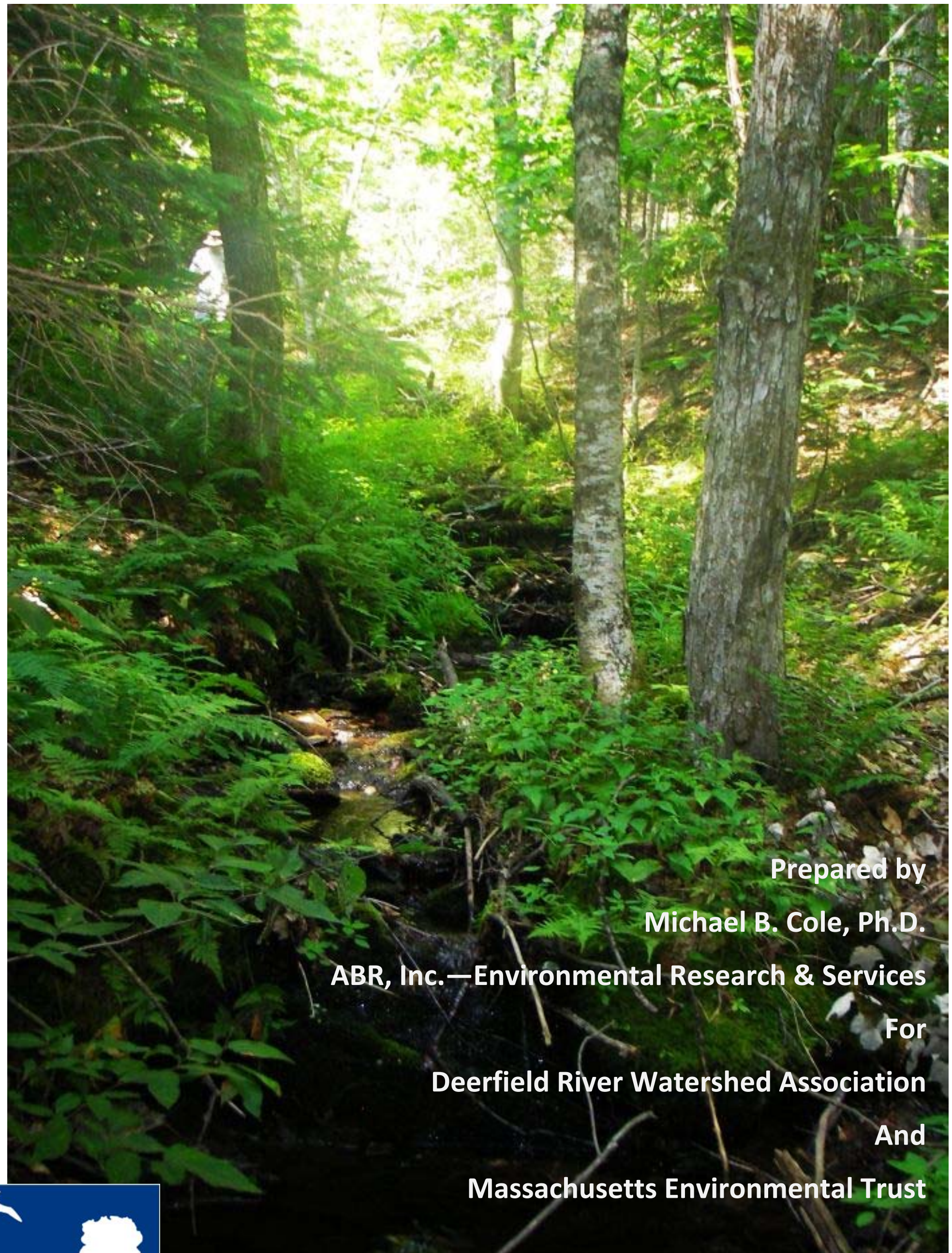
ASSESSMENT OF BIODIVERSITY IN DEERFIELD RIVER WATERSHED FORESTED HEADWATER STREAMS



Prepared by

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ABR, Inc.—Environmental Research & Services

For

Deerfield River Watershed Association

And

Massachusetts Environmental Trust

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FINAL REPORT

Prepared for

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EXECUTIVE SUMMARY

- The highlands region of western Massachusetts supports some of the most heavily forested watersheds in the state. These areas continue to provide valuable ecological functions and natural resource conditions, including excellent water quality necessary to support persistence of sensitive aquatic species that are dependent on clean water and un-degraded habitats. These functions and values have their source in the many headwater streams that occur across the forested areas of the region. A better understanding of headwater streams is necessary to ensure the preservation of their values and functions. Accordingly, the goal of this project was to characterize current conditions in forested headwater streams in the Deerfield River watershed with a focus on describing macroinvertebrate communities in these areas and the environmental conditions that support them.

- Twenty headwater sample sites were selected across the six State Forests occurring in the Massachusetts portion of the watershed. Nineteen of these sites were headwater stream reaches and one site was a small spring/seep associated with one of the 19 reaches. Macroinvertebrates, physical habitat, and basic water chemistry were sampled from each site in August 2011. Macroinvertebrate samples were collected from an additional 3 springs/seeps associated with other headwater sample reaches. In addition, temperature loggers were deployed at each site for the month of August to characterize the late-summer thermal regime of these systems.

- Macroinvertebrate communities in this study were diverse and included taxa that occur nowhere else in the drainage network. Macroinvertebrate community composition ranged widely among the 19 sampled stream reaches. Total richness averaged 41 taxa per reach and ranged from 25 to 56 taxa. Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness averaged 16 taxa per reach. Within this group, caddisflies exhibited the highest richness, averaging 8.3 taxa per reach. Chironomidae (midges) exhibited the highest richness of any insect family (higher than any order of insects other than Diptera), averaging 13.3 taxa per reach. Across all 23 headwater streams and springs/seeps 133 insect and 17 non-insect taxa were collected. Macroinvertebrate densities averaged 4,517 individuals/m^2 from the 19 stream reaches.

- The headwater streams in this study were characterized as having cool thermal regimes (mean daily maximum temperature averaged 60.2^{o}F), variable channel gradients (4% to over 19% slope), dominance by coarse substrates, and occurrence in areas of mature forest (i.e., no recent harvest activity). Among measured and calculated environmental variables, only stream pH and specific conductance were significantly correlated with measured macroinvertebrate community attributes. Stream pH ranged widely among study reaches, and tolerance to low pH varies considerably among macroinvertebrate taxa. As such, this one variable appears to exert a large measurable influence on headwater macroinvertebrate community structure and diversity in the study area.

- A number of taxa known only to occur in headwater streams and spring/seep habitats were sampled from the study reaches, including several taxa potentially not previously recorded from Massachusetts. Of 11 such taxa sampled during the study, 9 were caddisflies. The headwater obligate caddisflies, *Parapsyche apicalis* and *Pcynopsyche gentilis*, were collected from 15 and 14 of the 19 headwater stream reaches, respectively. *Adicrophleps hitchcocki* and *Palaeagapetus celsus* occurred in 5 and 4 reaches, respectively. *Molanna blenda* was sampled from 2 reaches, while *Homoplectra doringa* was sampled from only 1 reach. Two headwater obligate caddisfly taxa, *Psilotreta rufa* and *Frenesia difficilis/missa*, were sampled only from the spring/seeps sampled. One stonefly known to be confined to headwaters – *Malirekus iroquois* – was sampled from 13 of the 19 stream reaches. Similarly, one dipteran thought to be restricted to headwaters – *Glutops singularis* – was sampled. *G. singularis* was collected from only one reach.
- Brook trout were also observed in *nearly half of the sample reaches*, suggesting the ability of these extreme headwater areas to support this cold-water-dependent fish species. Un-assessed streams in Massachusetts are automatically considered Class B Warm Water streams and are protected as such under 314 CMR 4. This study demonstrates that the uppermost reaches of forested headwater streams in the watershed routinely support cold water invertebrate and vertebrate aquatic species and should be granted the higher level of protection afforded to Cold Water streams.
- The intact riparian conditions measured across the state forests in this study are likely responsible for the high macroinvertebrate diversity and occurrence of headwater obligate taxa observed in this study. An important extension in this work will be to examine environmental and biological conditions in headwater streams occurring in areas developed for agriculture and urbanization. Examining headwater biodiversity across a larger disturbance gradient will provide insight into the effects of higher levels of disturbance on macroinvertebrate community conditions in these sensitive habitats.

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ACKNOWLEDGEMENTS

This study was funded with a grant from the Massachusetts Environmental Trust (MET) to the Deerfield River Watershed Association. Caleb Slater of the Massachusetts Division of Fisheries and Wildlife loaned Onset Water Temp Pro temperature data loggers to the Deerfield River Watershed Association for this project. Field work was supported by several volunteers, including Jason Saltman and Chris Fishel. Jason Saltman of ABR also performed GIS analyses and prepared the maps contained in this report.

INTRODUCTION

The highlands region of western Massachusetts supports some of the most heavily forested watersheds in the state. These areas continue to provide valuable ecological functions and natural resource conditions. Among these functions and conditions is excellent water quality necessary to support both the abundance of recreational activities in the region as well as conditions necessary for the persistence of sensitive aquatic species that are dependent on clean water and un-degraded habitats. These functions and values have their source in the many headwater streams that occur across the forested areas of the region. A report co-produced in 2003 by American Rivers and the Sierra Club titled, *Where Rivers Are Born: The Scientific Imperative for Defending Small Streams and Wetlands*, states that, "Scientific research shows that healthy headwater systems are critical to the healthy functioning of downstream streams, rivers, lakes and estuaries. To provide the ecosystem services that sustain the health of our nation's waters, the hydrological, geological, and biological characteristics of small streams and wetlands require protection….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" (Meyer et al. 2007). Similarly, the Stroud Water Research Institute published a report in 2008 titled *Protecting Headwaters: The Scientific Basis for Safegaurding Stream and River Ecosystems* (Kaplan et al. 2008). The report synthesizes the findings of recent work that demonstrates the essential contributions that headwaters make to healthy watersheds and highlights their exceeding vulnerability to land use changes and other disturbances (Kaplan et al. 2008).

Unfortunately, it is currently unknown whether the level of protection afforded to headwater streams adequately protects their important functions and values, including providing habitat for potentially rare aquatic species. Despite their importance, headwater streams have been underrepresented in assessment and monitoring efforts. And, while the ecological systems of the highlands region are relatively intact, continued development of the region, coupled with the impending threat of global warming, present a persistent and long-term threat to the region's watersheds and the communities and economies they support. A better understanding of our headwater streams, the functions they serve, and the life they support is necessary to better manage, monitor, and perhaps mitigate for the effects of these threats to aquatic resources in the region. These are necessary pieces of a comprehensive approach to protecting natural resources of the watershed, which is necessary for ensuring long-term ecological and economic viability of the region.

In Massachusetts, streams less than 25 feet wide and that occur upslope of wetlands receive no mandatory protections from forestry practices unless they are known to support endangered or threatened species. Unfortunately, these small streams are so severely under-assessed that in almost all cases it is not known to what extent these unique habitats support potentially threatened or rare species. Moreover, un-assessed streams in Massachusetts are automatically considered Class B Warm water streams and are protected as such under 314 CMR 4. Headwater streams may in fact support cold water species, but without assessment there is no way of establishing higher protection. Many of these streams are not even listed on the Massachusetts Integrated List. This project seeks to determine the current status of forested headwater streams in relation to the life they support and conditions necessary for supporting these communities. This project will also assist with determining the adequacy of current stream and riparian protection policy for headwater streams.

To address these concerns and issues, this project assessed and characterized physical and biological conditions in forested headwater streams in the Deerfield River watershed, with an emphasis on describing the macroinvertebrate fauna that occur in our forested headwaters. A better understanding of headwater streams is necessary to ensure the preservation of their values and functions. Accordingly, the goal of this project was to characterize current conditions in forested headwater streams in the watershed with a focus on describing macroinvertebrate communities in these areas and the environmental conditions that support them. The objectives of this proposed project were:

1) To determine the composition (species diversity and uniqueness) of aquatic macroinvertebrate communities in headwater streams in the Deerfield River watershed.
2) Estimate the distribution and abundance of headwater-obligate macroinvertebrate species in the forested headwaters in the watershed.
3) Associate environmental conditions with observed community conditions (e.g., underlying geology, substrate, water chemistry, water temperature, adjacent forest stand conditions).

4) Educate members of the community on the importance of headwater streams and the functions they serve that contribute to maintenance of healthy watersheds and the human communities they support, as well as on the current state of stream and riparian protection policy and whether current policy provides adequate protection in the context of the findings of this study (for example, by determining whether headwater streams support unique species that occur only in these habitats).

STUDY AREA

The Deerfield River drains approximately 665 mi^2 in Massachusetts and Vermont. The river and its tributaries support multiple and diverse uses, including rafting, canoeing and kayaking, fishing, and swimming, as well as development interests such as power production and flood control. The watershed is primarily forested and is recognized as one of the cleanest and most undisturbed in Massachusetts. The Deerfield River watershed occurs primarily in the Northeastern Highlands Level III Ecoregion. Six Massachusetts State Forests occur in the watershed, including Catamount, Dubuque, H.O. Cook, Mohawk, Monroe, and Savoy. These forests all occur in either the Green Mountain/Berkshire Highlands or Vermont Piedmont (Catamount) Level IV Ecoregions (Griffith et al. 2009). Physiography of the study area is dominated by low mountains and open low mountains, with gently rounded to steep slopes and narrow valleys (Griffith et al. 2009). Vegetative composition on lower slopes is dominated by northern hardwood forest, with some northern hardwood, hemlock, white pine forest (Griffith et al. 2009). Precipitation ranges from 38 to 70 inches per year (Griffith et al. 2009).

METHODS

STUDY REACH SELECTION

Study reaches were selected using a stratified probabilistic sampling design. First, the total area (km^2) within each State Forest within the watershed was determined (Table 1). Then, the sample size of 20 sites was apportioned among the 6 State Forests in proportion to the total area of each forest (Table 1). Next, a nested grid overlay was superimposed over each forest and cell intersections on the grid randomly selected to choose sample site locations. The nearest headwater stream to each selected site was designated a primary (first 20 sites drawn) or secondary (second set of 20 sites drawn) site. Proximity of headwater streams to sample points was determined by topographic maps in GIS. Headwater streams were defined as those stream reaches that occur above all mapped confluence points and within 500m of mapped channel initiation points.

This random draw of sites was intended to produce a representative sample of sites across the population of interest (in this case, headwater streams within public forest lands in the Deerfield River watershed). Field sites were ground-truthed in July 2011. Suitability of sites was determined by accessibility (not more than 1/2 mile from a road or trail), safety (prohibitively steep terrain, active or planned timber harvest operations), and presumed perennial flow.

FIELD METHODS

The Deerfield River Watershed Association's macroinvertebrate monitoring program Quality Assurance Project Plan (QAPP) was updated to include this project and was approved by MA DEP. Field and laboratory methods followed those described in the QAPP (Cole and Walk 2011).

WATER TEMPERATURE MONITORING

Onset Water Temp Pro temperature loggers on loan to the project by the Massachusetts Department of Fish & Wildlife (Caleb Slater, DFW) were deployed at each site in late July 2011 and were programmed to record water temperatures every 15 minutes. Loggers were deployed in each of the 20 headwater stream study reaches according to DEP standard operating procedures in July and retrieved in the fall to collect data during the mid-to-late summer period when seasonal temperatures are normally highest. The Deerfield River Watershed Association's QAPP provides additional information regarding the details of and quality assurance measures taken in the deployment and retrieval of the temperature loggers.

MACROINVERTEBRATE AND PHYSICAL HABITAT SAMPLING

Macroinvertebrate communities were sampled from each site in early August 2011. Macroinvertebrate samples were collected using standard methods employed by the MA DEP for assessing the condition of macroinvertebrate communities in Massachusetts streams (Nuzzo, 2003) with modifications as noted below to render them more suitable for use in small headwater streams. These methods are based on the U.S. EPA Rapid Bioassessment Protocols (RBPs) for wadeable streams and rivers (Barbour et al., 1999). First, a 50-m section of stream reach was measured and marked with flagging tape tied to nearby trees. Macroinvertebrates were collected from each reach at 5-m intervals using a Surber sampler, a method by which organisms are sampled by disturbing streambed substrates in a standardized area delineated by a frame in front of the sampler opening.

One sample consisting of ten Surber samples of approximately 0.3 m x 0.3 m each was collected from each reach. Samples were labeled and preserved in the field with 95% denatured Ethanol for later processing and identification in the laboratory. Sampling at 5-m intervals ensured that each of the dominant representative habitats in the reach (pools, riffle, cascades, etc.) was sampled and taxa occupying each habitat type were collected.

Physical habitat sampling occurred in each 50-m reach using the Physical Habitat Characterization protocols of the EPA's Wadeable Streams Assessment Field Operations Manual (USEPA, 2004). The physical habitat assessment consisted of three components: channel and riparian cross-sectional characterizations, a thalweg profile, and a woody debris tally. At each of 11 channel cross sections within each monitoring reach, channel dimensions, bank height, and riparian overhead cover (densiometer) were measured to determine the amount of shading provided by riparian cover. Substrate size and embeddedness of particles were measured on each cross section to quantify substrate conditions in each reach. Riparian vegetation attributes were also recorded at each cross section. The thalweg profile consisted of measuring water depths and classifying habitat units at 10–15 equally-spaced intervals between each pair of cross sections to produce comprehensive descriptions of the types, sizes, and quality of aquatic habitats occurring in each reach.

LAB METHODS

Macroinvertebrate samples were sorted to remove a 300-organism subsample from the original sample using a Caton gridded tray. Specimens were identified to the lowest practical taxonomic level (generally genus or species) as allowed by specimen condition and maturity.

DATA ANALYSIS

Raw taxonomic and count data were entered into the Deerfield River Watershed Association's master macroinvertebrate database in Microsoft Access. Raw taxonomic and count data were exported into an Excel spreadsheet and cross checked for errors and omissions against laboratory bench sheets before analysis. Data were analyzed with a combination of graphic and statistical analyses of community data expressed by a series of metrics describing community attributes such as taxa richness, taxonomic composition, and relative abundance. Multivariate analyses were performed in PC-Ord Version 4 statistical software. Cluster analysis and non-metric multidimensional scaling were used to examine the data for relationships between measured environmental variables and biological conditions. Environmental data included both field measurements (pH, temperature, substrate, channel size etc.) as well as data derived from GIS (drainage area, geology, etc.). Drainage area was calculated by first delineating and then calculating the catchment area using topographic maps in GIS. Correlation analysis between a number of macroinvertebrate community attributes and measured/calculated environmental attributes was performed using Spearman rho rank correlation analysis.

RESULTS

Twenty headwater stream reaches were sampled between August 1 and August 5, 2011 (Table 1). One reach occurred in each of the Catamount and H.O. Cook state forests, 3 reaches occurred in Monroe, 4 occurred in Mohawk, 5 in Dubuque, and 6 in Savoy State Forest. One of the these reaches – Dubuque #2 – was a spring of approximately 20 m long that drained into the Dubuque #4 reach. Three springs/seeps were sampled in this study in addition to the 20 designated study sample reaches, but no physical habitat or water chemistry data were collected from these additional sites.

PHYSICAL CHARACTERISTICS

Study reach drainage area averaged 0.44 km^2 and ranged from 0.06 km^2 to 2.00 km^2. This range includes the Monroe #17 reach that was included in the study despite the reach occurring more than 1000 m downstream of mapped channel initiation. No other study reaches exceeded an upstream drainage area of 0.77 km^2. Channel gradient averaged 9.7% and ranged from 4 to over 19%. Bankfull width averaged 2.6 m ($\pm$ 0.8 m SD) and ranged from 1.7 to 4.3 m. Wetted width averaged 1.1 m ($\pm$ 0.3 m SD) and ranged from 0.6 to 1.8 m (Table 2).

Almost all reaches exhibited a forced step-pool morphology imposed by the lack of any floodplain, steeper gradients (all 4% or greater), and abundance of large woody debris or coarse (cobble and boulder) substrates in each reach. Consequently, pools were the most frequent habitat type across the twenty reaches (mean = 43.2%, $\pm$ 17.2% SD), followed closely by riffles (mean = 42.0%, $\pm$ 18.7% SD, Table 2). Substrate conditions (measured across all habitats) varied among reaches, but were generally dominated by coarse substrate in the cobble and gravel size-class ranges (Table 2). Sand and fine substrates averaged 15% across the study reaches, and ranged from 0 to 43.6%. Substrate composition was related to stream gradient, as the percent of coarse substrate showed a statistically significant positive correlation with steeper gradients (r^2 = 0.4617).

Adjacent riparian zone conditions were similar among the study reaches, as mature trees occurred in the riparian zone at all 20 reaches. Percent aerial coverage of large trees (dbh >0.3 m) in the immediate riparian zone averaged 69.5% and ranged from 48.9 to 85.0% (Table 2), while percent overhead canopy cover averaged 89.7% and ranged from 82.4 to 96.3% Table 2).

Temperature loggers were recovered from 14 of the 20 reaches in which they were deployed in late July or early August. Owing to high flows caused by Hurricane Irene, some recorders logged water temperatures only until August 28th because these recorders were stranded above the water line upon recession of flood waters. Therefore, analyses of water temperatures were restricted from the date of deployment to August 28th to allow comparison of temperature regimes across sites. Mean daily maximum water temperature averaged 60.2^{o}F across all 14 sites from which loggers were retrieved, and ranged from 46.6 to 65.2^{o}F. A logger was placed at the source of the spring seep (Dubuque #2) entering the Dubuque #4 reach. This seep, the only one from which water temperature was continuously recorded, maintained a relatively constant water temperature both day and night and through the summer into the fall. Excluding this spring seep site, daily average temperatures from late July into late August ranged from 57.3 to

65.2^{o}F. Excluding the Dubuque #2 spring seep, maximum 7-day average daily-maximum temperatures during this period averaged 63.2^{o}F and ranged from 60.5 to 68.2^{o}F.

WATER CHEMISTRY

Water chemistry also varied among the study reaches. Dissolved oxygen concentrations averaged 7.3 mg/L and ranged from 4.0 to 8.7 mg/L (Table 1). Specific conductance averaged 58.6 µS/cm and ranged from 13.4 to 486.2 µS/cm. Specific conductance exceeded 85 µS/cm in only one reach – Mohawk #11, where a reading on 486.2 µS/cm was recorded. This reach parallels Route 2 in Florida, MA and occurs downstream of a small pond. Stream pH averaged 6.4 across all reaches and ranged 4.8 to 7.6 (Table 2).

MACROINVERTEBRATE COMMUNITIES

Macroinvertebrate community composition ranged widely among the 19 sampled stream reaches. Total richness averaged 41 taxa per reach and ranged from 25 to 56 taxa (Table 3). Total richness was slightly lower among the 4 spring/seeps, averaging 31.8 taxa and ranging from 21 to 40 taxa. Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness averaged 16 taxa per reach and ranged from 7 to 25 taxa (Table 3). Within this group, caddisflies (Trichoptera) exhibited the highest richness, averaging 8.3 and ranging from 4 to 13 taxa per reach (Table 3). Chironomidae (midges) exhibited the highest richness of any insect family (higher than any order of insects other than Diptera), averaging 13.3 and ranging from 7 to 19 taxa per reach (Table 3).

Across all 23 headwater streams and springs/seeps 133 insect and 17 non-insect taxa were collected. Taxa showing the highest occupancy rates in the 19 headwater stream reaches included Tanypodinae midges (100%), *Micropsectra/Tanytarsus* (100%), *Leuctra* sp. (100%), *Lepidostoma* sp. (100%), and *Corynoneura* sp. (100%). *Polypedilum* sp. and *Eurylophella funeralis* were both collected from 18 of the 19 headwater reaches (Table 4). None these taxa are restricted to headwater environments, but also occur in higher-order (at least 2nd order) streams.

Macroinvertebrate densities averaged 4,517 individuals/m^2 from the 19 stream reaches and ranged from 1,231 to 10,237 individuals m^2 (Table 3). Chironomidae (midges) were the most abundant insect family sampled, accounting for 58.1% of all individuals sampled (Table 3). *Micropsectra/Tanytarsus* sp. (Diptera: Chironomidae) was the most abundant taxon collected, representing nearly 15% of all individuals sampled. Other numerically dominant taxa (in descending order of abundance) included *Parametriocnemus* sp. (Diptera: Chironomidae), *Leuctra* sp. (Plecoptera: Leuctridae), *Tvetenia* sp. (Diptera: Chironomidae), *Polypedilum* sp. (Diptera: Chironomidae), *Microtendipes* sp. (Diptera: Chironomidae), *Corynoneura* sp. (Diptera: Chironomidae), *Oulimnius latiusculus* sp. (Coleoptera: Elmidae), and *Thienemannimyia* Group spp. (Diptera: Chironomidae).

A number of taxa known only to occur in headwater streams and spring/seep habitats were sampled from the study reaches. Of 11 such taxa sampled during the study, 9 were caddisflies (Table 5). The headwater obligate caddisflies, *Parapsyche apicalis* and *Pcynopsyche gentilis*, were collected from 15 and 14 of the 19 headwater stream reaches, respectively. *Adicrophleps hitchcocki* and *Palaeagapetus celsus* occurred in 5 and 4 reaches, respectively (Table 5). *Molanna blenda* was sampled from 2 reaches, while *Homoplectra doringa* was sampled from only 1 reach. Two headwater obligate caddisfly taxa, *Psilotreta rufa* and *Frenesia difficilis/missa*, were sampled only from the spring/seeps sampled. *P. rufa* was collected from both the Savoy #9 and Savoy #13 seeps, while *F. difficilis/missa* was sampled only from the Savoy #13 seep (Table 5).

One stonefly known be confined to headwaters – *Malirekus iroquois* – was sampled from 13 of the 19 stream reaches. Similarly, one dipteran thought to be restricted to headwaters – *Glutops singularis* – was sampled. *G. singularis* was collected from only one reach.

Gatherer-collectors were the most abundant functional feeding group, averaging 31.9% (± 12.9% SD) of the total abundance across all 19 stream reaches (Table 3). Filterer-collectors were the second most abundant group, averaging 28.7%. Shredders and predators represented 16.7 and 14.2 of the total abundance, respectively; while scrapers averaged only 7.0 of the total abundance across all headwater stream reaches (Table 3).

Nine of twenty four macroinvertebrate samples were checked for sorting efficacy. All 9 samples passed the 95% macroinvertebrate removal rates with an average removal rate of 98.2%. Two of the project samples were inspected by a second taxonomist to assess taxonomic and count accuracy. Both samples passed the 95% similarity data quality objective with an average Bray-Curtis similarity of 97.4%.

ENVIRONMENTAL/BIOLOGICAL CORRELATIONS

NMS produced a two-dimensional ordination that explained 84% of the variation in the original site dissimilarity matrix with a stress of 12.5. The first axis explained 70% of the information, while the second axis explained only 14% of the variation. Few measured environmental gradients were associated with major patterns in the NMS ordination. Among measured physical and chemical variables, only pH was significantly correlated with NMS axis 1 (Figure 3). The NMS ordination revealed strong gradients associated with particular taxa. Thirteen macroinvertebrate taxa (*Baetis* sp., *Tallaperla maria*, *Diphetor hageni*, *Ectopria nervosa*, *Hydropsyche ventura*, *Lanthus* sp., *Malirekus iroquois*, *Neophylax* sp., *Oulimnius latiusculus*, *Parametriocnemus* sp., *Pteronarcys proteus*, *Acroneuria* sp., and *Dolophilodes* sp.) exhibited a significant negative correlation with NMS axis 1, while 8 taxa showed a significant positive correlation (*Leuctra* sp., *Lepisostoma* sp., *Microtendipes* sp., *Polycentropus* sp., *Psilotreta frontalis*, *Thienemannimyia* Gr., *Zavrelimyia* sp., and *Corynoneura* sp.).

Similarly, among 7 macroinvertebrate community attributes and 19 environmental attributes, only specific conductance and pH were significantly correlated with total taxa richness (specific conductance: Spearman rho = 0.660, $p = 0.002$; pH: Spearman rho = 0.720, $p < 0.001$) and EPT taxa richness (specific conductance: Spearman rho = 0.649, $p = 0.003$; pH: Spearman rho = 0.714, $p < 0.001$; Figure 4).

DISCUSSION

Despite their importance to overall watershed health, headwater streams have largely gone understudied and under-assessed. This study represents the first known effort to comprehensively assess physical and biological conditions in headwater streams in western Massachusetts. The headwater streams in this study were characterized as having cool thermal regimes, variable channel gradients, dominance by coarse substrates, and occurrence in only forested areas. Among environmental variables, stream pH and specific conductance showed the only significant correlation with measured biological (macroinvertebrate) community attributes.

Stream pH ranged widely among study sites, and tolerance to low pH varies considerably among macroinvertebrate taxa. Accordingly, this one variable appears to exert a large measurable influence on headwater macroinvertebrate community structure and diversity in the study area. Abundance patterns of a number of taxa were significantly correlated with NMS Axis 1, which was also significantly correlated with pH, suggesting a potential influence of pH on these particular taxa (listed individually in the results section).

Interestingly, no other environmental variables were significantly correlated with any macroinvertebrate community attributes. The streams in this study occurred exclusively on forested land, and none of the reaches surveyed were associated with any recent harvest activity. In fact, despite active searching for reaches that occurred in areas of immature forest, no such sites were identified. Similarly, we were unable to locate suitable headwater streams in the few small pockets of old growth forest that were identified for inclusion in this study. As a result, the forest stand conditions characterized by this work were relatively homogeneous and uniformly represent those expected to occur in association with little or no recent land-use disturbance. The lack of any correlative relationship between biological and forest stand conditions (as measured by canopy cover and percent aerial coverage by mature trees of the riparian zone) is likely the result of this narrow range of forest stand conditions measured in this study, as research of headwater streams from other regions have shown a relationship between forest stand age and macroinvertebrate community condition (e.g., Cole et al. 2003, Stone and Wallace 1998).

One recent study compared macroinvertebrate communities in paired headwater streams with differing riparian zone tree composition (deciduous versus coniferous) within the Harvard Experimental Forest of central Massachusetts (Willacker et al. 2009). Willacker et al. (2009) reported a mean per-sample taxa richness of 24.4 in the deciduous stream versus 11 in the hemlock stream and suggested that these differences were potentially related to the different riparian zone tree composition. In our study, riparian zone composition was either mixed or dominated by deciduous trees; in no case was the tree canopy dominated by conifers, thereby limiting our ability to further examine this potential relationship between riparian canopy structure and macroinvertebrate community composition.

Macroinvertebrate communities in the headwater reaches in this study were diverse and included taxa that occur nowhere else in the drainage network. A total of 150 taxa were sampled from the 23 headwater stream and spring/seep locations. Richness in this study (mean = 41 taxa per reach) was considerably higher than that reported by Willacker et al. (2009) in the two Swift River headwater tributaries in central Massachusetts (24.4 and 11 in the two streams they sampled). However, sampling methods (area sampled, live-field-picking versus whole-sample preservation and laboratory picking) and level of taxonomic resolution differed between the projects and likely contributed significantly to these differences. Similarly high richness has been measured in other studies of headwater streams, including those measured in the Oregon Coast Range Mountains, where richness averaged 45 taxa per reach (Cole et al. 2003), compared to 41 taxa per reach in this study. Taxonomic richness of headwater streams in the Deerfield River water also compares favorably to higher-order downstream reaches. While direct comparisons are limited to other samples from which 300 organisms were subsampled, a 2006 study of the mainstem Deerfield River and several tributaries, including the West Branch Deerfield River, the Cold River, and North River allows such comparisons. In the 2006 study, total richness averaged 30.6 taxa per sample versus 41 in the present study, while EPT richness averaged nearly 19.4 taxa per sample versus a slightly lower 16.4 EPT taxa per sample from the headwater stream reaches (Cole 2007). The lower EPT richness from the headwater sites is attributable to the distinct lower mayfly richness in the headwater sites.

Interestingly, macroinvertebrate densities also differed markedly between the Harvard Forest study and the present study, as the Harvard Forest study reported an average density of 343 individuals/m^2 (Willacker et al. 2009) whereas densities in this study averaged 4,517 individuals/m^2. Cole et al. (2003) reported an average macroinvertebrate density of 2,239 individuals/m^2 in their study of 40 western Oregon headwater streams. The large difference between the Harvard Forest and Deerfield watershed studies is again likely attributable to differences in sampling methods. Samples were field picked for the Harvard Forest study, almost certainly resulting in an under-sampling of small, difficult-to-see specimens without the aid of a microscope. Consequently, density estimates derived from the present study are likely more accurate with respect to total macroinvertebrate densities in regional headwater streams.

As in the study of Oregon Coast Range headwater macroinvertebrate communities by Cole et al. (2003), this present work also indicated that caddisfly assemblages are diverse, while mayfly and stonefly assemblages exhibit a relatively low richness. Caddisflies averaged 8.3 taxa per reach in this study, and 9 of the 11 taxa identified as headwater obligates were caddisflies, demonstrating the importance of these areas for a number of members of this insect order. Headwater stream reaches in the present study were numerically dominated by Diptera; an average of 62% of individuals sampled from each reach represented this order, similar to the Harvard Forest finding that dominance by Diptera averaged 52% between the paired streams (Willacker et al. 2009). In our study, Chironomidae (Order: Diptera) were both the most numerically dominant and the richest macroinvertebrate family. Based on the results of this study, headwater streams of the Deerfield River watershed could be said to be "dominated by midges".

The Deerfield River watershed Association has sampled macroinvertebrate communities in nearly 70 stream and river reaches since 2005; a number of taxa encountered during this survey have not been sampled in any of the higher-order streams during DRWA's annual surveys. Taxa occur in these reaches that occur nowhere else, and patterns of distribution and abundance appear to vary widely among these taxa. Several headwater taxa, including *Malirekus iroquois*, *Parapsyche apicalis* and *Pycnopsyche gentilis*, were sampled from most sample reaches, suggesting a general ubiquity across the forested landscape of the Deerfield River watershed.

Other headwater obligate taxa, such as *Adicrophleps hitchcocki*, *Rhycophila nigrita*, and *Palaeagapetus celsus* were sampled from fewer sites (between 20 and 35% of sites). However, because sampling was limited to approximately 1 m^2 of streambed and only 300 organisms were subsampled and identified from the original sample, actual occupancy of headwater streams by these taxa is undoubtedly higher than the encounter rates reported in this study. Interestingly, Wiggins (1996) describes the known distribution of *P. celsus* as the Appalachian Mountains of North Carolina and Tennessee and the Laurentians of Quebec, and further states that the species is local in occurrence. Although never recorded from the Deerfield River watershed and potentially never collected in Massachusetts before, the results of this study suggest that *P. celsus* may occupy headwater streams across the forested landscape of western Massachusetts.

Similarly, *A. hitchcocki* was described by Wiggins (1996) as occurring cold, rapid streams in Pennsylvania, Maryland, and Connecticut. While not previously recorded from Massachusetts, *A. hitchcocki* appears to be more than a rare occurrence on the western Massachusetts landscape. These results suggest that the lack of records from western Massachusetts result primarily from the extent to which headwater streams have been under-sampled rather than a general rarity of these headwater-obligate taxa across the landscape.

Only one headwater obligate taxa – *Homoplectra doringa* – was sampled from only one headwater reach during this study. One specimen of this caddisfly was sampled from site Monroe 19. The genus *Homoplectra* is described in Wiggins (1996) as known to occur in intermittent spring seeps, usually in the headwaters of mountain streams (Huryn 1989). *Homoplectra doringa* does not currently occur on MA DEP's master taxon list, suggesting the possibility that this represents the first record of this taxon in the state. The detection of this taxon at only one of 20 sites suggests that it may be relatively rare across the forested landscape of western Massachusetts.

Two caddisfly taxa – *Psilotreta rufa* and *Frenesia dificilis/missa* – were each sampled from only one of the four spring/seeps associated with the headwater stream reaches. *P. rufa* is known to be associated only with small spring-seeps and spring-fed streams (Parker and Wiggins 1987). *Frenesia* is described by Wiggins (1996) as occurring in cold streams and spring seepage areas. While this taxon may not be restricted exclusively to headwaters regionally, its absence from the MA DEP master taxon list suggests that it has not been collected from higher-order streams in the state. However, owing to the small number of springs/seeps sampled in this study, it is plausible that these two taxa also occur in springs and seeps in forested areas across the watershed. This study suggests that these headwater taxa that had not been sampled in the Deerfield River watershed or potentially elsewhere in Massachusetts are not only present, but are potentially well distributed in cold-water headwater streams across the forested landscape. Their persistence in these areas is likely afforded by the maintenance of healthy riparian forest conditions.

Generally, these headwater systems were characterized by a cool thermal regime, as maximum mean daily water temperatures averaged only 60^{o}F through August 2011. Many of these taxa, by their limited distribution to these headwater areas, are likely stenothermic, requiring cool water for their persistence. Brook trout were observed in *nearly half of the sample reaches*, suggesting the ability of these extreme headwater areas (most reaches occurred within 500 meters of channel initiation) to support this cold-water-dependent fish species. Un-assessed streams in Massachusetts are automatically considered Class B Warm water streams and are protected as such under 314 CMR 4. This study demonstrates that the uppermost reaches of forested headwater streams in the watershed in fact support cold water invertebrate and vertebrate aquatic species, and should be granted the higher level of protection afforded to Cold Water streams.

The intact riparian conditions measured across the state forests in this study are likely responsible for the high macroinvertebrate diversity and occurrence of headwater obligate taxa observed in this study. An important extension in this work will be to examine environmental and biological conditions in headwater streams occurring in areas developed for agriculture and urbanization. Examining headwater biodiversity across a larger disturbance gradient will provide insight into the effects of higher levels of disturbance on macroinvertebrate community conditions. Headwater work performed in New York and Pennsylvania has consistently shown that pollution-sensitive species such as mayflies, stoneflies, and caddisflies are lost as adjacent land use is converted from forest to agricultural or urban/suburban development (Kratzer et al. 2006).

Another consideration in assessing biodiversity in aquatic systems is the seasonal timing of the sampling. This study was conducted under the MET grant in the late summer of 2011. Additional volunteer sampling occurred in late fall 2011 and spring 2012 at a subset of sample reaches. The results of these additional seasonal sampling events are already providing further insight into biodiversity in these habitats. For example, the March 2012 sampling of the Savoy #13 seep revealed the presence of the caddisfly genus *Beraea*. Wiggins (1996) describes its colonies as “rare” in the eastern United States, and this likely the first colony found in Massachusetts. DRWA plans to continue to inventory biodiversity in these habitats and also sample in more disturbed areas to begin to assess changes associated with developed land uses.

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Table 1. List of 20 headwater stream reaches assessed in summer 2011 for macroinvertebrate community conditions, physical habitat conditions, and water quality in the Deerfield River watershed, Massachusetts.

Site #	State Forest	Lat	Long	Drainage Area (km^2)	Gradient (%)	Geology	Fish Bearing
1	Savoy	42.5618	-72.9783	0.19	4	granofels	Y
2	Dubuque	42.5741	-72.924	na (seep)	9.5	schist, amphibolite	N
3	Dubuque	42.5699	-72.9099	0.29	12	amphibolite, schist	Y
4	Dubuque	42.5737	-72.9231	0.33	4	schist, amphibolite	N
5	Dubuque	42.5719	-72.9184	0.56	14.2	schist, amphibolite	Y
6	Mohawk	42.6014	-72.9592	0.69	14.2	granofels	N
7	Mohawk	42.6204	-73.0005	0.30	6.4	greenstone, granofels	Y
8	Catamount	42.6365	-72.7408	0.28	16.2	schist	N
9	Savoy	42.6234	-73.0211	0.13	19.1	mica schist, schist	Y
10	Savoy	42.6202	-73.0193	0.06	12.1	schist, mica schist	N
11	Mohawk	42.6507	-72.9959	0.65	5	schist, amphibolite	Y
12	Dubuque	42.5637	-72.9121	0.21	5	amphibolite	N
13	Savoy	42.6359	-73.0233	0.39	9.2	mica schist, schist	Y
14	Mohawk	42.6287	-72.9936	0.49	12	granofels	N
15	Savoy	42.6378	-73.0554	0.19	5.8	schist	N
16	Savoy	42.6659	-73.0608	0.37	12	phyllite, mica schist	Y
17	Monroe	42.7204	-72.9956	2.00	15	mica schist	N
18	Monroe	42.7146	-72.995	0.77	4.5	schist	N
19	Monroe	42.7012	-72.9881	0.14	9.6	schist	N
20	HO Cook	42.7326	-72.7893	0.37	5	schist	Y

Table 2. Mean, standard deviation and range of environmental variables measured from Deerfield River watershed headwater stream reaches sampled in summer 2011.

Environmental Variable	n	Mean	SD	Min	Max
Drainage/Channel Size					
Drainage Area (sq km)	19	0.44	0.43	0.06	2.00
Mean thalweg depth (cm)	20	7.4	2.9	2.7	15.4
Mean wetted width (m)	20	1.1	0.3	0.6	1.8
Mean bankfull width (m)	20	2.6	0.8	1.7	4.3
Reach Gradient (%)	20	9.7	4.6	4.0	19.1
Habitat Frequencies					
% Pool	20	43.3	17.2	7.1	77.8
% Riffle	20	42.0	18.7	14.8	85.7
% Glide	20	4.5	5.0	0	16.1
% Cascade	20	9.5	10.0	0	29.0
% Chute	20	0.6	2.9	0	12.9
Channel Substrate					
% Bedrock	20	2.6	6.2	0.0	25.5
% Large boulder	20	4.1	6.2	0.0	20.0
% Small boulder	20	16.6	14.4	0.0	49.1
% Cobble	20	25.1	9.4	1.8	38.2
% Coarse Gravel	20	16.0	7.9	5.5	30.9
% Fine Gravel	20	17.9	12.3	3.6	50.9
% Sand	20	6.9	8.9	0.0	29.1
% Fines	20	8.4	9.2	0.0	38.2
% Wood	20	2.7	4.3	0.0	16.7
% Sand and Fines	20	15.2	11.7	0.0	43.6
% GF/Sand/Fines	20	33.1	19.0	3.6	78.2
% Coarse Substrate	20	61.7	19.3	16.4	94.5
% Embeddedness	20	41.8	16.0	21.0	77.0
Riparian					
% Canopy Cover	20	89.7	3.6	82.4	96.3
Big Trees (>0.3 DBH), (%)	20	69.5	8.8	48.9	85.0
Small Trees (<0.3 DBH), (%)	20	31.5	12.8	10.4	59.2
Woody Shrubs/Saplings (%)	20	19.3	11.3	7.0	57.1
Temperature Logger	14	36.9	4.7	25.0	39.0
Axg Daily Max	14	60.2	4.3	46.6	65.2
Max 7-day Avg Max	14	62.0	4.9	46.9	68.2
Water Chemistry					
DO (% SAT)	20	73.0	9.2	42.5	81.9
DO (mg/L)	20	7.3	1.0	4.0	8.7
Specific Conductance (µS/cm)	20	58.6	103.7	13.4	486.2
pH	20	6.4	0.9	4.8	7.6

Table 3. Mean, standard deviation, and range of community attributes of macroinvertebrates communities sampled from 19 headwater streams and 4 springs/seeps in the Deerfield River watershed in summer 2011.

	Streams					Seeps				
	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
Richness										
Total Richness	19	41.1	8.3	25	56	4	32.8	8.54	21	40
Mayfly Richness	19	3.1	2.1	0	7	4	0.75	0.5	0	1
Stonefly Richness	19	5.2	1.6	2	9	4	3.5	1.73	2	5
Caddisfly Richness	19	8.3	2.4	4	13	4	4.25	1.26	3	6
EPT Richness	19	16.5	4.4	7	25	4	8.5	2.38	5	10
Chironomidae Richness	19	13.3	3.1	7	19	4	10.8	7.37	0	16
HW Obl Taxa Richness	19	3.2	1.5	1	5	4	2.5	0.58	2	3
Taxonomic Composition										
% Mayfly Abundance	19	5.0	3.9	0.0	12.4	4	0.5	0.4	0.0	0.8
% Stonefly Abundance	19	11.6	5.5	3.2	25.6	4	30.3	23.3	11.3	64.0
% Caddisfly Abundance	19	13.5	6.5	5.4	27.9	4	13.8	4.5	8.5	19.3
% EPT Abundance	19	30.2	9.6	12.5	50.7	4	44.7	25.1	20.6	78.7
% Chironomidae Abundance	19	58.1	13.7	30.7	86.1	4	35.2	28.3	0.0	64.5
% Odonata Abundance	19	0.5	0.5	0.0	2.0	4	0.0	0.0	0.0	0.0
% Coleoptera Abundance	19	4.7	5.0	0.0	20.2	4	1.9	2.4	0.0	5.1
% Diptera Abundance	19	62.0	12.5	38.0	86.1	4	48.8	27.4	10.3	73.2
% Oligochaeta Abundance	19	1.0	0.8	0.0	2.7	4	0.9	0.6	0.3	1.5
% Pisidiidae Abundance	19	0.1	0.2	0.0	0.4	4	0.9	1.7	0.0	3.4
Functional Group Composition										
% Filterer-Collectors	19	28.7	10.0	9.5	45.1	4	8.8	6.55	0.74	14.6
% Gatherer-Collectors	19	31.9	12.9	13.0	63.2	4	24.8	17.8	2.94	42.8
% Predators	19	14.2	4.2	6.8	21.3	4	20.1	6.96	10.3	26.7
% Scrapers	19	7.0	5.2	1.3	23.3	4	3.99	5.15	0	10.8
% Shredders	19	16.7	7.1	6.4	33.8	4	38.4	27.3	13.8	77.2
Density										
Density (#/m^2)	19	4517	2306	1231	10237	4	1894	1911	189	3821

Table 4. Highest measured occurrence rates of macroinvertebrate taxa sampled from 19 headwater streams in the Deerfield River watershed in summer 2011. Taxa in bold are restricted to headwater streams.

MATaxon	Order	% Occurrence
Tanypodinae	Diptera	100%
Micropsectra/Tanytarsus sp.	Diptera	100%
Leuctra sp.	Plecoptera	100%
Lepidostoma sp.	Trichoptera	100%
Corynoneura sp.	Diptera	100%
Polypedilum sp.	Diptera	95%
Eurylophella funeralis	Ephemeroptera	95%
Tvetenia sp.	Diptera	89%
Thienemannimyia gr.	Diptera	89%
Sweltsa sp.	Plecoptera	84%
Oulimnius latiusculus	Coleoptera	84%
Brillia sp.	Diptera	84%
Psilotreta sp.	Trichoptera	79%
Parapsyche apicalis	***Trichoptera***	***79%***
Paracapnia sp.	Plecoptera	79%
Ceratopogoninae	Diptera	79%
Pycnopsyche gentilis	***Trichoptera***	***74%***
Hexatoma sp.	Diptera	74%
Dicranota sp.	Diptera	74%

Table 5. Occurrence rates of headwater-obligate macroinvertebrate taxa sampled from 19 headwater streams and 4 springs/seeps in the Deerfield River watershed in summer 2011.

Taxon	Order	% Occurrence
Diptera		
Glutops singularis	Diptera	5%
Plecoptera		
Malirekus iroquois	Plecoptera	63%
Trichoptera		
Parapsyche apicalis	Trichoptera	79%
Pycnopsyche gentilis	Trichoptera	74%
Adicrophleps hitchcocki	Trichoptera	37%
Rhyacophila nigrita	Trichoptera	26%
Palaeagapetus celsus	Trichoptera	21%
Molanna blenda	Trichoptera	11%
Homoplectra doringa	Trichoptera	5%
Psilotreta rufa	Trichoptera	*
Frenesia difficilis/missa	Trichoptera	*

* Sampled from only one seep/spring site

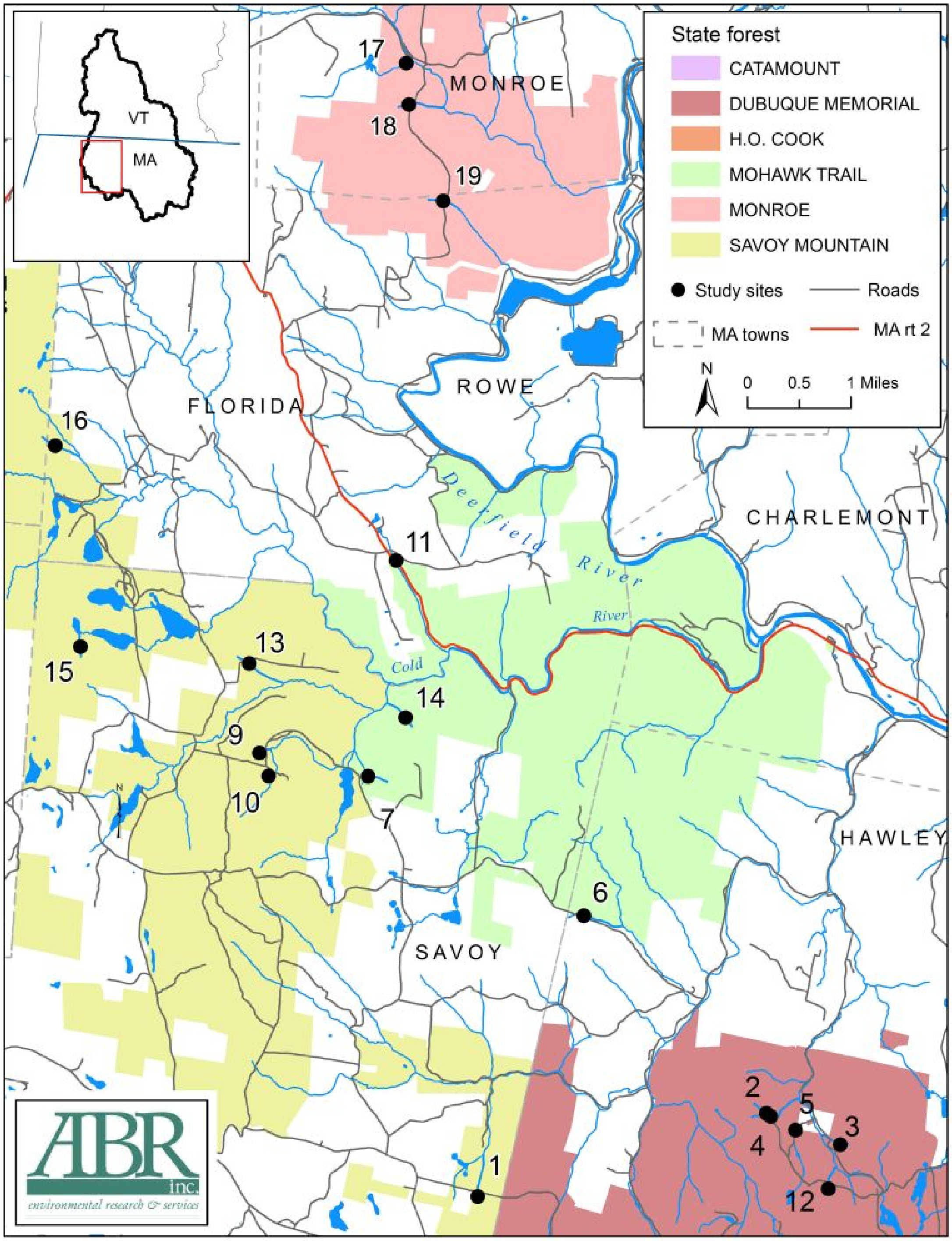

Figure 1. Locations of headwater stream sample reaches in the western portion of the Deerfield River watershed, Massachusetts.

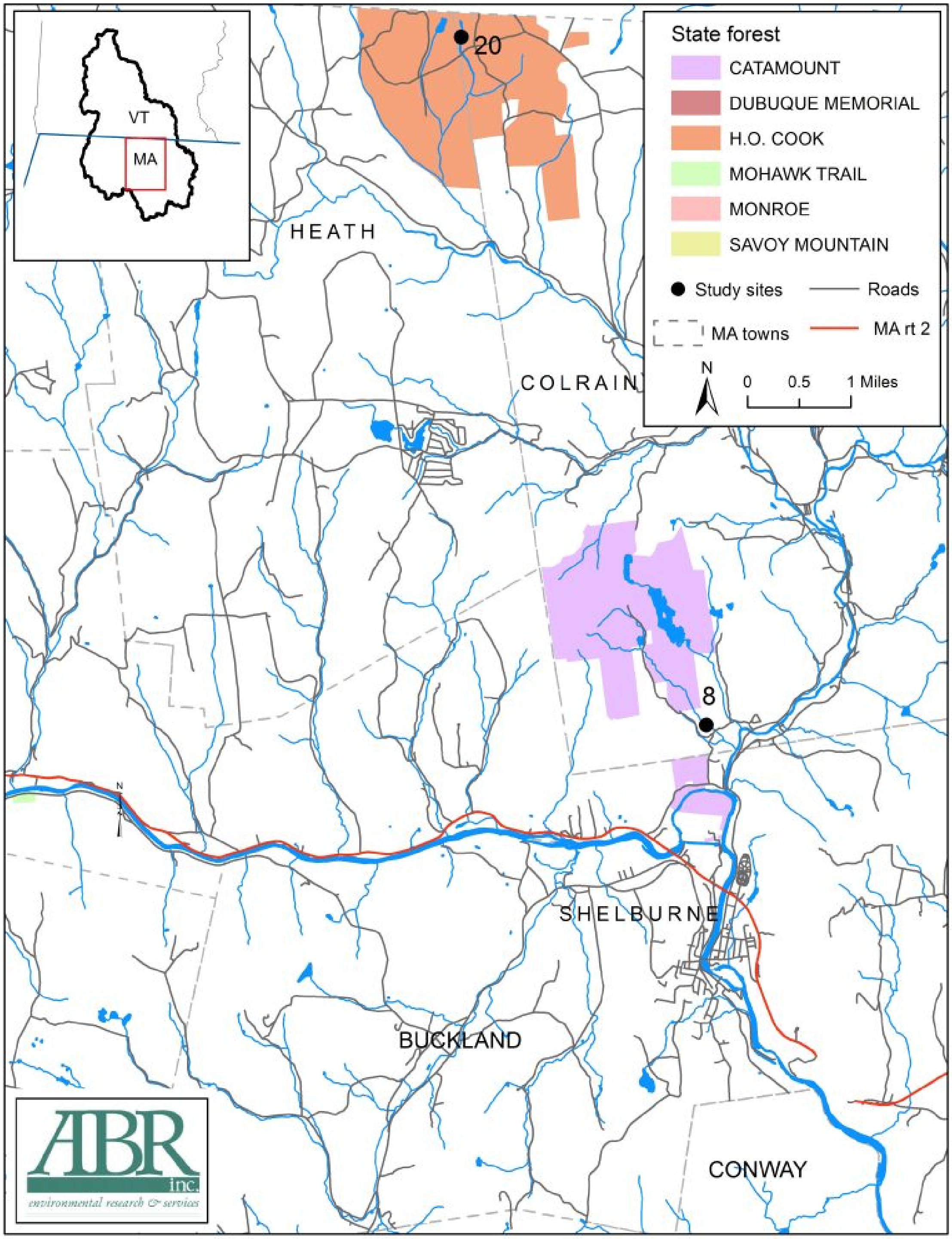

Figure 2. Locations of headwater stream sample reaches in the central/eastern portion of the Deerfield River watershed, Massachusetts.

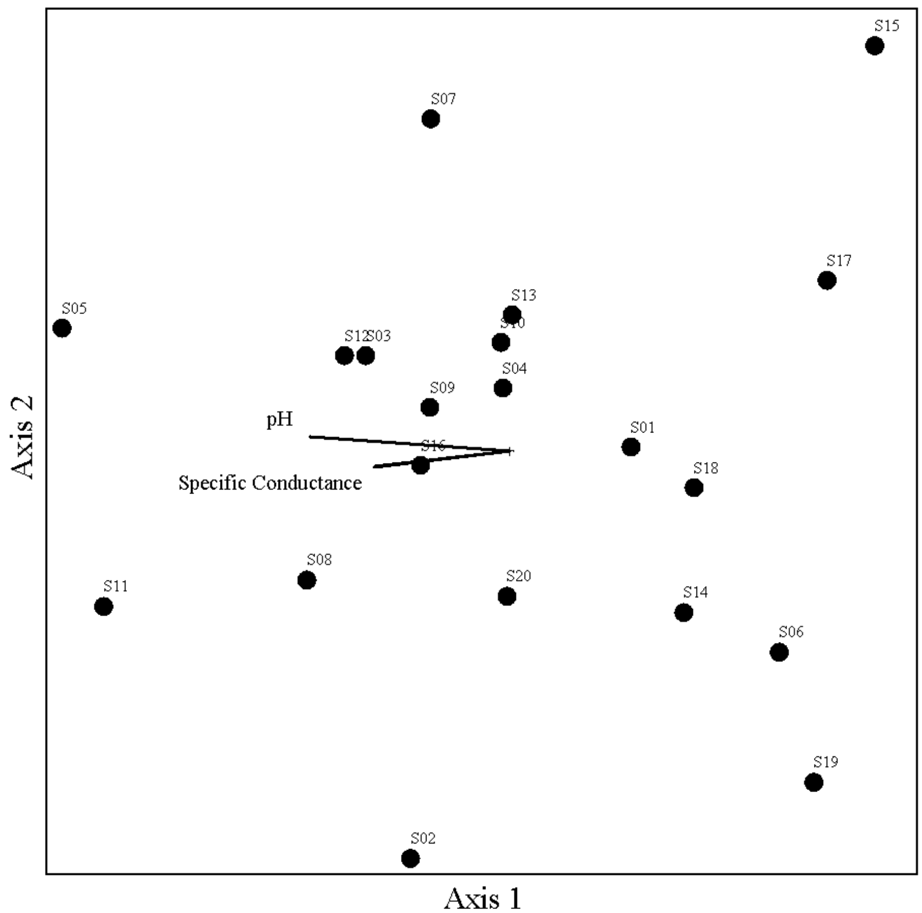

Figure 3. Nonmetric multidimensional scaling (NMS) bi-plot of macroinvertebrate communities sampled from 19 headwater streams in the Deerfield River watershed of western Massachusetts. Plots include vector overlays of environmental variables significantly correlated with NMS axes.

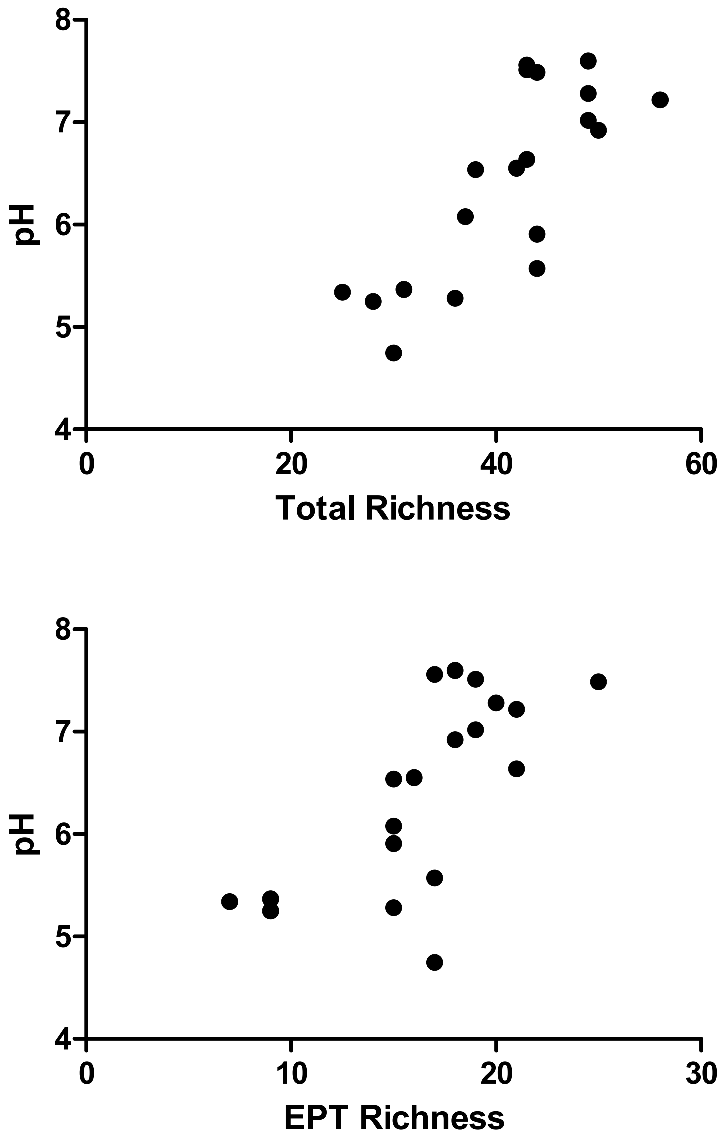

Figure 4. Relationships between stream pH and macroinvertebrate community richness measures from 19 headwater streams in the Deerfield River watershed of western Massachusetts.

Figure 5. *Beraea* sp. specimens collected from Savoy #13 Seep study site.