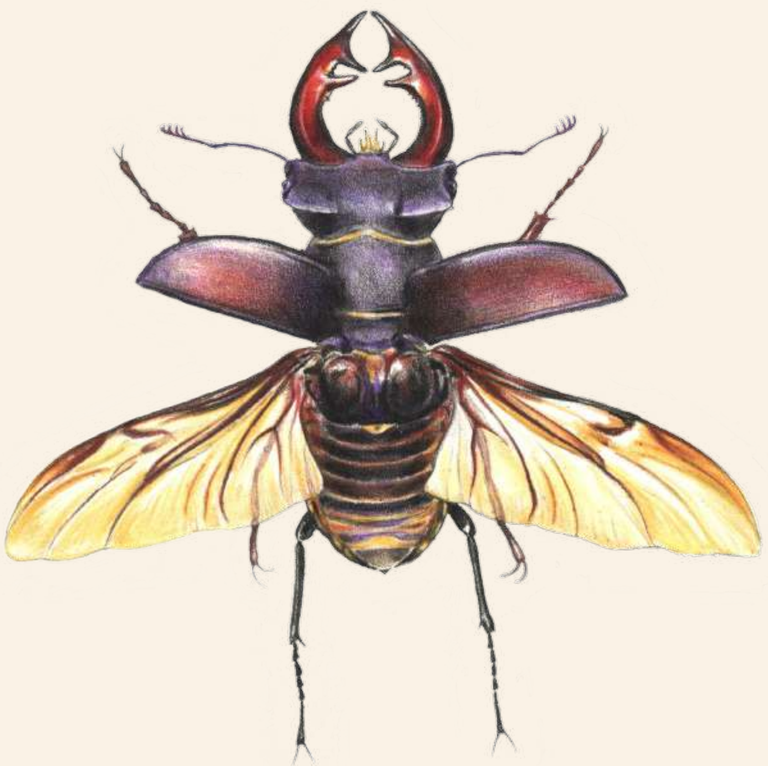
Insects are everywhere around us—an everyday part of our lives. We usually only notice them, however, when a mosquito buzzes in our ear or a colorful butterfly passes by our eyes. But did you know that insects are the world's largest group of animals? Or that we find them all over the place—in arid deserts, blooming meadows, deep forests, freshwater pools, dark caves, and even on the ocean's surface? They carry diseases, but they also pollinate fields and orchards. While insect pests may harm the forest, insect helpers protect it. Without pollinators, no flowers would grow, and without insects to feed on, songbirds would starve.

This book takes you deep into the realm of tiny creatures whose behavior, shapes, and colors will astonish you with their complexity. With fascinating descriptions by leading Czech entomologist Jiří Kolibáč, complemented by lifelike illustrations by Pavla Dvorská and Pavel Dvorský, we will explore complex courtship rituals, moving care for offspring, the organization of insect states, and wars over food sources. We will also learn about the scents, colorful wings, and sharp mandibles of the largest and the smallest of them. Soon, you'll start to realize how important insects are—for humanity and for all life on earth.



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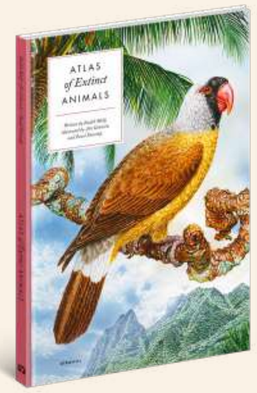

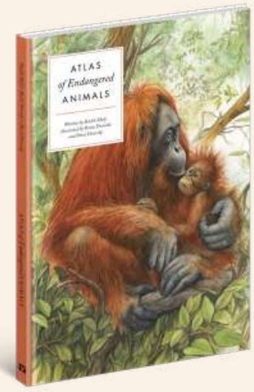

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