# STREAMKEEPERS

## *Aquatic Insects as Biomonitors*

# Part One

## *The Ecology of Rivers and Aquatic Insects*

# Living Water

*No fish could live out there where the river exploded into the colors and curves that would attract photographers. The fish were in that slow backwash, right in the dirty foam, with the dirt being one of the chief attractions. Part of the speckles would be pollen from pine trees, but most of the dirt was edible insect life that had not survived the waterfall.*

—Norman Maclean, *A River Runs Through It*

The human body consists mainly of water. So does a cucumber. So does the surface of the Earth. An odorless, tasteless liquid, say the scientific encyclopedias, abundant and widely distributed throughout the planet; built with simple elegance from two hydrogen atoms and an oxygen; essential in plant and animal nutrition; constituent of the crystals of many minerals; blue when encountered in thick layers: water. You can't get away from the stuff, and if you could, you wouldn't want to. It is an exaggeration to say that "Water is life," an exaggeration of the ubiquitousness, and perhaps the importance, certainly the durability, of life. Water came first, necessarily. Without life, there would still be water. Without water, no life.

The first primitive form of life was probably born about three and one-half billion years ago, when a bolt of lightning striking the primordial sea water delivered an energy jolt that spurred dissolved amino acids to cluster into self-interested coalitions of protein. The protein clusters began to grow into droplets, to pull water molecules up around themselves like cell walls, to compete with each other for the recruitment of further dissolved molecules—and the process of organic evolution was underway. But by that time it had already been raining on Earth, the seas had been rising and falling, the rivers had been flowing, for over a billion years.

Of all the types of hydrological features into which this planet's water has arranged itself—oceans, polar ice, glaciers, groundwater, fresh and salt lakes, soil moisture, atmospheric vapor—the least imposing, judged by volume, are rivers. Only one millionth part of our total water, as it turns out, is at this moment moving within the banks of rivers. Don't be fooled: They are important, in the history of life, in the history of man, far beyond their size. Rivers have served as crucibles of evolution, pathways of colonization, sources of power, and inspiration, and topsoil. They not only provide, they deliver. Glaciers come and go, lakes fill up and disappear, but rivers continue to follow their chosen routes with exceptional permanence, changing character gradually, maturing, cutting tight canyons and then wide valleys, shifting about restlessly within their domains, always wander-

**The ebony jewelwing, a damselfly, is common along creeks. *Calopteryx maculata* (Odonata: Calopterygidae). Photographed in Bryn Mawr, Pennsylvania by Edward S. Ross.**

ing, always leaving, never gone; offering to their living inhabitants that one crucial element that survival by evolution demands: time. Just recently—say within the last 7,000 years—the great early flowerings of human culture appeared, surely by no accident, in the Nile Valley, along the Indus, between the Tigris and the Euphrates, on the banks of the Hwang Ho. The sea is where we came from. Rivers are how we got here.

Every river on Earth is a symphony of elaborate, ordered entanglements—physical factors entangled with chemical factors entangled with biological ones—and as sure as the *Jupiter* symphony is not the *Pastorale*, every river is different from all others. But one thing remains common by definition, and represents the central, dominating fact to be coped with by the creatures that make their lives in rivers: The water never stops moving. The pressure of current never relents. The river, as the author Roderick Haig-Brown has said, never sleeps. To the plants and animals involved, the current brings food, oxygen and all the other nutrients they need for survival; it also, that same current, threatens every moment to sweep them downstream into drastically different habitats where they will quickly die. The current giveth, the current taketh away, the current has the power of a god. Because of this harsh reality, a river is perhaps the most challenging of ecosystems. It is also one of the most complicated and—thanks to that complexity—one of the richest.

Current speed is one of those complicating factors. It's a crucial variable in the makeup of any river, interdependent with a number of other physical variables, including source of the water, slope of the streambed, depth of the channel, width of the channel, and total volume of the water being moved. When any such variable changes, the others make compensatory adjustments, and the path and shape of the river reflect their compromise. For instance, if the source of a river is snow-melt from high mountainsides, the volume of discharge generally rises to a torrential peak in late spring or early summer, carrying sediments and pushing boulders, back-cutting by erosion to flatten the slope of the streambed, dismantling riffles and rebuilding them, widening and deepening the channel on the outside of the bends, sometimes gouging entirely new channels, short cuts, which might become permanent routes when the flooding subsides. If the source is a glacier, the pulse of high water comes later, in midsummer, and is less extreme, simply because ice melts more slowly than snow. If the source is a spring, there is no annual flood, little erosion, greater permanence to the shape of the channel. And if the source is groundwater seepage, the river is actually lowered in springtime, when riverside trees leaf out and begin competing to suck away moisture. Most rivers, of course, have a combination of sources and a mixture of these flow regimens. The whole system of discharge and channel adjustment tends, as the scientists say, toward conservative dynamic equilibrium. In other words: The water looks for the laziest way of getting itself fastest to the sea.

In times of normal flow, a streambed composed of rocks and large boulders retards current velocity, holding the water back by friction, while a sandy bottom offers little resistance. A wide and deep channel also entails less friction—which is why broad lower stretches of a river like the Mississippi, despite the gentle slope, despite the sluggish appearance, despite what we expect, may well be flowing faster than many steep mountain rivers. Whatever its size or shape, a river with current speed of four to six feet per second is moving quite swiftly. At eight feet per second, it is roaring. Very few creatures, even among those adapted to river habitats, can survive against such a constant force. So they have found and invented ways, not to live in the current, but to live out of it. The most important of those ways involves a feature called the boundary layer.

The boundary layer is a thin zone of still water at the interface between current and bed. Current speed at any point in a channel is inversely related to depth, with the surface water in midstream moving fastest, other water moving slower beneath the surface and nearer the banks, and the deep water moving slower still; but then a point is reached, about one to three millimeters above the streambed, where the water is not moving at all. Brought to a full stop by friction, this boundary layer of water allows a huge variety of small animals, mainly insects, to live and flourish along stream bottoms in even the stretches of heaviest current. This explains why most river insects are shaped more like alligators than like giraffes: They are adapted for life in the boundary layer, only millimeters thick, where it is a mortal necessity to keep your head down.

Also necessary to support life on the stream bottom are a variety of dissolved gases and solids, especially oxygen, carbon dioxide, calcium, potassium, nitrate, phosphate, and silica. Unless oxygen is present to the level of four or five parts per million, animals such as stoneflies and trout, with great respiratory needs, will suffocate. Under conditions of high temperature, the same animals may require twice as much oxygen—yet as the water temperature rises above 70 degrees Fahrenheit, oxygen will be forced out of solution and lost from the river. It is stirred back in by any turbulent movement, over riffles, down cascades, and then replaced during daylight by the photosynthetic activity of green plants. At night the concentration tends to fall again, with photosynthesis shut down for lack of light, and both animals and plants using oxygen for respiration. The decomposition of dead plant tissue, a massive continuing enterprise, conducted in rivers by bacteria and fungi, also consumes oxygen. Rivers are constantly depleting their oxygen, and constantly—unless they are dammed—replacing it. A river must tumble, must thrash, must dance along freely, or it goes blue in the face.

Meanwhile, the plants breathe in the carbon dioxide that the animals have exhaled. Thick layers of moss spread like green terry cloth over rocks in the shady areas where carbon dioxide is plentiful,

**Fallen leaves are the chief source of fuel for the river ecosystem. Alder trees along the bank of the Nehalem River. Photographed in Oregon by Dave Bohn.**

and provide habitat for tiny species of insects, crustaceans, and other arthropods. Dissolved carbon dioxide also nourishes algae (which serve as fodder for many insects), and allows calcium to remain in solution as calcium bicarbonate, an important mineral salt. This available calcium salt balances the acidity of the river's water, encourages algal growth, helps fish to breathe more efficiently, and provides snails, mussels, and crayfish with building material for their shells. It is precious useful stuff, calcium bicarbonate.

Potassium, nitrate, and phosphate are all essential plant nutrients, natural fertilizers, and even silica evidently spurs the growth of diatoms, those microscopic algae that coat stream boulders in a smooth slime. Nitrate and phosphate enter a river mainly through rainfall, runoff from the land surface and bank erosion. Nitrate also arrives, like a sprinkling of compost to help the river plants burgeon, in the dead foliage dropped on the water by streamside trees—particularly a common species of alder, which concentrates in its leaves exceptionally high levels of nitrate, and vastly enriches the food cycle of any river into which those leaves fall.

Fallen leaves, in fact, are the single chief source of fuel for the river ecosystem. The chain of river life begins—in the sense of energy transfer and the construction of living matter—in autumn, at just the time when life on land is closing down for the winter hiatus. Yellowed alder leaves, aspen and willow and cottonwood, drift onto the water and float for a while, then sink, to become wedged between rocks. Bacteria and fungi climb aboard, begin feasting, digesting, causing decay, until eventually the leaves crumble to a fine mulch that sails away on the current. Such rotting plant debris is called detritus. It is the manna of rivers.

Downstream a menagerie of bizarrely shaped insects, unlike anything you've ever seen on dry land, scoop in this manna with all fashion of ingenious equipment and strange anatomical apparatus—silken webs like a wind sock, lower lips like a cranberry rake—and devour it, bacteria and fungi included. These detritus-eaters are the larval stages of certain caddisflies and stoneflies and midges and mayflies, breathing through gills and making a hard living among the crevices of the riverbed. Grazing and cropping and savoring their tangy mulch, they are the primary consumers in the river ecosystem, the creatures responsible for turning vegetables into meat.

Preying upon those herbivores are the secondary consumers: carnivorous insects slightly bigger and more fierce, predatory species of stonefly and caddisfly and dragonfly and beetle. Put a seine in the water of a fertile mountain river, turn over a few rocks, and you can lift out handfuls of these amazing beasts, some of them up to two inches long, clambering harmlessly over your cupped palms like surreal variations of miniature six-legged dinosaurs. One type of caddisfly larva builds a conical silken net facing open to the current, then lurks at the narrow end and, when a smaller animal is swept in, rushes out like a spider to pounce on it. Large nymphs from a branch of the stonefly clan are also estimable predators, as are both the larvae and adults of some water beetles, and even a few species of mayfly. On their best days, these secondary consumers rule as lords of the stream-bottom jungle; one bad day, one mistake, one loss of footing, and they are in the belly of a trout.

**This mayfly nymph is a scraper; it uses a comb of spines on its mouthparts to feed on microscopic algae. This nymph is usually found in small, rapidly flowing streams among pebbles, near banks, and among vegetation and organic debris. Notice the oblong gills on its abdomen. *Ameletus* sp. (Ephemeroptera: Ameletidae). Photographed in Oregon on Knowles Creek, a tributary to the Siuslaw River, by Charley Dewberry.**

Thousands of bad days for millions of cold-water insects, and the result is what we often call, with some narrowness of vision, a good trout stream. But a good trout stream must first be an excellent insect stream, a superior haven for algae and fungi and bacteria, a prime dumping ground for dead leaves, a surpassing reservoir of oxygen and calcium. It will then also, and thereby, be a good osprey stream, a favorite among otters, a salvation to dippers and kingfishers and bank swallows and heron, mergansers and Canada geese and water shrews, mink and muskrat and beaver. Not to mention the occasional grizzly bear. And who knows but that, sometime, a human might want to drink.

The essence of vitality for any ecosystem is complexity and balance. In a free-flowing mountain river, the physical, chemical, and biological conditions that constitute habitat for a single living creature change drastically over short distances in all directions—upstream, downstream, shallower, deeper, in front of a rock, behind it, under it. This heterogeneity makes for spectacular diversity of species, comparable to an ocean shelf or to the heart of an equatorial rainforest. And that diversity in its turn makes for great complexity of interlocking relationships, great richness of life, and balance.

But the balance, in a river, is especially precarious, especially delicate: because the water never stops moving. The pressure never relents. The boundary between life and death is measured in millimeters. There is no room for error.

*—David Quammen*

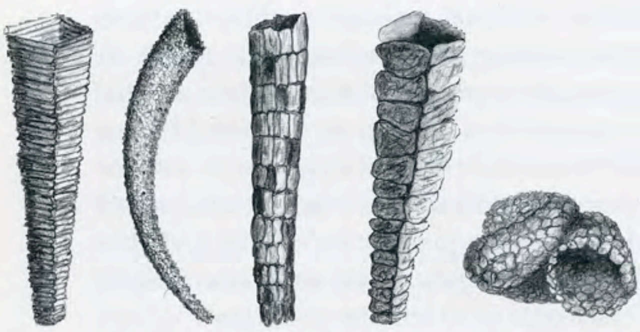
# Insect Architects: Caddisfly Larvae

*When we stand before great churches, temples, pyramids, and other works of architecture built hundreds, if not thousands, of years ago, our minds are filled with awe and admiration. Yet there have been architects millions of years before that. Their work, it is true, owes its existence not to the inspired genius of great artists, but to the unconscious, unremitting activity of the force of life itself.*

—Karl von Frisch, *Animal Architecture*

In the book *Animal Architecture*, Nobel laureate Karl von Frisch remembers how as a small boy he lay flat on his stomach in a meadow on a summer day on the banks of a pool, intently gazing into the water. Looking into a tangle of decaying leaves and reeds he was amazed to see a twig or piece of debris move and crawl away, suddenly realizing that he was, in fact, watching a case made by a caddisfly larva. "To unspoilt children who still enjoy simple pleasures," he remarked, such surprises "are a delight."

Caddisfly larvae are often incredibly common in healthy streams. Indeed, most of us who have peered into the shallow water of a stream or pond have been startled by the sight of a small, animated bundle of sticks or pebbles, the case of one of the freely-foraging caddisfly larvae. These larvae walk with head, thorax, and legs protruding from the front opening of their cases; a pair of abdominal hooks anchors them firmly inside. The case has a rear opening for the disposal of feces, and, in some species, the outflow of water. If disturbed, the larvae withdraw completely inside the sanctuary of their cases, much as a snail does. The larvae of one genus (*Heliopsyche*) even construct cases of tiny pebbles into a horn-like spiral tube, which so resembles a snail shell that they were first classified as such. There is amazing variation in building material used and the shape of caddisfly cases. Most cases, however, are elongate tubes constructed out of building materials characteristic to where the species lives, so that the animal is camouflaged. Building materials include sand grains, pebbles, bits of bark, twigs, leaves, cut plant stems, and combinations of the above in different proportions.



**Caddisfly larvae produce a great variety of intricate constructions. Drawing by Bernd Heinrich.**

**This caddisfly pupa seals off its case of tiny stones during its metamorphosis into an adult. *Dicosmoecus* sp. (Trichoptera: Limnephilidae). Photographed in Sagehen Creek, California by Edward S. Ross.**

In a Winter Ecology class that I teach to a dozen students at my cabin in the Maine woods each January, we try to enjoy the "simple pleasures" of watching caddisfly larvae. We chop a hole through the two feet of ice that covers Alder Stream, which runs below my cabin. Then we lie on our bellies in sub-zero temperatures and peer down to the bottom of the stream. Caddisfly larvae, their head and legs protruding from camouflaged protective cases, are active in mid-winter, when they consume the main energy input into the stream—the autumn's crop of decaying leaves that had fallen into the water. These larvae have evolved to be maximally active at temperatures near freezing. Their sensitivity to even slight temperature changes makes them vulnerable to deforestation, because sunshine has a significant effect on stream temperature.

The caddisflies (order Trichoptera) are an ancient group that has changed little in 250 million years. The adults are weak flyers that superficially resemble moths, and indeed the Lepidoptera (moths and butterflies), whose larvae feed primarily on green leaves, are evolutionarily derived from them. In fact, the gills of aquatic insect larvae (specifically those of mayflies, which are even more ancient than caddisflies) are probably the structures from which insect wings later evolved.

The cocoon-like cases they construct and inhabit protect caddisfly larvae from fish and other predators. Young larvae start by weaving dainty silk threads like those of silkworms and other caterpillars. Using their legs and mandibles, they then procure material from their surroundings and add the material to the front of their case, anchoring it with the silk produced by glands in their mouthparts. Depending on the species, pieces of debris or cut vegetation may be aligned parallel with the case, cross-ways, in a spiral, or haphazardly, to produce a great variety of beautiful and intricate constructions much prized by collectors. Upon completion of their larval stage, caddisflies seal their cases and transform into a pupa (the intermediate stage between larva and adult), just like a moth caterpillar inside its cocoon. Unlike moth cocoons, which only serve to hide and physically protect the pupae, caddisfly cases also shelter and conceal the insect throughout its entire larval life. Interestingly, the larvae of one group of moths (family Psychidae), commonly called bagworms, also make cases, and these caterpillar cases look almost exactly like many of the various kinds made by caddisfly larvae. Some (rare) moth larvae are aquatic as well.

Peering onto the bottom of Alder Stream, we usually see no insects at first. Then gradually hundreds of caddisfly larvae in their artfully constructed cases come into focus. The most common type of caddisfly case here is that of a species that glues twigs, spruce and fir needles, and bits of wood lengthwise into a tube. The larva's head, thorax, and six legs protrude from one end as the larva walks along the bottom, dragging its house along. On slight provocation it pulls its house up over itself, so that only a small, neat bundle of stream debris remains to be seen.

In Alder Stream we found several species of larvae with very different cases. One type had its tubular silk domicile covered with sand grains and attached beneath a sheet of sand pebbles glued together into a flat structure blending perfectly into the loose, pebbly gravel on which they were found. We found another species living among vegetation. Its cases were made of small bits of plant stems that were attached crossways rather than lengthwise. The animals never outgrow their cases. As caddisflies grow, they continue to add new material at the mouth end; most cases are gradually flaring tubes.

The shape and composition of the cases are functionally related. One species of predatory larvae bites off plant stems to very precise lengths and then binds them about itself with silk in a spiral ribbon. The result is a sleek and cryptic case, which is easily maneuvered through thick vegetation. In contrast, some stream-dwelling, herbivorous larvae attach sticks of odd lengths that stick out at right angles to the long axis of the case. Like anchor hooks, these laterally protruding sticks probably aid in securing the case to the weedy substrate of their feeding grounds in a current. Species living in

***Pycnopsyche*** **larvae build tubular cases of silk and various combinations of vegetable and mineral matter.** ***Pycnopsyche*** **sp. (Trichoptera: Limnephilidae). Photographed in Nesowadnehunk Stream, Baxter Park, Maine by David H. Funk.**

swift, sandy-bottom streams weigh their cases down with pebbles called "ballast stones." For example, *Neophylax* species use two such stones and *Goera* always use four. Others attach their cases to the bottom with silk anchor lines at the end of which they may swing in the current.

While case building among caddisflies has been primarily driven by considerations of shelter and camouflage, it has also evolved in a direction that has no parallel among the Lepidoptera: the development of feeding devices. Building cases with silk enabled many species of caddisfly larvae to evolve the ability to filter food from water. One species, *Arctopsyche irrorata*, turns its case into a feeding trap for small prey by the simple addition of a net built into the wall of the structure. The larvae have merely enlarged the front opening and angled it off from the rest of the tubular larval retreat. A "window" is then placed in the elbow of this curve and the larvae spin a net across the window. The free-moving larvae orient the opening of the tube upstream and feed on food particles deposited on the net by the water flowing through.

The same basic trap design has been further elaborated in the cases of *Diplectrona* and *Macronema*, in which the areas for water intake and outflow through the net have become elongated into separate tubes. The larval retreat protrudes in front of the net, so that the water intake tube doubles as the feeding chamber. The larval retreat is permanently attached to the bottom substrate and, in at least one species, the retreat is completely submerged and protected in sand.

One of the most impressive larval feeding and dwelling structures is built by *Macronema transversum*, where the larval

**Caddisfly larvae of the genus *Hydropsyche* have cases with exposed nets. Drawing by Bernd Heinrich.**

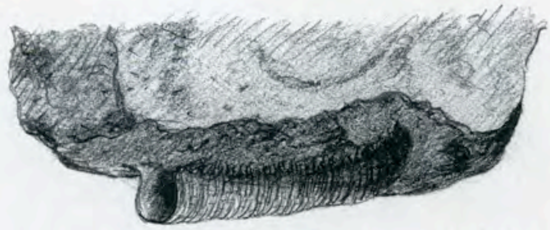
retreat curves around, connecting the intake and outflow tubes. Rather than requiring a separate exit for voiding feces, this larva is able to feed on the upstream side of the net while simultaneously using the downstream side as a continually flushing waste disposal mechanism. This arrangement also enhances water flow, and hence oxygenation, over the gills.

Some net-building larvae, which have more exposed nets, have evolved the ability to replace damaged nets rapidly and "cheaply." *Hydropsyche* larvae meticulously gather up all the net remnants into a ball, eat the ball of silk along with the prey it has entangled, then immediately string a new net across the remaining, more durable frame.

Psychomiidae and Philoptamidae have evolved to make conical net-traps that act as a seine. The larvae wait at the bottom, feeding upon food particles swept into the trap by the slow-moving currents of their habitats. These nets probably evolved from free-living ancestors living in cases, by greatly enlarging the case entrance and also deleting the addition of sticks or other substrate. The result was a fragile "leaky" case that came to be used as a seine but that must be anchored to the stream bottom. In *Neuroclipsis* (Psychomiidae) the net is shaped like a cornucopia. Both the entrance and the tip of the cone are attached to vegetation. As the water flows through, the seine bows downstream past the anchored tip where the larva waits. The net of *Neuroclipsis* may be more than 20 cm long (7.75 inches), with an opening of 13 cm diameter (5 inches).

The seine net of *Dolophilodes distinctus* (Philoptamidae) differs from this in that the 4.5 mm (.25 inch) opening hangs from rocks (to which pebbles have been attached for a partial frame), while the tip of the seine floats freely in the current. There is a 1 mm opening at the tip of the cone for outflow of water and larval feces.

Working from the outside in, a *D. distinctus* larva builds its seine net in several layers. First the larva roughs out the shape of the seine by laying down large threads semi-randomly or in a loose spiral. This framework is strengthened by a tight spiral of silk laid down the length of the developing seine. Next the larva strings a series of closely and evenly spaced longitudinal threads down the inside of the seine. With the framework thus completed, the final and innermost mesh is then laid. The fineness of the inner mesh varies directly with the size of the larva, but even in the largest larvae the minute threads are an evenly spaced 0.0005 mm or 0.00002 of an inch apart! As many as seventy of the small threads are laid down at a time, in one sweep of the mouthparts. Since the opening of the silk gland is ridged with seventy or so grooves, the silk is probably squeezed through these grooves. The resulting net is so fine-meshed that even the largest larvae capture single-celled diatoms and bacteria.



**The caddisfly *Dolophilodes distinctus* hangs a seine from rocks. The net is so fine-meshed that it traps single-celled diatoms and bacteria. Drawing by Bernd Heinrich.**

***Neophylax* larvae are found crawling around on the top of rocks in riffle reaches, grazing for algae from rock surfaces. They construct their cases from coarse rock fragments and larger pebbles, presumably for ballast. *Neophylax* sp. (Trichoptera: Uenoidae). Photographed in White Clay Creek, Pennsylvania by David H. Funk.**

The small-mesh nets likely evolved from large-mesh nets, which specialize primarily on small invertebrate animal prey, and they in turn were probably derived from freely-foraging predaceous ancestors. Those larvae that were able to construct finer-meshed nets were able to trap ever smaller particles that were very abundant and relatively unutilized by others. Consequently, direct competition for food is reduced and a succession of different feeding specialists now process almost all food that streams provide.

The different species of larvae even aid one another. The feces released by those free-living larvae that eat leaves and invertebrate animals serve as food for micro-organisms, and the micro-organisms, in turn, become food for the filter-feeders. Additional space may also be created by some species for others. Recently Declan McCabe, a graduate student at the University of Vermont, has shown that a whole host of many other insect larvae preferentially colonize rocks in streams to which caddisfly larvae are already attached. Apparently the larvae attached to rocks provide a substrate where others can then hang on as well.

Whenever we seine with our own nets over the stream bottom under the thick ice of Alder Stream, we bring up caddisfly larvae in strange and wonderful cases, but we have seen only a very few of the many that exist. There is still much to look forward to in our exploration of other streams, where there will be other species. Many of these are undescribed, because new ones are now still being found even in the Northeast.

Some of these insect treasures are hard to find, which makes them all the more enticing, but most are exceedingly common. Caddisflies, and other aquatic invertebrates, are keystone organisms upon which much of stream life depends. One species prepares the way for others. Caddisfly larvae consume plant material that falls into the stream and that, through decay, would deplete the stream's oxygen supply; as adults, caddisflies serve as fish food. Both as larvae and as adults, caddisflies help make a stream a habitat for trout and a vital and balanced ecosystem.

*—Bernd Heinrich*

**Often referred to as "log cabin" style, cases made by *Brachycentrus* larvae are four-sided and consist of neatly arranged, narrow pieces of plant material held together by silk. Large individuals such as the one pictured here attach the front end of their case to a substrate and filter particles from the water column using their outstretched legs. *Brachycentrus* sp. (Trichoptera: Brachycentridae). Photographed at Two Oceans Lake outlet, Wyoming by David H. Funk.**

# Under the Silver Ceiling

*In ice-cold rushing mountain streams, in tiny puddles that collect in tree holes and crotches, at the bottom of deep lakes, on the wet mossy rock faces of waterfalls—wherever there is fresh water—insects can be found.*

—Adrian Forsyth, *Exploring the World of Insects*

One January twenty years ago, I scuffled through the snow along a tiny stream that bisects our mountain land in Colorado. Out of idle curiosity I knelt down, reached into the frigid water, and picked up a cobble. On its underside, to my surprise, something moved: a small, dark creature with two "tails," fan-like gills along its thorax, and six clawed legs inched along beneath a gleaming film of moisture. I was entranced by this elaborate little entity able to exist in water too cold to keep my hands in. The object of my fascination turned out to be a stonefly, a member of the order Plecoptera—"the folded wings."

My fascination with the six-legged prowlers and wafters, spinners and jumpers, burrowers and clingers that inhabit our rivers and streams began at that moment. That tiny black nymph initiated me into the intricacies and complexities of life beneath a silvery ceiling.

Twenty years and two seasons later, I watch a female stonefly drop her pinpoint eggs on the water surface. They will sink and hatch into tiny nymphs that molt every time they grow too large for their current exoskeleton. Their simple metamorphosis from egg to nymph to adult may take up to three years and require as many as twenty-two molts. Given that they live in cold streams, and that molting depends upon constantly changing factors—temperature and food supply—the time span between molts has to be elastic.

Stonefly nymphs breathe underwater through tracheal gills—small, bushy filaments attached to the base of their legs. The surfaces of the gills are rich in tracheae, through which an interchange of gasses occurs. To see stoneflies in our stream pleases me, for their presence indicates good water quality and a healthy oxygen supply.

When a stonefly nymph transforms into an adult, it crawls out of the water, clings to a sedge stem along the stream, and sheds its exoskeleton for the last time. Wings unpleat, dry and stiffen, and another stonefly is ready to begin a new life.

Stonefly nymphs may be vegetarians, or they may be ravenous little carnivores. Some of the latter prefer to dine on common mayfly nymphs of the genus *Baetis*, which spend the first part of their lives in our stream. (Insects are a great source of protein, even for other insects). Much of stonefly predation is "sublethal," which means that the predator misses, does not catch and devour its prey, but simply disturbs it. However, the disturbance may be sufficient to affect the mayfly nymph's ability to grow and reproduce. A *Baetis* needs only be touched by a marauding stonefly nymph to let go of its substrate and drift upward, abandoning food for safety, a short-term choice that may eventually doom it to less than complete and healthy development.

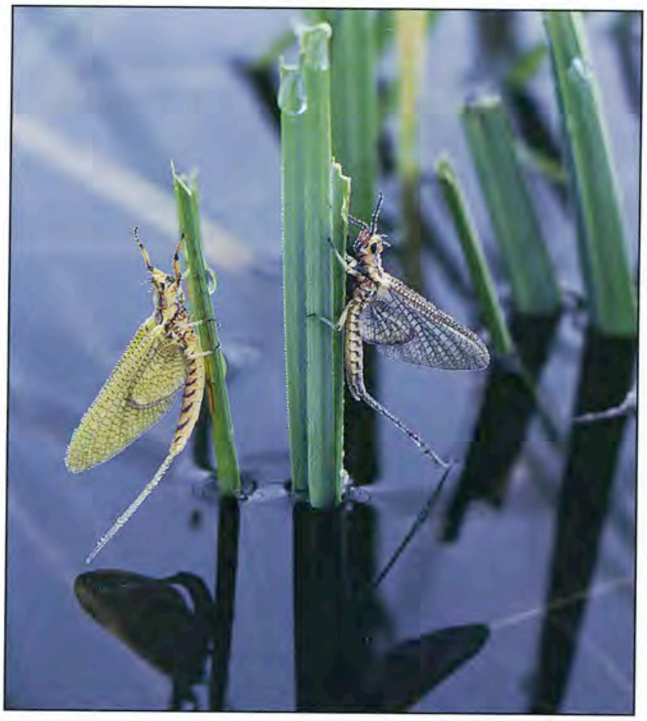
Mayfly nymphs usually have three "tails" (caudal cerci), and paddle-shaped gills arrayed along their abdominal segments. When the nymphs forsake their nourishing nursery for the world of flight, they climb out of the water and molt into a "subimago" form, a brief, next-to-last stage before adulthood. This is unique to mayflies, and it marks their order as a primitive one. This drab creature is called a "dun" and, as every trout fisher knows, a massive hatch of duns brings trout leaping to the surface. The final adult (or imago) that replaces the dun is a shining, graceful insect with delicate wings, two long, elegant cerci curving out behind, and forelegs held out as if in supplication: a lovely creature, fleeting, diaphanous, momentary, hence its order, Ephemeroptera, the wings that last but a day.

*Baetis* mayflies are tiny winged flutterers, scarcely half a centimeter long. Finding a mate presents a huge challenge, which many small insects solve by aggregating into swarms. Swarms work, judging from the new clouds I watch each year. Swarming provides a mass of male bodies, which females, perched on branches nearby, can see.

This evening I watch a swarm of male mayflies at the edge of the meadow. They ascend, then drift downward with wings spread, the mass fuming like a cloud of thin, sooty smoke. The females waft into this male mob, and mate before leaving the party.

Success in mating usually comes to the larger males, those that have not been subject to the disturbances in feeding that would deprive them of food, slow their growth, and make them the least attractive of the mayfly set. Males may live a few days, participating in swarms several days in succession, but once she lays eggs, the female dies.

Near the stream I spot another swarm composed of even smaller insects. Watching this cloud of minute insects too tiny to see with the naked eye is nearly as hypnotic as gazing into a campfire. One pepper-speck mote lands on my arm. Its feathery antennae, seen with the aid of a hand lens, identify it as a male chironomid midge. Midge swarms may contain



**Big yellow may duns. *Hexagenia limbata* (Ephemeroptera: Ephemeridae). Photographed on the Upper Williamson River in Oregon by Jim Schollmeyer.**

**A mayfly nymph amidst blackfly pupae. This nymph can swim easily by rapidly flipping its three tail-like caudal filaments. *Baetis tricaudatus* (Ephemeroptera: Baetidae). Photographed at Two Ocean Lake Creek, Wyoming, by David H. Funk.**

thousands of individuals, and some create a humming that may be heard some distance away. Midges have been recorded with wing-beat speeds of more than a thousand times per second. Wings blur as midges rise and fall and swirl above a clump of cow parsnip that stands high near the stream edge.

The larvae of chironomid midges also spend their salad days in the water. But unlike stoneflies and mayflies, these larvae flourish in the still, mucky backwater of our stream, where oxygen is low. Where the water hangs still and silt is thick, I scoop the midge larvae up in a collecting jar. Called "bloodworms" because they are bright red with hemoglobin (unlike most insects, which have yellow-green blood), midge larvae use that substance for the same purpose that humans do—to transfer oxygen to body tissue.

High populations of chironomid larvae indicate polluted water, and statistics gathered on individual species index the precise water quality of their specific waters. I gaze at the red threads, curling up and snapping open in their peculiar progress across the jar, lively and efficient, one of a group of animated motes that transform the water into a three-ring circus of minuscule trapeze artists tumbling through space.

Adult chironomid midges are nonbiters. Still, I'm sorry to say, we swat them with the same devotion that we give to a mosquito or a black fly. Unfortunately "midge" is a generic term that encompasses a large number of infinitesimal two-winged flies, of which mosquitoes, sand flies, and black flies (a.k.a. buffalo gnats) are the most notorious members, for they bedevil not only the unsuspecting camper but all warm-blooded animals.

I find blackfly larvae, looking like snippets of black buttonhole twist, wavering in the fastest-flowing part of our stream. They need a current of at least one foot per second to deliver fine tidbits of vegetable matter (like diatoms and microscopic algae) and oxygen to them. They attach themselves to the rocks by suckers, strong enough to anchor them against the current. They can also move about by spinning a life-line. This keeps them from being swept away when they detach themselves momentarily and position themselves in the optimum place to feed.

When female blackflies reach adulthood, the former vegetarians require a protein meal in order to fertilize and lay eggs. This is the source of considerable trouble for warm-blooded animals who serve as unsuspecting and unwilling hosts. Blackfly bites develop into welts and tiny boils that itch to distraction, and drive otherwise sensible human beings to unknown heights of invective. Adult male blackflies are upright citizens who do not bite.

The swarms that I observe tonight are non-biting midges, so I watch them with impunity. The throng looks choreographed: near-invisible insects looping in a quiet, flowing rhythm, a gentle rising and falling, a peaceable flow so different from the frenetic bloodworms in the collecting jar.

The evening cools and the dancers drift off to spend the night under the nearest leaf. In the cooling dusk I muse about the pinpoint eggs that hatch and the larvae that flicker through the water of the stream, small beings that hang on with a claw or float free, that filter and scrape and inhale. They live a lifespan adjusted to the vagaries of the stream's conditions, and change from one form of life to another, from crawling nymph to gossamer-winged adult, moving from silvery ceiling to twilight sky.

These minute water babies give me bright pleasure and insight into a world totally different from mine. They call this stream home. And so do I.

*—Ann Haymond Zwinger*

**Top: Blackfly larvae in a stream. Center: Blackfly emerging from its pupal skin. Bottom: Blackfly adult resting on water surface after emerging from its pupa. (Diptera: Simuliidae). Photographed in a Maine stream by Dwight R. Kuhn.**