Freshwater Mussels
and the
Connecticut River Watershed

Chapter 3: Status and Threats

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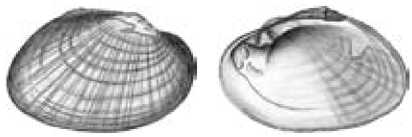

CHAPTER 3

Status and Threats

When first learning about freshwater mussels, people commonly ask, "Are there more than one kind?" Most people have probably only encountered a single, common species—the eastern elliptio—or just assumed that every large clam-like creature in freshwater belongs to a single species. This misperception often leads people to think that mussels are everywhere and abundant, when in reality, nine of 12 species in the Connecticut River watershed are imperiled in all or parts of their range. Raising awareness about the status and the need to protect all species and their habitats is a conservation challenge. Protection relies on first identifying relevant threats for each species, from small dams that may impede movement of host fish to global threats such as climate change.

I. STATUS

Freshwater mussels are one of the most endangered groups of animals on Earth. Nearly three-quarters of the 297 native mussel species in North America are imperiled and 35 species are thought to have gone extinct in the last century (Bogan 1996). Sixty-nine species (23 percent of North America's mussel fauna) are listed as endangered or threatened under the federal Endangered Species Act. Some species may not persist longer than the life span of the individuals that are alive today.

Of the 12 species of freshwater mussels that occur in the Connecticut River watershed, eight are listed by one or more states as endangered, threatened, or special concern (Table 4). Some of these species are also imperiled in other parts of their North American range. The dwarf wedgemussel is a federally endangered species, and is listed as endangered by each state in the watershed. Precise definitions and legal implications of the terms endangered, threatened, and special concern vary by state. Endangered species are thought to face a significant risk of extinction or extirpation, threatened species could become endangered in the foreseeable future, and special concern species may be declining but more information is needed.

The most endangered species in the Connecticut River watershed are the yellow lampmussel, brook floater, and dwarf wedgemussel. The yellow lampmussel was once considered

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Photo: The Nulhegan River is one of five Connecticut River tributaries in Vermont that support four or more mussel species. The landscape of the Nulhegan River is also well protected by state and federal agencies and conservation groups. Ethan Nedeau

Table 4. Legal status of freshwater mussels in the Connecticut River watershed and elsewhere in their range. E = Endangered, T = Threatened, SC = Special Concern, P = present but not protected, NP = not present.

Special note: Status current as of April 2008 with two exceptions: the yellow lampmussel was listed as Special Concern in Connecticut as of January 2008 because it was long considered extirpated, but its discovery in Connecticut in 2006 means that it will be listed as Endangered pending final approval by the Connecticut Department of Environmental Protection (DEP) in 2008. Also in Connecticut, the status of the tidewater mucket is proposed to change from Threatened to Special Concern and the DEP is expected to approve this change in 2008.

	State				
Species	CT	MA	NH	VT	Elsewhere
Dwarf Wedgemussel *Alasmidonta heterodon*	E	E	E	E	Federally endangered. E in every state throughout its range. Extirpated in Canada and RI
Triangle Floater *Alasmidonta undulata*	P	SC	P	P	E in MD. T in NJ
Brook Floater *Alasmidonta varicosa*	E	E	E	T	E in MD, VA, NJ. T in ME, NY. Extirpated in RI and DE.
Alewife Floater *Anodonta implicata*	P	P	P	P	
Eastern Elliptio *Elliptio complanata*	P	P	P	P	
Yellow Lampmussel *Lampsilis cariosa*	E	E	NP	NP	T in ME, NJ. “At risk” in Nova Scotia
Eastern Lampmussel *Lampsilis radiata*	P	P	P	P	T in NJ. Species of “Concern” in RI
Tidewater Mucket *Leptodea ochracea*	SC	SC	NP	NP	T in NJ, ME. “At risk” in Nova Scotia
Eastern Pondmussel *Ligumia nasuta*	SC	SC	SC	NP	T in NJ. Species of “Concern” in RI
Eastern Pearlshell *Margaritifera margaritifera*	SC	P	P	T	E in PA, RI
Eastern Floater *Pyganodon cataracta*	P	P	P	P	
Creeper *Strophitus undulatus*	P	SC	P	P	SC in ME. “At risk” in Nova Scotia. Species of “Concern” in RI

extirpated in Connecticut and nearly extirpated in Massachusetts. It is now known to inhabit a 50-mile segment of the Connecticut River spanning both states, although it has a discontinuous distribution. The brook floater occurs in six tributaries of the Connecticut River and its populations are highly isolated and fragmented; it has been eliminated from portions of its native range in the watershed. The dwarf wedgemussel occurs in the mainstem Connecticut River and eight tributary watersheds. The Connecticut River watershed supports the largest remaining populations of the dwarf wedgemussel on Earth, making it a globally important watershed for freshwater mussel conservation.

Species that are not protected by state or federal endangered species laws are considered stable or there is not enough evidence to justify legal protection. Some of these species—such as the eastern elliptio, eastern lampmussel, and eastern floater—have a wide distribution and may be abundant where they occur. Common species can be locally rare in some waterbodies, and may be adversely affected by a variety of threats, yet there are no foreseeable threats to their overall viability. Little effort goes into surveying or monitoring non-protected species.

ENDANGERED, THREATENED, AND SPECIAL CONCERN

The terms endangered, threatened, and special concern are designated to species that are listed under endangered species regulations at the state level. The terms imply different levels of concern and the need for conservation and management. Each state defines these terms in a slightly different way although the general meaning is consistent among the states. Specific definitions are available through the primary natural resource agency for each state, including the Connecticut Department of Environmental Protection, Massachusetts Natural Heritage and Endangered Species Program, Vermont Fish and Wildlife Department, and the New Hampshire Fish and Game Department (Appendix 2). Species may also be protected under the federal Endangered Species Act; currently only the dwarf wedgemussel receives such protection among the mussels that inhabit the Connecticut River watershed. Information about federally endangered species can be obtained from the U.S. Fish and Wildlife Service.

Definitions below are adapted from the Massachusetts regulations.

Endangered species are native species which are in danger of extinction throughout all or part of their range, or which are in danger of extirpation, as documented by biological research and inventory.

Threatened species are native species which are likely to become endangered in the forseeable future, or which are declining or rare as determined by biological research and inventory.

Special concern species are native species which have been documented by biological research or inventory to have suffered a decline that could threaten the species if allowed to continue unchecked, or which occur in such small numbers or with such restricted distribution or specialized habitat requirements that they could easily become threatened.

II. THREATS

The loss and decline of freshwater mussels is a symptom of worldwide degradation of freshwater ecosystems, and is mirrored by declines of other freshwater fauna (Richter *et al.* 1997, Malmqvist and Rundle 2002, Dudgeon *et al.* 2006). The Connecticut River is not immune to the myriad threats that are causing a national and global conservation crisis, yet the watershed still contains some of the best remaining native mussel assemblages in the world. No threats in the Connecticut River watershed are unique to mussels; rather, the threats affect nearly every component of the watershed's aquatic biodiversity. Therefore, addressing these threats—whether for mussels, fish, or to have fishable and swimmable waterways—will have far reaching benefits. This section uses local examples to illustrate why these major threats are important. Readers are encouraged to review the cited literature to learn more about these topics. The *Connecticut River Corridor Management Plan*, completed by the Connecticut River Joint Commissions (www.crjc.org), is an excellent overview for Vermont and New Hampshire.

Habitat Loss and Fragmentation

Dams contribute to habitat loss and fragmentation in the Connecticut River watershed. The watershed has a higher density of dams than any other watershed in the United States (Graf 1999), and among the highest densities of dams in North America, Europe, and the former Soviet Union (Dynesius and Nilsson 1994). The Nature Conservancy estimated 2,722 dams in the Connecticut River watershed, including 16 flood control dams and 125 hydropower dams

Dams profoundly affect streams and rivers. Dams shown here include the McIndoe Falls hydropower dam on the upper Connecticut River (left), the Colebrook River Lake dam on the West Branch Farmington River (top right), and a small dam on Raymond Brook in the Salmon River watershed in Connecticut. The Raymond Brook dam was removed in 2007 through the cooperative efforts of the Connecticut River Watershed Council, The Nature Conservancy, American Rivers, Connecticut DEP, and the National Oceanic and Atmospheric Administration.
Ethan Nedeau (left, bottom right), U.S. Army Corps of Engineers (top right)

(The Nature Conservancy 2008). All dams, regardless of their size, may affect hydrology, water temperature, water quality, sediment transport and other channel processes, nutrient cycles, and migration routes (Poff *et al.* 1997, Richter *et al.* 1997, Bunn and Arthington 2002).

Dams have greatly affected freshwater mussels throughout North America (Bogan 1993, Watters 1995, Vaughn and Taylor 1999). The effects of dams on mussels depend on the geographic and ecological context of the dam, the size of the dam, and how the dam is designed and operated (e.g., flood control, power generation, seasonal storage, or run-of-river). The following concerns are the most prevalent in the Connecticut River watershed (Zimmerman 2006).

- Conversion of rivers into deep impoundments and the resulting loss of riverine species
- Fragmentation of rivers by multiple dams in a watershed, leading to isolated mussel populations that face a higher risk of extirpation
- Dams that impede or block the natural movement of native fish
- Dams that alter thermal regimes in impoundments and downstream areas
- Loss of species downstream of hydroelectric dams due to loss of fine sediments and hydropeaking (i.e., unnaturally high flow variations on short time scales, i.e., hourly to daily)
- Dam maintenance that requires a drawdown of the impoundment, which, if unmanaged, can cause high mortality of mussels that inhabit the impoundment

Poorly designed road-stream crossings, such as this one in the Deerfield River watershed in Massachusetts, break stream continuity and impede fish passage. Ethan Nedeau

Road-stream crossings far outnumber dams. Trombulak and Frissell (2000) estimated nearly 8.15 million miles of road lanes, paved and unpaved, in the United States. An estimated 10,000 miles of roadways will be built annually in the coming decade (Elvidge *et al*. 2004). This transportation infrastructure cuts across watersheds and has profound effects on aquatic ecosystems (Forman and Alexander 1998, Trombulak and Frissell 2000, Jones *et al*. 2000). The nation's stream crossings have not been tallied, but there are probably several million bridges and culverts on fish-bearing streams, and tens of millions more on headwater streams (Meyer *et al*. 2003). The Massachusetts Riverways Program estimated that 28,500 road and railroad crossings exist on fish-bearing streams in Massachusetts, outnumbering dams by more than ten to one. The Nature Conservancy has been involved with stream crossing surveys in the Eightmile River, Salmon River, Westfield River, Ashuelot River, and West River. Stream crossings have been assessed, or assessments are being planned, in several other watersheds by state agencies and watershed groups.

Although many stream crossings are bridges that span the streambanks, most are culverts that constrict streamflow. Some disrupt stream continuity by impeding the movement of biota and creating unnatural habitat conditions that may be detrimental to native species. Culverts are the greatest culprits, particularly those that are perched (i.e., raised above the level of the stream, thereby creating a hurdle for organisms trying to get upstream), undersized, too long, or made of materials that restrict passage of aquatic organisms (Massachusetts Riverways Program 2005). More information is available through the River and Stream Continuity Project of the University of Massachusetts (www.streamcontinuity.org).

The effect of poorly designed road-stream crossings on freshwater mussels has not been studied but can be inferred from studies that have focused on physical habitat, hydraulics, and fish (for a review pertinent to the Connecticut River watershed, see Nedeau 2006f). Effects are expected to be most acute for mussels that occur in small streams, or whose host fish populations rely on seasonal movement into small streams. These include the creeper, triangle floater, brook floater, dwarf wedgemussel, and eastern pearlshell.

Habitat loss and fragmentation can also result from poorly planned land use and development in river corridors (Paul and Meyer 2001, Allan 2004, de la Cretaz and Barten 2007). Deforestation in the Connecticut River watershed, followed by intensive agriculture and urbanization, degraded many miles of rivers and decimated native fauna in some areas. Portions of a valley that contribute strongly to the degraded condition (e.g., sedimentation, loss of habitat, water quality) of a river can fragment aquatic habitat in the same way that a dam might. For example, sensitive species are often absent in portions of rivers flowing through urban areas and intensively farmed lands. The more prevalent these areas are in a watershed, the more likely that sensitive species will be confined to small and isolated patches of suitable habitat, and the more likely that the viability of these populations will be at risk.

Portions of the Sugar River that flow through industrialized areas of Claremont and Newport, New Hampshire, are degraded and support poor mussel communities. Populations of two highly sensitive species—the brook floater and eastern pearlshell—exist in the watershed but are restricted to one high quality tributary, and their ranges end abruptly at the confluence with the mainstem Sugar River (Nedeau 2006b). Much of the Fort River in Amherst and Hadley, Massachusetts, exhibits signs of historic degradation and most of its length is inhabited by only two species. Yet, overall diversity for the Fort River is high—nine species, including the dwarf wedgemussel and three other state-listed species—but most species are represented by small numbers of animals that are restricted to a small portion of the river (Nedeau 2008). Commercial and residential development is intense in lower portions of the Fort River watershed, where agricultural land is succumbing to development, driven by skyrocketing land value and pressure on landowners to sell their land (Clay *et al.* 2006).

Alteration of Natural River Processes

Many of the subtle yet pervasive threats to streams and rivers in the watershed stem from alterations to the natural flow regime and fluvial geomorphic processes (this refers to the way that rivers flow through their valleys and transport sediment; this field of study is called fluvial geomorphology). A flow regime describes the full range of a river's natural flow variability, including the timing, magnitude, and duration of different flow conditions, and rates of change (Richter *et al.* 1996, Poff *et al.* 1997). The flow regime is a driving force in river ecosystems and affects nearly all aspects of their biology. The flow regime is influenced by river size, climate, geology, elevation, groundwater influence, position within a watershed, nature of upland and riparian areas, channel form, and of course, human activity. Flow regimes vary within and among rivers, as do the effects of altered flow regimes.

In addition to their effects on habitat, dams have the potential to greatly alter natural flow regimes. Recent studies by The Nature Conservancy have documented the extent and effects of flow alteration in the Connecticut River watershed, focusing primarily on the effects of dams (The Nature Conservancy 2008). Key findings of these studies are as follows:

- Flow has been moderately to severely impaired in 17 of 44 major tributaries, mainly in the southern half of the watershed.
- Flood control dams have dramatically stabilized flow regimes by decreasing the frequency and magnitude of floods, decreasing the frequency (timing) of low-flow periods, and increasing the magnitude (volume) of low flows.
- Reaches downstream of hydropower dams exhibit a high frequency and magnitude of within-day flow fluctuations; associated channel dewatering and high ramping rates are considered detrimental to aquatic life.

Many threats to habitat quality and water quality exist in this portion of the Mill River in Hadley, Massachusetts. Historically, the river was re-routed and channelized. Agriculture and livestock grazing occur along its banks that have little or no riparian buffer. Stormwater runoff from the town of Amherst (via Tan Brook), nearby roadways, and the campus and athletic fields of the University of Massachusetts enter the river here. The wastewater treatment plant that services the town and campus discharges its effluent into the river here also. The cumulative effects of these stressors has created a highly degraded stream. Massachusetts Office of Geographic and Environmental Information

The effects of flow alterations on freshwater mussels are varied and complex. Mussel assemblages in rivers whose flow regimes are stabilized by dams may benefit from flow stability (Hoey and Thomas 2006, Haag and Warren 2007). For example, one of the best freshwater mussel assemblages in the Connecticut River watershed, which includes one of the highest concentrations of dwarf wedgemussels in the world, exists just downstream of a flood control dam in the Ashuelot River in New Hampshire (Nedeau 2006a). The abundance of mussels is anomalously high compared to many other rivers in the watershed. This is partly attributed to flow stability. Nevertheless, floods are essential to the form and function of rivers, and locally enhanced mussel assemblages should not be justification for flow regulation that threatens other components of aquatic ecosystems.

Unnaturally high flow fluctuations, such as what occur downstream of large hydropower dams, have a strong negative effect on mussels. Fluctuations regularly dewater portions of the streambed, effectively eliminating mussels from those portions of the river channel. Scouring flows, high shear stress (i.e., the ability of current to move particles downstream), and loss of fine particle substrates have been implicated in the loss of mussels from areas downstream of large hydropower dams (Layzer *et al.* 1993, Hardison and Layzer 2001, Vaughn and Taylor 2001). No studies have carefully examined mussel assemblages in areas of the Connecticut River downstream of the major hydropower dams.

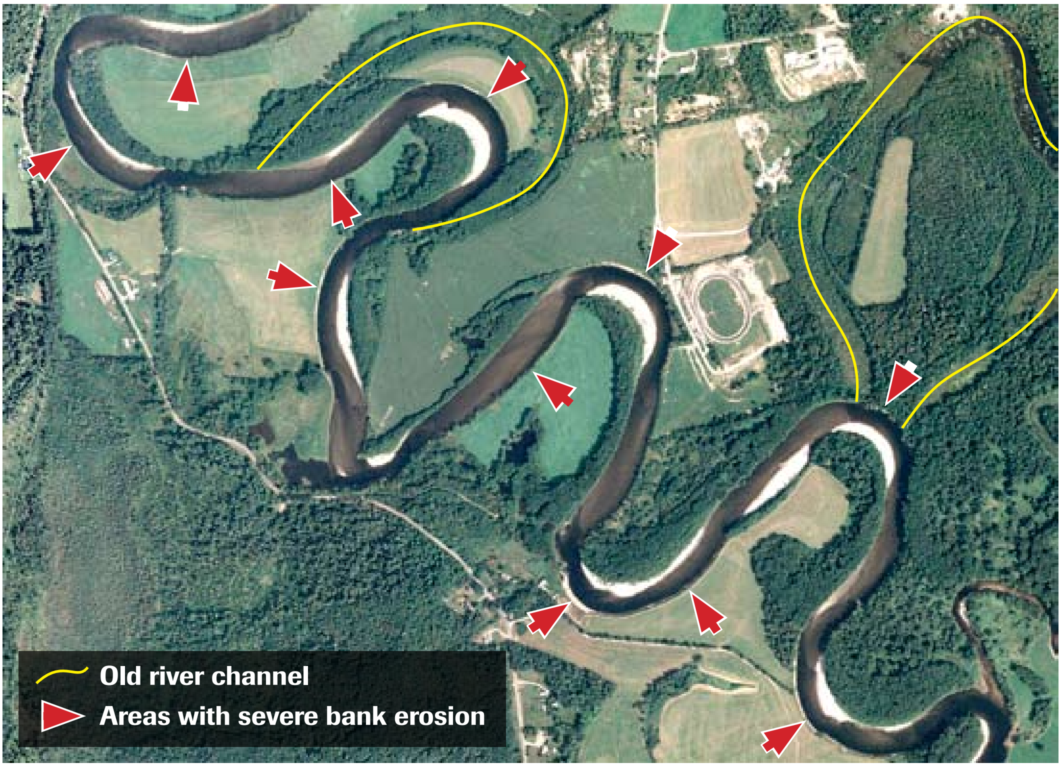
Flow regimes are also affected by landscape alterations, loss of wetlands, and withdrawal of water for human use. There is growing concern about persistent low flow conditions in basins throughout the Connecticut River watershed (Trout Unlimited 2006). Low flows are partly the result of weather but are exacerbated by conditions in the landscape and extraction of groundwater and surface water for human use. Periods of greatest human use usually coincide with periods of naturally low water (mid to late summer), resulting in dangerously low water levels in some rivers. Water demand—for consumption, energy, agriculture, industry, and wastewater treatment—is expected to increase as the human population increases. One of the most pressing challenges facing a burgeoning human population in the Connecticut River watershed is developing policies and laws that provide drinking water and sustain quality of life while protecting aquatic ecosystems (Trout Unlimited 2006).

Lack of water, warm water temperatures, low dissolved oxygen, and concentrated pollutants contribute to high mortality of aquatic fauna during droughts (Lake 2003, Dewson *et al.* 2007). Freshwater mussels are particularly vulnerable because, unlike fish, they cannot swim long distances to seek more favorable conditions. During low flow periods, some mussels may die due to thermal stress, desiccation, and exposure to predators. Similar effects are expected to result from unnaturally high flow fluctuations downstream of large hydropower dams. More studies are needed on the flow needs of freshwater mussels—particularly imperiled species—to protect populations when water is in short supply and resource allocation is contentious.

The flow regime and fluvial geomorphic processes are intimately linked. Together, they determine the distribution and movement of sediment within a river corridor, the size and shape of the channel, the stability of channels and banks, and the connection between the river and its floodplain (Rosgen 1996). Dams, landscape alterations (e.g., conversion of forests to agricultural fields and cities), encroachment on rivers (e.g., channelization, development in floodplains), and persistent hydrologic alteration have altered many rivers throughout the Connecticut River watershed. The most widespread symptoms are channel restriction, significant bank erosion, channel incision, sediment accumulation due to loss of flushing flows, reduced or lost sources of sediment, and loss of riparian wetlands.

A geomorphic assessment of 85 miles of the upper Connecticut River, which was directed by the Connecticut River Joint Commissions, found that more than 25 percent of the river banks were eroded and 15 percent more were stabilized by riprap (Field Geology Services 2004, 2006). Bank erosion could be traced to historic river channelization, and the influence of sediment from tributaries and tall eroding banks. Humans straightened more than 30 percent of the river and a riparian buffer was absent along 20 percent of the river. The net result is that large portions of the upper Connecticut River have highly unstable channels and severely eroding banks. This part of the Connecticut River also supports the largest concentration of dwarf wedgemussels in the world. Channel instability and bank erosion are two major threats to this population. For example, dwarf wedgemussels are often confined to narrow bands of suitable habitat along the outside of river bends, often near banks. These areas are highly susceptible to sedimentation. More information pertaining to geomorphic studies on the upper Connecticut River can be found at the Connecticut River Joint Commissions' website (www.crjc.org). The Vermont Department of Environmental Conservation has produced a series of excellent papers on geomorphic processes and river management (www.anr.state.vt.us/dec/waterq/rivers).

Humans try to fix some of the symptoms of altered geomorphic processes, particularly bank erosion when it threatens private or public property, roadways, and railroads. Eroding banks have been stabilized with materials such as rock, timbers, concrete blocks, concrete and asphalt ripped from roadways, sheets of chain-link fencing material, tires, and even old automobiles! Lacking permits to place these materials into rivers, some landowners placed piles of debris along the lip of eroding banks and eventually these materials would slide down the bank. Whether permitted or not, efforts to stabilize banks may kill mussels in that area.



The Maidstone Bends region of the upper Connecticut River is an amazing example of a highly dynamic river channel that is in a continual state of erosion and deposition. The aerial photograph shows erosion on the outsides of bends and deposition of sand on the insides of bends. Patterns on the landscape indicate where the river once flowed before oxbows formed, filled in, and were claimed for agriculture. The two bottom photos show severe bank erosion and sand deposition in this area. Mussels are sparse or absent along severely eroding banks and in depositional areas. A geomorphic perspective on this area, including the role of humans, is provided in Field Geology Services (2004, 2006), available at the website of the Connecticut River Joint Commissions (www.crjc.org).

Aerial: USDA-Natural Resources Conservation Service. Ethan Nedeau photos

Water Pollution

Effluent from a wastewater treatment plant is discharged into the middle of the Farmington River in Connecticut, a short ways upstream of one of the best freshwater mussel assemblages in New England. It is important to support the use of best available technology for waste treatment in facilities that discharge effluent into the Farmington River. Ethan Nedeau

The quality of water and sediment in the Connecticut River watershed has been affected by nearly four centuries of land conversion, agriculture, industries, urbanization, and by industrialization elsewhere in North America. The Connecticut River was once considered America's "best landscaped sewer" and suffered immeasurably from bacterial, nutrient, and chemical pollution. Agencies and private organizations have contributed to the remarkable recovery of the Connecticut River, aided by the passage and implementation of the federal Clean Air Act of 1970 and the Clean Water Act of 1972. Public perceptions of the river as a resource for recreation and fishing are now overwhelmingly positive (Mullens and Bristow 2003). Currently, the greatest challenges are managing nonpoint source pollution from rapidly urbanizing areas, eliminating combined sewer overflows in some communities, dealing with contaminant spills, and addressing pervasive airborne contaminants such as mercury and sulfates.

Nonpoint source pollution poses the greatest challenges for the health of our watershed and the future of our aquatic biodiversity. Nonpoint source pollution stems from a variety of sources in the landscape and reach waterbodies via surface runoff, groundwater, or atmospheric deposition. Primary pollutants include nutrients (mainly nitrogen and phosphorus), bacterial pathogens, sediment, road salt, metals, pesticides, hydrocarbons (oils, grease, and exhaust residues from combustion engines), a variety of other toxic chemicals, and thermal pollution (heated runoff from urban areas). Atmospheric deposition of acids, nutrients, mercury, and lead is also considered nonpoint source pollution.

Nutrients, particularly nitrogen and to a lesser extent phosphorus, cause a variety of problems in aquatic ecosystems when they greatly exceed natural levels (Smith 1998, Carpenter *et al.* 1998). The increase in the rate that nutrients are supplied to ecosystems is called eutrophication. Human-related sources of nutrients may include atmospheric deposition, runoff from agricultural fields (particularly fertilizers), pastures and feedlots, septic fields, wastewater treatment plants, and surface runoff from urban areas. Effects on freshwater are varied and complex, but in general, eutrophication causes the following:

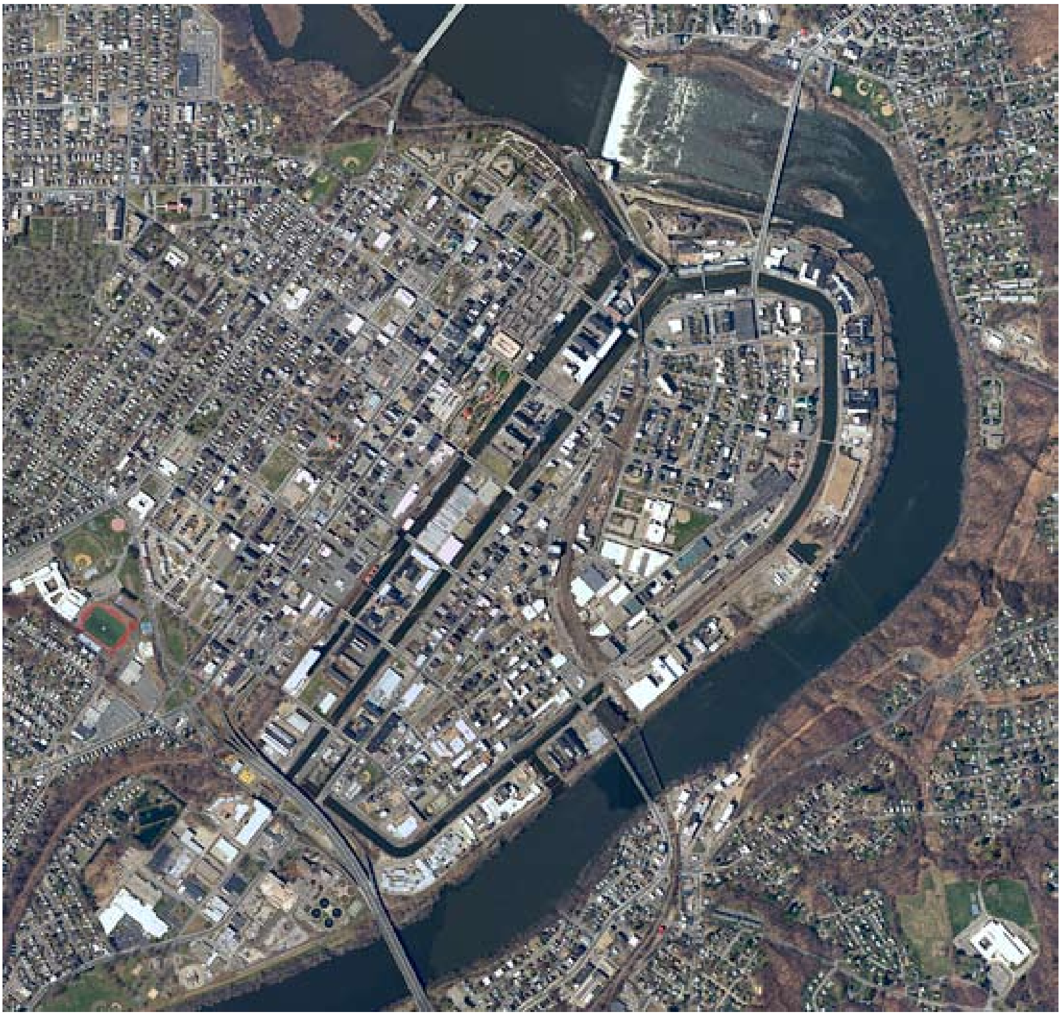
- Increased biomass of phytoplankton, especially species that form harmful algal blooms
- Changes in the biomass or species composition of aquatic plants
- Increased turbidity
- Oxygen depletion due to high biological and chemical oxygen demand
- Reduction in sensitive fish and invertebrate species, and increase in tolerant (and undesirable) species
- Reduced biological diversity

A CSO outfall in Springfield, Massachusetts. Billions of gallons on polluted urban runoff and untreated domestic wastewater enter the Connecticut River each year via CSOs such as this one. Connecticut River Watershed Council

Freshwater mussels are likely affected by eutrophication, although some species appear to be more sensitive than others. The eastern pearlshell has been shown to be intolerant of eutrophication (Bauer 1988, Dolmen and Kleiven 2004). Other studies have suggested that species of *Alasmidonta* in the Northeast—including the brook floater, triangle floater, and dwarf wedgemussel—might be affected but further research is needed (Strayer 1993). Often, a species' tolerance for eutrophication can only be inferred from the types of waterbodies where it is found or not found, but cause-effect relationships are weakly demonstrated.

Nitrogen in the form of ammonia (NH_4) and nitrates (NO_3^-) can be toxic to freshwater mussels and other aquatic animals (Newton *et al.* 2003, Mummert *et al.* 2003, Camargo *et al.* 2005). In 2001, concentrated runoff from a small farm killed more than 25 dwarf wedgemussels and hundreds of other mussels in the Mill River in Hatfield, Massachusetts. This was likely due to a form of nitrogen in the runoff. Wastewater treatment plant effluents and other sources of concentrated nutrients are often implicated in the localized decline of freshwater mussels and other fauna. However, evidence is often tenuous and it is hard to understand the effects of a single stressor—such as nitrogen toxicity—in rivers that are exposed to myriad stressors.

Combined sewer overflows (CSOs) are often a problem in rivers downstream of cities. Older sewer systems in urban areas used a single pipe to carry sewage and stormwater runoff. During wet weather when stormwater entered the sewer system, the systems were designed to purposefully overflow and convey sewage and stormwater into nearby waterways. Billions of gallons of overflow, which contains untreated domestic sewage, enters the Connecticut River each year. This threatens human health, recreational use of the river, and the river's natural resources (Pioneer Valley Planning Commission 2005). For at least 48 hours after rain events, people are advised to not come into contact with Connecticut River water from Holyoke, Massachusetts, all the way to its mouth. Similar problems exist in the upper Connecticut



The Connecticut River and Holyoke Canals in Holyoke, Massachusetts, downstream of the Holyoke Dam. Rivers flowing through urban areas are often affected by stormwater runoff, combined sewer overflows, contaminant spills, a legacy of industries that discharged materials onto its banks or into the river, loss of floodplain and wetland habitat, and severe riverbank alteration. Massachusetts Office of Geographic and Environmental Information

River downstream of Lebanon, New Hampshire and in the Passumpsic River downstream of St. Johnsbury, Vermont. Unfortunately, mussels and fish cannot escape this threat. CSOs and other types of pollution have likely been the foremost cause of impaired water quality and historic losses of freshwater mussel diversity in the lower Connecticut River. Apparent recovery of species in recent years may be due in large part to efforts to address the problem of CSOs.

Sediment pollution is a problem in rivers throughout the Connecticut River watershed. Nationally, sediment pollution impairs more than 40 percent of all river miles and is considered the most pervasive pollutant in freshwater (Waters 1995). Large amounts of sediment are often transported to rivers from disturbed portions of the landscape, such as deforested areas, agricultural lands, eroding banks, and sand and gravel mines. Removal of bank vegetation and floodplain forests mobilizes easily erodible alluvial soils. Alteration of hydrologic and geomorphic processes, described in the previous section, contributes to sedimentation. Effects of sedimentation on freshwater mussels include loss of habitat diversity, channel instability, loss

Understandably, cows want to spend a hot afternoon standing in a stream. But they destabilize and erode streambanks, urinate and defecate in the water, and trample the stream bottom. These cows are in Stony Brook in Connecticut, a watershed that historically supported the endangered brook floater and dwarf wedgemussel. These species are now considered extirpated or highly endangered in the watershed, due in part to a degraded landscape and highly altered stream channel. Ethan Nedeau

of sensitive fish species, and disruption of feeding and respiration by suspended sediments that clog the gills (Box and Mossa 1999).

A striking example of the effect of sedimentation on freshwater mussels was observed in the Nepaug River, a tributary of the Farmington River in Connecticut (Nedeau 2007a). A spring flood transported large amounts of sediment to the river from nearby agricultural lands and from a new house lot that had failed to implement adequate erosion control. At least 350 yards of the stream was blanketed with sand up to two feet thick, covering the original gravel-cobble that had supported a very high density of the eastern pearlshell. A survey in early May discovered thousands of mussels fleeing areas of the streambed that were inundated with sand; mussel trails extended for tens of meters and mussels were crowded into areas where their preferred gravel habitats still existed. Hundreds of recently dead animals were observed. Based on mussel densities in non-impacted areas, tens of thousands of eastern pearlshells were likely killed or displaced by sedimentation. The sediment was slowly working its way downstream and engulfing habitats and mussels as it went. Surviving animals were vulnerable to geomorphic changes as the stream tried to regain equilibrium. This observation highlighted the importance of protecting rivers from sediment by identifying potential sources of sediment on the landscape, using erosion control measures, and establishing sufficient riparian buffers.

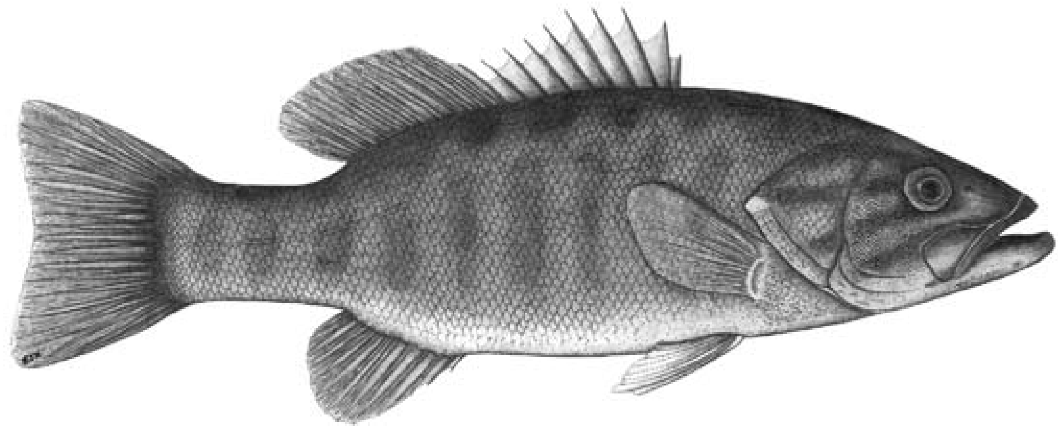
Acidic precipitation largely originates outside of the watershed and is transported in the atmosphere. It has long been considered a threat to freshwater ecosystems and mollusks

Highly eroded shells, as shown by this pair of brook floaters, can be a symptom of acidic water with low calcium availability but may also result from physical abrasion. Ethan Nedeau

(Haines 1981). Acidity has acute and chronic effects on mussels, especially through its effects on respiration, ionic balance, blood chemistry, and other physiological functions. Acidity disrupts the retention and deposition of calcium needed to produce shells. Visible symptoms of acid-related stress in freshwater mussels may include weak and highly eroded shells due to loss of calcium. Acidity increases the availability and toxicity of metals such as aluminum, mercury, lead, and cadmium (Wren and Stephenson 1991). The combined effects of acidic precipitation, disruption of calcium cycles, and elevated aluminum have severely stressed aquatic ecosystems throughout much of the Northeast (Driscoll *et al*. 2001). Acid rain is implicated in the decline of the eastern pearlshell in Europe (Dolmen and Kleiven 2004). Reductions in industrial emissions of sulfur from coal burning industries and other sources, as well as observed ecosystem effects that seemed less severe than what was predicted in the 1960s and 1970s, quelled some concern about acidic precipitation. However, industrial emissions of nitrogen (another contributor to acid rain) have not declined and acid rain continues to plague aquatic and terrestrial ecosystems in the Northeast (Driscoll *et al*. 2001).

Mercury occurs naturally but humans have greatly increased its availability in the environment. Scientists estimate that two-thirds of global mercury emissions are from human sources, such as metal manufacturing, fossil fuel combustion, and waste incineration. In northeastern North America, mercury reaches the landscape at rates two to four times higher than before the Industrial Revolution. Most atmospheric mercury is an inorganic form that is only mildly toxic at low doses. In freshwater, inorganic mercury is converted into a toxic substance called methylmercury. Methylmercury enters the bodies of small aquatic organisms and is then passed to larger and larger predators in the food chain, in a process called biomagnification. Mercury accumulates in freshwater mussels and it may affect their reproduction, growth, or survival (Naimo 1995, Boening 2000). It also poses a threat to predators such as otter and muskrat (Yates *et al*. 2005, Scheuhammer 2007). More about mercury in the environment can be found at the U.S. Environmental Protection Agency website, www.epa.gov/mercury.

Other toxic chemicals prevalent in the Connecticut River watershed include PCBs, dioxins, and a variety of pesticides. Levels of these contaminants, as well as mercury, in freshwater fish have resulted in watershed-wide fish consumption advisories (EPA 2006). Clearly, levels of toxic materials are high enough to cause concern about human health. Effects on wildlife and ecosystem health are not fully realized. These materials enter the bodies of mussels and are thought to decrease metabolism and respiratory rate, disrupt ionic balance, disrupt enzyme function, disrupt endocrine function, decrease glycogen content (the main energy reserve for mussels), destroy cells, reduce growth rate, and cause death (Farris and Van Hassel 2006).



The smallmouth bass is a non-native predator that exists throughout the Connecticut River watershed and is highly sought by anglers. Yet, its prevalence in the watershed may have come at the expense of its native prey, and of the mussels that use those native species to reproduce. Ethan Nedeau

Non-native and Invasive Species

Widespread introduction of non-native and invasive fish in the Connecticut River watershed has greatly influenced native fish and other aquatic fauna. Nearly one-third to one-half of all fish species found in southern New England have been introduced (Simmons and Tisa 1994, Hartel *et al.* 2003, Werner 2004). Largemouth bass, smallmouth bass, black crappie, bluegill, rainbow trout, brown trout, northern pike, walleye, and carp are some of the non-native fish deliberately introduced to the watershed to enhance fishing opportunities. This practice began in the 1800s. Many of these are top predators that eat native fish or compete with them for resources. Alterations to aquatic ecosystems—especially due to dams, flow regulation, and warmer water temperatures—tend to favor habitat generalists and non-native species. Since freshwater mussels rely on native species as hosts, the loss or decline of native fish due to introduced species may affect mussel reproduction. This is expected to be most acute for mussels that parasitize small-bodied forage species and that may be host-specific, such as the brook floater, dwarf wedgemussel, eastern pearlshell, and alewife floater.

Some species of mussels use a variety of fish hosts, including non-native fish. The introduction and spread of non-native species that are adapted to warm water may have increased the distribution and abundance of some species of mussels, although there is no published evidence of this. The abundance of eastern pearlshell in rivers whose water is now too warm to support brook trout reproduction, and whose salmonid population is comprised largely of stocked brown trout and rainbow trout, suggest that the eastern pearlshell has benefited from the stocking of non-native salmonids. Native fish hosts that mussels have coevolved with might be better hosts than non-native species because native fish are adapted to local environmental conditions and their populations may be more stable in the long-term. Also, mussel species may be specialized for unique traits of their native hosts such as habitat use, behaviors, and immune responses to parasitism.

Two destructive bivalves that threaten native mussels throughout central and eastern North America are the zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena bugensis*). The zebra mussel was introduced into North America in the 1980s by cargo ships carrying freshwater ballast water from eastern Europe. Within ten years, the zebra mussel had spread from the Great Lakes east to Vermont and Connecticut, south to New Orleans, and west to Oklahoma and Minnesota. During that time, the quagga mussel was introduced into the Great Lakes in the same manner.

The zebra mussel (left) and Asian clam (right) are non-native bivalves that could harm native mussels and ecosystems in the watershed. Zebra: U.S. Geological Survey. Asian Clam: Ethan Nedeau

A cluster of zebra mussels. These have the ability to smother and kill native mussels, in addition to their other effects on aquatic ecosystems U.S. Environmental Protection Agency/Great Lakes

The zebra mussel and quagga mussel are extraordinarily effective at reproducing and dispersing into new habitats (Hebert *et al.* 1989, Mills *et al.* 1996). Like blue or ribbed mussels in marine environments, these introduced bivalves attach to solid objects—including the shells of native freshwater mussels. They can severely restrict the ability of the mussel to reproduce, feed, and move. These species have had enormous negative impacts on native freshwater mussels (Mackie 1991, Schloesser *et al.* 1996, Strayer 1999, Strayer and Malcom 2007). Native freshwater mussels have declined precipitously in portions of the Great Lakes and the Mississippi River basin where zebra mussel densities are the highest.

The zebra mussel and quagga mussel do not yet occur in the Connecticut River watershed. As of 2007, the only areas in New England that supported zebra mussels were Lake Champlain and Lake Bomoseen in Vermont and East Twin Lake in northwestern Connecticut. Since no waterways connect these lakes to the Connecticut River watershed, zebra mussels are only likely to enter the watershed if transported by humans. Bait buckets, bilge water, boat hulls, live wells, and trailers with aquatic vegetation (and mussels) attached are common ways that zebra mussels are accidentally introduced into new waters. Every effort must be made to keep the zebra mussel and quagga mussel out of the Connecticut River. These species would likely flourish in lakes, large impoundments, and the lower mainstem Connecticut River.

The Asian clam (*Corbicula fluminea*) was also introduced into North America (Counts 1986, Strayer 1999). In New England, the Asian clam was once restricted to a portion of the Connecticut River downstream of the nuclear power plant in Haddam, Connecticut, and it was thought to rely on warm water that was discharged from the plant. Biologists thought that it would not spread farther into New England because the lower lethal temperature for the species was 35º–37ºF. However, it is now abundant in portions of the mainstem Connecticut River near the Massachusetts border and appears to be spreading rapidly into tributaries, as well as to lakes and rivers in Rhode Island (Raithel and Hartenstine 2006) and southeastern Massachusetts. Nedeau and Low (2008b) found that although it was present in nearly one-

Didymosphenia geminata, or "rock snot" was discovered in the upper Connecticut River and White River in 2007. It poses a serious risk to fish, invertebrates, and overall health and aesthetic beauty of the Connecticut River. In the left photo, Vermont Agency of Natural Resources biologist Steve Fiske holds a clump of rock snot. The right photo shows rock snot in a New Zealand river, providing a glimpse of what might be expected in our rivers if rock snot flourishes in the watershed. Steve Fiske/Vermont Agency of Natural Resources (left), New Zealand Federation of Freshwater Anglers (right)

half of the ponds surveyed in southeastern Massachusetts, its distribution within those ponds was restricted to areas near large public boat launches. This suggests that boaters and fishermen are the primary vectors for this species, and that because the clams have not yet spread throughout these lakes, the full ecological effects of the species have not been realized. Asian clams may compete with native mussels for food or space, consume larval mussels, and alter nutrient cycling and productivity of waterbodies (Leff *et al.* 1990, Strayer 1999, Vaughn and Spooner 2006).

In 2007, a new threat was discovered in the northern reaches of the Connecticut River in New Hampshire and in the White River of Vermont. The invasive diatom *Didymosphenia geminata*, commonly known as "rock snot" or "didymo" was found in the clear shallow waters of these two rivers. Didymo is a filamentous diatom that grows on stable substrates in shallow rivers. It forms extensive mats that can smother the stream bottom and occlude habitat for aquatic insects, mussels, and fish (Spaulding and Elwell 2007). It is native to northern North America and was thought to be confined to cold, low-nutrient habitats, but has been spreading southward. In 2007, it was also found in the Batten Kill of Vermont and New York, and in the East Branch Delaware River in New York. Anglers and boaters are believed to hasten its spread in North America. Anglers and boaters are strongly urged to thoroughly clean their gear after being in contaminated areas, and to stop using felt-soled waders because the diatom can survive for a long time in the felt fibers. It is hard to predict the long-term effect of didymo in the Connecticut River, but if it becomes as abundant here as it has elsewhere, it could have enormous negative consequences for mussels and overall health of our fisheries and rivers.

Climate Change

Global climate models predict a 3.6-18.0°F (2-10°C) warming of average North American air temperatures by 2100 (IPCC 2007). Climate change is expected to affect fish assemblages by warming water temperatures of lakes and rivers (Schuter and Post 1990, Eaton and Scheller 1996, Meyer *et al.* 1999, Hostetler and Small 1999, Stefan *et al.* 2001). Loss of coldwater habitats and an increase in warmwater habitats, along with related changes in dissolved oxygen, stream and lake levels, lake mixing regimes, and nutrient cycles, will affect nearly everything about rivers and lakes (Schindler 2001). The effects of thermal pollution will compound the effects of climate change; warm-water discharges from industries have already changed the thermal environment of some portions of rivers in the watershed and allowed the Asian clam to gain a foothold. Stormwater runoff, especially from urban areas, creates pulses of hot water into cool streams and may harm non-adapted invertebrates and fish.

Eaton and Scheller (1996) predicted an average range reduction of approximately 50% for cold-water and cool-water fish in streams of the United States because of climate change. Effects will be most acute in streams that are already near the upper thermal limit for cold- and cool-water species, and that are affected by poor land-use practices, hydrologic alteration, and urbanization. Likewise, warm-water fish, such as smallmouth bass, largemouth bass, and bluegill, will likely expand their range as waters warm (Schuter and Post 1990, Stefan *et al.* 2001). In the Connecticut River, most of the warm-water fish are also non-native predators that will continue to gain competitive advantage over native species as waters warm.

Temperature-induced changes in fish communities could have a profound influence on the availability of hosts for freshwater mussels. Mussels most vulnerable to this threat are those that inhabit small streams and rivers and rely on fish adapted for cooler water. Fish species of concern include several species of dace, minnows, sculpins, darters, trout, suckers, and fallfish. The brook floater, eastern pearlshell, creeper, dwarf wedgemussel, and triangle floater might be most affected by climate change. Mussels that flourish in warmwater habitats and are host-generalists, such as the eastern elliptio, eastern floater, and eastern lampmussel, may not be as threatened by climate change.

Water quantity may become a problem if there are extended periods of drought, though some climate models predict an increase in precipitation in the Connecticut River watershed. Drought has been a periodic problem in recent years, however, causing low stream flows and low reservoir levels. Increased precipitation, particularly due to an increase in the intensity of storms, might increase the number of damaging floods. More about climate change can be found at the U.S. Environmental Protection Agency's website, www.epa.gov/climatechange.

III. SUMMARY

- Freshwater mussels are one of the most endangered groups of animals on Earth. Nearly three-quarters of the 297 native mussel species in North America are imperiled and 35 species are thought to have gone extinct in the last century.
- Of the 12 species of freshwater mussels that occur in the Connecticut River watershed, eight are listed by one or more states as endangered, threatened, or special concern. The three most endangered species are the brook floater, yellow lampmussel, and dwarf wedgemussel.
- The Connecticut River watershed contains some of the best remaining freshwater mussel assemblages in North America and no species have been eliminated from the watershed, yet the watershed faces many of the same challenges that are causing a national and global freshwater conservation crisis.
- The estimated 2,722 dams in the watershed represent one of the highest densities of dams in the northern hemisphere, and these have greatly altered the fundamental nature of our rivers and the distribution of mussels and fish.
- Road-stream crossings greatly outnumber dams and when designed improperly may dis-

rupt stream continuity, impede migratory species, and create habitat conditions that are detrimental to native species.

- Four centuries of intense deforestation, conversion of the landscape to agriculture, dams, and urbanization have degraded and fragmented mussel habitats throughout the watershed, restricting the range and reducing the viability of some species.
- One of the most pressing challenges facing a burgeoning human population in the Connecticut River watershed is developing policies and laws that provide drinking water and sustain quality of life while protecting aquatic ecosystems. This will require a better understanding of the instream flow needs for mussels, fish, and healthy ecosystems.
- The history of landscape alterations and efforts to control natural river processes such as flooding and sediment transport, along with the current need to protect human interests (e.g., infrastructure, homes, property) along river corridors, pose strong challenges to river management that seeks to restore naturally functioning rivers.
- Although water quality has improved since the passage of the Clean Air Act of 1970 and Clean Water Act of 1972, the river still faces challenges from nonpoint source pollution from a variety of sources, combined sewer overflows, contaminant spills, and pervasive airborne pollution such as acidic precipitation and mercury.
- Non-native and invasive aquatic species are prevalent throughout the watershed. Among these are fish that prey on, or compete with, native species and therefore may indirectly affect mussels by reducing the availability of host fish. Asian clams have become increasingly common in the Connecticut River and large tributaries in Connecticut, and zebra mussels would pose a grave threat if they were to be introduced into the watershed from nearby sources in Connecticut and Vermont.
- The discovery and rapid spread of the diatom *Didymosphenia geminata*, or "didymo" in the northern Connecticut River and White River is of grave concern for mussels, fish, and overall ecosystem health. Its potential spread into southern tributaries that support the watershed's best mussel assemblages could pose insurmountable challenges to mussels.
- Potential effects of climate change include warmer water and loss of cold- and cool-water fish (and the mussels that rely on these species), changes in natural flow regimes, and possible increases in the frequency and severity of drought conditions.