Adaptations to aquatic life

For Alaska's aquatic insects, underwater is home; they are as comfortable in their liquid world as we are in the world of dust and sky. Like us, they breathe, move, feed, and endure by virtue of adaptations that suit them to their own particular niches in the aquatic landscape.

Breathing

As mammals, we get the oxygen we need by pulling air into our lungs. There, the oxygen diffuses through delicate membranes and into our blood. Our hearts pump the blood throughout our bodies, delivering oxygen to nerves, muscles, glands, and other tissues. Waste gases such as carbon dioxide are removed from the body by the same process in reverse.

Insects need oxygen, too, and they also must get rid of carbon dioxide. But their capture-and-transfer system is quite different from ours. Instead of arteries and veins, insects' bodies have air-filled tubes. Roughly similar in pattern to our blood vessels, the tubes divide into fine branches to reach individual cells. Thus, an insect's entire body is, in a sense, filled with air. Oxygen diffuses almost directly from the air into the tissues.

How does the air get inside the insect? In many insects (particularly terrestrial ones), the air tubes originate at small openings called spiracles in the exoskeleton. This lets the air around the bug exchange with air inside the bug. Although insects don't have lungs, some do assist air circulation with movements of their bodies.

This Whirligig Beetle has trapped a bubble of air at the end of its abdomen so it can obtain oxygen while underwater.

If you sneak up slowly on a Mosquito-filled pond, you may see the little snorkeling larvae resting just under the surface, and the surface film dimpled where their breathing tubes emerge.

Taking this system underwater means modifying it a little. That can be done by keeping at least some spiracles in touch with the air, or by developing ways to extract oxygen from the water.

Snorkelers

The aquatic larvae of some Mosquitoes and flower flies (the latter known rather unpoetically but descriptively as "Rattailed Maggots") keep spiracles in contact with the air through tubes. The tips of these tubes often have hairs that repel water, helping to keep them on the surface.

SCUBA divers

Other aquatic insects take the atmosphere with them when they dive, carrying along air bubbles next to their spiracles. For example, most adult water beetles trap bubbles of air under their wing covers or on the ends of their abdomens. The bellies of Water Boatmen and adult Riffle Beetles are covered with a dense growth of unwettable hairs, which trap a thin, silvery sheath of air called a plastron against spiracles on their abdomens.

Bubbles like this act a little bit like SCUBA tanks, but they're even better: as the insect uses oxygen from the bubble, more oxygen can diffuse in from the surrounding water. Only after the bubble collapses due to nitrogen diffusing out into the water does the insect have to return to the surface for more air. Watch the adult diving beetles in a pond as they pop to the surface to replenish their bubbles, or try to get a glimpse of a boatman's silvery, air-covered abdomen as the boatman darts below.

Gills and other adaptations

To eliminate the need to go to the surface, some aquatic insects have evolved the ability to get their oxygen from the water through special membranes. For example, dragonfly larvae gently inflate and deflate their abdomens to circulate water through internal gills. Many underwater breathers even have appendages (sometimes also called "gills") that can provide more surface area for oxygen to pass through. These appendages may look like paddles or leaves (as in damselflies and some mayflies), like tufts (some mayflies and stoneflies), or like tiny strands (in Black Fly pupae).

Underwater breathing specialists are more vulnerable to low oxygen levels in the water than "snorkelers" or "scuba divers." But most have strategies to help them breathe in lower oxygen environments such as warm, still water. Some of them make interesting motions to enhance their respiration: mayflies flap the gills along their abdomens, damselflies wave their tail-like gills, and stoneflies do "push-ups" to increase water flow and oxygen uptake in less-than-ideal conditions. A few types of beetles, flies, and Mosquitoes extract oxygen from aquatic plants, which produce oxygen as a byproduct of photosynthesis.

Locomotion

Alaska's aquatic insects have many different ways of exploring their world. Some drift with the whims of the current. Some scuttle, some squirm, some paddle. Some use jet-propulsion. And some pretty much just stay put until it's time to emerge as adults.

Scuttlers and squirmers

Six strong legs (or an assortment of leg-like appendages) can get you quite a ways underwater, and many aquatic insects rely on their appendages to crawl from food source to food source, or to scamper away from predators. Some use claws to cling to surfaces. Others burrow into sand or mud.

Swimmers

The ability to swim—even just a little—is very helpful to aquatic insects. If a bug can move about efficiently in the water by itself, it has access to more foods and other resources. It also has a means of escape from trouble.

The most rudimentary swimmers are those that wriggle vigorously to swim but don't really possess any specialized swimming structures. These include some Mosquitoes, and many mayflies and stoneflies. Some Mosquitoes and mayflies are actually quite good at this. They're able to dart quickly away from a curious finger probing in a collection pan.

Some aquatic insects are far more accomplished swimmers. The masters are Water Boatmen, Whirligig Beetles, and adult Predaceous Diving Beetles. They cruise through still waters with ease, propelling themselves with powerful beats of their long legs. The "rowing" legs of many of these master swimmers are lined with stout hairs that form paddle-like structures.

The overlapping gills surrounding the abdomen of this Flat-headed Mayfly work like a suction cup.

Damselfly larvae have three leaf-shaped gills at the tips of their abdomens. These gills also function as swim fins.

Dragonfly larvae do a lot of crawling. If they want to get somewhere in a hurry, they can inflate their abdomens with water, then squirt the water quickly out their rear ends, shooting forward as they fold their legs back to make themselves more streamlined.

Mosquito larvae are nicknamed "wrigglers" because of the motion they use to dart about. Water Boatmen (far right) use their long legs like oars to swim about.

Staying put

For insects that live in areas of strong current, one of the biggest challenges isn't moving around, but staying in place. Without adaptations to avoid being swept away, these bugs would be at the mercy of the stream. Many have flattened bodies, which makes them more streamlined as they cling to surfaces. Some cling tightly with stout claws and powerful legs. Others have strong hooks on the ends of their abdomens to anchor them in place. Still others have specialized suction structures that help them attach.

The larvae of Net-winged Midges live in very fast-flowing streams, and use suction cups (a) to hold themselves in place. A larva can create a vacuum in each cup as it is pressed down, forming a tight and stable seal.

Common Net-spinner Caddisflies use hooks (b) at the tip of their abdomen to cling to rocks in swift-flowing streams.

Drifters

Stream-dwelling mayflies, stoneflies, caddisflies, and other insects sometimes hitchhike in the stream itself to move away from an area they find unsuitable—where food is scarce, for example. They do this by crawling to a place where the current is flowing, then letting go and allowing the current to carry them downstream to a new home. Of course, when a stream goes on a tear with heavy rain or snowmelt, bugs may have no choice but to set sail—a phenomenon known as "catastrophic drift."

Depending on currents and obstacles, a drifter can be carried a few feet or several yards. Once it settles, it may choose to drift again. To avoid predation by drift-feeding fishes, most drifters set out at dawn and dusk.

Feeding

Like Alaska's ocean waters, our freshwater world is filled with potential foods. Most aquatic insects have fairly specific diets and use specialized feeding structures and behaviors to find, capture, and consume foodstuffs that suit their particular skills and preferences.

Dead stuff and scummy stuff

Ask any eight-year-old naturalist and she'll confirm that Alaskan streams and ponds are filled with dead stuff: wads of leaves and twigs, broken grass stems, fallen trees, spawned salmon. She might also point out that the dead stuff—along with live plants, and rocks and other non-organic items—is often covered with scummy stuff: a slimy, usually dark brown or greenish film that can be quite thick. Called biofilm, this slime is a living layer of bacteria, *Many stoneflies and caddisflies are shredders. They are responsible for the skeletonized leaves found at the bottoms of streams and ponds.*

algae, and fungi. Rock slime is generally made up of algae—mostly diatoms—while bacteria and fungi colonize and help decompose dead leaves and other organic material. Biofilm that grows on live plants is an important primary step in the food chain, especially in standing water.

Both the dead stuff and the scummy stuff are important foods for aquatic insects. Some insects, known technically as *collectors-gatherers*, collect small particles of organic matter from the stream bottom. Others, known as *scrapers or grazers*, carefully scrape the biofilm away from the detritus or stones like cows grazing on grass. Members of a third group, called *shredders*, munch the whole package: detritus, biofilm, and all. Like someone snacking on a peanut butter-covered cracker, they may be getting richer nutrition from the topping, but they eat the whole thing. As they eat large pieces of detritus, such as dead leaves, shredders produce fine particles of fecal matter that provide food for filter feeders.

Tiny stuff

Pond and stream water is a soup of microscopic organisms and miniscule bits of organic debris. In streams, certain aquatic insects specialize in capturing these tiny drifting pieces of food. Black Fly larvae have comb-like appendages that filter food from the water as it flows by. Some Mosquito larvae use vibrating brushes to filter tiny food particles. Some caddisflies and Chironomids create and deploy nets to trap food particles; they tend their nets carefully, gleaning the particles and making repairs as necessary. Whether they use body parts or nets, these insects are known as *collectors-filterers*.

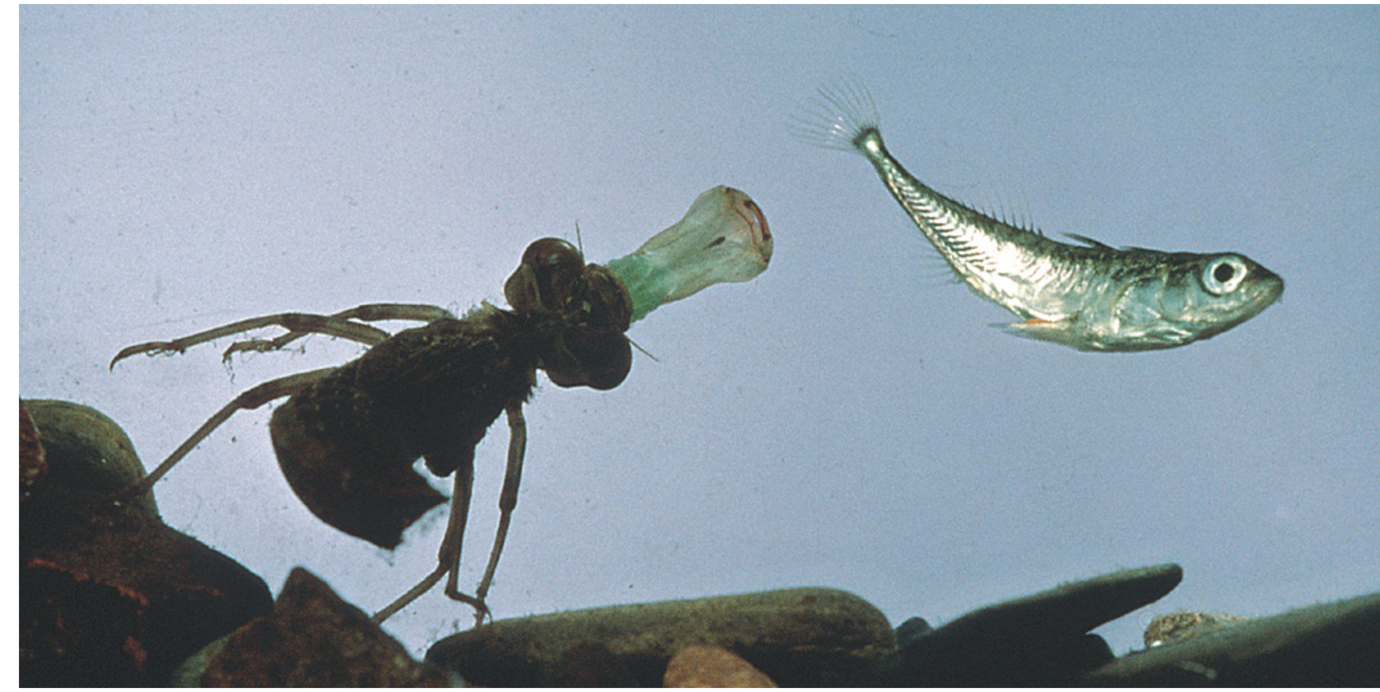
Green stuff

Live plants provide a good source of food for aquatic insects. Some insects eat leaves, others suck the juices from stems. Others, such as some aquatic caterpillars, burrow into stems for food and shelter until they emerge as adults.

Moving stuff

Finally, many aquatic insects are *predators* chasing down and eating other aquatic invertebrates, or even fish. Some are ambush hunters, staying still and camouflaged until the prey is close enough, then reaching or darting out to grab. Others chase their prey down like wolves (or perhaps like swallows capturing flying insects on the wing). To kill and

This Predaceous Diving Beetle larva has captured and is eating a smaller diving beetle larva.



This dragonfly larva is trying to capture a threespine stickleback using its specialized extendable and grasping lower lip.

The ultimate predators

Dragonflies and damselflies may be the ultimate aquatic predators. The larvae of all dragonfly and damselfly species are carnivorous. Whether they ambush their prey or actively hunt it down, all possess a bizarre secret weapon: a lower "lip" (called the labium) that is held, folded, under the jaw. When prey gets close enough, the labium propels forward, unfolding, and grabs or impales the prey. The labium then drags the prey to the mouth where sharp mandibles reduce it to bite-size bits.

Captive dragonfly or damselfly larvae, supplied with a few live Chironomid larvae, mayfly larvae, or worms, will often demonstrate how the labium works, which is well worth watching. Larger dragonfly larvae can capture and eat small fish, too.

consume their prey, these predatory insects may have piercing-sucking mouthparts (such as those of Giant Water Bugs) or powerful sharp jaws armed with sharp teeth (such as those of Predaceous Diving Beetles).

Avoiding being eaten

It's important to be able to get food, but it's equally important to avoid becoming food—especially for aquatic insects, which are favorite food items for many animals (see pages 18-24). Most aquatic insects have one or more forms of physical or behavioral defense.

Most aquatic insects are camouflaged—they have dull colors, stripes, or speckles—and some, including very hairy species of Forestflies (stoneflies) and dragonflies, even develop coverings of fine particles and/or biofilms that help them blend into their surroundings. Some deter smaller predators with hard exoskeletons and spines or stiff hair. The elaborate cases built by some caddisflies can be a form of camouflage as well as a protective retreat.

Forestfly larvae (stoneflies) are well camouflaged when sand grains and other small particles become trapped in their dense covering of fine hairs.

One of the best camouflages that we've seen is created by these Northern Case Maker caddisflies. They are almost impossible to see amongst the debris in the ponds where they live.

Whirligig Beetles secrete a distasteful chemical when captured. In trying to flush their mouths of the bad taste, fish often spit the beetles back out to freedom.

Larger predators such as big insects, birds, rodents, and toads may be fended off with nasty-tasting chemicals—a defense that's shared with many terrestrial insects.

Aquatic insects can also defend themselves through the way they behave. Many are most active after dark, when fish, birds, and other predators can't see them. Some have swift escape responses—think of Mosquitoes wriggling quickly away from the surface when a shadow passes over. Some, such as Giant Water Bugs, will defend themselves when attacked by biting back—a habit that has earned them the nickname "toe biters."

Freezing and drying

Two of the biggest challenges faced by Alaska's aquatic insects are cold and drought. Cold winter weather freezes streams and ponds—often stopping the water altogether. Combined with shorter daylight this reduces the food resources many aquatic insects need to grow. Summer and winter droughts can dry up streams, leaving only disconnected pools on the surface. They can also shrink ponds, sometimes to nothing but patches of cracked mud. To thrive in this dramatic environment, aquatic insects have to deal with both challenges.

Avoiding the freeze

One method to avoid freezing is to simply stay in liquid water, which is the warmest environment when all else is frozen. Here insect larvae can even feed and grow in the world below the ice.

Some insects avoid freezing by supercooling—manufacturing cryoprotectants and antifreezes so their body fluids are maintained at temperatures considerably lower than the freezing point of water.

Another method for avoiding freezing is to form winter cocoons such as those made by larvae of Chironomids living in the Arctic. These cocoons apparently prevent the formation of ice crystals within larval tissues.

"Sleeping" through it

To withstand tough conditions such as temperatures too cold for feeding or growth, or ponds or streams that dry out, some aquatic insects effectively sleep through the problem. Their movements slow or stop, they stop eating, and they stop growing and metamorphosing. Eggs, larvae, pupae, or adult insects may go dormant, depending on the species and the season. In a drought, larvae may burrow into mud, hide in the crevices of logs or stones, or work their way down into the still-wet gravel of the stream bed. When the water returns after a drought, or warms after a cold spell, the insects can return to their active lives.

Avoiding the issues

One way to escape freezing or drought is to avoid being in the water when challenging weather arrives. Many aquatic insects' growth and development are timed to the seasons, with the aquatic phase in the water at the optimum time. In northern streams that run reliably year-round, some stream insects spend months or years in the water as larvae, and the cold-susceptible adults emerge to take advantage of brief summer warmth.

Some aquatic insects have extremely short generation times, so that the aquatic larval phase is very brief. This reduces the chance that the larvae will be left high and dry by drought, so these insects can be successful in using even the smallest, shortest-lived pools (think of the

Surviving the freeze

One of the biggest dangers to living tissue is ice. Freezing binds up water that is essential to life, and sharp ice crystals pierce cell walls, damaging or destroying them. But many aquatic insect larvae in Alaska can survive being frozen into ice. When the ice melts, the insect comes "back to life."

How do they do it? They build up high concentrations of sugars or sugar alcohols that serve as antifreeze within their cells. Ice may form in the fluid outside the cells, where there is no antifreeze, but there it can't bulge the cells out or puncture their critical membranes.

Photo by Todd Sformo

Larvae living in Arctic streams and ponds that freeze solid in winter can survive temperatures as low as -20° to - 30° C. This photo shows several Nemoura arctica *stoneflies (Forestflies) frozen in ice. When the ice melts they will "come back to life."*

Mosquito wrigglers you may find in an old tire). Many of these short-timers spend winters in the egg stage, which can endure cold and drought.

Life cycles

Imagine if we humans were born in one form, then transformed into a completely different form right before kindergarten, and then changed again, into something else, sometime around middle school. That's the life of an insect. Insects—including aquatic insects—go through several transformations, often quite dramatic, during their lives. This process is called *metamorphosis*.

All insects begin as *eggs*, where the insect embryo grows and develops, fueled by nutrients in the yolk. Eventually, the embryo is ready to emerge, and works its way out of the egg. At this stage it's known as a *larva* or *nymph*. Insect larvae often look very little like their *adult* parents, and often (as in the case of insects with aquatic larvae) they have very different lifestyles.

Most insect eggs are extremely tiny, so a larva has a long way to grow before it reaches adult size. But insects don't grow as we do. Their bodies are encased in outer layers called *exoskeletons*, which are often quite hard, and have a relatively fixed size. To get bigger, the bug must *molt*: it must break through its exoskeleton and form a new, larger exoskeleton over its new form. The exoskeleton is made up of various sizes and shapes of interconnected rigid plates, or *sclerites*, which are made of a type of protein called *chitin*.

Insect larvae may go through dozens of these molts as they grow, and their shapes may change during the process. For example, older dragonfly larvae (ones that have gone through several molts) have large wing pads that the younger larvae lack.

An insect's adult form is the form in which it reproduces. In the case of most aquatic insects, the adult form is winged. Wings help the insects range more broadly: to find mates and food, and to find suitable places to lay eggs. For those stream insects that drift downstream as larvae, it is the winged adults that carry the next generation (as eggs) back upstream.

Complete or incomplete

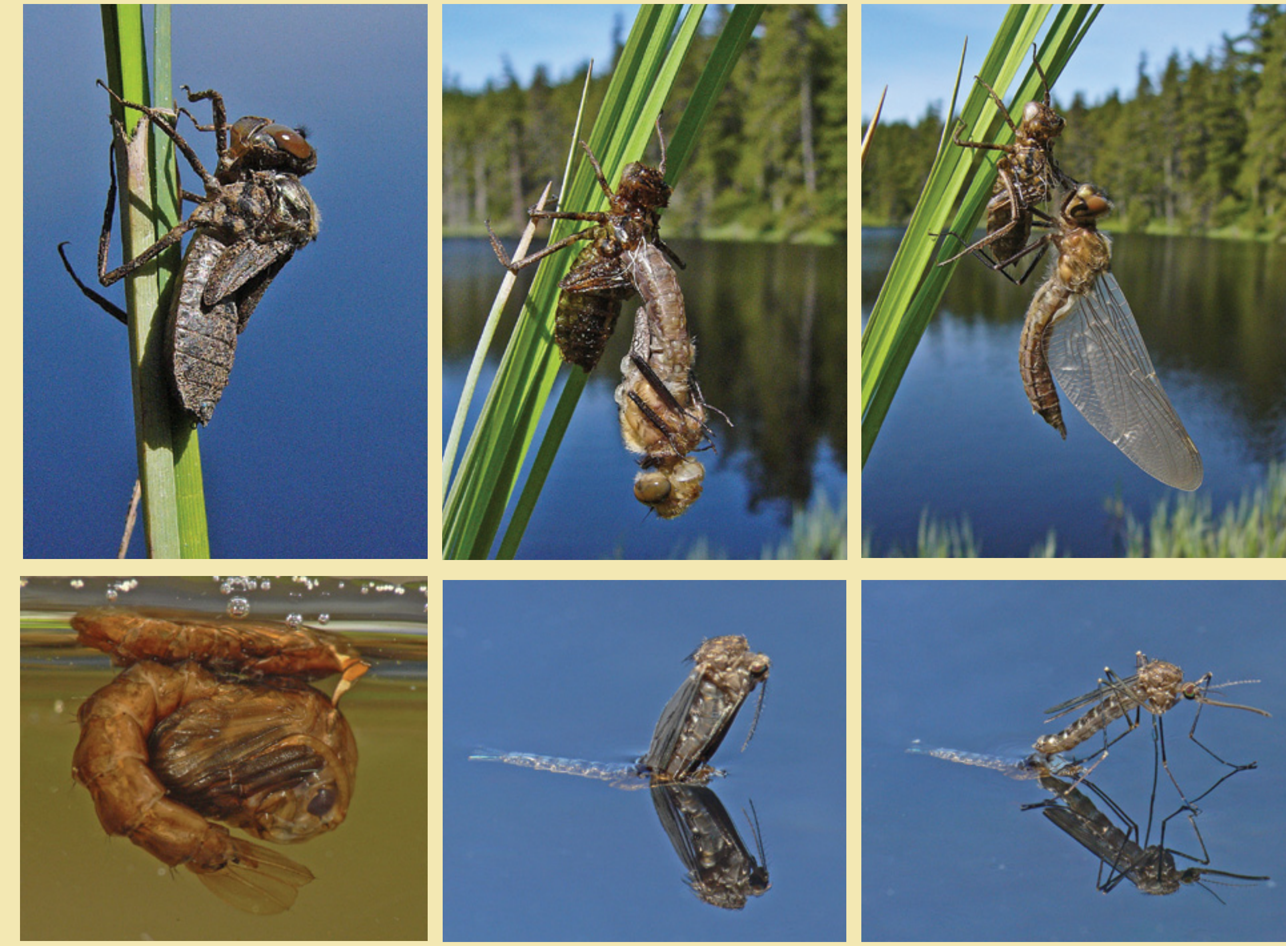
Many insect types go straight from their last larval stage to their adult stage. A stonefly larva, for example, will—when it is ready for its last molt—crawl from the water onto streamside rocks or vegetation, where it emerges from its last larval exoskeleton as a winged adult.

Some insects have an extra stage between

This adult caddisfly (top photo) is laying eggs in the thin film of water flowing down a rock face. The eggs she has been laying (middle photo) probably number into the thousands.

Even some of Alaska's largest insects, the dragonflies, lay very tiny eggs (lower photo). They are smaller than the head of a pin. One female dragonfly may lay thousands of eggs during the few weeks she is alive.

Emergence



Whether metamorphosis is complete or incomplete, eventually a developing larva or pupa contains a fully formed adult insect ready to enter the terrestrial world. For dragonfly larvae the process of emergence (upper photos) involves leaving the water, grasping vegetation tightly, and wriggling out of the exoskeleton. Next, fluid is pumped into the wings and abdomen to expand them. Within an hour the dragonfly is ready for its maiden flight. In contrast, adult Mosquitoes leave their pupal skins by emerging at the water's surface, a process that takes less than five minutes (lower photo series).

the larva and the adult. This stage is called the *pupa*, and it usually looks quite different from either the larva or the adult (although if you look closely, you can often see a bit of both in it). While it's a pupa, the insect is fairly quiet. It doesn't eat or swim much; some pupae don't move at all. But under its exoskeleton, big things are happening: the insect larva is being reconstructed into an adult.

This process of metamorphosis with a pupal stage is called *complete metamorphosis*. For insects that skip the pupal stage and instead transform into the adult within the larval exoskeleton, the process is called *incomplete metamorphosis*. Aquatic insect groups that go through complete metamorphosis are considered more evolutionarily advanced and include Mosquitoes and Chironomids, diving beetles, and caddisflies. In the incomplete metamorphosis group, considered more primitive, are mayflies, dragonflies and damselflies, and stoneflies, among others. The water bugs, such as Water Striders, undergo gradual metamorphosis in which the larva resembles a small adult without fully developed wings.