Salamanders in a Changing Environment on Hemlock Hill

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One way ecologists measure changes in the environment is by monitoring animal populations over long periods. Over the past five years, for example, Robert G. Mayer has documented 126 bird species at the Arnold Arboretum, including 46 confirmed breeders and another five probable breeders. Using data from several earlier studies, Mayer was able to document the absence of at least 27 species that had once bred successfully at the Arboretum over the past century and the occurrence of seven new breeding species. In 2004 researchers at the Harvard Forest extended their studies of salamander populations in New England to the Arboretum's Hemlock Hill. No studies of salamanders at the Arboretum existed, but we have now compiled baseline data on species composition and abundance for use in future monitoring of this ecologically important group.

PHOTOS BY THE AUTHOR

Red-back salamanders occur most commonly in two color morphs, the leadback morph and the striped morph. The percentage of leadback morphs in red-back salamander populations increases with warmer temperatures.

Salamanders of Massachusetts

Of the 4,600 known species of amphibians in the world, approximately 400 are salamanders, of which 127 are found in the United States and Canada. Salamanders are morphologically distinct from the other two amphibian orders, Anura (frogs and toads) and Gymnophiona (caecilians), in that they possess tails. They are also characterized by four toes on their front feet and five on the back. Like other amphibians they are ectotherms (cold-blooded) and have no epidermal structures, such as scales, feathers, or hair.

Ten salamander species from three families are found naturally in Massachusetts. (In addition, one species from a fourth family, the mudpuppy *(Necturus maculosus)*, was introduced into the Connecticut River, probably late in the nineteenth century.) Perhaps the most familiar salamander family is the mole salamanders, Ambystomatidae. Four representatives of this family are found in the state: the Jefferson salamander *(Ambystoma jeffersonianum)*, the blue-spotted salamander *(A. laterale)*, the marbled salamander *(A. opacum)*, and the spotted salamander *(A. maculatum)*. They spend the majority of their lives in underground burrows in upland woods surrounding the ephemeral vernal pools in which they breed. The largest and most common is the spotted salamander. Adults of this species measure between six and ten inches and are very distinctive in appearance, with two rows of bright yellow spots prominently displayed on their black backs. On the first warm rainy night of the year, when the temperature approaches roughly 50 degrees F (10 degrees C), these animals migrate up to half a mile from upland woods to vernal pools to breed in a dramatic event that has been dubbed "The Big Night" by naturalists and conservationists.

During their terrestrial juvenile—or "red eft"—phase, eastern red-spotted newts are ten times more toxic than during their aquatic adult phase. They are often seen foraging in forests adjacent to breeding ponds.

Another commonly observed species in Massachusetts is the eastern red-spotted newt *(Notophthalmus viridescens)*, the state's lone representative of Salamandridae. While this species is aquatic both as larva and adult, it also has a terrestrial juvenile, or "red eft," phase that lasts from two to seven years. As a deterrent to potential predators, red efts are equipped with toxic chemicals in their skin similar to those produced by puffer fish. Consequently, on days that are wet enough to keep their skin moist, they are able to forage in the open without fear of predation—often in such abundance as to make hikers fear stepping on one by accident.

The fourth family of salamanders occurring in Massachusetts, the plethodontids, or lungless salamanders, are considered especially valuable indicators of environmental health, thanks to their position in the middle of the food web, their great abundance, and their relatively stable population size. Plethodontidae is the largest family of salamanders in the world, consisting of 240 species in 27 genera. The five representatives found in Massachusetts are the northern two-lined salamander *(Eurycea bislineata)*, the dusky salamander *(Desmognathus fuscus)*, the spring salamander *(Gyrinophilus porphyriticus)*, the four-toed salamander *(Hemidactylium punctatus)*, and the eastern red-backed salamander *(Plethodon cinereus)*.

The eastern red-backed salamander is the only one of these that is a fully terrestrial breeder. Since amphibian eggs do not have calcareous shells, they are vulnerable to desiccation; therefore, most species deposit their eggs in aquatic environments where they pass through a gill-bearing larval stage that is not present in other vertebrates. Red-backed salamanders are an exception to this rule, laying their eggs in moist locations under logs and rocks on the forest floor and completing the larval stage within the egg. Incubation of the eggs by the mother and sometimes the father over a six-week period helps prevent the gelatinous egg mass of three to fourteen eggs from drying out.

Since red-backs do not need to be near aquatic breeding habitats, they are far more ubiquitous than other salamander species. At Hubbard Brook Experimental Forest, a northern hardwood forest in the White Mountains of New Hampshire, red-back densities were estimated to be 0.25 individuals per square meter. In fact, the biomass of plethodontid salamanders at the Forest—of which red-backs contributed 95 percent—was found to be double the breeding bird biomass and equal to the biomass of all small mammals. Similar high densities have been found in other parts of its range.

Red-backs are small and slender, measuring only three to five inches in length and weighing about a gram—less than half a penny. Their legs are short relative to their body size, and they have 18 to 20 grooves along the side of the body. In most populations red-backs occur in two forms, a striped morph, with a red stripe

on a black back and a darkly mottled stomach, and a lead-backed morph, which lacks the red stripe. In New England, where the striped is the more common morph, a 1977 study by Fred Lotter and N. J. Scott found that the frequency of lead-back color morphs was positively correlated with warmer climates. In contrast to red efts, which are often seen on the surface of the forest floor during the day, red-backs are rarely seen, spending most of their lives in the soil or under such cover objects as decaying logs on the forest floor and emerging only on warm, rainy nights in the summer.

The Ecological Role of Salamanders

Salamanders are an important link in the food web between small soil fauna on which they prey and the larger vertebrates that prey on them, such as American robin *(Turdus migratorius)*, hermit thrush *(Hylocichla mustelina)*, wild turkey *(Meleagris gallopavo)*, and garter snakes *(Thamnophis sirtalis)*. As ectotherms with low metabolic demands, salamanders convert newly ingested material into biomass very efficiently. In addition, salamanders have high protein content, making them attractive prey items.

The diet of the red-back salamander consists primarily of invertebrates that live in the soil—adult and larval beetles, adult and larval two-winged flies, mites, ants, centipedes, millipedes, snails, slugs, and spiders. Yearly consumption of these invertebrates by red-backs can exceed five times the total biomass of these organisms living at any one point in time. The soil invertebrates are important to the process of leaf decomposition since they fragment the leaves for the primary decomposers, bacteria and fungi. As leaf litter decomposes, an important greenhouse gas, CO^2, is emitted into the atmosphere. Consequently, a change in decomposition rates may lead to changes in the global carbon budget.

A study conducted by Richard Wyman in 1998 found that decomposition rates were between 11 and 17 percent lower in artificial enclosures installed in the field that contained salamanders versus enclosures without salamanders. Wyman also found, not surprisingly, a significant decrease in the numbers of invertebrates in the enclosures containing salamanders. He speculates that salamanders indirectly reduce decomposition rates by reducing the abundance of leaf litter fragmenters and, subsequently, the surface area of leaf litter available to bacteria and fungi.

Red-backs are lungless and breathe through their skin, which must remain moist for efficient gas exchange. The required moisture appears as a film on the red-back's skin.

In addition to being extremely abundant and positioned in the middle of the food web, plethodontid salamanders are good indicators of overall ecosystem health because populations do not fluctuate greatly from one year to the next. An extensive survey of time series data gleaned by monitoring a number of taxonomic groups found that annual counts of plethodontid salamanders varied less than counts of passerine birds, small mammals, and butterflies, as well as other

amphibians. This population stability is thought to be partially explained by salamanders' site fidelity and the small size of their home territories.

Since plethodontid abundance does not fluctuate dramatically under normal conditions, when changes do occur they could provide valuable warnings of the impacts of global stresses caused by human activity. For example, acid rain resulting from nitrous oxide and sulphur dioxide being emitted into the atmosphere and reacting with water vapor to produce nitric and sulphuric acids can lower soil pH to levels that may prevent red-backed salamanders from occupying them. In Albany County, New York, eastern red-backed salamanders are far less abundant where the soil pH is below 3.7. In fourteen eastern hemlock-dominated forests in north-central Massachusetts, where the average soil pH was 3.7, red-back abundance was negatively correlated with soil pH. Warmer temperatures on the forest floor as a result of global climate change could also have a negative impact on red-back abundance. As mentioned above, plethodontid salamanders are lungless and breathe through their skin and the linings in their mouth. To respire efficiently they must remain moist. In fourteen hardwood stands in north-central Massachusetts, the most important predictor of red-back abundance is the temperature on the surface of the forest floor, with abundance decreasing as the temperature rises.

As top-level predators of soil fauna, red-backs are believed to regulate biodiversity in the soil community by reducing the number of leaf litter fragmenters, chiefly adult and larval beetles and larval two-winged flies. By reducing their numbers the salamanders indirectly lower the rate of decomposition of the leaf litter on the forest floor.

Hemlock Hill in Transition

The Arnold Arboretum provides important habitat for many wildlife species. It is a critical time to be conducting this study on Hemlock Hill as the area is undergoing significant changes. The hemlock woolly adelgid (*Adelges tsugae*, or HWA), an invasive insect pest that causes mortality within four to ten years of infestation, was discovered on Hemlock Hill in 1997. Native to Japan, HWA is believed to have been introduced into Virginia in the 1950s and since then has been spreading throughout eastern hemlock's range. Currently, fifty percent of eastern hemlock-dominated stands in Massachusetts are infested with HWA, and no fail-proof way has been found to treat the affected trees or eliminate the pest.

Eastern hemlock-dominated stands are structurally distinct in having dense canopies and little understory. Being shade tolerant, hemlocks retain their lower branches, creating a cool, dark microenvironment on the forest floor that provides habitat for many species of wildlife that require mature forests for their growth and/or reproduction. Among the migratory breeding birds found to be strongly associated with this forest type are black-throated green warblers *(Dendroica virens)*, blackburnian warblers *(D. fuscus)*, and solitary vireos *(Vireo solitarius)*; full-year residents include black-capped chickadees *(Parus atricapillus)* and red-breasted nuthatches *(Sitta canadensis)*. In addition, 23 of the 32 small mammal species and thirteen of the fourteen large mammalian carnivore species occurring in New England use this forest type, as do white-tailed deer *(Odocoileus virginianus)*, especially in winter when these

Left to right, the black-throated green warbler, blackburnian warbler, and red-bellied nuthatch drawn and published by John James Audubon in Birds of America, *vol. ii, 1841, and vol. iv, 1844.*

forests have less snow cover than hardwood stands. In my 2003–2004 study conducted at the Harvard Forest I found higher red-back salamander abundance in eastern hemlock-dominated stands than in hardwood stands. A follow-up study conducted throughout north-central Massachusetts found no difference in red-back abundance in the two forest types, but the populations in hemlock-dominated forests did contain a higher percentage of larger individuals than populations in hardwood stands.

The potential loss of eastern hemlock from this region provides an opportunity to study how the loss of a dominant tree species changes the forest ecosystem. Researchers at the Harvard Forest, who are conducting several studies to assess ecosystem changes and wildlife response to the loss of eastern hemlock are interested in further exploring some of their results, which suggested that pre-logging of hemlock stands to prevent the spread of HWA causes much more abrupt changes than does the gradual loss of hemlock to HWA infestation when left alone. Hemlock Hill provides an opportunity to explore this hypothesis and to examine the impacts of the loss of a hemlock-dominated forest in an urban environment.

Currently, seventy percent of the trees on Hemlock Hill are infested with HWA and are in severe decline. While the trees at the base of the hill can be reached with a spray truck and treated with horticultural oil, the remaining trees are inaccessible and are expected to die over the next two to ten years. The Arnold Arboretum's management plan calls for removal of hazardous trees as needed while encouraging the regeneration of native species such as red oak *(Quercus rubra)*, red maple *(Acer rubrum)*, black birch *(Betula lenta)*, sugar maple *(Acer saccharum)*, and white pine *(Pinus strobus)*. Since 2004 researchers from the Arboretum and the Harvard Forest have been monitoring nutrient cycling and microenvironmental changes as well as vegetative succession in three experimental plots totaling roughly 2,000 square meters (one-half acre) on Hemlock Hill. In February and March of 2005 all eastern hemlocks were removed from two of the three experimental plots, with the third plot left unchanged as the control.

In the summer of 2004, before trees were removed from the two experimental plots, I initiated a study of red-back salamander abundance on Hemlock Hill. With the help of

Richard Schulhof and Peter Del Tredici I set out 8 one-inch-thick eastern hemlock boards measuring 36 by 12 inches to serve as artificial cover objects (ACOs, used to avoid disturbing natural cover objects) in each of the three study plots. I made 5 observations of each ACO from mid August 2004 to the end of October 2004 and 12 observations from early April 2005 to the middle of November 2005. Previous studies have found that differences in salamander abundance on the surface of the forest floor correlate directly with differences in total abundance, including in the soil.

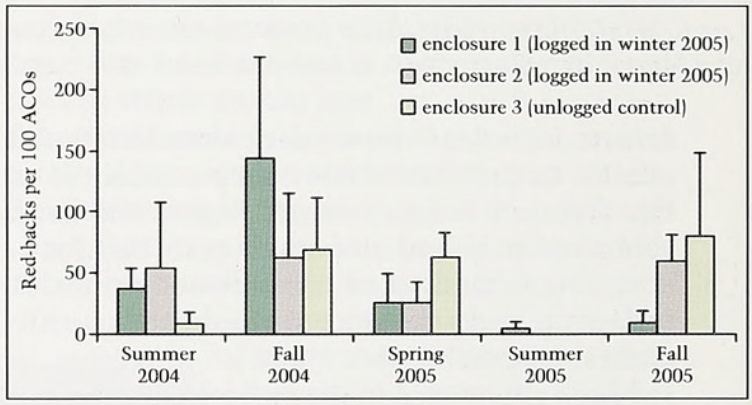
Reptiles and Salamanders Found on Hemlock Hill

During the course of the study, I recorded 139 observations of eastern red-backed salamander, twelve of American toad, three of northern dusky salamander, and one garter snake. Forty percent of the red-backs observed were lead-back morphs and sixty percent were striped. This is a higher percentage of lead-back morphs than in any of the fifty populations observed in Lotter and Scott's 1977 New England study although comparable to populations found in Pennsylvania, Maryland, and Ohio.

The three observations of northern dusky salamanders occurred under the same ACO in successive visits, suggesting that all were of the same individual. Northern dusky salamanders are slightly longer and weigh about three times as much as red-backs, and like most stream-breeding plethodontids, their tails are laterally compressed, in contrast to the round tails of terrestrial species.

A recent study by Mike Bank and colleagues (2006) found northern dusky salamanders in only one of the 37 streams surveyed (out of 41 total streams) in Acadia National Park, Bar Harbor, Maine, between 2000 and 2003. Amphibian surveys conducted in the 1950s found that northern dusky salamanders were widely distributed in streams throughout Acadia. The exact cause of this decline is unknown, but regular acidification of Acadia's streams, causing toxic aluminum and mercury to leach, may be part of the explanation. Further monitoring efforts along Bussey Brook at the base of Hemlock Hill, where northern dusky salamanders may be breeding, would be worthwhile.

The two non-salamander species I observed, the American toad and the garter snake, are widespread, occurring in diverse habitats ranging from gardens and suburban yards to moist upland woods. American toads belong to Bufonidae, one of the four families in the order Anura that occur in New England. Like salamanders, they prey on terrestrial invertebrates such as insects, sowbugs, spiders, centipedes, millipedes, slugs, and earthworms. One of their most important predators, the garter snake, also preys on both species of salamander observed on Hemlock Hill; indeed, red-back salamanders have been found to contribute as much as 38 percent of the diet of garter snakes.



Eastern red-back salamander relative abundance over five seasons in three enclosures (each containing 4 stations consisting of paired 3ft x 1ft hemlock boards which were used as artificial cover objects (ACOs)) on Hemlock Hill at the Arnold Arboretum.

Given the lack of ponds or vernal pools near Hemlock Hill, I was not surprised to find neither red efts or mole salamanders. The three ponds surrounding the Bradley Collection of Rosaceous Plants may provide breeding habitat, however, and these species might be found in the woods to the west of the ponds. Another species not found on Hemlock Hill that could be present in other areas of the Arboretum is the northern two-lined salamander, a plethodontid, like the red-backed. This common species occurs in and near streams and may inhabit either Bussey Brook or the stream running

through The Meadow. The other two plethodontid species that occur in Massachusetts, the four-toed salamander and the northern spring salamander, are uncommon-to-rare and are unlikely to be found at the Arboretum. Four-toed salamanders prefer acidic, wet woodlands and bogs with sphagnum moss, and spring salamanders are found in and near clear, cold streams and seeps.

The Impact of Logging on Red-back Salamander Abundance

In the spring of 2004, immediately following logging, red-backed salamander abundance declined significantly, dropping 83 percent in Plot 1 and 63 percent in Plot 2. Meanwhile, abundance changed little in the unlogged control plot (minus-9 percent). Temperature measurements on ACO observation days show that in the logged plots the average temperature was 10.3 degrees F (5.7 degrees C) warmer on the surface of the forest floor and 2.3 degrees F (1.2 degrees C) warmer two inches beneath the surface than it was in the control plot. In addition, the average relative humidity was 3.4 percent lower in the logged plots than in the unlogged plot. The large drop in red-back abundance in the logged plots is likely due to these microclimatic differences.

While red-back abundance declined substantially in both logged plots in the spring following logging, by fall of 2005 it had nearly recovered in plot 2, where observations were only 8 percent fewer than in the pre-logging fall of 2004. In plot 1, by contrast, abundance had declined even farther, by 94 percent of the pre-logging number. In fall 2005, plot 1, which is more exposed than plot 2 and seems to get more direct sunlight, was found to have higher average air and soil temperatures as well as lower average relative humidity than plot 1. These results suggest that the effect of logging on red-back abundance is site-specific.

The large number of red-back salamanders on Hemlock Hill suggests that relatively small forest fragments within the larger urban landscape can sustain healthy populations of this ecologically important animal. Hemlock Hill is likely to change significantly over the next decade, however, as declining eastern hemlocks are replaced by hardwood species. This study establishes a baseline that can be used to track population changes in these ecologically important organisms as the ecological conditions at the Arboretum change.

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