

THE IN A HURRY SERIES

Insects *in a Hurry*

The tiny majority that rules the planet

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The Whole Thing in One Page

An insect is easy to dismiss because it fits beneath a shoe. That view mistakes human scale for planetary scale. On land and in fresh water, usable space is divided into bark crevices, leaf layers, dung, carrion, pollen, roots, temporary pools and narrow windows of weather. Insects fit those openings. We notice the wasp indoors. We miss the millions of routes outside.

Their success begins with a reusable plan: an external skeleton, a segmented body, six jointed legs and appendages that selection can turn into cutters, straws, drills, sponges, oars and traps. Smallness opens spaces and food sources that cannot support a larger animal. It also imposes costs. A rigid cuticle must be shed for growth. A tiny body exchanges heat and water quickly. Air reaches tissues through branching tubes, an efficient arrangement at insect scale that becomes harder to supply as bodies enlarge.

Then came flight. One major molecular-clock analysis placed insect flight near 406 million years ago, although the earliest dates and the origin of wings remain disputed. Flight connected temporary resources. Food could vanish because the eater could leave. Mates could be scattered. A pond could dry, a tree could fall or a carcass could be exhausted without ending the lineage.

The next great move was to stop asking one body to do every job. A caterpillar is built largely for eating and growth. A butterfly is built for dispersal and reproduction. Complete metamorphosis, used by more than 80 per cent of described insect species, lets one genome construct sharply different bodies in sequence. Beetles, flies, moths, ants, bees and wasps inherit that divided life.

Those innovations spread through more than one million described species, well over half of named animal species, while millions more probably remain unnamed. Majority here means species richness. It does not mean that insects outweigh plants or outnumber every other form of life under every

counting method.

Plants multiplied the opportunities. Insects chewed, mined and bored through them, induced galls, guarded some plants and carried pollen. Plants answered with structure and chemistry; insects answered with enzymes, behaviour and alliances. Meanwhile odour plumes, songs, flashes and vibrations brought mates together, guided animals to hosts and organised colonies. A small nervous system need not represent the whole world. It needs to extract the right signal from the world the animal occupies.

Some lineages distributed that work across societies. Ant trails, termite nests and honeybee swarms are coordinated without a ruler allocating every task. Queens concentrate reproduction and influence colonies chemically, while daily order emerges from local decisions, feedback and information passed among workers.

This is what ruling means. Insects do not dominate the open ocean or act as one force. Their power lies in relationships. They pollinate, consume, hunt, parasitise, decompose, bury, aerate, recycle and feed larger animals. They also damage crops and transmit pathogens. Humans depend on insects while spending heavily to suppress selected species.

The bill is hidden inside the design. Fine specialisation creates diversity, but it also creates dependence on a host, season, temperature, nesting material or juvenile habitat. Severe losses are documented in several well-monitored regions and groups, yet no defensible single percentage describes the planet. To understand either insect success or insect decline, follow the complete life cycle and every link it requires.

That is the book.

Why You Should Care

Stand on a patch of ordinary ground and you are probably above ants. A 2022 synthesis estimated almost twenty quadrillion of them on Earth, millions for every person alive. Some habitats were poorly sampled, and ants are only one branch. Even so, the estimate corrects the view from eye level. The large animals are the visible minority.

The useful comparison is between the jobs each can reach. A person cannot enter a fig through a hole narrower than a pinhead and carry pollen between its hidden flowers. A bird cannot spend its youth between the upper and lower surfaces of a leaf. A mammal cannot lay one egg inside a particular species of caterpillar and have the offspring eat its host from within. Size closes those possibilities to us. For insects, they are industries.

That matters because terrestrial life is built from interactions rather than a list of species. Animal pollination reaches an estimated 87.5 per cent of flowering-plant species. Around three-quarters of leading food crop types benefit from it to some degree, although that is not three-quarters of the food on your plate. Dung beetles return waste to soil. Termites process dead plant material and alter tropical soils. Predatory beetles, lacewings and parasitoid wasps suppress other insects. Caterpillars and grasshoppers convert leaves into bodies that birds, bats, reptiles and fish can eat. Remove the animal at the centre of one photograph and the landscape may look similar. Remove enough of the exchanges and it works differently.

You also need insects because some of them are exceptionally good at using you. Malaria parasites move between humans through particular mosquitoes. The World Health Organization estimated 282 million malaria cases and 610,000 deaths in 2024. The mosquito does not cause malaria, and most mosquitoes cannot transmit it, but the right insect can join a pathogen, a climate and a human population into one deadly system. Fleas, lice, sand flies, blackflies and true bugs have made similar arrangements with other pathogens.

Then there is the practical reason. Insect control often begins with disgust

and ends with chemistry. A damaged leaf is treated as proof that everything with six legs should die. Broad control can remove predators and pollinators alongside the target, select for resistance in survivors and leave crops exposed when the chemical fades. Modern integrated pest management starts somewhere less theatrical: identify the species, understand its life cycle, measure whether damage has crossed a threshold, protect natural enemies and use targeted controls when justified. Entomology becomes a way of making better decisions under incomplete information.

The subject also changes how intelligence looks. A honeybee brain contains roughly one million neurons, yet trained bees can distinguish quantities and, in a controlled experiment, place an empty set below one. Bumblebees have learned artificial tasks from other bees and solved novel object-moving problems. These results do not make bees tiny humans, and they do not settle whether insects are conscious. They do remove the excuse that flexible behaviour requires a large brain as a rule.

Finally, insects expose a measurement problem that reaches far beyond natural history. Species richness, number of individuals, biomass, geographical range and ecological function can move in different directions. A site may keep the same number of species while losing its once-common moths. A city may gain heat-loving insects while a cold-adapted specialist vanishes. One long-running German study measured flying biomass. A large United States study measured butterflies. Neither is a gauge for every insect on Earth.

Care, then, without turning insects into saints. They are neither a benevolent workforce nor an invading enemy. They are the small machinery through which much of life eats, reproduces, decomposes and moves. Once you can see that machinery, an empty windscreen is no longer the whole argument, and a bee on a flower is no longer the whole system.

The Core Ideas

A Body Built from Reusable Parts

The basic adult insect plan has six legs, one pair of antennae and a body organised into head, thorax and abdomen. The definition matters because the casual category of bug includes spiders with eight legs, centipedes with one pair of legs per trunk segment, land-living crustaceans such as woodlice, and ticks that are arachnids. Insects belong inside the arthropods, the joint-legged animals, but they are one particular solution within that larger design space.

The inheritance is modular. Arthropod ancestors were segmented, with paired appendages repeated along the body. Evolution did not preserve a row of identical units. It grouped segments into working regions and altered their attachments. On an insect, the head concentrates senses and feeding. The thorax carries all six legs and, where present, the wings. The abdomen handles much of digestion, excretion, reproduction and breathing. The boundaries are not perfect engineering compartments, but they let different parts change without rebuilding the animal from the beginning.

Look at the mouth. A grasshopper has opposing mandibles that cut leaves. A butterfly forms a long coiled proboscis from paired mouthpart structures and unrolls it into flowers. A housefly spreads liquid through a sponging tip. A blood-feeding female mosquito carries a bundle of slender piercing parts inside a flexible sheath. A dragonfly nymph turns its lower lip into a hinged capture device that shoots forwards underwater. These are variations on inherited appendages. The body plan did not predict nectar, blood or tadpoles. It supplied parts that could be recruited when those opportunities appeared.

The outer covering makes the system possible and awkward. Insect cuticle is a layered composite, rich in chitin and proteins, secreted by living cells beneath it. It supports the body, anchors muscles, protects against damage and slows water loss. It also cannot enlarge continuously. Growth happens behind a temporary new cuticle, then the old one splits. The insect pulls

free, expands the soft replacement with air or fluid, and waits while it hardens. For that interval, the armour becomes a liability. A cicada shell left on a tree is therefore not a dead cicada. It is the previous limit of a body that escaped.

Joints solve the obvious problem of moving inside a rigid coat. Muscles attach to the inner surface and pull across articulated plates. The result can be strong at low mass, but it is not a magic suit. Thickening an external skeleton adds weight, while larger bodies demand more support and longer transport distances. The design excels at small and moderate sizes. It does not scale into a rhinoceros with six legs.

Modularity also explains why insects can look unrelated while remaining recognisably one machine. A beetle turns its forewings into hardened covers. A fly reduces its hindwings to balancing organs called halteres. A mantis converts its front legs into folding traps. A water boatman rows with its hind legs. A louse flattens and grips hair. Selection keeps editing attachments while leaving the central plan legible.

That is the first source of insect diversity. Evolution did not invent millions of animals separately. It kept finding new uses for an old box of parts.

Smallness Is an Operating Scale

Small animals do not inhabit a reduced version of our world. Surface tension can hold them, a raindrop can knock a flier from the air, and the boundary layer of still air over a leaf becomes a climate. A crack in bark is a corridor. The underside of one leaf differs in heat, wind and humidity from the upper surface. Scale changes the forces that matter, and insects have spent hundreds of millions of years turning that change into territory.

The first advantage is access. A leaf miner lives between two sheets of plant tissue, eating a pale tunnel that records its route. Gall-forming insects redirect plant growth to build chambers around themselves. Fig wasps enter the enclosed inflorescence of a fig through a tight opening, losing parts of their wings and antennae as they squeeze inside. Parasitoid wasps can locate a host concealed in wood and place an egg with an ovipositor longer

than the rest of the body. Large animals see a plant. Insects encounter a stack of habitats.

Smallness also changes cost. A light body needs less material, matures quickly in many lineages and can exist on food patches too slight or brief to support a vertebrate. A pool in a tree hole can raise mosquito larvae. A small patch of fruit, dung or carrion can support flies and beetles while it lasts. High reproductive rates and short generations do not belong to every insect, but where they occur they let populations track opportunity and evolution test variation quickly.

The physics sends an invoice. Surface area rises faster relative to volume as bodies shrink, so heat and water exchange quickly. Many insects can warm and cool with the air in minutes. They risk desiccation because so much body lies close to the outside. Waxy layers in the cuticle, closable spiracles, sheltered behaviour and concentrated excretion help conserve water. Desert insects can be superb at this, but no adaptation abolishes the budget. A small insect on a hot dry surface may be living close to a water balance that a mammal barely notices.

Breathing follows the same scale. Air enters through spiracles and moves along branching tracheae and finer tracheoles towards tissues. Oxygen need not follow the long route from lungs through blood to every working cell. In many small or resting insects, diffusion does much of the transport. Larger or active insects pump the abdomen, compress air sacs or use movements of the body to ventilate the network. Haemolymph circulates nutrients, hormones and waste, but usually carries little oxygen. The tubes put the atmosphere close to the muscle.

This arrangement helps explain both performance and limit. A hovering insect can deliver oxygen through an extensive tracheal system, while a rigid body and tiny mass give high strength relative to weight. Yet tracheae occupy space. As an insect enlarges, the distance and volume needed to supply deep tissues increase. Fossil insects reached spectacular sizes during parts of the Palaeozoic, when atmospheric oxygen was often higher than today, but oxygen is not a complete answer. Development, ecology,

predation, tracheal geometry and temperature also mattered, and recent work has challenged some proposed hard respiratory limits.

Smallness, then, is not a stage on the way to becoming large. It is the scale at which the insect machine works. It opens habitats, speeds exchanges and permits numbers that larger bodies cannot sustain. It also makes weather intimate. A dry week, a missed host plant or a few degrees of warming can transform the entire usable world of an animal shorter than your thumbnail.

Wings Turned Habitat into a Map

Powered flight appeared in insects long before it appeared in pterosaurs, birds or bats. A major phylogenomic analysis placed its origin near 406 million years ago, though the fossil record is patchy and molecular dates depend on models. The wings themselves have no neat origin story. Current developmental and fossil evidence supports contributions from ancestral limb-associated structures incorporated into the body wall, but the sequence is still being argued over. The most important fact is less disputed: once insects flew, land stopped being a collection of prisons.

A wing does more than extend range. It changes which resources can be used. Fruit, dung, flowers, carcasses and temporary pools appear in scattered places and vanish. A walking animal must survive the ground between them. A flying insect can treat each patch as a destination. The adult may emerge, feed briefly, find a mate, locate the next host and place offspring where their food will exist. This is why flight and metamorphosis reinforce each other. A larva can become locally specialised because the adult can carry the lineage elsewhere.

The first winged insects probably held their wings out or upright because they could not fold them flat over the abdomen. Living mayflies and dragonflies preserve versions of that older arrangement. Folding evolved later in the lineage called Neoptera and changed the geometry again. Wings could be protected while crawling under bark, entering soil or squeezing through vegetation. Most living insect diversity belongs to groups with that

ability. A beetle takes protection further by hardening the forewings into elytra and flying with the hindwings beneath. A true fly keeps one working pair and turns the hind pair into halteres, small oscillating organs that sense rotation and help stabilise manoeuvres.

Insect flight is mechanically varied. Dragonflies control their two wing pairs with substantial independence. Many other insects power flight mainly by deforming the thorax, using large indirect muscles rather than pulling each wing down like an oar. In flies, bees and some beetles, stretch activation lets the muscles cycle faster than nerve impulses could command every stroke. This permits wingbeat frequencies and manoeuvres that would be difficult with one nerve signal per beat. The animal sets a vibrating system in motion and steers it through smaller adjustments.

The consequences range from a few metres to continents. Aphids ride air currents between host plants. Desert locusts shift from solitary to crowding-associated forms and can join migratory swarms when conditions concentrate them. Monarch butterflies move across North America in a relay that no individual completes as a round trip. Some hoverflies cross seas and mountain passes during seasonal migrations. Flight carries genes, parasites and pathogens as well as bodies.

It also creates new ways to be found and killed. Light can attract or disorient nocturnal insects. Wind can blow a small flier away from the only suitable habitat. Flight muscle is expensive tissue, wings tear, and warm-up can consume time and energy. Some lineages reduce or lose the equipment. Worker ants develop without wings, female winter moths walk up trunks, fleas lost wings as they specialised on hosts, and many island insects have reduced them where being blown to sea is worse than staying put.

The achievement was therefore not permanent escape. It was optional connection. Wings let insects search a world whose useful places are brief and separated. Once a lineage can leave, specialisation no longer has to mean confinement.

Metamorphosis Split One Life into Different Jobs

A young grasshopper resembles a small wingless grasshopper. It grows through a series of moults, acquiring adult structures gradually, without a pupal stage. A caterpillar and a butterfly seem to have misplaced each other. One is a soft-bodied leaf processor with chewing jaws and many gripping prolegs. The other flies, drinks through a coiled tube and carries reproductive organs. Both are phases of one individual. Complete metamorphosis makes identity serial.

Insect development spans a range. Silverfish and their relatives hatch in a broadly adult form and continue moulting. In insects with incomplete metamorphosis, the nymph changes step by step. Dragonfly nymphs are aquatic predators with a projectile mouthpart and internal gills; the adult leaves the water, flies and hunts in air. In complete metamorphosis, egg becomes larva, larva becomes pupa, and pupa becomes adult. Beetles, flies, butterflies, moths, fleas and the order containing ants, bees and wasps all use this route. Together they account for more than 80 per cent of described insect species.

The familiar phrase about a caterpillar dissolving into soup mistakes demolition for chaos. During pupation, hormones coordinate cell death, tissue remodelling and new growth. Some larval structures are broken down extensively. Others persist and are rebuilt. Clusters of cells and developing adult tissues expand into wings, legs, eyes and reproductive organs. The gut, nervous system and muscles can be reorganised in species-specific ways. A pupa may look inactive from the outside, yet internally it is one of the most ordered construction sites in biology.

Two hormone systems help control the sequence. Pulses of ecdysteroids trigger moulting processes. Juvenile hormone helps determine what the next moult produces. When juvenile hormone remains high, a larva usually becomes another larval stage. When it falls at the relevant time, the developmental programme can move towards pupa and adult. This is a simplified outline of a network with many genes and tissues, but it explains why a moult is not merely getting a larger coat. The same physical act can

reveal a different kind of body.

Why make the change so severe? One benefit is division of labour across time. Larvae often specialise in growth and food intake. Adults often specialise in dispersal, mating and placing eggs. A maggot can exploit wet decay without carrying wings through it. A moth can travel without maintaining the heavy gut and feeding machinery of its caterpillar. The stages may use different foods and habitats, reducing direct competition between young and adults. Complete separation is too strong, since nutrition, disease and damage can carry effects across metamorphosis, and some larvae and adults still share resources. The useful claim is decoupling, not independence.

The split also makes an insect difficult to understand from one sighting. The adult antlion is a delicate flier; its larva waits at the bottom of a sand pit and seizes animals that slide in. A caddisfly adult lives in air; its larva builds a case underwater from sand, leaves or twigs. A parasitoid wasp may feed as an adult on nectar and develop as a larva inside another arthropod. One name can conceal two habitats, two diets and two sets of enemies.

That is the gain and the vulnerability. Metamorphosis allows extreme specialisation without demanding that one body compromise between every task. It also means survival requires a route through every stage. Save the flower and lose the larval host plant, and the butterfly still disappears. Protect the pond and remove the emergence vegetation, and the dragonfly's life remains broken. An insect does not occupy one niche. It passes through a sequence of them.

Plants Made Enemies and Partners

Plants cannot run, which sounds like an invitation until you try to eat one. Their tissues contain cellulose, silica, resins, latex, tannins, alkaloids, terpenes and compounds that interfere with digestion or poison nervous systems. Their useful nitrogen is often dilute. Leaves can be tough, chemically defended and brief. Insects still made plants into the largest menu on land, then divided the menu with astonishing precision.

The techniques are visible in damage. Caterpillars and beetles remove tissue from the edge or centre of a leaf. Aphids and other true bugs insert slender mouthparts into vascular systems and tap moving fluids. Leaf miners live inside the leaf. Bark beetles tunnel beneath bark. Seed weevils place larvae inside packages of stored energy. Gall makers manipulate plant development so that a local swelling becomes shelter and food. A plant may therefore host different insects on its roots, stem, buds, leaves, flowers, fruit and seeds, each using a separate structure or season.

Chemical defence encourages specialisation. An insect that evolves enzymes, gut microbes or behaviour able to handle one plant's chemistry gains access to food many rivals cannot use. The price is dependence. Some caterpillars accept a narrow range of host plants because their sensory systems and metabolism are tuned to them. A female may drum, taste or probe a leaf before laying. She is choosing food for an offspring she will never meet. Put the adult in a garden full of nectar but remove the correct larval host, and abundance becomes decorative starvation.

Plants are not passive. Physical barriers and toxins vary with tissue, age and damage. Some plants release volatile chemicals after herbivory that can attract predators or parasitoids of the attacker. Others tolerate damage, shed attacked parts or alter growth. Insects counter with sequestration, using plant toxins in their own defence, or with ways of cutting veins before feeding so that latex pressure falls. The interaction can drive reciprocal adaptation, but the grand story of a universal arms race creating all plant and insect diversity is too clean. Host shifts, geography, climate, chance and one-sided adaptation matter too. Insects were already diverse before flowering plants transformed terrestrial ecosystems.

Flowers changed the relationship because they offered payment for transport. Pollen must move, and an animal already visiting for pollen, nectar, oils, scents or warmth can carry it. The result ranges from loose markets, where many visitors use many plants, to tight partnerships. Fig wasps enter the enclosed flowers of figs and reproduce inside while transferring pollen. Some yucca moths actively gather pollen, place it on a

stigma and lay eggs so their larvae can eat a share of the developing seeds. The bargain is real, but it contains conflict. Too many eggs and the plant aborts the fruit; too little pollination and the insect's nursery fails.

Across flowering plants, animal pollination is estimated to reach about 87.5 per cent of species. Insects do most of it, though birds, bats and other animals matter. Human crops require a narrower description. Around three-quarters of leading crop types benefit at least partly from animal pollination, while staple grains such as wheat, rice and maize rely mainly on wind or self-pollination. The service affects variety, quality and many fruits, nuts and vegetables more than it determines every calorie.

Plants gave insects food, shelter, poison, signal and transport work. Insects answered by becoming herbivores, pollinators, bodyguards, seed predators and architects of plant tissue. Neither side rules the other. Their long negotiation built much of the diversity we mistake for background scenery.

A Small Brain Can Run a Large System

A honeybee enters a flower with several problems already solved. It must stabilise flight in moving air, judge distance, distinguish colours, learn which scent predicts reward, manipulate petals and return home across a changing landscape. Much of that work happens through a brain smaller than a sesame seed. The comparison with a human brain is impressive and often unhelpful. The bee is not a reduced person. It is a nervous system built around different sensors, time scales and decisions.

Compound eyes divide the visual field among many optical units. They trade the fine detail of a camera-like vertebrate eye for a broad view and strong sensitivity to movement. Simple eyes on the top of many insect heads register light and horizon. Antennae sample odours, touch, humidity, airflow and vibration. Flies estimate self-motion from patterns sweeping across the eye and use halteres to detect rotation. Moths follow odour plumes that break into filaments in turbulent air. What looks sparse from our scale is dense with usable information.

Communication is fitted to those senses. Male crickets generate songs by

rubbing specialised parts of the forewings, and females respond to the timing and frequency patterns of their species. Many moths release sex pheromones that potential mates track through moving air. Fireflies exchange patterned flashes. Leafhoppers and other insects send vibrations through stems that a nearby animal can detect while a distant observer hears nothing. These signals solve practical problems: find the right mate, at the right time, in a crowded world of similar small bodies. Noise, artificial light and broken habitat can disrupt the exchange.

The processing can be flexible. Bumblebees have learned to pull strings, move balls for rewards and copy parts of a solution from demonstrators. Honeybees trained to choose a smaller number have treated an empty display as less than one. In 2026, bumblebees trained to associate a blue floor ring with reward moved a ball beneath the ring after it was relocated to the ceiling, even in controls that hid the target during transport. These artificial tasks do not establish language, human arithmetic or general reasoning. They show that small circuits can learn rules, combine cues and alter behaviour when a familiar procedure fails.

Social insects add another level. Eusocial colonies combine overlapping generations, cooperative brood care and a reproductive division of labour. The arrangement evolved several times and has also been lost in some lineages. Ants, many bees and wasps use it. Termites do too, which is less intuitive because termites are deeply modified cockroaches rather than close relatives of ants. Their colonies arrived at workers, defenders and reproductives from a different evolutionary starting point.

The queen is central without being a monarch in the human sense. She lays most or all of the colony's eggs and produces chemical signals linked to fertility and social organisation. She does not inspect tunnels, allocate every forager or issue a daily plan. Work emerges from encounters, thresholds and feedback. An ant that finds food lays a pheromone trail; other ants reinforce a profitable route and let an unprofitable one fade. Termites add or remove material in response to local structure and signals, producing organised nests without a blueprint held by one builder.

Honeybee nest-site choice makes the mechanism visible. Scouts inspect cavities and advertise them with dances. Support shifts as more scouts visit competing sites. Once attendance at one candidate reaches a quorum, the swarm prepares to move. No bee compares a complete table of options. The colony reaches a decision by distributing inspection and allowing recruitment to amplify agreement. Computation is built from bodies and repeated encounters.

Distributed organisation has costs. Dense colonies can spread parasites and disease. Workers and reproductives can have conflicting interests, and policing is needed in some species. A trail can lock a group into a poor route until feedback changes. Colonies fail when local rules no longer match conditions. Their order is neither obedience nor magic. It is a fitted response to recurring problems.

The larger lesson is about where information can reside. It can sit in one nervous system, pass through signals between two insects or accumulate across repeated interactions in a colony. Insects did not overcome small brains. They built lives in which specialised senses, selective learning and distributed information are enough.

Dominance Is a Web, Not a Throne

Call insects the majority and a measurement problem appears at once. Roughly one million insect species have formal scientific names, and insects make up well over half of described animal species. The living total is far larger. A widely used 2018 synthesis estimated about 5.5 million insect species. A 2026 study began with more than 1.6 million DNA-barcoded specimens from fifteen traps in one protected Costa Rican landscape, corrected the local undercount and scaled the result against several better-known groups. Its authors proposed a lower-bound range of 14.2 to 20.3 million species. That is an important challenge, not a settled inventory. The estimate depends on two large extrapolations from one unusually rich tropical site.

Species count is only one kind of dominance. Plants outweigh insects by a

huge margin. Insects scarcely occupy the open ocean, where five ocean-skater species are the striking exception. Even on land, another arthropod group or a worm may dominate a particular soil sample. The subtitle does not claim that one class owns every habitat or tops every table. It describes reach: insects have multiplied forms, individuals and ecological relationships across most terrestrial and freshwater systems.

Ants reveal what numerical abundance can mean. A 2022 synthesis estimated almost twenty quadrillion living ants. The figure came from hundreds of studies and remains uncertain because many regions and habitats were poorly sampled. It is not a census and says nothing about all insects. It does show how a small body, social organisation and repeated local success can produce numbers beyond ordinary intuition.

The more consequential measure is work. Insects remove plant tissue and influence which plants reproduce. They kill other arthropods, raise fungi, disperse seeds, consume dung and carrion, burrow through soil and convert leaves into prey for fish, birds, bats and reptiles. Parasitoid wasps turn other insects into nurseries. Termites alter the movement of water and nutrients. Mosquitoes and other vectors join pathogens to hosts. None of these roles belongs to insects alone, and no single insect performs them all. Their collective importance comes from the density of links.

That same density makes loss difficult to summarise. In protected areas of western Germany, traps recorded a 76 per cent seasonal fall in flying-insect biomass across twenty-seven years. Across the contiguous United States, thirty-five monitoring programmes recorded a 22 per cent decline in total butterfly abundance from 2000 to 2020. A 2024 synthesis of 923 long-term terrestrial assemblages found the strongest average losses among species that had once been locally abundant, but the available records were heavily biased towards Europe and North America. These studies examine different groups, places and quantities. They cannot be averaged into a planetary speedometer.

The pattern that survives comparison is uneven change under several pressures. Habitat conversion removes food and nesting sites. Simplified

farmland shortens the calendar of flowers and host plants. Pesticides can kill targets and non-targets, while repeated use selects resistant survivors. Artificial light alters nocturnal behaviour. Climate shifts seasons and ranges, helping some insects while separating others from hosts or exposing them to unsuitable extremes. Pathogens and introduced species add further stress. Effects combine differently in each landscape.

Now the first idea returns with its cost attached. Modular bodies, flight and metamorphosis let insect lineages divide the world finely. A species can depend on one plant part, one host, one soil condition and one brief season. That precision creates diversity while the links persist. It creates brittleness when several stages must cross a landscape whose pieces no longer connect.

Insects rule in the only defensible sense: much of life passes through relationships they make possible. There is no throne and no central species to save. The strength is the web. So is the vulnerability.

How It Actually Works

The crustacean inheritance

Long before an insect flew, its ancestors belonged to a much older experiment in jointed bodies. Arthropods had already divided themselves into repeated segments, wrapped those segments in cuticle and moved them with articulated limbs. Trilobites carried versions of the plan through ancient seas. Crustaceans elaborated it into antennae, jaws, swimmerets and walking legs. Modern genetic and anatomical evidence places insects within that crustacean branch rather than beside it.

The move produced a useful historical correction. Six legs were not invented as six legs. Paired appendages were inherited and reassigned. Some became mouthparts. Three pairs remained as walking legs on the thorax. Abdominal appendages were reduced, lost or converted for specialised tasks. The insect head itself is a fusion of ancestral segments whose appendages now taste, bite, smell and feel.

That marine ancestry did not mean the ocean became insect territory. Breathing air through tracheae, conserving water with cuticle and reproducing on land opened a different world. A springtail appears in the Devonian Rhynie chert, about 407 million years old, already living among low plants, fungi and damp litter. It was not an insect in the strict sense, but it shows that small six-legged arthropods had entered terrestrial food webs early.

Land offered dead vegetation, fungal growth, spores, microbial films and sheltered cracks. It also offered desiccation. The first success was therefore physiological before it was spectacular: keep the internal fluids in, let gases cross, moult without dying, and place eggs where the young can survive.

The first air

Molecular estimates put the origin of insects hundreds of millions of years ago and powered flight near the early Devonian. Fossils do not provide a clean sequence. Delicate wings preserve badly, and several famous fragments have changed identity under closer inspection. By the Carboniferous, however, the sky held unmistakably winged insects.

Early flight changed selection even if the first flights were clumsy. An animal could escape a predator by leaving the surface, cross water or unsuitable ground, and reach reproductive partners beyond walking distance. The advantage did not require a continent-spanning migration. Clearing a fern, landing on another trunk or reaching the next pool was enough to alter which habitats counted as connected.

The earliest winged lineages could not fold their wings flat. Mayflies and dragonflies retain versions of that constraint. Their ancestors were followed by Neoptera, the insects able to flex the wing base and lay the wings back over the abdomen. Folding made flight compatible with concealment. An animal could fly to bark, then crawl beneath it without dragging two exposed sails. That change sits behind most living insect diversity.

Carboniferous and Permian forests also produced the famous giants. Griffinflies related to dragonflies reached wingspans above half a metre.

High atmospheric oxygen probably helped large tracheal breathers, but it did not act alone. Temperature, development, habitat and the later spread of flying vertebrate predators also changed the feasible body size. The lesson is not that oxygen once made insects enormous. It is that the same respiratory design operates inside an environment that sets different limits at different times.

Folding, shields and one-pair flight

Once wings existed, lineages modified them rather than pursuing one ideal aircraft. Beetles hardened the front pair into elytra. These covers sacrifice some lifting surface but protect the abdomen and the folded hindwings while the animal tunnels, digs or pushes through litter. The result works in wood, soil, dung, carcasses, freshwater and flowers. That combination helped beetles become one of the largest named animal orders: a flying body could also be armoured for close work.

Flies chose another compromise. Their forewings provide lift; the hindwings became halteres. Each haltere swings during flight and detects rotation through forces acting on its base. The nervous system uses that signal to correct turns and disturbances. A housefly's irritating ability to leave just before a hand arrives is partly the product of a fast visual system joined to this mechanical gyroscope.

True bugs altered the mouth more than the wing. Their piercing and sucking apparatus reaches plant sap, seeds, blood or other insects. Grasshoppers and crickets kept chewing jaws and enlarged hind legs. Lacewings and beetles produced predatory larvae unlike their adults. Dragonflies remained aerial hunters whose aquatic young dominate small underwater spaces.

This is how orders form in practice. A major inherited innovation changes the range of workable designs. Descendant lineages then combine it with different mouthparts, development, habitats and behaviour. The result is not a ladder from crude to advanced. Mayflies are not failed beetles, and cockroaches are not waiting to become ants. Each living order is the surviving tip of a separate history.

Surviving the great edits

Insects passed through mass extinctions that removed many other lineages, but survival did not leave the community unchanged. The end-Permian crisis about 252 million years ago disrupted terrestrial ecosystems on a scale difficult to reconstruct from the patchy insect record. Several ancient orders vanished. Possible advantages included small bodies, flexible diets, resistant eggs, aquatic stages and wide geographical ranges, though the fossil record cannot assign one survival mechanism across every group.

The Triassic and Jurassic worlds then reorganised around new forests, new predators and new opportunities. Beetles diversified through decaying wood, fungi and plants. Early flies spread through wet habitats and rotting material. Wasps developed the parasitoid strategy in many forms: the adult locates another arthropod, places an egg on or inside it, and the larva develops by consuming the host. This is predation delayed and specialised enough to generate an immense hidden diversity.

Complete metamorphosis had appeared earlier, but its lineages became increasingly prominent. The advantage was not a miraculous pupa. It was the ability to let larval and adult structures respond partly independently. Selection could improve a grub for feeding beneath bark without preserving that shape for flight. It could improve an adult for mating and dispersal without asking it to grow through the same machinery. The developmental boundary opened room for divergence.

The young still paid for the adult. A poorly fed larva may emerge small, short-lived or with fewer eggs. Parasites and toxins can cross the transition. Metamorphosis separates tasks; it does not erase history.

Flowers open, insects divide the market

Flowering plants expanded sharply during the Cretaceous. Their leaves, wood, pollen, nectar, fruit and seeds created new resources, while their chemistry created barriers that rewarded specialisation. Insects were already diverse, and flowering plants were not a single switch that caused the modern fauna. The two groups nevertheless entered an extraordinary period of ecological sorting.

Moths and butterflies developed scales on the wings and a coiled feeding tube in most adults. Their caterpillars kept chewing mouthparts and became close readers of host plants. Bees emerged from predatory wasp ancestors and shifted towards collecting pollen and nectar for their young. Flies, beetles, wasps and true bugs also became pollinators. Flowers recruited many kinds of carrier before humans decided the story belonged to honeybees.

The exchange created both generalists and locked pairs. A hoverfly can visit several flower shapes. A fig wasp must enter a fig's enclosed flowering structure. Some orchids deceive male insects with chemical and visual signals rather than paying nectar. Some plants trap visitors temporarily to ensure contact with pollen. Pollination is cooperation only at the level where both lineages reproduce. At the moment of contact, each partner is pursuing its own advantage.

Herbivory generated a second set of networks. Plant toxins selected for detoxification, avoidance and sequestration. An insect able to tolerate a compound could gain a private food source and then use the toxin against predators. Predators answered with learning or counter-adaptation. Parasitoids followed the herbivores by smell, vibration or chemicals released from damaged plants. A leaf became a meeting place for several levels of information.

The great living orders

By the Cenozoic, after the extinction that ended the non-avian dinosaurs, the main architecture of the living insect fauna was in place. Beetles occupied almost every land and freshwater substrate. Flies included pollinators, decomposers, predators and blood feeders. Butterflies and moths linked specialised larvae to mobile adults. Wasps, ants and bees combined parasitoids, herbivores, pollinators, predators and social colonies. True bugs tapped fluids. Grasshoppers, crickets and their relatives processed vegetation and communicated through sound. Dragonflies, mayflies and caddisflies tied freshwater development to aerial adulthood.

Fresh water contains whole insect lives. Mayfly, stonefly, caddisfly, dragonfly and mosquito young spend much or all of their juvenile stages in ponds, streams or water held by plants. Depending on the group, they graze algae, shred fallen leaves, filter particles or hunt other animals. When winged adults emerge, part of that aquatic production moves onto land, where spiders, birds and bats consume it. The life cycle ties a stream to its banks.

Reproduction links adult signals to the next usable patch. Crickets sing, moths release pheromones, fireflies flash and many insects send courtship vibrations through leaves or stems. Recognition must be selective enough to find the right species and flexible enough to work in wind, darkness or vegetation. After mating, egg placement becomes the decisive choice. An ovipositor may put offspring into soil, water, plant tissue, dung or a living host. The adult can fly widely, but the egg commits the juvenile to one place.

The familiar adult can hide the dominant stage. Many mayflies spend months or years underwater and hours or days as winged adults. Periodical cicadas remain underground for thirteen or seventeen years, feeding from roots, then emerge in synchrony, mate and die within weeks. Some female scale insects settle on plants, lose obvious mobility and become egg-producing bodies beneath protective coverings. Male scale insects may be tiny winged adults that do not feed.

Season is part of anatomy. Insects survive winter or drought as eggs, larvae, pupae or adults according to species. Diapause is a regulated pause in development and metabolism triggered before conditions become lethal, often by day length. It is not the same as being chilled into inactivity. The animal uses reliable cues to prepare for an unreliable future.

These life histories help explain how several insects can share one tree without sharing a life. One uses spring buds, another summer leaves, another dead wood, another prey beneath the bark. Time divides habitat as effectively as space.

Societies without managers

Social living appears in many degrees. Some insects aggregate because a resource is concentrated. Others guard eggs or feed young. Eusociality adds cooperative brood care, overlapping generations and reproductive division. The full arrangement evolved independently in several branches of bees and wasps, in ants, in termites and in a few other insects.

Termites demonstrate how misleading appearance can be. They were once classified as a separate order but are now placed within cockroaches. A termite colony is therefore a cockroach lineage that evolved permanent family societies, gut partnerships able to process difficult plant material and castes suited to reproduction, work or defence. Both sexes can become workers and soldiers, unlike the female worker systems of ants and most eusocial bees and wasps.

Colonies expand what an insect body can build and defend. Leafcutter ants harvest vegetation to feed cultivated fungi rather than eating the leaves directly. Termites move soil and regulate gases through mound and nest structures whose operation depends on species and site. Honeybees store enough concentrated food for a perennial colony to survive seasons when flowers disappear.

Yet the superorganism metaphor has limits. A colony is made of related individuals whose interests overlap without becoming identical. Workers may lay eggs. Reproductives can compete. Colonies rob, raid and fight.

Cooperation persists because ecology, kinship, policing and developmental control make it productive, not because individuality has vanished.

Humans enter the network

People met insects as food, nuisance, material, omen and disease long before entomology existed. Ancient Chinese sericulture turned the silkworm's cocoon into a textile industry and gradually made the domesticated moth dependent on human care. Beekeeping converted stored nectar into honey and wax. Lac insects supplied resin. Scale insects such as cochineal produced dyes. Insects also ate grain stores, damaged crops and moved pathogens through settlements.

Agriculture enlarged both sides of the bargain. A field concentrates one plant across an area, offering a specialist herbivore a resource abundance rarely found in wild vegetation. Planting dates, irrigation and stored harvests extend the opportunity. Farmers respond with cultivation, barriers, resistant varieties, predators, timing and chemicals. The pest is therefore not a fixed biological category. It is an insect whose abundance and behaviour collide with a human objective.

Scientific entomology grew through cabinets, microscopes, field collections and experiments. Classification supplied names, but insects also became tools for discovering general biology. In the early twentieth century, Thomas Hunt Morgan's laboratory used the vinegar fly *Drosophila melanogaster* to connect inherited traits with chromosomes. Short generations and visible mutations made crosses legible. Later work on flies helped expose developmental genes shared far beyond insects, including genes that help organise animal body plans.

Disease research made another relationship visible. Mosquitoes, fleas, lice, sand flies and tsetse flies do not manufacture the pathogens they transmit. They act as biological or mechanical bridges whose feeding, physiology and distribution complete a transmission cycle. Breaking that cycle can involve nets, housing, drainage, treatment, vaccination where available, targeted insect control and surveillance. Killing every insect in a district is neither

possible nor necessary.

Chemicals, resistance and restraint

The twentieth century made insect control fast. Synthetic insecticides could suppress mosquitoes, crop pests and household infestations across large areas. DDT had major public-health and agricultural effects, especially before resistance spread, but persistence and movement through food webs also exposed non-target costs. Later compounds offered different modes of action, durations and risks. None escaped evolution.

Resistance begins with variation. A rare insect may detoxify a compound more effectively, carry a changed target site, avoid treated surfaces or reduce penetration through the cuticle. Spraying kills susceptible individuals and leaves a larger share of resistant ones to reproduce. Repeated use of the same mode of action turns control into selection. Resistance can also carry costs, so rotations, refuges and reduced exposure can change how quickly it spreads, but no schedule guarantees reversal.

Broad treatment can remove natural enemies that were suppressing the target. A secondary pest may then increase. Pollinators may encounter residues through flowers, dust, soil or water. The practical question is therefore not whether a chemical is good or bad in the abstract. It is which organism, dose, route, timing and landscape produce which benefit and harm.

Integrated pest management emerged from that accounting. Monitor the organism and damage. Identify a threshold at which intervention is justified. Use crop rotation, sanitation, resistant varieties, biological control and physical methods where they fit. Choose targeted chemicals when needed, then evaluate what happened. The method does not ban pesticides and does not promise a farm without insects. It replaces automatic treatment with diagnosis and a sequence of options.

The same logic works in homes and public health. Remove standing water that produces mosquitoes. Seal entry points before fogging a room. Confirm bedbugs before applying treatments. Preserve predators where they are

helping. An insect problem becomes manageable once the life cycle, source and threshold are known.

The present change

Industrial landscapes alter insects through several channels at once. Large uniform fields reduce plant diversity and remove uncultivated edges.

Mowing and tidying can erase stems, leaf litter and bare ground used for nesting or overwintering. Artificial light pulls nocturnal insects away from feeding and mating, changes predation and can make a bright corridor behave like a barrier. Roads, drainage and buildings divide small habitats whose residents may disperse poorly despite belonging to a flying class.

Climate change shifts development, emergence and range. Some warm-adapted species expand. Cold-adapted or moisture-dependent insects lose suitable conditions. A pollinator and flower may respond differently to temperature and day length. A pest can gain extra generations in a longer season while its natural enemy does not. These are specific mechanisms, not one universal direction.

Monitoring has found severe losses in some places and stability or increase in others. Common species can decline while local species counts change little. Some monitored freshwater assemblages have recovered after pollution controls even as farmland moths have fallen elsewhere. A city can gain generalists and lose specialists. The correct response is neither reassurance from one increasing insect nor apocalypse from one collapsing trap sample.

The causal sequence ends where it began. The insect advantage was the ability to divide land into fine opportunities and pass through several bodies in one life. The modern danger is that each opportunity can disappear separately. A meadow with flowers but no nesting ground, a pond without emergence plants or a hedge cut before overwintering may retain the appearance of habitat while breaking the route through it.

How we know

Insect history is reconstructed from several incomplete records.

Compression fossils preserve wings and outlines. Amber can retain hairs, mouthparts, parasites and behaviour frozen in contact, but it samples resin-producing forests rather than the whole world. Molecular phylogenies compare living genomes and estimate branching dates with models calibrated by fossils. Developmental genetics tests which structures share underlying programmes. No source alone settles wing origins, early dates or the causes of large radiations.

Living insects are measured with nets, traps, counts, acoustic sensors, museum collections, experiments and DNA barcodes. Each method selects. Light traps favour insects attracted to light. Malaise traps catch particular flying routes. Butterflies are monitored better than soil larvae or tropical canopy species. Biomass, abundance, occupancy, richness and ecological function answer different questions.

Confidence is strongest where anatomy, fossils, genes and observed development agree. It is weakest where soft bodies rarely fossilise, tropical sampling is sparse or a global total must be inferred from a few intensive sites. New barcoding and imaging can enlarge the inventory quickly. They do not remove the need to state what was sampled, where, when and by which method.

What People Get Wrong

"Every bug is an insect"

The household category bug means small, jointed and unwanted. Biology is less forgiving. Count the adult legs first: an insect has three pairs attached to the thorax, one pair of antennae, and three main body regions. Spiders and ticks have eight legs and belong to the arachnids. Centipedes and millipedes carry legs along many body segments. Woodlice are land-living crustaceans. Worms are outside the arthropods altogether.

Entomologists then make the word bug narrower than ordinary speech. Hemiptera is the order commonly called the bugs, all with piercing and sucking mouthparts. In stricter usage, true bug refers to the heteropteran branch that includes shield bugs and bedbugs; aphids and cicadas are hemipterans outside that branch. Beetles, flies, ants and butterflies are neither. The naming is historical rather than a claim that one group is more authentic.

The distinction matters when action depends on identity. A pesticide, trap or habitat change aimed at a fly may fail against a mite. A red insect with black spots may be a ladybird predator or an unrelated plant feeder. Counting legs and locating the antennae is not pedantry. It is the beginning of diagnosis. Immature forms complicate the job, since a larva may look nothing like its winged adult, but the relationship still determines what control or protection will work.

"A caterpillar dissolves into soup"

The image survives because a pupa looks still while the adult emerges transformed. Some larval tissues do break down, and their materials can be reused. That is far from a bag of undirected liquid.

Metamorphosis is controlled remodelling. Hormones alter which genes are active and when. Adult structures grow from tissues established earlier, while parts of the gut, muscles and nervous system are retained, reorganised or replaced to different degrees in different species. The pupa continues to regulate gas exchange and water balance. Some pupae wriggle, rotate or respond to threat. Developmental biologists can follow cell lineages and gene activity through the transition, revealing a timed programme rather than a disappearance.

The adult is not a complete miniature waiting inside the caterpillar. Nor is it assembled from nothing after the larva vanishes. Developing adult tissues, surviving larval structures, stored nutrients and extensive cell death all contribute to the change. Different insects remodel different organs in different ways, which is why one slogan cannot describe every pupa.

The correction matters because metamorphosis is the insect achievement, not a biological magic trick. One genome constructs successive specialised bodies through an ordered transition. The apparent stillness hides development; it does not erase continuity.

"Insects are mindless reflex machines"

Reflexes matter to every nervous system. A fly's rapid escape and a moth's turning response can be studied as compact sensor-to-action circuits. It does not follow that all insect behaviour is fixed.

Bees, wasps, ants and flies can learn odours, colours, routes and reward patterns. Some generalise from training, reverse a learned choice when conditions change or use social information. Bumblebees have solved unfamiliar object tasks in laboratories. Honeybees trained on relative number have treated an empty set as less than one. These are real capacities under defined conditions.

The inflation comes next. A bee succeeding in a task designed by humans does not prove that it understands zero as a mathematician does, possesses language or can reason across any domain. Nor does flexible behaviour by itself settle whether insects are conscious or feel pain. Those questions require separate evidence and remain debated.

The useful correction is neither tiny genius nor biological robot. Insect brains are specialised, plastic systems. Their size tells you little until you know the problem, senses, circuitry and test. A capacity that looks modest in a box may be exactly what navigation, foraging or courtship requires in the field.

"The queen commands the colony"

The title queen smuggles a palace into an insect nest. In ants, honeybees and termites, the principal reproductive female can be indispensable. She produces eggs and chemical signals linked to fertility, caste behaviour and colony organisation. She does not issue instructions to named workers.

Workers respond to local information. Food odour, brood hunger, nest temperature, encounters with other workers and the strength of a

pheromone trail alter what each animal does. Recruitment grows when a resource is profitable and fades when it is not. Honeybee scouts advertise possible nest cavities; support shifts through repeated visits until one site reaches a quorum. Termite builders react to nearby material and signals rather than reading a central plan.

Queens still influence the system, and colonies are not pure democracies. Reproduction is highly unequal, larvae can be channelled into castes, and workers may police one another's eggs. The correction is about mechanism. Central reproductive status is not central executive control.

This matters because distributed order is easy to misread. A coordinated result can emerge from many partial decisions without any participant holding the complete design. The colony is organised, but organisation need not mean command.

"Honeybees are the world's pollination system"

Honeybees are efficient, manageable and familiar. Colonies can be moved into crops, their honey is valuable, and their waggle dances made them famous. The result is a conservation logo that places one social species in front of an enormous ecological process.

Wild pollination is shared among solitary bees, bumblebees, flies, beetles, moths, butterflies, wasps and other animals. Which visitor matters depends on flower shape, season, weather, geography and crop. Across forty-one crop systems, wild insect visitation improved fruit set independently of honeybee visitation. Managed honeybees remain useful, but adding hives does not replace nesting habitat, continuous forage or the insects adapted to plants honeybees use poorly.

The category can also hide geography. The western honeybee, *Apis mellifera*, is native across much of Europe, Africa and western Asia, but managed populations are introduced elsewhere. High hive densities can compete with wild insects for flowers or move pathogens, with effects that vary by setting.

Saving pollination means protecting a network, not installing one branded bee everywhere. A hive is livestock. A pollinator community is habitat, seasons and many life cycles. Crop service and wild-plant reproduction overlap, but they are not interchangeable conservation targets.

"Most insects are pests"

Pests dominate attention because they impose visible costs. A moth in stored grain, an aphid-covered crop or a mosquito bite announces itself. The insects decomposing waste, feeding birds, moving pollen or being eaten by other insects usually work outside human notice.

Pest is a relationship, not a taxonomic rank. A bark beetle in a forest helps process dead wood; at outbreak density, some species can kill living trees across large areas. A caterpillar on its native host is part of a food web; on a commercial crop it may cross an economic threshold. Even a useful predator can become unwelcome inside a house.

The repeatedly managed species form a narrow slice beside more than a million described insects, but no stable global percentage is available. Definitions change with place, abundance and human purpose. That slice still matters enormously. Romanticising insects would be as foolish as treating all of them as enemies.

The correction changes control. Identify the organism and the damage before acting. Preserve predators and pollinators where possible. Treat a verified problem at the stage and scale where intervention works. The category pest should begin a diagnosis, not end one.

"Insect decline is one global percentage"

A single rate is attractive because it turns a sprawling biological change into one dial. The data do not supply that dial. Studies sample different places, seasons and groups with different traps. Some measure individuals, some biomass, some occupancy and some species richness. A falling count of common moths is not the same result as the disappearance of species.

Severe losses are established in particular records. Protected-area traps in

western Germany found a large fall in flying-insect biomass over twenty-seven years. Thirty-five monitoring programmes found a broad decline in butterflies across the contiguous United States from 2000 to 2020. A wider synthesis found losses concentrated especially among formerly abundant terrestrial species, but its usable records were heavily biased towards Europe and North America.

The urge to manufacture a world rate has already caused trouble. A 2020 global meta-analysis was corrected in its publication year and received an editorial expression of concern in January 2026 after further methodological criticism. That does not reverse the regional studies or prove that unmonitored insects are safe. It means the headline estimate should not be repeated as a planetary law.

The conclusion is narrower and more useful. Many insect populations are in serious decline; some populations are stable or increasing; the causes and measurements differ by place; tropical, soil and canopy insects remain poorly monitored. Precision is not reassurance. It tells conservation which link, taxon and landscape may be failing.

Use It

Find the whole life cycle

An adult is often the least informative part of an insect problem. The adult clothes moth near a wardrobe did not chew the wool; its larva did. The mosquito biting at dusk developed in water. The beetle emerging from timber may be leaving damage made by its larva months earlier. Begin by asking where the eggs are placed, what the young eat, where each moult happens, how the pupa or resting stage survives and what lets the adult disperse.

This changes both control and conservation. Removing adult flies while leaving wet organic material treats the symptom. Planting nectar flowers for a butterfly while removing its caterpillar's host plant creates a feeding stop, not a population. Clearing every dead stem in autumn may erase

overwintering chambers before spring adults appear.

The portable rule is to draw the sequence. Egg, juvenile stages, transition, adult, next egg. Put habitat, food, season and main risk beside each stage. The weakest link usually explains why an insect is abundant, absent or difficult to manage.

Ask what scale the animal inhabits

A garden looks continuous to a person and fragmented to a ground beetle. A hedge can be a continent, a road a sea and one damp hollow a refuge from a hot afternoon. Before judging an intervention, shrink the map to the animal's operating scale.

That means measuring conditions where the insect experiences them. Air temperature from a nearby weather station may miss the leaf surface, soil crack or tree cavity that controls development. A pesticide applied to a field can reach pollen, ditch water or dust at concentrations and times unlike the average. A patch described as small may contain every resource a specialist needs; a large lawn may contain none.

Scale also changes danger. Surface tension can support a springtail and trap another insect. A raindrop can dislodge a tiny flier. Wind across bare ground can make two flower beds functionally disconnected. Ask which distance, temperature, moisture and structure matter to the body in question, not to the observer standing above it.

Follow the relationship, not the specimen

Collecting or photographing one insect can tell you its shape. It may tell you little about its place in the system. Ask what it is eating, what eats it, which plant receives or loses pollen, which host carries its offspring and which signal led it there.

This lens prevents easy moral categories. An aphid is a plant feeder, food for a ladybird and a source of honeydew for ants. The ant may protect it from predators. A parasitoid may develop inside it. A flower visitor may pollinate one plant and rob nectar from another without touching the

reproductive parts. Function belongs to an interaction, not to a species name in isolation.

The same rule improves diagnosis. If a crop pest rises, look for changes in its host, predators, planting schedule, weather and surrounding habitat. If a pollinator disappears, count more than flowers. Find nests, larval food and the route between them. The relationship is where cause becomes visible.

Separate diversity, abundance, biomass and function

Four questions that sound alike can produce opposite answers. How many species are present? How many individuals? How much living mass? What ecological work is being done? Never let one answer stand in for the others.

A site can retain twenty species while losing most individuals because rare species remain and a once-common species collapses. Biomass can rise if a few large insects replace many small ones. Pollination can fall even when bee counts look stable if the missing species visited different plants or worked in colder weather. A pest outbreak can increase abundance while reducing diversity.

Choose the measure that matches the claim. A windscreen memory concerns large flying insects encountered by cars. A light trap samples insects attracted to a particular lamp. A butterfly transect says little about soil-dwelling beetles. DNA barcodes can reveal hidden diversity without measuring population size.

This discipline applies beyond insects. A total can be accurate and still answer the wrong question. State the unit, method, place and period before deciding what changed.

Replace eradication with thresholds and diagnosis

The presence of an insect is not proof that intervention is justified. A few chewed leaves may have no material effect on yield. One wasp at a window may be searching for an exit. Treatment has costs, and broad treatment can remove predators, pollinators and susceptible competitors while selecting resistant survivors.

Start with identity. Then measure damage, risk or transmission rather than disgust. Establish the level at which harm exceeds the cost of action.

Remove the resource or entry route where possible. Use timing, barriers, sanitation, habitat management or biological control where they fit. Apply a targeted chemical when the expected benefit is greater than the likely collateral cost, and check whether it worked.

Some situations demand low tolerance. A confirmed disease vector in a high-risk setting, an invasive species near eradication or bedbugs in a home cannot be managed like cosmetic leaf damage. The threshold is contextual, not lenient. The gain comes from making it explicit.

Eradication is a result, not a default method. Most useful insect management is continued pressure on a population while preserving the rest of the system.

Design continuity through time

Habitat is a calendar. A meadow rich in flowers for two weeks can still fail insects that need food from early spring to autumn. A pond may support larvae and strand emerging adults if its margin is cut at the wrong time. A dead tree removed after eggs are laid can become a trap whose occupants never complete development.

Map resources by month and life stage. Leave some stems, litter, bare ground, cavities and dead wood where safety allows. Stagger mowing rather than resetting every patch at once. Keep connections between nesting, feeding and overwintering sites. In farmland or cities, small areas can matter when they form a sequence rather than isolated decoration.

Continuity does not mean freezing a landscape. Disturbance creates open soil, new growth and temporary water used by many insects. The aim is variation in timing and intensity so that every refuge is not removed together. A system can tolerate local change when another suitable stage remains within reach.

The design question is therefore not how natural a place looks. It is whether an insect can finish its route through the year.

The limits

Insects do not provide a moral or engineering template for human life. Ant colonies are efficient at some tasks because reproduction is concentrated, workers are replaceable and individuals operate through inherited rules in environments that repeatedly killed failed colonies. None of that recommends organising a company, city or family like an anthill.

The subject also resists one cause. Flight, metamorphosis, smallness, plant relationships and sociality each explain parts of insect success. No one feature generated millions of species by itself. Similar traits can succeed in one lineage and fail in another because history and environment differ.

Practical action remains local. A flower strip, reduced pesticide use or darker night may help some insects and disadvantage others. Disease control can require killing vectors. Invasive insects can destroy habitats that native species need. Conservation choices contain conflicts, costs and uncertainty.

Finally, the evidence is uneven. Temperate butterflies and moths are easier to monitor than tropical canopy larvae, soil insects or parasitoids inside hosts. Numbers from one trap cannot carry the planet. The proper response is better measurement and narrower claims, not paralysis.

The one thing to keep

Keep the route.

The insect in front of you is one temporary body in a chain of places, stages

and relationships. The adult bee contains a larva that needed pollen in a nest. The butterfly contains a caterpillar that needed a particular plant. The dragonfly over a path contains an aquatic predator that climbed from a pond. The wasp on a flower may contain a search for a host its offspring will consume.

This is why insects can seem everywhere and vanish without the landscape looking empty. The flower remains after the nesting bank is paved. The tree remains after dead wood is cleared. The pond remains after drought shifts its timing. Human eyes see the object still standing. The life cycle sees a broken connection.

Once that model is installed, ruling the planet looks different. It is not command from above. It is access to countless small routes through matter, season and other lives. Insects became the tiny majority by dividing those routes more finely than any other animal group.

See the route and you can understand the success, locate the harm and notice the loss before the final adult disappears.

Terms

Arthropod

An animal with a segmented body, jointed appendages and an external cuticle. Insects, spiders, centipedes and crustaceans are arthropods, which explains their shared machinery and important differences.

Hexapod

A six-legged arthropod. Insects are hexapods, but springtails and two smaller wingless groups sit outside Insecta in many classifications. The term helps separate ancestry from familiar appearance.

Insect

A hexapod whose adult body is organised into head, thorax and abdomen, with three pairs of thoracic legs and one pair of antennae. Wings are common, not required.

Cuticle

The layered covering secreted by the epidermis. It supports the body, anchors muscles, protects tissues and limits water loss. Its rigidity makes periodic moulting necessary for growth.

Exoskeleton

A supporting structure outside the living tissues rather than an internal bony frame. In insects it is formed by specialised cuticle, joints and flexible membranes, not one solid shell.

Chitin

A tough carbohydrate polymer found in arthropod cuticle and fungal cell walls. Mixed with proteins and other materials, it helps produce coverings that can be flexible, hard or light.

Ecdysis

The act of shedding the old cuticle during a moult. The insect then expands the new soft covering before it hardens, creating a brief period of unusual vulnerability.

Instar

One developmental stage between two moults. Counting instars clarifies growth because a larva may change shape, behaviour and diet several times before pupation or adulthood. The number can be fixed or environmentally variable.

Thorax

The middle body region, built from three segments and carrying all six legs. Wings, when present, attach to the second and third thoracic segments, concentrating locomotion in one module.

Abdomen

The rear body region, containing much of the digestive, excretory and reproductive machinery. Spiracles often open along it, and its appendages may be reduced or highly specialised.

Spiracle

A controlled opening through which air enters or leaves the tracheal system. Valves and opening patterns help balance oxygen demand against the danger of losing water, especially in dry air or during intense activity.

Trachea

One of the branching air tubes that carry gases between spiracles and tissues. The system places oxygen close to working cells and helps define insect performance and size constraints.

Haemolymph

The circulating fluid of an insect's open circulatory system. It moves nutrients, hormones, immune cells and waste, but in most insects carries little of the oxygen used by tissues.

Diapause

A programmed pause in development and metabolism that prepares an insect for an unfavourable season. It is often triggered by cues such as day length before cold, drought or food shortage arrives, and can occur in the egg, juvenile, pupal or adult stage.

Compound eye

An eye composed of many optical units called ommatidia. It provides a broad field and strong motion detection, while spatial detail, colour range and sensitivity vary greatly by species.

Antenna

A paired sensory appendage on the head. Antennae detect combinations of odour, touch, air movement, vibration, heat and humidity, making them central to navigation, feeding, mate choice and communication.

Mandible

One of a paired set of jaw-like mouthparts. Mandibles can cut leaves, crush prey, move soil, defend nests or manipulate brood, showing how inherited appendages acquire new tasks.

Proboscis

An elongated feeding structure, built differently in different orders. Butterfly mouthparts form a coiled drinking tube, while mosquito piercing elements create a more complex bundle of stylets.

Elytron

One hardened forewing of a beetle. The paired elytra cover the abdomen and folded hindwings, allowing a flying animal to crawl, dig or tunnel with protected flight equipment.

Haltere

One of the small balancing organs formed from the hindwings of true flies. Halteres oscillate during flight and sense rotation, supplying rapid information used to stabilise manoeuvres.

Nymph

An immature stage in an insect with incomplete metamorphosis. A nymph resembles the adult in broad plan but lacks full wings and reproductive maturity, changing through successive moults.

Larva

A specialised juvenile form, often unlike the adult. Caterpillars, grubs and maggots concentrate on feeding and growth, allowing the later adult to use a different body and habitat.

Pupa

The reorganising stage between larva and adult in complete metamorphosis. It may appear still, but regulated cell death, tissue remodelling and adult development continue inside, fuelled largely by resources gathered during larval life.

Hemimetaboly

Development through egg, nymph and adult without a pupal stage. Wings and adult features appear gradually across moults, although aquatic nymphs can still differ sharply from aerial adults.

Holometaboly

Development through egg, larva, pupa and adult. Complete metamorphosis lets juvenile and adult bodies specialise for different tasks and characterises most described insect species, including beetles, flies, moths, ants, bees and wasps.

Ovipositor

An egg-laying structure formed from abdominal appendages. It may place eggs in soil, plants or hosts, and in many wasps is related to the apparatus modified into a sting.

Pheromone

A chemical signal released by one member of a species and detected by another. Pheromones can organise trails, mating, alarm, aggregation, caste development or reproductive status.

Eusociality

A social system with cooperative brood care, overlapping generations and reproductive division of labour. It evolved independently in several insect lineages and permits long-lived, organised colonies whose members can specialise in reproduction, defence, care or foraging.

Parasitoid

An organism whose juvenile develops on or inside one host and ultimately kills it. Many wasps and some flies use this strategy, linking predation to extreme host specialisation.

Integrated pest management

A decision system combining identification, monitoring, action thresholds and compatible cultural, biological, physical and chemical controls. It aims to manage harm while reducing needless treatment and resistance selection.

Go Deeper

The inviting tour

Anne Sverdrup-Thygeson, *Extraordinary Insects: Weird. Wonderful. Indispensable. The Ones Who Run Our World* (Mudlark, 2019), translated by Lucy Moffatt. Start here if the examples in this book made you want to look more closely. Sverdrup-Thygeson moves quickly through pollinators, decomposers, parasites, chemical defences and strange life cycles without turning the subject into a textbook. The selection is deliberately spectacular, so use it as an opening into insect variety rather than a balanced guide to every order. It is the easiest of these four to read in short stretches and the likeliest to send you outside with a hand lens and a better question.

The experimental naturalist

Thomas Eisner, *For Love of Insects* (Belknap Press of Harvard University Press, 2003). Eisner helped found chemical ecology, and this book shows how the field is made: observe a beetle, ask what a secretion does, design an experiment, and follow the result into another species. Bombardier beetles, moths, spiders and plants become participants in testable exchanges rather than cabinet specimens. The prose is accessible, while the experiments retain enough detail to reveal how evidence is built. It is strongest on defence, predation and chemical signalling, not as a complete survey of anatomy, development or deep history.

The deep history

David Grimaldi and Michael S. Engel, *Evolution of the Insects* (Cambridge University Press, 2005). This is the large scholarly map: fossils, relationships, wing origins, metamorphosis, major orders and the radiations that produced modern diversity. The illustrations and fossil record make it valuable even when the technical sections outrun a general reader. Some phylogenetic details and divergence dates have changed through later genomic work, so treat it as a major synthesis from its period rather than the last word. Read selected chapters beside current papers instead of attempting the volume straight through on a first visit to the subject.

The warning

Dave Goulson, *Silent Earth: Averting the Insect Apocalypse* (Jonathan Cape, 2021). Read this for the conservation case, the pressures behind documented losses and the practical argument for changing farms, gardens, lighting and pesticide use. Goulson writes as a scientist and campaigner, and the urgency is intentional. The evidence is strongest in Europe and North America, while global monitoring remains uneven and no single decline rate describes all insects. That limitation does not cancel the regional records. It tells you to read the book as a forceful brief for action, checked against the expanding literature, rather than as a complete global census of insect change.

Notes and Sources

Scope and terminology

This book uses insect for the class Insecta and hexapod for the wider six-legged lineage that also contains springtails, proturans and diplurans. Relationships among the earliest branches have changed with molecular analysis, but the basic adult insect plan used here is stable: three main body regions, three pairs of thoracic legs and one pair of antennae. General anatomy, physiology, development, signalling, reproduction, order-level diversity and applied entomology follow Gullan and Cranston, *The Insects*, and Chapman, *The Insects: Structure and Function*. Grimaldi and Engel provide the principal fossil synthesis, updated where later phylogenomics altered relationships or dates.

The subtitle uses majority in the defensible sense of described animal diversity and probable species richness. It does not claim that insects constitute most animal biomass, most individual animals under every counting method or most life on Earth. Rule refers to the number and importance of ecological relationships. The open ocean is a clear limit.

The Whole Thing in One Page and Why You Should Care

Species richness. Stork's 2018 review estimated about 5.5 million living insect species, with roughly one million then described. In 2026, Colwell and colleagues analysed 1,633,855 DNA-barcoded specimens representing 53,945 species-level clusters from fifteen core Malaise traps in Costa Rica's Area de Conservacion Guanacaste. They adjusted for undetected diversity using intensive records of microgastrine parasitoid wasps, estimated nearly 333,000 insect species in the protected area, then scaled that result against trees and several animal groups. The resulting 14.2 to 20.3 million global range is described by the authors as a lower-bound estimate. The manuscript treats it as a major model-based challenge, not a settled inventory, because it transfers an undersampling ratio from one wasp group and then transfers one tropical landscape to the world.

Ant abundance. Schultheiss and colleagues combined hundreds of studies to estimate almost twenty quadrillion ants and about twelve megatonnes of dry-carbon biomass. Sampling was concentrated in some habitats and regions, and subterranean and canopy ants remained difficult to count. The individual estimate is used as a scale anchor and is not extrapolated to insects as a whole. The phrase millions for every person avoids tying the comparison to a rapidly changing human-population denominator.

Flight and metamorphosis. The dates near 479 million years for insect origins and 406 million years for flight come from the molecular-clock analysis by Misof and colleagues. They are model estimates calibrated with fossils, not observed first appearances. Ohde and Prokop review current evidence that insect wings incorporated ancestral limb-associated structures into the body wall, while leaving important details unresolved. Rolff, Johnston and Reynolds support the statement that more than 80 per cent of described insect species undergo complete metamorphosis.

Pollination. Ollerton, Winfree and Tarrant estimated that 87.5 per cent of flowering-plant species receive animal pollination. IPBES reported that about 75 per cent of leading food crop types benefit at least partly from

animal pollination. These figures count plant or crop types, not the fraction of harvest mass, calories or human survival supplied by pollinators. Staple cereals are mainly wind-pollinated or self-pollinated, while many fruits, nuts, vegetables and stimulants are more dependent.

Malaria. The World Health Organization published *World Malaria Report 2025* on 4 December 2025. Its latest completed burden estimates cover 2024: 282 million cases and 610,000 deaths. Malaria is caused by *Plasmodium* parasites and transmitted by particular *Anopheles* mosquitoes. The wording separates pathogen from vector and does not imply that most mosquito species transmit human disease.

Bee cognition. Howard and colleagues trained honeybees on relative numerosity and found that they ordered an empty set below one in the tested task. Loukola and colleagues demonstrated social learning and improvement in a ball-moving task. Bhambore and colleagues reported in June 2026 that bumblebees trained to associate a blue floor ring with reward moved a ball beneath the ring after it was relocated to the ceiling. Hidden-target controls supported goal-directed action rather than movement guided only by immediate perceptual feedback. These experiments establish task-specific learning and flexibility. They do not establish human-like mathematics, language, general reasoning or consciousness.

Evidence for the seven ideas

Cuticle, respiration and scale. The description of cuticle as a chitin-rich composite, the mechanics of ecdysis, the tracheal system and the limited role of haemolymph in oxygen transport follow Chapman and Gullan and Cranston. Size limits are treated as multicausal. Elevated Palaeozoic oxygen probably contributed to giant insects, but tracheal geometry, development, temperature, ecology and predation also affected viable size. The manuscript avoids the common claim that oxygen alone explains every giant form.

Wing origins and flight mechanics. Ohde and Prokop summarise the current composite account of wing origins. The uncertainty concerns the

exact tissues, sequence and original function, not whether flight transformed dispersal. The accounts of folding wings, elytra, halteres, indirect flight muscles and secondary wing loss follow standard comparative entomology. Haug and Haug are cited because their reassessment of *Rhyniognatha* shows why a fragmentary fossil should not be treated as a secure first flying insect.

Metamorphosis. Rolff and colleagues and Truman support the developmental and endocrine account. Hall and Martin-Vega show why the popular soup description fails: some tissues undergo extensive cell death, while others persist, reorganise or develop into adult structures. The final text does not claim that larval memories survive metamorphosis because results vary by species, task and mechanism and are unnecessary to the explanation.

Plants and diversification. The manuscript treats plant-insect coevolution as a mosaic rather than a universal reciprocal radiation. Suchan and Alvarez found weak broad support for the strongest co-diversification account. Peris and Condamine's fossil-based analysis found that flowering plants mitigated insect extinction in the Cretaceous and promoted origination more strongly in the Cenozoic, alongside temperature, existing insect diversity and other plant groups. Garibaldi and colleagues support the claim that wild-insect visitation improved fruit set across forty-one crop systems independently of honeybee visitation.

Signals, reproduction and societies. The accounts of cricket song, moth pheromones, firefly flashes, substrate-borne vibrations, mate recognition and oviposition follow the comparative treatments in Chapman and Gullan and Cranston. They are presented as widespread mechanisms with lineage-specific forms, not as universal behaviours. Inward, Beccaloni and Eggleton provide the molecular case for termites as eusocial cockroaches within Blattodea. Seeley's work on honeybee nest-site choice supports the distributed account of scouts, recruitment and quorum. Queen signals can affect worker physiology and reproduction, but detailed work allocation is not issued as a sequence of commands.

Open-ocean limit. Cheng and Mishra review the five *Halobates* species that live exclusively on the open-ocean surface. Many other insects tolerate salt marshes, shores or intertidal conditions but remain tied to land or coastal substrates. The evolutionary reasons for the scarcity of marine insects remain partly unresolved, so the manuscript uses the pattern without asserting a single cause.

Operating history and mechanisms

Early history. Molecular data place insects among pancrustaceans, nested among lineages traditionally called crustaceans. The Rhynie chert provides an approximate 407-million-year anchor for early terrestrial hexapods, including springtails rather than crown insects. The fossil record becomes clearer for winged insects in the Carboniferous. The sequence distinguishes molecular divergence estimates, first secure fossils and living lineages.

Orders, freshwater and life histories. The accounts of Neoptera, beetle elytra, fly halteres, hemipteran mouthparts, aquatic juveniles, dragonflies, parasitoid wasps, diapause, periodical cicadas and scale insects follow the comparative syntheses by Gullan and Cranston, Chapman, and Grimaldi and Engel. Aquatic larvae graze, shred, filter or prey according to group; adult emergence can transfer insect production from fresh water to terrestrial consumers. These examples illustrate mechanisms rather than serving as a complete order-by-order catalogue.

Flowers and diversification. Insects pollinated gymnosperms before flowering plants appeared, and most living orders began before the main angiosperm radiation. Peris and Condamine support the later, mixed effect of flowering plants. This is why the chronology avoids saying that flowers created insects or that modern diversity came from one paired radiation.

Human use and research. Silk, honey, wax, lac and cochineal are long-standing insect products covered in general entomological histories. The account of *Drosophila melanogaster* refers to the early twentieth-century chromosome work associated with Thomas Hunt Morgan's laboratory and the later use of flies to uncover conserved

developmental genes. No claim is made that one organism or laboratory created modern genetics alone.

Vectors. The account separates pathogen, vector, host and environment. Mosquitoes, fleas, lice, sand flies and tsetse flies transmit particular pathogens under particular conditions. Control can target any link in the transmission cycle. WHO provides the current malaria burden; the broader mechanism follows medical entomology in Gullan and Cranston.

Insecticides and integrated pest management. Stern and colleagues' 1959 paper established the integrated-control concept around economic thresholds and the combined use of biological and chemical methods. Current Food and Agriculture Organization and United States Environmental Protection Agency guidance supports identification, monitoring, prevention, thresholds and the use of lower-risk compatible methods before non-specific treatment. Integrated pest management does not prohibit pesticides. It changes the decision sequence and treats resistance and non-target effects as part of the problem. EPA guidance was current when checked on 4 September 2026.

What People Get Wrong and Use It

Bugs and true bugs. Hemiptera is commonly called the bug order. Stricter usage reserves true bug for Heteroptera, which includes shield bugs and bedbugs but not aphids or cicadas. Ordinary English uses bug much more broadly. The distinction is explained because identification determines life cycle, damage and control.

Pollinator substitution. Garibaldi and colleagues show that wild pollinators contributed to crop fruit set independently of honeybees. The manuscript therefore distinguishes managed honeybees, which can be valuable livestock, from the wider habitat requirements of wild pollinator communities. Competition and pathogen transfer from dense managed colonies vary by species and landscape and are presented as possible effects rather than universal outcomes.

Pests. No percentage is given for the share of insect species that are pests

because global denominators and definitions are unstable. Pest is treated as a relationship between an organism, its abundance and a human objective. A species can contribute to decomposition or food webs in one setting and cross an economic or health threshold in another.

Decline and data vintage. Hallmann and colleagues measured a 76 per cent seasonal decline in flying-insect biomass across twenty-seven years in protected areas of western Germany, with observations ending in 2016. Edwards and colleagues published in 2025 using 12.6 million butterfly records from more than 76,000 surveys in thirty-five programmes; the observation period was 2000 to 2020 and the estimated total abundance decline was 22 per cent across 554 recorded species. Van Klink and colleagues' 2024 synthesis analysed 923 long-term terrestrial assemblages and found declines concentrated especially among formerly abundant species, while warning that available data were strongly biased towards Europe and North America.

The widely repeated global trend estimate from van Klink and colleagues' 2020 *Science* paper was corrected in October 2020. *Science* then published an Editorial Expression of Concern on 22 January 2026 following further methodological criticism. The final manuscript does not repeat its rate as fact or use it to counterweight regional records. It retains the narrower conclusion supported across the remaining sources: severe declines occur in documented regions and groups, winners and losers coexist, causes interact, and global monitoring remains uneven.

Practical habitat and control. The life-cycle, scale, relationship and continuity lenses are deductions from the mechanisms in the book. They are not universal prescriptions. Flower strips, dead wood, reduced lighting, altered mowing or targeted control can help or harm different species depending on place and timing. The decision method is to identify the organism, map every life stage, specify the desired outcome and measure the relevant response.

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