CHAPTER 1: INTRODUCTION

The Rock Pack Experiment

The Rock Pack Experiment combines topics in environmental science, technology, engineering, and math (E-STEM) with freshwater ecology and geomorphology through the unique world of the **net-spinning caddisfly** (Order Trichoptera, Family Hydropsychidae). For gathering water quality data for monitoring purposes or for teaching the scientific method follow the procedures outlined in Chapter 2. To further extend the rock pack experience with students for learning about macroinvertebrate identification, stream geomorphology and more, see Chapter 3.

Now back to Caddisflies! During their larval lives underwater, this group of globally distributed aquatic insects spin silk mesh nets that they use to filter feed. The silk mesh nets are important ecosystem engineering structures in flowing waters that can regulate sediment erosion, provide natural flood control, and enhance habitat availability for other macroinvertebrates (Cardinale et.al. 2004; Albertson et al. 2014; Albertson et al. 2019; Tumolo et.al 2019).

The Rock Pack Experiment includes interdisciplinary, inquiry-based, and hands-on activities that can be used indoors or outdoors in a middle or high school lesson plan and that equip students with E-STEM skills with real-world research applications. Each Rock Pack experiment has the same outcome:

- To provide an understanding of the structure, function, and adaptations of freshwater macroinvertebrates, with an emphasis on the net-spinning caddisfly larvae, within a stream community and the greater ecosystem
- To relate the abundance of net-spinning caddisflies colonizing artificial rock packs to:
  - fluvial geomorphological features, including the influence of silk and ecosystem engineering on sediment erosion, streambed stabilization, and flood control
  - the general ecological health of the stream community

Students study these incredible larvae by creating artificial "**rock packs**," or dry rocks in mesh bags that simulate the naturally available rock habitat found in a stream riffle area. By filling the bags with gravel (sizes 10-60 millimeter) at weights between 1,000-3,000 grams, participants provide ideal habitat for net-spinning caddisfly retreats. Packs are left in the stream for three to four weeks, during which they are colonized by macroinvertebrates. Participants then quantify the relative abundance and diversity of the macroinvertebrates with a special focus on net-spinning caddisfies, either back in the classroom or streamside as an outdoor field experience.

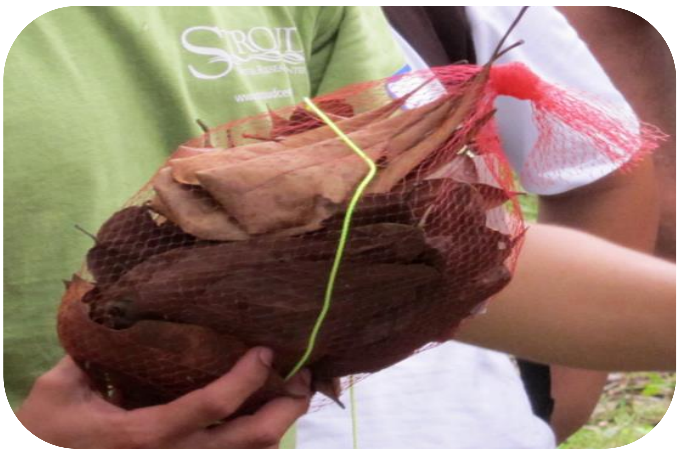
How do I get involved with the Rock Pack Experiment?

- ✓ Rock Pack Manual
- ✓ Materials to conduct the experiment listed in Chapter 2 and 4 and printable data sheets from Chapter 5
- ✓ Access to the internet with a computer or smart device, such as a phone or smart pad
- ✓ A stream that is safely accessible

For more specific information on how to become a part of the Rock Pack Network or to determine the availability of a workshop in your area, contact the Leaf Pack Administrator (the Rock Pack Experiment is an extension of the Leaf Pack Network) at: leafpacknetwork@stroudcenter.org

A Rocky History: Origin of Rock Pack

Leaves form natural "packs" in streams year-round.



Artificial leaf packs provide unique learning opportunities.

In 1989, a scientist at Stroud Water Research Center (Stroud Center) was invited to his daughter's ninth grade classroom to conduct a lesson on streams. The stars of the show were **"leaf packs,"** or dry leaves in a mesh bag that mimic the natural process of leaves forming packs in streams. The scientist thought leaf packs would be an easy way to not only bring macroinvertebrates to the classroom, but to engage the students. He was right, and thus was born the Leaf Pack Network®.

Today, the network of citizens, teachers and students continue to use leaf packs to investigate their local stream ecosystems. By using the Leaf Pack Network Stream Ecology Kit sold by the LaMotte Company and original curricula by Stroud Water Research Center, participants enhance their understanding of stream ecosystems, learn scientific principles, and demonstrate the importance of streamside forests. The resources and activities available through the network are valuable tools for establishing baseline water quality conditions and periodic monitoring of a local waterway.

In 2016, scientists and educators from Montana State University and Stroud Water Research Center began exploring the role of net-spinning caddisfly larvae (Order Trichoptera, Family Hydropsychidae) in stream erosion regimes. Funded by a Division of Environmental Biology Ecosystem Studies grant funded by the National Science Foundation, the collaborative research focused on how silk webs created by the crafty critter bind together gravels on the riverbed. By 2017, this partnership launched an exciting extension of the Leaf Pack Network: the Rock Pack Experiment. The team discovered that like leaf packs, rock packs simulate natural processes in healthy streams while creatively engaging everyday citizens and students in freshwater science. The new programming integrated many of the concepts that make leaf packs powerful learning tools, such as the role of freshwater macroinvertebrates in food webs and water quality. However, its focus on the net-spinning caddisfly integrated new topics like ecosystem engineering, fluvial geomorphology, sediment erosion, and flood control to create real-world connections between land use and water quality.

NOTE: The Rock Pack Manual provides a brief summary of freshwater macroinvertebrate fauna, but its focus is the net-spinning caddisfly. For more information on macroinvertebrates' unique life cycles, functional feeding groups, and roles as water quality indicators, please visit the Leaf Pack Manual on the Leaf Pack Network website: https://leafpacknetwork.org/resources/manual/.

Linking Rocks to Streams

All **ecosystems** rely on the steady supply of energy or nutrient cycling, and streams are no exception. Pick up any rock from a streambed. On its surface you can discover a complex network of energy, including slimy detritus from leaves swept downstream; tufts of aquatic plants like algae; creeping, crawling macroinvertebrates (e.g., insect larvae, crustaceans); and assemblages of microorganisms or microbes (e.g., fungi and bacteria) undetected by the naked eye. Each play a critical role in producing or processing the flow of energy through the system.

As students, we often learn that this system begins with the sun. Solar energy drives photosynthesis, which supplies carbon (chemical energy) for the rest of the system. In many small, densely forested streams, however, sunlight cannot reach the water's surface due to shading from the forest canopy. Leaf fall from the forest canopy prevails as the dominant food resource for these small streams, supplying much of the carbon needed to support the stream throughout the year. As leaves fall or are blown into the stream, they float downstream until catching on rocks; the more rocks in a streambed, the greater the surface area for leaves to become trapped and accumulate in natural "packs." After a few weeks of submersion, the leaves become slimy with the colonization of fungus and bacteria (decomposers) and, in time, are colonized by many macroinvertebrates.

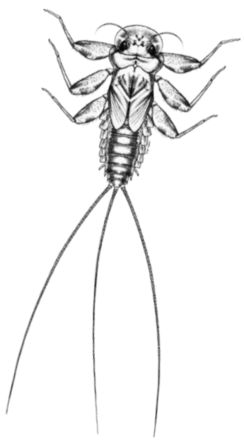
Riffle sections harbor a diversity of stream life and are ideal locations for net-spinning caddisfly colonization.

Rocks likewise play an important role in the freshwater food web. Rock surfaces in streams can form blankets of algae and biofilm, a matrix of freshwater microbes, sand, and silt. Algae and biofilm on rocks provide important food sources, acting much like peanut butter on a cracker for hungry macroinvertebrates. Here, rocks of varying density and grain size provide important shelter and **habitat** for macroinvertebrates, fish, and other aquatic fauna. Rocks are important physical features of the healthy streams that offer many different types of habitats, which in turn support aquatic animals specially adapted to certain niches in each of those different habitats.

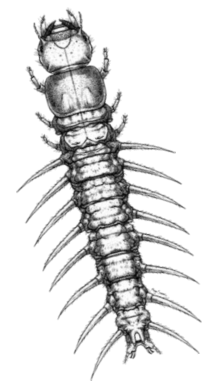
For example, **riffles** (shallow, fast-flowing, rocky areas) characteristically offer diverse environments, and the fast-flowing water offers a continuous supply of oxygen and food to macroinvertebrates. Slow-flowing, muddy-bottomed habitats, such as pools, facilitate a very different habitat; they support macroinvertebrates adapted to these specific conditions and contain different species compared to the macroinvertebrates found in riffles. Other stream habitats to investigate include sandy/silty bottoms, areas near vegetated banks, and areas having an accumulation of woody debris. Each habitat type may offer a unique assemblage of macroinvertebrate species, and the density and grain size of the rocks present in each habitat further determine which specially adapted macroinvertebrates has moved into the neighborhood.

Freshwater Benthic Macroinvertebrates

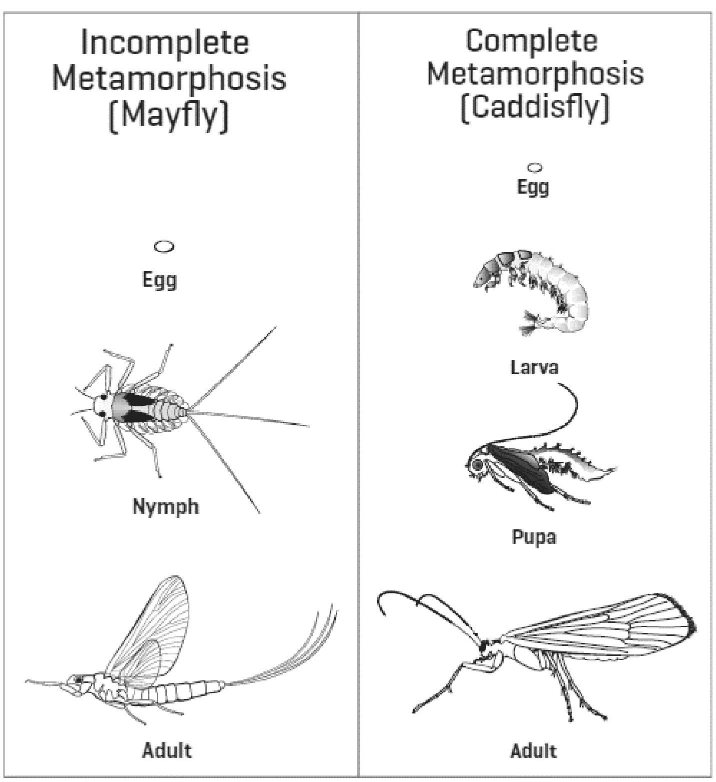
Once a rock pack has been submerged in the stream for several weeks, algae may begin to grow, detritus (dead particulate organic material) like leaves may accumulate in packs behind the rocks, and microbes (decomposers like bacteria and aquatic fungi) will begin to colonize the rocks' surface. Slimy biofilms, a matrix of freshwater microorganisms, sand, and silt, may coat the rocks' surface. Soon, **benthic freshwater macroinvertebrates** also enter the rock pack to discover new habitats beneath and between the rocks, feed off of the algae, and further break down detritus. Benthic freshwater macroinvertebrates can be defined as the following:



Benthic	=	inhabit bottom areas/substrates
Freshwater	=	streams, rivers, lakes, ponds
Macro	=	relatively "large" (> 0.2 - 0.5 mm)
Invertebrate	=	animal without vertebrae



These macroinvertebrates play important roles in the food webs of the stream ecosystem, but algae and detritus can be difficult for macroinvertebrates to digest and contain nutrients that are hard to absorb. The aquatic fungi and bacteria that colonize the rock packs act as a first step in the decomposition process and provide an essential component to the macroinvertebrate diet.



Many macroinvertebrates are aquatic insects that go through several stages from egg to adult. The number of stages depends on the type of metamorphosis, or the series of developmental changes, the insect follows. Insects that undergo **incomplete metamorphosis** follow three stages. They begin as eggs that hatch into **nymphs**, which then grow into adults. The immature period is called the nymphal stage. Examples of insects that undergo incomplete metamorphosis are mayflies, dragonflies, damselflies, stoneflies, and true bugs. Many of the insects that undergo incomplete metamorphosis are aquatic only during the egg and nymphal stages. The winged adults do not live in the water. Dragonflies, for example, can often be seen in the adult form flying along streams and rivers in the summer.

Insects that undergo **complete metamorphosis** have four stages: egg, larva, pupa, and adult. They begin as eggs that hatch into tiny **larvae**. The immature period is called the larval stage. These larvae grow and eventually enter a pupal stage, in which the insects are transformed into an adult. Many are familiar with the complete metamorphosis of the butterfly, during which a caterpillar (larval stage) emerges from a chrysalis (pupal stage) as a fully transformed butterfly (adult stage). Examples of aquatic insects that go through complete metamorphosis are true flies, beetles, dobsonflies, and the focus of the Rock Pack Experiment: caddisflies.

Many insects that undergo complete metamorphosis are aquatic during the egg, larval, and pupal stages, but not as adults. However, some insects like the whirligig beetle and predaceous diving beetle pupate out of the water into overhanging tree branches, and others like the whirligig beetle and predaceous diving beetle also return to the water as adults.

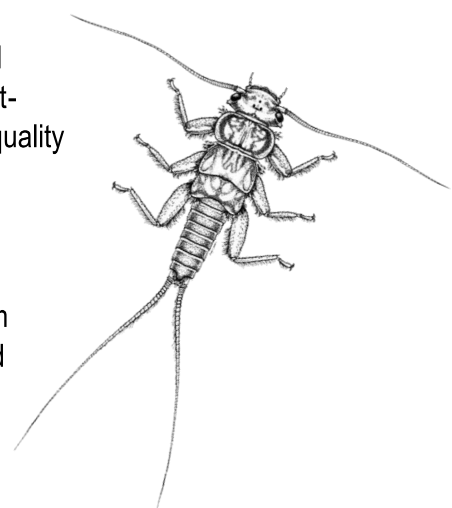
The majority of insects found in the rock packs will be in the nymph or larval stage, with the total life cycles of macroinvertebrates ranging from less than two weeks for some true flies (e.g., midges and mosquitoes), to two years or longer for some stoneflies, dragonflies, and dobsonflies.

Water Quality Indicators

The ability of freshwater macroinvertebrates to flourish not only depends upon optimal physical factors, but also on chemical factors in their environment. Many macroinvertebrates require a specific range of chemical parameters (pH, dissolved oxygen, temperature, alkalinity, etc.) to survive. Generally, unpolluted waters support a greater variety of freshwater macroinvertebrates than polluted waters. Some tolerant macroinvertebrates can tolerate polluted waters, and these may be found in a greater abundance in polluted waters than in unpolluted waters.

Other macroinvertebrates, meanwhile, are highly sensitive to pollution and habitat disturbance, meaning they typically cannot survive polluted waters. As "canaries of the stream," these organisms function as living barometers that indicate changes in water quality. Therefore, macroinvertebrates act as **bioindicator organisms** whose presence or absence in a stream can be used to estimate the **water quality** and the overall health of the stream community. Wherever you are in the world, macroinvertebrates can paint valuable portraits of stream communities, water quality, and watershed health.

On the spectrum of pollution tolerance among macroinvertebrates, organisms may fall roughly in between tolerant and sensitive. These macroinvertebrates, including the net-spinning caddisfly, are facultative or semi-sensitive, meaning they prefer good water quality but are somewhat tolerant of impaired water.



Please note that because streams are complex ecosystems, a combination of macroinvertebrate, chemical, and physical data provides the most comprehensive assessment of the stream. When introducing artificial rock packs to a particular stream environment, it is informative to supplement macroinvertebrate data with chemical and physical data using a variety of field test kits and visual surveys.

Functional Feeding Groups

Macroinvertebrates can be divided into groups, known as **functional feeding groups**, based on their feeding methods and adaptations. In a simplified view of the food web, these groups process detritus in a stepwise fashion. Large detrital pieces and their associated microorganisms (fungi and bacteria) are eaten by certain, highly specialized macroinvertebrates. This “eating” process yields smaller particles (feces and leaf fragments), much like “crumbs” created after eating crackers, that provide food for other functional feeding groups further downstream. These macroinvertebrates, in turn, are an important food source for predators. Ecologically, the macroinvertebrates are a primary link between the base of the food web (algae, detritus, microorganisms) and larger animals like fish.

The shredders are the first group of macroinvertebrates to break down large organic material like leaves. Shredders (which include crane flies, some caddisflies and stoneflies, sowbugs, and scuds) break the leaves down into fine particles by eating them. Drifting downstream, the fine particles become food for another group of detritus feeders, the collectors. Collectors use various methods to filter or gather the fine particles. Gathering collectors include some mayflies and midges. **Filtering collectors**, such as the black fly, use fanlike filaments near the mouth to capture food particles. **<u>Other filtering collectors, such as the net-spinning caddisflies, construct web-like nets.</u>**

The grazers (also known as scrapers) are another group of freshwater macroinvertebrates present in the stream community. However, these organisms feed on the algae that grow on the surface of rocks. They include some caddisflies, the water penny (a beetle), and certain midges and mayflies. The shredders, collectors, and grazers are food sources for predators, which include other macroinvertebrates such as dobsonflies and the dragonflies. Predators have large, powerful mouth parts used for grasping prey. All macroinvertebrates, in turn, are food for fish and birds.

Feeding Strategy	Food Category
I. Shredders	dead leaves/live macrophytes
II. Collectors	fine organic particles (live/dead)
Filter Feeders	particles in water column
Miners	buried particles
Browsers	bottom surface deposits
III. Scrapers	live benthic algae (diatoms)
IV. Piercers	live filamentous algae
V. Predators	other invertebrates + small fish

Macroinvertebrates are classified based on feeding adaptations and/or food preferences.

For a more detailed look at functional feeding groups and their relationship to stream size in the watershed, please visit: https://www.leafpacknetwork.org/learn/linking-trees-streams.

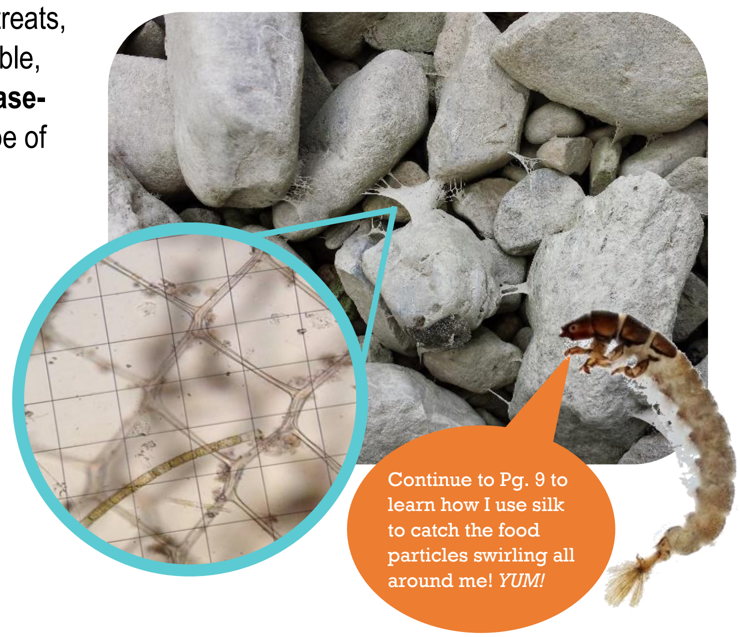
Life History of the Caddisfly

The northern caddisfly (Family Limnephilidae) spends its larval stage (A) underwater as a case-builder, using sticky silk to construct portable cases from plant and mineral materials. It spends its adult stage (B) on land.

Caddisflies (Order Trichoptera) are a highly advanced and diverse group of macroinvertebrates that live in fresh water for part of their life cycle. Caddisflies spend their egg, larva, and pupal stages in water (aquatic), before undergoing complete metamorphosis into a winged adult that lives on land (terrestrial). Closely related to butterflies and moths (Order Lepidoptera), caddisflies earn their names from their characteristic adult wings, which possess small hairs rather than the scales seen in butterflies. In the scientific name for this special insect order, *trichos* means “hair” and *pteron* means “wing.”

This caddisfly life cycle typically includes one generation per year, with new adults sometimes emerging in large numbers to mate on vegetation or rocks near water and to deposit eggs directly in the water. As aquatic larvae, caddisflies are adapted to an incredible array of microhabitats in streams and lakes alike with varying substrates. In streams and rivers, caddisfly eggs, larvae, and pupae often inhabit rocky streambeds in fast-flowing riffles. Here, the sediment ranges from the size of your thumbnail to the size of large boulders. The turbulent water is rich in **dissolved oxygen** and helps water temperatures remain relatively cool. Meanwhile, natural leaf and rock packs in the riffle provide important food and shelter for the caddisflies.

From family to family and species to species, the larvae are highly specialized in their underwater behaviors. Most are classified by scientists as sedentary or as crawlers, but scientists classify many others as burrowers or active swimmers. Due to their incredible diversity, caddisflies play a pivotal role in freshwater food webs, with different kinds adapted for shredding, collecting, grazing, scraping, or even predation on fellow macroinvertebrates. Perhaps the behavior caddisflies are most known for is silk production. Emitted from their mouths at the tip of the labium, the **caddisfly silk** functions like sticky, stretchy, waterproof tape for the complex creation of cases, retreats, nets, and cocoons. Caddisfly groups that use silk to craft portable, protective cases from small rocks and detritus are known as **case-building caddisflies**. Read on to discover another exciting type of caddisfly!



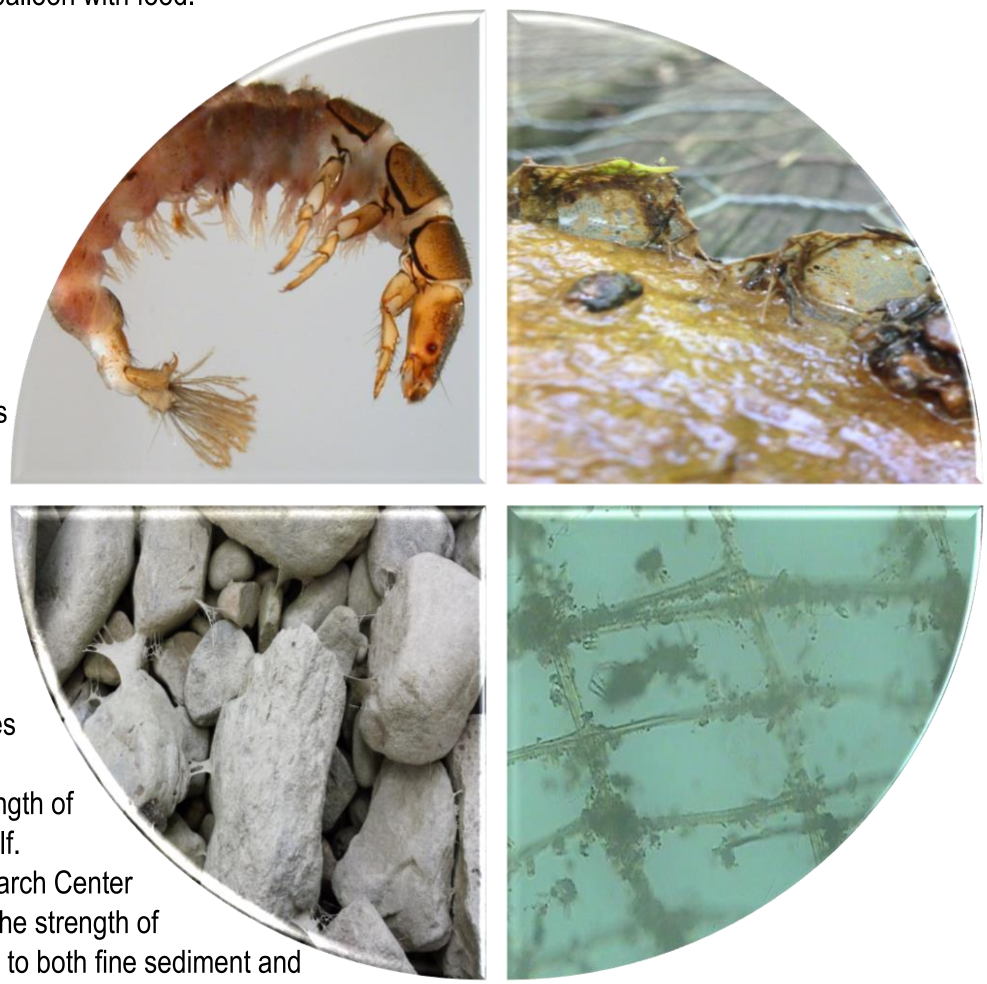
TECHNOLOGY CONNECTION!

For a digital introduction to caddisfly ecology, watch this video lecture by Dr. Lindsey Albertson:
https://youtu.be/It9MxtzGCDY

Looking for a shorter video that creatively engages all ages in the wonders of caddisfly silk? ROCK OUT to this 4-minute video by PBS Digital Studios!
https://youtu.be/Z3BHrzDHoYo

The Craftiest Critter: The Net-Spinning Caddisfly

The Rock Pack Experiment focuses on the **net-spinning caddisfly** (Family Hydropsychidae), a group of globally distributed aquatic insects and the most abundant caddisflies in many parts of North America. This crafty critter produces its own silk for a clever purpose: to trap and eat its food. Similar to how a spider catches food in silk webs, net-spinning caddisfly larvae use a homespun net to capture food from the water column. The nets resemble strings in a tennis racket, with each silk thread placed into just the right spot to create mesh webbing that will stretch and balloon with food.



But what is on the menu for the net-spinning caddisfly? As a filtering collector and ominivore-detritivore during at least part of its larval stage, the animal uses a feeding strategy called filter-feeding to pull suspended particles, such as broken-down leaf detritus and even animal parts, out of the stream and into its net. It then uses its mouth to feed directly off of the silk – no silverware needed! This feeding strategy is similar to how a mussel or oyster pulls water over its gills to filter-feed suspended particles.

Many types of net-spinning caddisflies call streams home, and each one can build a different type of silk net. Individual species vary in the silk they produce, including the number of silk threads in their net, the strength of the silk threads, and the size of the net itself. Moreover, scientists at Stroud Water Research Center and Montana State University have found the strength of net-spinning caddisfly silk is highly resilient to both fine sediment and drought (Albertson et al. 2019).

Even among different species, the silk maintains its overall structure and strength under both stressors. As streams worldwide experience record flooding and drought due to climate change and human impacts, the research points to caddisfly silk as a potentially powerful tool in the recovery of aquatic communities after short-lived disturbances (Cardinale et al. 2004, Tumolo et al. 2019).

The larva doesn’t only use its silk to catch dinner. When it is not harvesting food from its net, the animal hunkers down in its **retreat**, or a crude dwelling crafted from rock and/or detritus fragments and bound together with sticky silk. The silk helps each building block adhere to another, while also anchoring the retreat to rocks or woody debris so the caddisfly’s shelter is not swept downstream by the swift current. Tucked inside its retreat and sheltered from predators, the larva can send its silk net billowing out of one open end of the retreat when appetite strikes. Particles floating downstream are quickly ensnared in the net’s sticky strands, a key reason the caddisflies require flowing water for their special feeding method.

The larva may not be the only inhabitant of its tiny house. When abandoned by a larva, a retreat often becomes food or shelter for another macroinvertebrate.

FUN FACT! The silk threads produced by net-spinning caddisflies play an important role in modifying erosion and water flow in the stream. Keep reading to find out how!

A net-spinning caddisfly larva climbs out of its retreat after the rock the retreat is adhered to is removed from the stream

Fluvial Geomorphology

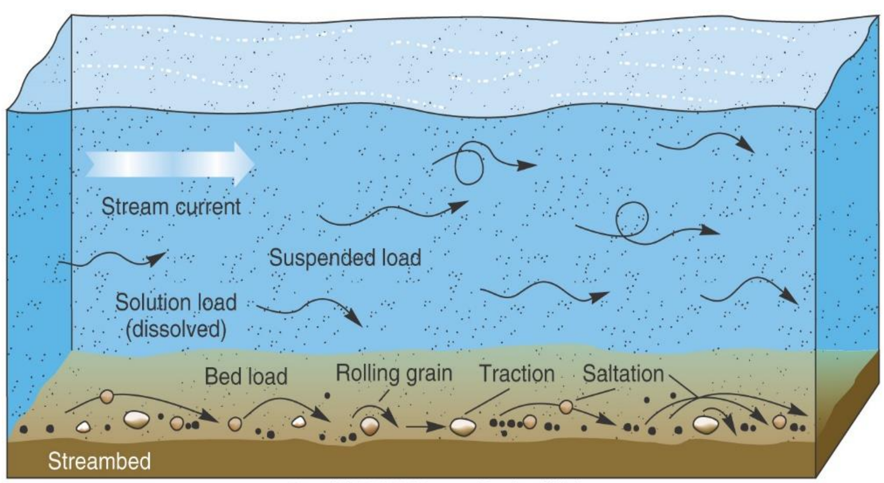
TECHNOLOGY CONNECTION!

For a digital introduction to fluvial geomorphology, watch this video lecture by Dr. Lindsey Albertson: https://youtu.be/MtJyYywarE0

Fluvial geomorphology is a scientific discipline that studies the physical shape of rivers and the processes that change them over time. The shape of a river is important because it is the home, or **habitat**, for all living things in a river ecosystem. The shape of a river determines how water flows through it, how water influences organisms like fish and macroinvertebrates, and what the water quality will be. Patterns of channel shape and sediment size are driven by the geology or rock type of the area, the river channel's location in the watershed, how steep the slope is, land use in the watershed, and the local climate.

Rivers are essentially transportation pathways for water and sediment. In the highest points of a **watershed**, large amounts of sediments are generated by hillslope erosion, delivered to stream channels, and broken down into smaller pieces as they are carried downstream. As more streams combine and the slope declines, the sediment size in rivers also decreases, and a lot is stored in riffles and in floodplains. Eventually the sediment size in the river declines as it reaches sea or lake level, where sediment is deposited into long-term storage in very large floodplains and in coastal deposits like deltas, beaches, barrier islands, and the ocean/lake floor.

In the headwaters and transport zones, sediment is often sorted into distinctive habitat features called pools and riffles. Riffles are temporary storage zones for gravels and cobbles, and they also form very important habitat for specialized macroinvertebrates, fish, and other aquatic animals that live amongst the gravels and cobbles. The water is typically shallow but fast in riffles, while it is slow and deep in pools. The sediments stored in riffles do move during large flow events as **bedload**. This term refers to gravels and cobbles that are rolled, hopped, pushed, and pulled along the bed of the river – these rocks are too heavy for the water to actually lift up into the flow for more than a few seconds.



E-STEM CAREER HIGHLIGHT

Watch a 1-minute video on the daily life of a fluvial geomorphologist: https://youtu.be/OteypmM5yeY

Melinda Daniels, Ph.D. (left), associate research scientist in the fluvial geomorphology group at Stroud Water Research Center, and Lindsey Albertson, Ph.D. (right), assistant professor in the Department of Ecology at Montana State University, are the principal investigators of a project on ecosystem engineering by net-spinning caddisfly larva.

This process of sediments being broken down by natural agents like water and wind, or **erosion**, is a very important process in river ecosystems. As humans alter land use around rivers or climate in ways that change water flow patterns and flooding regimes, understanding erosion helps us understand how to keep our streams healthy. In fact, two of the most common consequences of land use and climate change are 1) increased fine sediment loads, and 2) shifts in hydrological regimes in freshwater ecosystems (Richter et al.1997). To put it simply, erosion, flooding, and drought are big problems for the health of our streams. A growing number of studies indicate that these environmental stressors will likely have direct effects on the **species composition** (the identity of all the different organisms that make up a community) and **biodiversity** (different kinds of specialized organisms in an ecosystem) of life in our streams. Little is known, however, about how biological structures produced by aquatic organisms will respond or recover.

Ecosystem Engineers

Scientists at Stroud Water Research Center and Montana State University are working to improve that knowledge through research on **ecosystem engineers** (Jones and Shachak 1994; Moore, J.W. 2006), or animals or plants that maintain, modify, or create habitats. The animals can do so through their everyday activities. These organisms live in all types of habitats, but are especially important in rivers. Crayfish that burrow for food, beavers that build structures like dams, and plants that produce root networks that stabilize and hold together sediment on riverbanks are all well-known examples of ecosystem engineers.

Less-well-known ecosystem engineers are net-spinning caddisflies. Recent studies have found that the biological structures produced by caddisflies – silk mesh nets – have an important influence on the geomorphology in flowing waters. To the very hungry caddisfly's benefit, silk increases food particle delivery by altering near-bed current velocities (Albertson et al. 2014; Maguire et al. 2020). The benefits of silk extend to the entire stream community and ecosystem. On the riverbed, the silk threads bind together rocks as large as an orange! This reduces sediment erosion, helps regulate flooding impacts, and enhances habitat availability for other macroinvertebrates. Sometimes, the density of caddisflies can be greater than 10,000 individuals in one square meter. In cases like these, the silk nets have a particularly strong influence on reducing rock erosion and increasing how stable the rocks are. Did you ever realize that the handiwork of animals so tiny could have such big impacts?

TECHNOLOGY CONNECTION!

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Looking for a shorter video that creatively engages all ages in ecosystem engineering by net-spinning caddisflies? ROCK OUT to this 4-minute video by San Francisco State University, Montana State University, and Stroud Water Research Center! https://vimeo.com/273597362