

Small Streams and Wetlands Provide Beneficial Ecosystem Services



A headwater stream channel near Toledo, OH relocated to accommodate development. Photo courtesy of Marshal A. Moser

Natural processes that occur in small streams and wetlands provide humans with a host of benefits, including flood control, maintenance of water quantity and quality, and habitat for a variety of plants and animals. For headwater streams and wetlands to provide ecosystem services that sustain the health of our nation's waters, the hydrological, geological and biological components of stream networks must be intact.

Small Streams and Wetlands Provide Natural Flood Control

Floods are a natural part of every river. In times past, waters of the Mississippi River routinely overtopped its banks. Floodwaters carried the sediment and nutrients that made the Mississippi Delta's soil particularly suitable for agriculture. But floods can also destroy farms, houses, roads and bridges.

When small streams and wetlands are in their natural state, they absorb significant amounts of rainwater, runoff and snowmelt before flooding. However, when a landscape is altered, such as by a landslide or large forest fire or a housing development, the runoff can exceed the absorption capacity of small streams. Moreover, the power of additional water coursing through a channel can change the channel itself. Humans often alter both landscape and stream channels in ways that result in larger and more frequent floods downstream.

A key feature of streams and rivers is their shape. Unlike a concrete drainage ditch, a natural streambed does not present a smooth surface for water flow. Natural streambeds are rough and bumpy in ways that slow the passage of water. Particularly in small narrow streams, friction produced by a stream's gravel bed, rocks, and dams of leaf litter and twigs slows water as it moves down-

stream. Slower moving water is more likely to seep into a stream's natural water storage system—its bed and banks—and to recharge groundwater. Slower moving water also has less power to erode stream banks and carry sediment and debris downstream.

In watersheds that are not carefully protected against impacts of land development, stream channels often become enlarged and incised from increased runoff. Changed channels send water downstream more quickly, resulting in more flooding. For example, after forests and prairies in Wisconsin watersheds were converted to agricultural fields, the size of floods increased. This change in land use had altered two parts of the river systems' equation: the amount of runoff and shape of the stream channel. Cultivation destroyed the soil's natural air spaces that came from worm burrows and plant roots. The resulting collapse of the soil caused more rainfall to run off into streams instead of soaking into the ground. Additional surface runoff then altered the stream channels, thereby increasing their capacity to carry large volumes of water quickly downstream. These larger volumes flow downstream at much higher velocity, rather than soaking into the streambed.

Urbanization has similar effects; paving previously-vegetated areas leads to greater storm runoff, which changes urban stream channels and ultimately sends water more quickly downstream. Covering the land with impermeable surfaces, such as roofs, roads, and parking lots, can increase by several times the amount of runoff from a rainstorm. If land uses change near headwater streams, effects are felt throughout the stream network. In an urban setting, runoff is channeled into storm sewers, which then rapidly discharge large volumes of water into nearby streams. The additional water causes the stream to pick up speed, because deeper

water has less friction with the streambed. The faster the water moves, the less it can soak into the streambed and banks. Faster water also erodes channel banks and beds, changing the shape of a channel. The effect is magnified downstream, because larger rivers receive water from tens, sometimes hundreds, of small headwater basins. When such changes are made near headwater streams, downstream portions of the stream network experience bigger and more frequent flooding.

As regions become more urbanized, humans intentionally alter many natural stream channels by replacing them with storm sewers and other artificial conduits. When larger, smoother conduits are substituted for narrow, rough-bottomed natural stream channels, flood frequency increases downstream. For example, three decades of growth in storm sewers and paved surfaces around Watts Branch Creek, Maryland more than tripled the number of floods and increased average annual flood size by 23 percent.

Small Streams and Wetlands Maintain Water Supplies

Headwater systems play a crucial role in ensuring a continual flow of water to downstream freshwater ecosystems. Water in streams and rivers comes from several sources: water held in the soil, runoff from precipitation, and groundwater. Water moves between the soil, streams and groundwater. Wetlands, even those without any obvious surface connection to streams, are also involved in such exchanges by storing and slowly releasing water into streams and groundwater, where it later resurfaces at springs. Because of these interactions, groundwater can contribute a significant portion of surface flow in streams and rivers; conversely, surface waters can also recharge groundwater. If connections between soil, water, surface waters, and groundwater are disrupted, streams, rivers, and wells can run dry. Two-thirds of Americans obtain their drinking water from a water system that uses surface water. The remaining one-third of the population relies on groundwater sources.

The quality and amount of water in both of these sources respond to changes in headwater streams.

USGS estimates that, on average, from 40 to 50 percent of water in streams and larger rivers comes from groundwater. In drier regions or during dry seasons, as much as 95 percent of a stream's flow may come from groundwater. Thus, the recharge process that occurs in unaltered headwater streams and wetlands both moderates downstream flooding in times of high water and maintains stream flow during dry seasons.

"ALTERATION OF SMALL STREAMS AND WETLANDS DISRUPTS THE QUANTITY AND AVAILABILITY OF WATER IN A STREAM AND RIVER SYSTEM."

Headwater streams and wetlands have a particularly important role to play in recharge. These smallest upstream components of a river network have the largest surface area of soil in contact with available water, thereby providing the greatest opportunity for recharge of groundwater. Moreover, water level in headwater streams is often higher than the water table, allowing water to flow through the channel bed and banks into soil and groundwater. Such situations occur when water levels are high, such as

during spring snowmelt or rainy seasons. During dry times, the situation in some reaches of the stream network, particularly those downstream, may reverse, with water flowing from the soil and groundwater through the channel banks and bed into the stream. This exchange of water from the soil and groundwater into the stream maintains stream flow. However, if land-use changes increase the amount of precipitation that runs off into a stream rather than soaking into the ground, the recharge process gets short-circuited. This increased volume of stream water flows rapidly downstream rather than infiltrating into soil and groundwater. The consequence is less overall groundwater recharge, which often results in less water in streams during drier seasons.

Therefore, alteration of small streams and wetlands disrupts the quantity and availability of water in a stream and river system. Protecting headwater streams and wetlands is important for maintaining water levels needed to support everything from fish to recreational boating to commercial ship traffic.

Small Streams and Wetlands Trap Excess Sediment

Headwater systems retain sediment. Like the flow of water, movement of sediment occurs throughout a river network. Thus, how a watershed is managed and what kinds of land uses occur there have substantial impact on the amount of sediment delivered to larger rivers downstream. Increased sediment raises water purification costs for municipal and industrial users, requires extensive dredging to maintain navigational channels, and degrades aquatic habitats. Intact headwater streams and wetlands can modulate the amount of sediment transported to downstream ecosystems.

Runoff from rain, snowmelt and receding floodwaters can wash soil, leaves and twigs into streams, where the various materials get broken up into smaller particles or settle out. If natural vegetation and soil cover are disturbed by events and activities such as fires, farming or construction, runoff increases, washing more materials into streams. At the same time, the increased velocity and volume of water in a stream cause erosion within the streambed and banks themselves, contributing additional sediment to the stream system. Moreover, the faster, fuller stream can carry more and larger chunks of sediment further downstream.

One study found that land disturbances such as urban construction can, at minimum, double the amount of sediment entering headwater streams from a watershed. A Pennsylvania study showed how, as a 160-acre headwater watershed became more urbanized, channel erosion of a quarter-mile stretch of stream generated 50,000 additional cubic feet of sediment in one year—enough to fill 25 moderate-sized living rooms. In a non-urban watershed of the same size, it would take five years to generate the same amount of sediment. Such studies demonstrate that landscape changes such as urbanization or agriculture, particularly without careful protection of headwater streams and their riparian zones, may cause many times more sediment to travel downstream.

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EXCESS SEDIMENT IN DOWNSTREAM ECOSYSTEMS COSTS MONEY

Keeping excess sediment out of downstream rivers and lakes is one ecosystem service intact small streams and wetlands provide. Once sediment moves further downstream, it becomes an expensive problem. Too much sediment can fill up reservoirs and navigation channels, damage commercial and sport fisheries, eliminate recreation spots, harm aquatic habitats and their associated plants and animals, and increase water filtration costs.

Additional sediment damages aquatic ecosystems. Sediment suspended in the water makes it murkier; as a result, underwater plants no longer receive enough light to grow. Fish that depend on visual signals to mate may be less likely to spawn in murky water, thereby reducing fish populations. High levels of sediment suspended in water can even cause fish kills. Even as it settles to the bottom, sediment continues to cause problems because it fills the holes between gravel and stones that some animals call home, smothers small organisms that form the basis of many food webs, and can also smother fish eggs.

Getting rid of sediment is expensive. For example, keeping Baltimore Harbor navigable costs \$10 to \$11.5 million annually to dredge and dispose of sediment the Patapsco River deposits in the harbor.

SMALL STREAMS AND WETLANDS RETAIN SEDIMENT

Headwater streams and wetlands typically trap and retain much of the sediment that washes into them. The faster the water travels, the larger the particles it can carry. So, natural obstructions in small streams—rocks, downed logs, or even just a bumpy stream bottom—slow water and cause sediment to settle out of the water column. Wetlands, whether or not they have a surface connection to a nearby stream, are often areas where runoff slows and stops, dropping any debris the water may be carrying. Because headwater streams represent 75 percent or more of total stream length in a stream network, such streams and their associated wetlands retain a substantial

amount of sediment, preventing it from flowing into larger rivers downstream.

Even ephemeral streams can retain significant amounts of sediment. Such small headwater streams expand and contract in response to heavy rains. During expansion, a stream flows over what was a dry or damp streambed. Most of the water at the leading edge of a growing stream, called the “trickle front,” soaks into the streambed and does not carry sediment downstream. In a small watershed near Corvallis, Oregon, researchers found that 60 to 80 percent of sediment generated from forest roads traveled less than 250 feet downstream before settling out in stream pools. Headwater streams can store sediment for long periods of time: research in Oregon’s Rock Creek basin found that headwater streams could retain sediment for 114 years.

Natural Cleansing Ability of Small Streams and Wetlands Protects Water Quality

Materials that wash into streams include everything from soil, leaves and dead insects to runoff from agricultural fields and animal pastures. One of the key ecosystem services that stream networks provide is the filtering and processing of such materials. Healthy aquatic ecosystems can transform natural materials like animal dung and chemicals such as fertilizers into less harmful substances. Small streams and their associated wetlands play a key role in both storing and modifying potential pollutants, ranging from chemical fertilizers to rotting salmon carcasses, in ways that maintain downstream water quality.

EXCESS NUTRIENTS CAUSE PROBLEMS IN RIVERS AND LAKES

Inorganic nitrogen and phosphorus, the main chemicals in agricultural fertilizers, are essential nutrients not just for plants, but for all living organisms. However, in excess or in the wrong proportions, these chemicals can harm natural systems and humans.

In freshwater ecosystems, eutrophication, the enriching of waters by excess nitrogen and phosphorus, reduces water quality in streams, lakes, estuaries and other downstream waterbodies. One obvious result is the excessive growth of algae. More



algae clouds previously clear streams, such as those favored by trout. In addition to reducing visibility, algal blooms reduce the amount of oxygen dissolved in the water, sometimes to a degree that causes fish kills. Fish are not the only organisms harmed: some of the algae species that grow in eutrophic waters generate tastes and odors or are toxic, a clear problem for stream systems that supply drinking water for municipalities. In addition, increased nitrogen can injure people and animals. Excess nitrogen in the form called nitrate in drinking water has been linked to “blue baby disease” (methemoglobinemia) in infants and also has toxic effects on livestock.

HEADWATER STREAMS TRANSFORM AND STORE EXCESS NUTRIENTS

Headwater streams and associated wetlands both retain and transform excess nutrients, thereby preventing them from traveling downstream. Physical, chemical and biological processes in headwater streams interact to provide this ecosystem service.

Compared with larger streams and rivers, small streams, especially shallow ones, have more water in physical contact with a stream channel. Therefore, the average distance traveled by a particle before it is removed from the water column is shorter in headwater streams than in larger ones. A study of headwater streams in the southern Appalachian Mountains found that both phosphorus and the nitrogen-containing compound ammonium traveled less than 65 feet downstream before being removed from the water.

Stream networks filter and process everything from leaves and dead insects to runoff from agricultural fields and animal pastures. Without such processing, algal blooms can ruin living conditions for fish and the quality of drinking water. Here, algae overtakes a lake in Iowa. Photo courtesy of Lynn Betts, USDA NRCS

In headwater streams and wetlands, more water is in direct contact with the streambed, where most processing takes place. Bacteria, fungi and other microorganisms living on the bottom of a stream consume inorganic nitrogen and phosphorus and convert them into less harmful, more biologically beneficial compounds. A mathematical model based on research in 14 headwater streams throughout the U.S. shows that 64 percent of inorganic nitrogen entering a small stream is retained or transformed within 1,000 yards.

Channel shape also plays a role in transforming excess nutrients. Studies in Pennsylvania have shown that when the forest surrounding headwaters is replaced by meadows or lawns, increased sunlight promotes growth of grasses along stream banks. The grasses trap sediments, create sod, and narrow the stream channel to one-third of the original width. Such narrowing reduces the amount of streambed available for microorganisms that process nutrients. As a result, nitrogen and phosphorus travel downstream five to ten times farther, increasing risks of eutrophication.

Streams do not have to flow year-round to make significant contributions to water quality. Fertilizers and other pollutants enter stream systems during storms and other times of high runoff, the same times that ephemeral and intermittent streams are most likely to have water and process nutrients. Federal, state and local programs spend considerable sums of money to reduce non-point source inputs of nutrients because they are a major threat to water quality. One principal federal program, the EPA's 319 cost-share program, awarded more than \$1.3 billion between 1990 and 2001 to states and territories for projects to control non-point pollution. Failure to maintain nutrient removal capacity of ephemeral and intermittent streams and wetlands would undermine these efforts.

Wetlands also remove nutrients from surface waters. Several studies of riparian wetlands have found that those associated with the smallest streams to be most effective in removing nutrients from surface waters. For example, headwater wetlands comprise 45 percent of all wetlands able to improve water quality in four

Vermont watersheds. Another study found that wetlands associated with first-order streams are responsible for 90 percent of wetland phosphorus removal in eight northeastern watersheds. Such studies demonstrate that riparian wetlands, especially those associated with small streams, protect water quality.

As land is developed, headwater streams are often filled or channeled into pipes or paved waterways, resulting in fewer and shorter streams. For example, as the Rock Creek watershed in Maryland was urbanized, more than half of the stream channel network was eliminated. In even more dramatic fashion, mining operations in the mountains of central Appalachia have removed mountain tops and filled valleys, wiping out entire headwater stream networks. From 1986 to 1998, more than 900 miles of streams in central Appalachia were buried, more than half of them in West Virginia.

If headwater streams and wetlands are degraded or filled, more fertilizer applied to farm fields or lawns reaches larger downstream rivers. These larger rivers process excess nutrients from fertilizer much more slowly than smaller streams. Losing the nutrient retention capacity of headwater streams would cause downstream waterbodies to contain higher concentrations of nitrogen and phosphorus. A likely consequence of additional nutrients would be the

further contamination and eutrophication of downstream rivers, lakes, estuaries and such waters as the Gulf of Mexico.

Natural Recycling in Headwater Systems Sustains Downstream Ecosystems

Recycling organic carbon contained in the bodies of dead plants and animals is a crucial ecosystem service. Ecological processes that transform inorganic carbon into organic carbon and recycle organic carbon are the basis for every food web on the planet. In freshwater ecosystems, much of the recycling happens in small streams and wetlands, where microorganisms transform everything from leaf litter and downed logs to dead salamanders into food for other organisms in the aquatic food web, including mayflies, frogs and salmon.

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Like nitrogen and phosphorus, carbon is essential to life but can be harmful to freshwater ecosystems if it is present in excess or in the wrong chemical form. If all organic material received by headwater streams and wetlands went directly downstream, the glut of decomposing material could deplete oxygen in downstream rivers, thereby damaging and even killing fish and other aquatic life. The ability of headwater streams to transform organic matter into more usable forms helps maintain healthy downstream ecosystems.

HEADWATER STREAM SYSTEMS STORE AND TRANSFORM EXCESS ORGANIC MATTER

Intact headwater systems both store and process organic matter in ways that modulate the release of carbon to downstream lakes and rivers. Headwater systems receive large amounts of organic matter, which can be retained and transformed into more palatable forms through decomposition processes. This organic matter is anything of biological origin that falls into, washes into or dies in a stream. Plant parts, such as leaves, twigs, stems and larger bits of woody debris, are the most common of these items. Another source of organic material is dead stream organisms, such as bits of dead algae and bacteria or bodies of insects and even larger animals. Waste products of plants and animals also add organic carbon to water. Water leaches dissolved organic carbon from organic materials in a stream and watershed like tea from a tea bag.

Much of the organic matter that enters headwater systems remains there instead of continuing downstream. One reason is that the material often enters headwater streams as large pieces, such as leaves and woody debris, that are not easily carried downstream. In addition, debris dams that accumulate in headwater streams block the passage of materials. One study found four times more organic matter on the bottoms of headwater streams in forested watersheds than on the bottoms of larger streams.

Another reason material stays in headwater streams is that food webs in small streams and wetlands process organic matter efficiently. Several studies have found that headwater streams are far more efficient at transforming organic matter than larger streams. For exam-

ple, one study showed that, for a given length of stream, a headwater stream had an eight-fold higher processing efficiency than a fourth-order channel downstream. Microorganisms in headwater stream systems use material such as leaf litter and other decomposing material for food and, in turn, become food for other organisms. For example, fungi that grow on leaf litter become nutritious food for invertebrates that make their homes on the bottom of a stream, including mayflies, stoneflies and caddis flies. These animals provide food for larger animals, including birds such as flycatchers and fish such as trout.

HEADWATER SYSTEMS SUPPLY FOOD FOR DOWNSTREAM ECOSYSTEMS

The organic carbon released by headwater streams provides key food resources for downstream ecosystems. Headwater ecosystems control the form, quality and timing of carbon supply downstream. Although organic matter often enters headwaters in large amounts, such as when leaves fall in autumn or storm runoff carries debris into the stream, those leaves and debris are processed more slowly. As a result, carbon is supplied to downstream food webs more evenly over a longer period of time. Forms of carbon delivered range from dissolved organic carbon that feeds microorganisms to the drifting insects such as mayflies and midges that make ideal fish food. Such insects are the preferred food of fish such as trout, char and salmon. One study estimated that fishless headwater streams in Alaska export enough drifting insects and other invertebrates to support approximately half of the fish production in downstream waters.

Processed organic matter from headwater streams fuels aquatic food webs from the smallest streams to the ocean. Only about half of all first-order streams drain into second-order streams; the other half feed directly into larger streams or directly into estuaries and oceans, thus delivering their carbon directly to these larger ecosystems. The health and productivity of downstream ecosystems depends on processed organic carbon-ranging from dissolved organic carbon to particles of fungus, and leaf litter to mayflies and stoneflies-delivered by upstream headwater systems.

"THE ABILITY OF HEADWATER STREAMS TO TRANSFORM ORGANIC MATTER INTO MORE USABLE FORMS HELPS MAINTAIN HEALTHY DOWNSTREAM ECOSYSTEMS."

Headwater Streams Maintain Biological Diversity

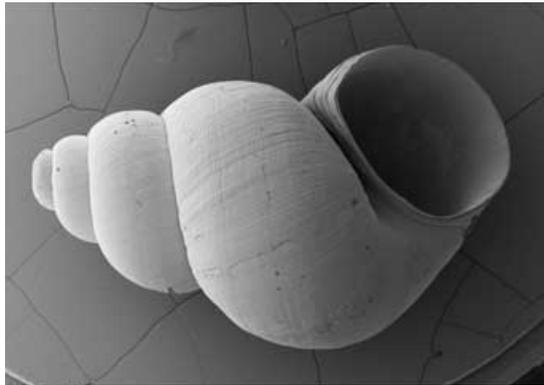
HEADWATER HABITATS ARE DIVERSE

Headwater streams are probably the most varied of all running-water habitats; they range from icy-cold brooks tumbling down steep, boulder-filled channels to outflows from desert springs that trickle along a wash for a short distance before disappearing into sand. As such, headwater systems offer an enormous array of habitats for plant, animal and microbial life.

*Top left: Populations of the ellipse mussel (*Venustaconcha ellipsiformis*) have disappeared from many of its native Midwestern headwaters. Photo courtesy of Kevin Cummings, Illinois Natural History Survey*



*Top right: A hydrobiid snail [*Pyrgulopsis robusta*] found in the headwaters of the Snake River in Wyoming. Photo courtesy of Dr. Robert Hershler*



*Center: Caddis flies and other aquatic insects spend their larval stage in streams, feeding on the algae, vegetation and decaying plant matter. The *Brachycentris*, a caddis fly found in headwater streams of eastern North America, constructs a protective case out of twigs, leaves and other debris. Photo courtesy of David H. Funk*



Bottom: American dippers rely on headwater streams for sustenance, walking along stream bottoms and feeding on insect larvae and crustaceans among the rocks of the streambed. This American dipper was photographed at Tanner's Flat, just east of Salt Lake City. Photo courtesy of Pomera M. France



This variation is due to regional differences in climate, geology, land use and biology. For example, streams in limestone or sandy regions have very steady flow regimes compared with those located in impermeable shale or clay soils. Plants or animals found only in certain regions can also lend a distinctive character to headwater streams. Regionally important riparian plants, such as alder and tamarisk, exercise a strong influence on headwater streams. Headwater streams in regions with beavers are vastly different from those in regions without beavers.

Environmental conditions change throughout a stream network. In wet regions, streams grow larger and have wider channels, deeper pools for shelter, and more permanent flow as they move downstream. In arid regions and even humid regions during dry periods, headwater streams may become smaller downstream as water evaporates or soaks into a streambed. Because marked changes in environmental conditions can occur over very short distances, conditions required by a headwater species may exist for as little as 100 yards of stream. Consequently, local populations of a species may extend over just a short distance, particularly in spring-fed headwaters with sharp changes in environmental conditions along the length of a stream.

With this variety of influences, headwater streams present a rich mosaic of habitats, each with its own characteristic community of plants, animals, and microorganisms.

HEADWATER SYSTEMS SUPPORT A DIVERSE ARRAY OF ANIMALS AND PLANTS

There has never been a complete inventory of the inhabitants in even a single headwater stream, much less surveys across many types of headwaters that would permit a thorough understanding of biodiversity in headwater streams. Nevertheless, it is clear that individual headwater streams support hundreds to thousands of species, ranging from bacteria to bats.

The species in a typical headwater stream include bacteria, fungi, algae, higher plants, invertebrates, fish, amphibians, birds and mammals. Headwater streams are rich feeding grounds. Large amounts of leaves and other organic matter that fall or blow into streams, the retention of organic matter in a

channel or debris dams, and the high rates of plant and algal growth in unshaded headwaters all supply food sources for animals such as caddis flies, snails and crustaceans. These animals become food for predators such as fish, salamanders, crayfish, birds and mammals, which, in turn, become prey for larger animals, including herons, raccoons and otters. Many widespread species also use headwaters for spawning sites, nursery areas, feeding areas, and travel corridors. Thus, headwater habitats are important to species like otters, flycatchers, and trout, even though these species are not restricted to headwaters. The rich resource base that headwaters provide causes the biotic diversity of headwater streams to contribute to the productivity of both local food webs and those farther downstream.

Diversity of headwater systems results in diverse headwater plants and animals. Many of these species are headwater specialists and are most abundant in or restricted to headwaters. For example, water shrews live along small, cool streams, feed on aquatic invertebrates, and spend their entire lives connected to headwater streams. Because different headwaters harbor different species, the number of headwater-dependent species across North America is far greater than the number of species in any one headwater.

Headwater specialists often have small geographic ranges. These species, many of which are imperiled, include: species of minnows, darters, and topminnows in southeastern springs and brooks; aquatic snails in spring-fed headwaters in the Great Basin, the Southeast, Florida, and the Pacific Northwest; crayfish in small streams from Illinois and Oklahoma to Florida; and salamanders and tailed frogs in small streams, springs, and seeps in the Southeast and Pacific Northwest. Two factors contribute to specialists' small ranges: their limited ability to move between headwaters and high diversity of headwater habitats. Unlike mobile animals, such as mammals and birds, fully aquatic animals like fish and most mollusks cannot move from one headwater stream to another. As a result, local evolution may produce different species in adjacent headwater systems. Moreover, environmental conditions often differ greatly between adjacent headwater streams and even within the course of a single stream. For example, in a spring-fed headwater stream in western Pennsylvania, one species of caddis fly inhabits head-



A water shrew (Sorex palustris) in the water's of Oregon's Mt. Hood. Photo courtesy of RB Forbes, Mammal Images Library

waters starting at the spring and going downstream about 200 yards. A different species of caddis fly inhabits the stream after that point.

Animals may use headwater streams for all or part of their lives. Although many fish species live exclusively in headwater systems, others use headwaters only for key parts of their life cycle. For example, headwaters are crucial for the diversity of salmon stocks in the Pacific Northwest because salmon spawn and rear in headwater streams. In other parts of the country, trispot darters, brook trout and rainbow trout spawn in small streams. Young cutthroat trout use shelter formed by streams' debris dams but move onto larger portions of a stream network as they mature. Intermittent streams can offer special protection for young fish, because the small pools that remain in such streams often lack predators. Still other fish species use headwater streams as seasonal feeding areas.

Both permanent and intermittent streams provide valuable habitat for microorganisms, plants and animals. Generally, biodiversity is higher in permanent streams than in intermittent streams, but intermittent streams often provide habitat for different species. Some species that occur in both types of streams may be more abundant in predator-free intermittent streams. For example, because of the lack of large predatory fish, salamanders and crayfish are sometimes more abundant in fishless intermittent streams rather than those with permanent flow. In contrast, for animals such as brook trout that require steady water temperatures and constant water flow, perennial streams provide better habitat.



A coho salmon migrating up a spring-fed tributary of the Snoqualmie River watershed in Washington's Puget Sound region. Many anadromous fish species spawn in headwater streams that are so small as to be omitted from standard USGS topographical maps. Photo courtesy of Washington Trout.



A westslope cutthroat trout from Deep Creek, a headwater of the Kettle River. Cutthroat trout spawn in headwaters where the young trout seek shelter amid piles of debris, moving on to larger waters for their adult lives. Photo courtesy of Bill McMillan, Washington Trout

Canelo Hills ladies' tresses [*Sprianthes delitescens*] in a southwestern freshwater marsh known as a cienega. The cienegas of Arizona and New Mexico and Mexico, are the exclusive habitat for this member of the orchid family.

Photo courtesy of Jim Rorabaugh, USFWS



LINKAGES BETWEEN HEADWATER AND STREAMSIDE ECOSYSTEMS BOOST BIOLOGICAL DIVERSITY

The movement of plants and animals between headwater and streamside ecosystems boosts biodiversity in both areas. Headwater streams are tightly linked to adjacent riparian ecosystems, the zones along a stream bank. Riparian ecosystems have high species diversity, particularly in arid environments where the stream provides a unique microclimate. Typical riparian vegetation depends upon moist streamside soils. Some plants must have “wet feet,” meaning their roots have to stretch into portions of soil that are saturated with water. Seeds of some riparian plants, such as those of cottonwood trees found along rivers in the Southwest, require periodic floods to germinate and take root.

The Cleistes, a member of the orchid family, is found in pocosin wetlands of North Carolina. Photo courtesy of Vince Bellis



Another link between stream and land is often provided by insects, such as mayflies, that emerge from streams and provide a vital food resource for animals, including birds, spiders, lizards and bats. For example, insect-eating birds living by a prairie stream in Kansas consume as much as 87 percent of the adult aquatic insects that emerged from the stream each day. Such exchanges between land and water help maintain animal populations across landscapes. In many landscapes, the network of headwater streams is so dense that it offers a nearly continuous system of interconnected habitat for the movement of mobile species that rely on streams and riparian areas.

BIOLOGICAL DIVERSITY OF HEADWATER SYSTEMS IS THREATENED BY HABITAT DESTRUCTION

Because of their small size and intimate connections with surrounding landscape, headwaters and their inhabitants are easily influenced by human activities in watersheds and riparian zones. Changes to riparian vegetation or hydrology, water pollution, or the introduction of exotic species can have profound effects on biota living in headwaters.

Specialized headwater species can be particularly sensitive to habitat destruction because of their small geographic ranges, sometimes as small as a single headwater stream or spring. Thus, human activities have driven some headwater specialists, like the whiteline topminnow, to extinction, and imperiled many others. Furthermore, as the natural disjunction of headwater systems is increased by human activities such as pollution, impoundment, and destruction of riparian vegetation, more populations of headwater specialists may be extirpated.

Many headwater species, including fish, snails, crayfish, insects and salamanders, are now in danger of extinction as a result of human actions. A few dozen headwater species are already listed under the U.S. Endangered Species Act; hundreds of others are rare enough to be considered for listing. Given the diversity and sensitivity of headwater biota, it seems likely that continued degradation of headwater habitats will put more species at risk of extinction.



WETLANDS MAKE KEY CONTRIBUTIONS TO BIOLOGICAL DIVERSITY

The presence of wetlands adds another aspect of habitat diversity to headwater systems and therefore increases the variety of species a headwater system may support. Most headwater wetlands are depressions in the ground that hold water permanently or seasonally. Wetlands provide critical habitat for a variety of plants and animals. Scientists usually distinguish between ephemeral and perennial wetlands.

BIODIVERSITY IN EPHEMERAL WETLANDS

Some species of plants and animals prefer or require ephemeral wetlands. Certain zooplankton, amphibians, and aquatic plants need the wet phase of an ephemeral wetland to complete all or part of their life cycles. Other species that rely on ephemeral wetlands wait out the aquatic phase, flourishing only when pools shrink or disappear. For example, although adult spotted salamanders are generally terrestrial, during the springtime they trek to vernal pools to breed and reproduce. So-called amphibious plants, includ-

ing button celery, meadowfoam, woolly marbles and many others do the opposite; although they live in water, they cannot reproduce until water levels drop. Some plants and crustaceans most strongly identified with ephemeral wetlands worldwide, including quillworts, fairy shrimp, and tadpole shrimp, are ancient groups that probably originated at least 140 million years ago. The disappearance of ephemeral wetlands would mean the loss of these highly specialized and ancient groups of plants and animals.

One type of ephemeral wetland found in both California and the Northeast is known as a vernal pool because it generally fills with water in the spring. In California, blooming flowers ring the edges and fill depressions of such pools. Of the 450 species, subspecies, or varieties of plants found in California's vernal pools, 44 are vernal pool specialists. Several such plants are already on the Endangered Species list. If California's vernal pool habitats were completely destroyed, at least 44 species would disappear. Although vernal pool animals are less well known, there appear to be at least as many



Pitcher plants, such as this white top (*Sarracenia leucophylla*), pictured top left; and sundews, such as this *Drosera brevifolia*, pictured bottom right; are among the carnivorous plants found in the Carolina Bay wetlands of the Southeastern U.S. Photo courtesy of David Scott/SREL



Although spotted salamanders are generally terrestrial animals, they only breed and reproduce in vernal pools.

Photo courtesy of Vernal Pool Association

specialized animals as plants. New species of specialists such as fairy shrimp and clam shrimp continue to be discovered.

Other ephemeral wetlands also make significant contributions to biodiversity. A study of wetlands in the Southeast including cypress-gum swamps, cypress savannas, and grass-sedge marshes, found that plants from one wetland are often very different from those in others nearby. Such differences in nearby habitats increase overall biodiversity in a region. In some cases, differences in periods of wetting and drying appear to be important for the persistence of many species. Different wetting and drying patterns explain some differences between Gromme Marsh and

Stedman Marsh, two prairie pothole wetlands in Wisconsin. Although the two marshes are only about 450 yards apart, they have different species of dragonflies; also, Stedman Marsh has damselflies and caddis flies that Gromme Marsh lacks.

Amphibians are key parts of the food web in small wetlands. Some wetlands are hot spots for amphibian biodiversity; twenty-seven amphibian species, one of the highest numbers of amphibian species known from such a small area, inhabited a 1.2-acre ephemeral wetland in South Carolina. Other small wetlands in the region have been found to have similar numbers of amphibian species, demonstrating how small wetlands are especially important for maintaining the regional biodiversity of amphibians. Larger, more permanent wetlands may be less diverse because they may also be home to predators—such as crayfish and dragonfly larvae—that eat amphibian larvae.

BIODIVERSITY IN FENS (A TYPE OF PERENNIAL WETLAND)

Plant biodiversity peaks in fens, unique perennial wetlands that occur where groundwater flows to the surface. Fens also provide clean water that supports downstream ecosystems; outflows from such wetlands are critical to the formation of the cold, low-nutrient streams that are ideal for trout. Although fens are rarely inundated, water seeps continuously into root zones.

Similar to other wetlands, the small land area covered by fens belies the high biodiversity found within them. For example, in northeastern Iowa, fens contain 18 percent of the state's plant species but cover only 0.01 percent of the land surface. Fens are probably the wetlands with the greatest numbers of plant species. Because groundwater that comes to the surface is typically low in available nutrients, fen plants are often dwarfed and the total mass of vegetation is typically low. As a result, no one species can become dominant and exclude other species.

In the Upper Midwest, more than 1,169 species of plants have been identified in fens, with more than half needing wet conditions. Fens also have

A female fairy shrimp from the Ipswich River Basin in Massachusetts. Fairy shrimp spend their entire life cycles in vernal pools. Photo courtesy of Vernal Pool Association



a high proportion of plant species known to occur primarily in pristine sites. Often, such species are listed as rare, threatened or endangered. Of 320 vascular plant species found within fens in northeastern Iowa, 44 percent are considered rare. Fens themselves are imperiled: 160 fens that one researcher sampled in northeastern Iowa were all that remained from 2,333 historic fens.

Because diversity in fens stems from low nutrient availability, overfertilization can harm fens and, in turn, downstream ecosystems. Examining one fen in New York, researchers found the lowest diversity of plants where nitrogen and phosphorus inflows were greatest. Both nutrients came from agricultural activities: phosphorus was entering the fen primarily through surface water flows, while the nitrogen-containing compound nitrate was flowing with the groundwater. Thus, a loss of plant diversity in fens is a clear indication they are receiving excess nutrients, such as can occur when fertilizer runs off a field or urban lawn or water carries animal waste from farm-



yards. Allowing excess nutrients to enter fens can also damage downstream trout streams because trout prefer cold, low-nutrient streams. Therefore, the low-nutrient conditions of fens require protection from nutrient contamination.

*A wood frog (*Rana sylvatica*) in an autumnal vernal pool in central Pennsylvania. Photo courtesy of Gene Wingert*



Fens are unique perennial wetlands that occur where groundwater flows to the surface. Plant biodiversity peaks in fens: Among the 320 vascular plant species found in northeastern Iowa fens, 44% are considered rare. However, fens themselves are imperiled. Pictured is a fen wetland in Illinois. Photo courtesy of Steve Byers, Bluff Spring Fen Nature Preserve

Conclusion

Headwater streams and wetlands abound on the American landscape, providing key linkages between stream networks and surrounding land. Although often unnamed, unrecorded, and underappreciated, small headwater streams and wetlands—including those that are dry for parts of the year—are an integral part of our nation’s river networks. Small wetlands, even those without visible surface connections, are joined to stream systems by groundwater, subsurface flows of water, and periodic surface flows. Current databases and maps do not adequately reflect the extent of headwater streams and associated wetlands. The resulting underestimate of the occurrence of such ecosystems hampers our ability to measure the key roles headwater systems play in maintaining quality of surface waters and diversity of life.

Essential ecosystem services provided by headwater systems include attenuating floods, maintaining water supplies, preventing siltation of downstream streams

Photo courtesy of
Raymond Eubanks.



and rivers, maintaining water quality, and supporting biodiversity. These small ecosystems also provide a steady supply of food resources to downstream ecosystems by recycling organic matter.

Small streams and wetlands provide a rich diversity of habitats that supports unique, diverse, and increasingly endangered plants and animals. Headwater systems, used by many animal species at different stages in their life history, provide shelter, food, protection from predators, spawning sites and nursery areas, and travel corridors between terrestrial and aquatic habitats.

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STREAMS.”*

Since the 1970s, the federal Clean Water Act has played a key role in protecting streams and wetlands from destruction and pollution. We have made progress toward cleaner water, in part because the law has historically recognized the need to protect all waters of the United States. The health of downstream waters depends on continuing protection for even seemingly isolated wetlands and small streams that flow only part of the year.

These small streams and wetlands are being degraded and even eliminated by ongoing human activities. Among the earliest and most visible indicators of degradation is the loss of plant diversity in headwater wetlands. The physical, chemical, and biotic integrity of our nation’s waters is sustained by services provided by wetlands and headwater streams.

Today’s scientists understand the importance of small streams and wetlands even better than they did when Congress passed the Clean Water Act. If we are to continue to make progress toward clean water goals, we must continue to protect these small but crucial waters. The goal of protecting water quality, plant and animal habitat, navigable waterways, and other downstream resources is *not achievable* without careful protection of headwater stream systems.

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