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Hemlock Legacy Project (HeLP): A paleoecological requiem for eastern hemlock

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Abstract

Eastern North American forests have effectively lost two major tree species (American chestnut and American elm) in the last 100 years and two more, eastern and Carolina hemlock, will be functionally extinct over much of their ranges within a couple of decades. The loss of eastern hemlock is of particular concern because hemlock is: (1) a foundation species; (2) one of the longest-lived tree species over much of temperate eastern North America; and (3) sensitive to climatic variation and ecosystem disturbance, making it an ideal species for the reconstruction of environmental history. Unlike American chestnut, we have a small window of opportunity to salvage environmental histories from hemlock before they are lost. In this progress report, we review the extensive body of science derived from this paleoenvironmental archive and urge scientists from eastern North America to sample and archive old-growth hemlock while living and dead material remain. Here we describe a community-based approach to salvaging paleoenvironmental archives that could serve as a model for collections from other foundation species currently threatened by exotic forests pests and pathogens (e.g. whitebark pine, ash). The approach supports Schlesinger's (2010) call for 'translational ecology' by building connections between scientists, students, environmental NGOs, and land managers focused on old-growth forests.

Keywords
eastern hemlock, hemlock woolly adelgid, paleoclimatology, paleoecology, tree rings

I Introduction

Over the last century, eastern North America has essentially lost two major tree species, American chestnut (*Castanea dentata* L.) and American elm (*Ulmus americana* L.). Two more, eastern hemlock (*Tsuga canadensis* (L.) Carr.) and Carolina hemlock (*Tsuga caroliniana* Engelm.), are currently threatened with functional extinction over much of their range (Figure 1). Ecologically, hemlock is a foundational species: a primary producer that exerts substantial influence on the structure and function of an ecosystem while controlling its community dynamics (Ellison et al., 2005; Orwig et al., 2002). Unfortunately, the invasive hemlock woolly adelgid (HWA, *Adelges tsugae*) is causing rapid decline and mortality in a large portion of hemlock's range (Bonneau et al., 1999; Ellison et al., 2005; Orwig and

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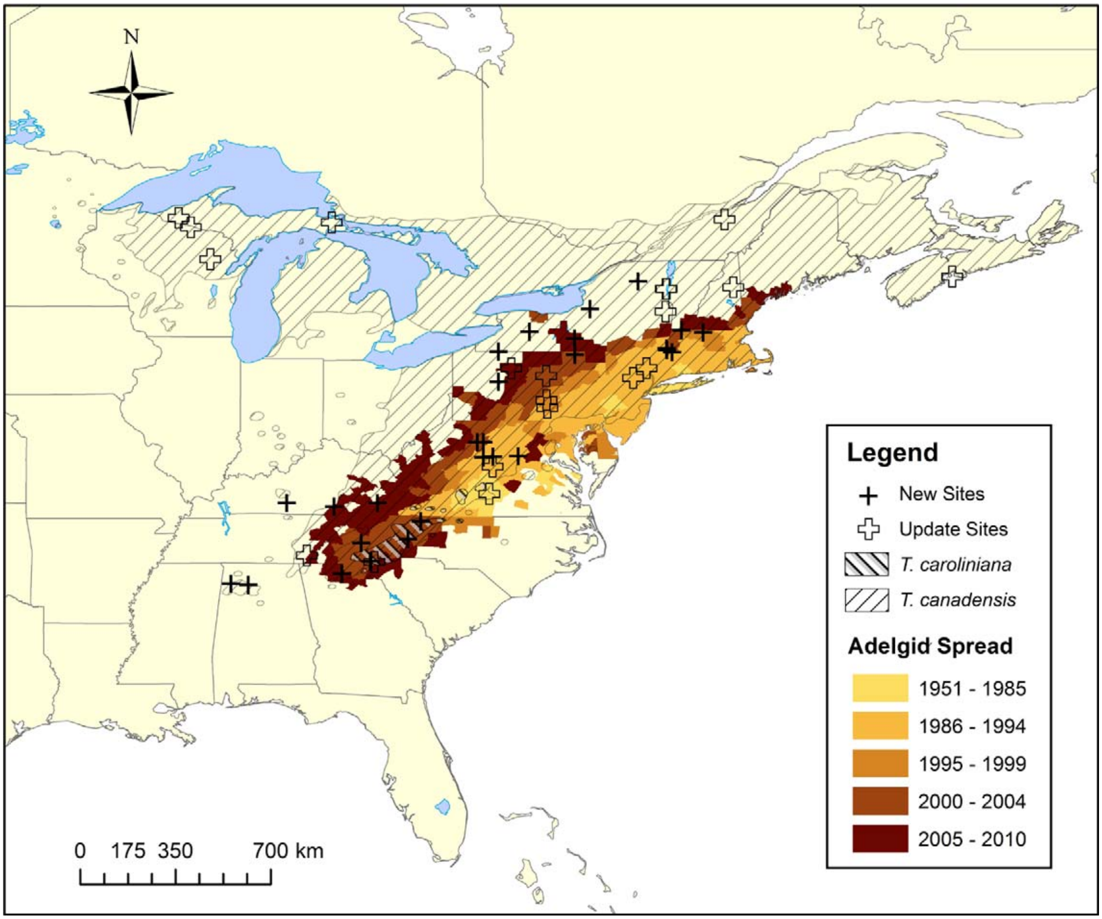

Figure 1. Range of eastern and Carolina hemlock, and range of the hemlock woolly adelgid since 1951 (USDA Forest Service, 2012). Potential new old-growth hemlock sites and existing hemlock tree ring sites to update are noted. (See colour version of this figure online).

Foster, 1998). This is especially true in the southern Appalachian Mountains where many old-growth hemlock forests are approaching functional extirpation at a higher rate than in other parts of hemlock's range (Nuckolls et al., 2009). Even when treated, infested old-growth hemlock trees show a precipitous decline in growth (Figure 2). In the northern portions of hemlock's range, cooler temperatures currently limit levels of HWA. However, warming temperatures will likely increase the geographic extent of suitable habitat in future (Paradis et al., 2008). Time is running out to salvage ecological and tree-ring data from hemlock before stands are infested, ecosystem properties change, and wood decays.

Hemlock is not only important ecologically, but is arguably the most important natural archive of annually resolved paleoenvironmental data across eastern North America. For instance, 102 references can be found for *Tsuga canadensis* in the Bibliography of Dendrochronology alone (Swiss Federal Institute for Forest, Snow and Landscape Research, 2010). Hemlock is the fifth longest-lived tree species in eastern North America (Pederson et al.,

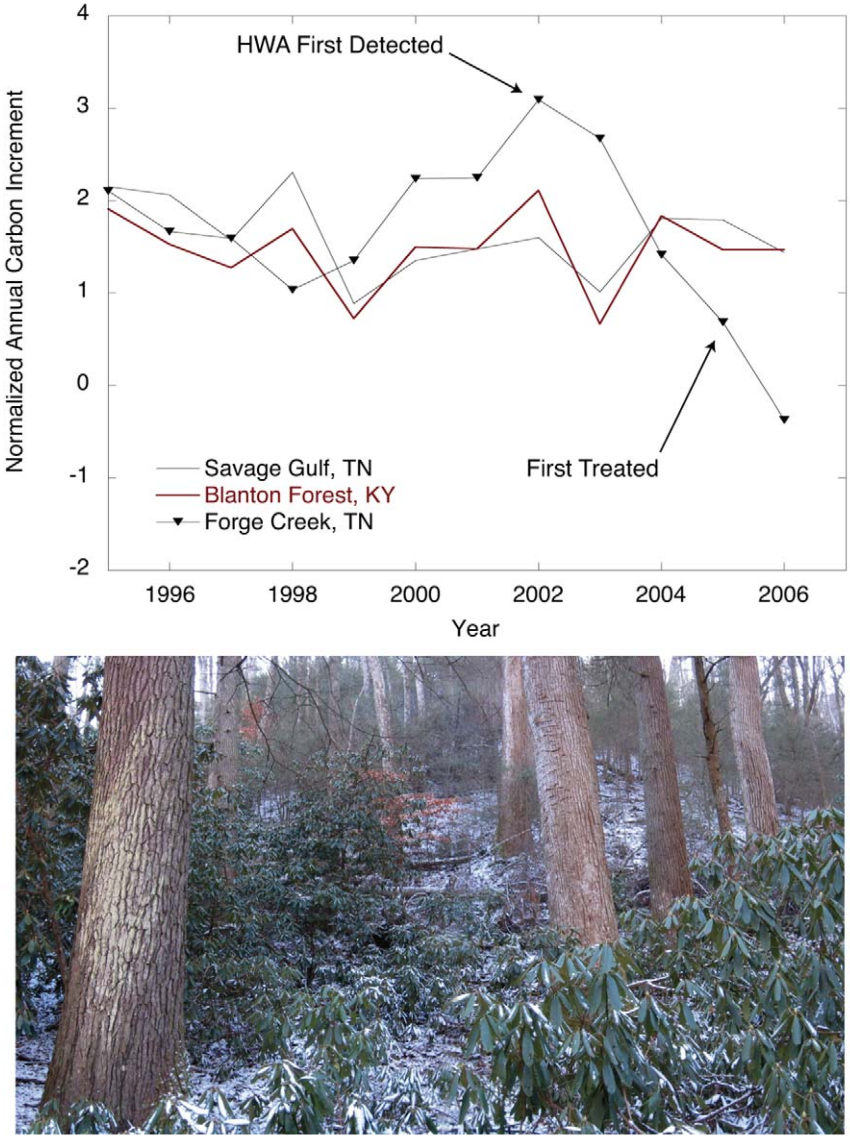

Figure 2. Top: annual aboveground biomass production in healthy (Savage Gulf, Tennessee and Blanton Forest, Kentucky) and infested but treated (Forge Creek, Tennessee in Great Smoky Mountain National Park) eastern hemlock. Bottom: the rapid decline beginning in 2003 in the 50–190-year-old Forge Creek population, occurring one year after HWA was observed in the GSMNP, even after treatment of these specific trees in 2005, illustrates the rapidity in which this collection must be made. Virtually no growth occurred in 2007, the last growing season prior to sampling. (Photo: N. Pederson). (See colour version of this figure online).

2012) and its range is expansive, covering much of eastern North America. Unlike other long-lived species from eastern North America, such as northern white cedar (*Thuja occidentalis*) and eastern redcedar (*Juniperus virginiana*) that reach extreme ages only under specific conditions, hemlock reaches close to its maximum age over most of its range and across several site types, allowing scientists to develop continental-scale networks of past climate and disturbance from tree rings. Hemlock radial growth is sensitive to variations in both temperature and precipitation (Cook, 1991; Cook and Cole, 1991; Hart et al., 2010) and is a primary eastern species used to reconstruct past drought in the North American Drought Atlas (Cook et al., 1999).

In addition to its role as a climate proxy, hemlock has served as one of the primary recorders of past canopy disturbance in eastern North America (Abrams and Orwig, 1996; Black and Abrams, 2004, 2005; Bratton and Meier, 1998; D'Amato et al., 2008; Druckenbrod, 2005; Foster, 1988; Henry and Swan, 1974; Lorimer, 1980; Marshall, 1927; Parshall, 1995; Runkle, 1982; Ziegler, 2000). Hemlock's shade tolerance allows it to persist in deep shade for decades to centuries while adding minimal radial increment. Mortality of neighboring canopy trees releases suppressed hemlock from energy-limiting conditions. The timing and change in local competition from this release from overstory competition is reflected in the tree rings of the surviving, suppressed trees (Lorimer, 1980; Lorimer and Frelich, 1988; Marshall, 1927). By sampling increment cores from surviving trees in old-growth forests, investigators can reveal annual patterns of forest stand dynamics at centennial scales. The functional extinction of hemlock from eastern forests will be a significant loss for future paleoecological investigations of past climate and disturbance. However, tree-ring data collected now could serve science for decades to come.

I Natural history of hemlock

Hemlock is found over an estimated 10 million ha of forest in eastern North America (Figure 1) with a natural range that extends from the southern Appalachian Mountains in Georgia to New Brunswick, Canada, and from the east coast of North America to the southern shores of Lake Superior (Little, 1971). Disjunct stands of hemlock are common in the southern and western portions of its range, though abiotic conditions of only a few of these isolated stands have been studied (Bormann and Platt, 1958; Hart et al., 2010). Eastern hemlock's conspecific, Carolina hemlock, is native to Virginia, Tennessee, North Carolina, and Georgia, and is also experiencing rapid mortality due to HWA. With its more limited range and more southerly extent, Carolina hemlock is arguably more imperiled than eastern hemlock. Hereafter, we refer to both species simply as 'hemlock'.

Interestingly, hemlock did not reach its modern range until around 1000–2000 years before present (Davis, 1981). In fact, hemlock is the only tree species known to have had a population crash during the Holocene (until *Franklinia alatamaha* went extinct in the wild during the early 19th century). The fossil pollen record documents that hemlock experienced an approximately simultaneous decline across much of its range approximately 5500 years before present (Bhiry and Filion, 1996; Davis, 1981; but see Booth et al., 2012). Initially, the decline was thought to be the result of an insect outbreak (Bhiry and Filion, 1996; Davis, 1981). More recently, others have argued that drought was a contributing factor to the decline of hemlock (Foster et al., 2006; Shuman et al., 2004). Still other studies indicate that hemlock had experienced smaller but significant declines earlier in the Holocene (Oswald and Foster, 2012). Regardless of the cause, the pollen record suggests that at least 1000 years passed before hemlock began to approach pre-decline levels (Booth et al., 2012); in many areas it might not have fully recovered. Some have argued that the Holocene decline might have led to unusually low levels of genetic diversity in extant populations (Potter et al., 2012; Zabinski, 1992) potentially leaving hemlock open to widespread infestation by the adelgid.

Modern ecological studies of hemlock indicate that it is a versatile species that plays an important role in a variety of community types and settings. Eastern hemlock is one of the most shade-tolerant tree species in eastern North America, making it capable of living in the understory for up to 400 years (Godman and Lancaster, 1990). It is also capable of rapidly exploiting new resources after canopy-opening disturbances (Black and Abrams, 2004; Davis et al., 1996; Foster and Zebryk, 1993; Godman and Lancaster, 1990), which is valuable in reconstructing multi-annual to decadal-scale forest dynamics. It can occur in almost pure stands, especially on lower slopes and in stream valleys of Appalachian forests (Ellison et al., 2005; Godman and Lancaster, 1990; Kessell, 1979; Shankman and Hart, 2007). In these settings, hemlock controls population and community dynamics and regulates ecosystem processes (Ellison et al., 2005; Orwig et al., 2002). Hemlock trees have dense canopies and transpiration characteristics that differ from co-occurring deciduous species (Catovsky et al., 2002). These characteristics decrease the light availability, temperature, and moisture loss in the understory, create conditions favorable for other species, and stabilize ecosystem processes (Ellison et al., 2005; Hadley, 2000; Rankin and Tramer, 2002). Hemlock litter decomposes slowly, which creates deep acidic humus with low rates of nitrogen mineralization and nitrification (Finzi et al., 1998; Lovett et al., 2004). Hemlock also has distinct effects on aquatic ecology. For example, streams draining hemlock forests support significantly more taxa of aquatic invertebrates than those draining hardwood forests (Snyder et al., 2002). As forests transition from hemlock to hardwood species, the annual water balance of watersheds will likely change, especially during the growing season when some hardwood species have significantly higher water demands (Daley et al., 2007). Without hemlock, eastern forests and their watersheds will look and behave quite differently than they do today.

2 Hemlock woolly adelgid invasion

HWA is an aphid-like insect introduced to eastern North America in the early 1951 from Japan (Havill et al., 2009; USDA Forest Service, 2011). In eastern North America, HWA reproduces parthenogenetically two times per year, feeds in the winter, and lays eggs in the spring. Cold winter temperatures increase mortality and reduce population growth (Evans and Gregoire, 2007; Parker et al., 1998) while warmer temperatures allow for increased survivorship and spread of infestation. HWA feeds on hemlocks of all ages and infested stands can be entirely wiped out. Though western North American hemlock species have resistance to HWA (recent genetic studies indicate HWA is native to western North America; Havill et al., 2009), eastern hemlock species show few signs of resistance and mortality rates approach 100% (Orwig et al., 2002). Mortality can occur quickly in a stand, especially in the presence of other stressors, or can occur slowly and in patches over more than a decade (Eschtruth et al., 2006). For example, hemlock stands located on xeric sites tend to succumb to HWA infestation more rapidly than those on mesic sites. Regardless of site conditions, however, the duration of the HWA infestation ultimately controls the intensity of decline and mortality (Orwig et al., 2002).

HWA has spread across the range of eastern hemlock at a rapid rate since the first major outbreaks in the 1980s. Estimates of the current rate of spread range from 12.5 km/year in the northeast to much faster rates of 20–30 km/year in the southern Appalachian Mountains (Evans and Gregoire, 2007). These rates of spread indicate that there is limited time to collect tree-ring samples over much of eastern hemlock's range before infestation, growth decline, and eventual mortality occur. HWA has already caused rapid growth decline and widespread mortality in the southern portions of hemlock's range (Evans et al., 2011), including Shenandoah

National Park (National Park Service, 2012) (Figure 1). As with American chestnut when first infested with chestnut blight, hemlock is being harvested in anticipation of infestation (Kizlinski et al., 2002), so, even if mortality of eastern hemlock proves to be less than 100%, many of the oldest and best recorders of past climate and environment could either be harvested or die within the next 5–15 years.

There are currently no effective means of biological or chemical control of the adelgid in eastern forests. Though many commercial treatments to protect individual hemlock trees from HWA exist, they are expensive, labor intensive, and must be repeated every few years. Even with these intensive treatments, some of the large, old trees appear to be susceptible to the disease (W. Blozan, personal communication, 2012). For instance, large mature hemlock trees in a cool, moist stream bottom of Great Smoky Mountain National Park infested in 2002 experienced a precipitous decline in aboveground biomass beginning in 2003 (Figure 2). Even trees treated with Imidacloprid in 2005 continued to decline such that 30% of all radii had no ring present in 2006 and 58% of all radii had no ring in 2007 (Figure 2). A handful of individual trees will probably be treated and survive, but those numbers will likely be extremely low. Furthermore, though northward spread of HWA is currently slow due to low winter temperatures, projections of warmer winter temperatures for the northeast indicate that the continued spread of HWA across the northeast is likely, and could accelerate, over the coming century (Paradis et al., 2008). Evidence suggests that HWA induces tree mortality at a faster rate in southern versus northern areas. If this pattern holds, current and near-term winter warming will likely increase hemlock mortality rates over the next 5–15 years in the northern areas of current infestation. Though sampling and archiving efforts should initially focus on the southern and western portion of hemlock's range where infestations are currently common, it would be proactive to sample stands north of the current extent of HWA infestation.

II Hemlock as a paleoclimate archive

Hemlock tree rings have yielded important insights into past moisture variability of eastern North America prior to instrumental records. Although hemlock typically grows in moist, cool microenvironments (Godman and Lancaster, 1990), hemlock radial growth is often drought-sensitive (Cook and Cole, 1991; Cook et al., 1999). A recent analysis of eastern hemlock growing on talus in eastern New York identified a classic drought signal: radial growth is strongly and positively correlated with May–June precipitation and significantly and negatively correlated with May temperatures (Cook and Pederson, 2011). At the southwestern border of hemlock's distribution, the climate signal is similar; hemlock trees are mostly drought-sensitive (Hart et al., 2010). Even hemlock trees on mesic sites and in wetlands are drought-sensitive and contribute information to reconstructions of drought (Cook and Krusic, 2004; Cook et al., 1999; Pederson et al., 2012, forthcoming a). In an analysis of a tree-ring network across the eastern United States using 97 chronologies composed mostly of hemlock, oak, juniper, pine, and spruce, the first principal component strongly resembled variation in drought, with a correlation of 0.73 with a drought reconstruction (1700–1971) and 0.58 with an instrumental drought record (1895–1971) (Cook, 1991). Most of these chronologies were collected from moderately well-drained upland sites, although some hemlock samples were collected from much wetter sites. Hemlock's demonstrated sensitivity to drought across its range allows for annually resolved, regional reconstructions of past drought variability, extending for the last 300–500 years across broad swaths of eastern North America.

Though hemlock is clearly drought-sensitive, it might be possible to use hemlock with red spruce and white cedar as a part of a multi-species reconstruction of temperature in eastern North America. Spring temperatures have been reconstructed in Maine from maximum latewood densities of red spruce (Conkey, 1986), which is still the only tree-ring reconstruction of temperature in the northeastern United States. In the central and northern portion of its range, hemlock responds positively and significantly to March temperatures (Cook and Cole, 1991). Given that Atlantic white-cedar radial growth is positively and significantly correlated to November through March temperatures in the same region (Hopton and Pederson, 2005) and that species replication appears to aid tree-ring based climate reconstructions (Cook and Pederson, 2011; García-Suárez et al., 2009; Maxwell et al., 2011; Pederson et al., 2012), a reconstruction of temperature might be possible through the combination of hemlock, red spruce, and Atlantic white-cedar tree-ring records. Updating extant and creating new hemlock records towards the northern end of its range could aid in reconstructing historical temperature variations over the past 300–500 years.

III Hemlock as a paleoecological archive

Hemlock's ability to persist for centuries below the forest canopy makes it an ideal species for studying long-term forest dynamics in extant old-growth forests. In one of the first reconstructions of forest history in the eastern USA, Marshall (1927) noted:

> Almost as soon as the first hemlocks had been felled, it was noticed that at the center of every stump was a core of wood from one to five inches in diameter which frequently had taken one hundred or more years to grow. (Marshall, 1927: 5)

He further observed that an 'abrupt change in growth rate' occurred at nearly the same time as logging scars and inferred that the increase in light 'released the long stunted hemlocks from suppression'. This basic observation was formalized decades later in a study of an old-growth, hemlock-mixed species forest at Joyce Kilmer Memorial Forest, North Carolina (Lorimer, 1980). The Marshall (1927) and Lorimer (1980) studies helped set the groundwork for the development of methods for the detection of canopy disturbance from hemlock and other shade-tolerant species (Black and Abrams, 2003; Lorimer, 1985; Lorimer and Frelich, 1989). Since that time, hemlock has been used dozens of times for forest history research.

For example, at Joyce Kilmer, increased radial increment growth occurred at the same time as peak recruitment, indicating that canopy disturbance stimulated radial growth (Lorimer, 1980). A study of an old-growth, northern hemlock-hardwood forest in the Sylvania Wilderness, Michigan, revealed that the release from competition occurred coincident with drought, suggesting that drought synchronized forest recruitment (Parshall, 1995). A dendroecological study of an old-growth forest with eastern white pine (*Pinus strobus*) and eastern hemlock on Pennsylvania's Alleghany Plateau documented that, after centuries of continuous tree recruitment, severe deer grazing had inhibited recruitment in the 50 years prior to the investigation (Abrams and Orwig, 1996). In another study of old-growth Pennsylvanian hemlock, the forest experienced frequent, small-scale disturbances and two stand-wide disturbances since the late 1400s (Black and Abrams, 2005). Together, these studies indicated that small-scale disturbances, i.e. gap dynamics, were a constant factor of forest development in temperate forests, but that a changing climate (drought variation) or an 'imbalance' of other agents (fluctuating herbivore populations) could disrupt the timing and frequency of ecosystem processes.

While these studies have yielded major insights into local-level disturbance in hemlock and other forest types in eastern North America, fewer studies have investigated landscape- to regional-scale disturbance. A study of a 23,000 ha forest composed primarily of sugar maple (*Acer sacharrum*) and eastern hemlock in Upper Michigan points to large-scale synchronous stand dynamics in a forest traditionally thought to be regulated by small canopy gaps (Frelich and Lorimer, 1991). Disturbances were spatially clustered, recruitment occurred in large cohorts, and large patches approximately 2 km in radius indicated a history of major disturbance. Even in humid, closed-canopy forest, widespread drought could drive recruitment and mortality of a substantial portion of the forest. In fact, paleoecologists across eastern North America have noted simultaneous changes in forest composition broadly (e.g. Gajewski, 1987; Gajewski et al., 2006; Jackson and Booth, 2002; Jackson and Whitehead, 1991; Shuman et al., 2004; Spear et al., 1994). Most regional analyses based upon tree-ring investigation, however, have not substantiated paleoecological observations of regional-scale forest dynamics (D'Amato and Orwig, 2008; Rentch, 2003), although a new investigation of more stands over a larger region provides evidence of regional-scale stand dynamics in extant forests (Pederson et al., in review). Given that many old-growth forests have a substantial component of hemlock and that hemlock lives for more than 300 years over much of its range, a large tree-ring network of disturbance histories from hemlock would support research on regional-scale disturbance and would complement sediment core analyses of forest history. If supported, the idea that regional-scale droughts lead to widespread mortality would fundamentally alter our understanding of disturbance in temperate forests globally.

IV A call to action

High rates of HWA spread indicate that there is limited time to collect tree-ring samples in eastern hemlock's range before infestation, growth decline, and eventual mortality occur (Figure 1). The cost of sampling hemlock across its range is high and, with no clear scientific hypothesis to test, funding for such a project is unlikely. However, tree-ring scientists, students, citizen scientists, and private agencies could, in a short period of time, develop a large archive. The data that scientists and citizens collect could make important contributions across a wide range of ecological and paleoecological studies, including: (1) improved resolution of the North American Drought Atlas; (2) new multi-species reconstructions of past temperature; (3) regional-scale reconstructions of disturbance; (4) enhanced climate reconstruction and other applications possible through carbon, nitrogen, and oxygen isotopes; and (5) evaluation of the impact of the loss of major canopy species on the ecology of an ecosystem. These efforts would complement existing joint programs between the US Forest Service and the non-profit group Camcore (Raleigh, North Carolina) to preserve the genetic diversity of hemlock through seed collection (Camcore, 2010). The long history of public archives developed by tree-ring scientists, through the International Tree Ring Data Bank (ITRDB), has allowed hundreds of scientists from a wide range of disciplines access to tree-ring data. The ITRDB would provide an excellent platform for distribution of hemlock data to the broader scientific community. Hemlock data collected in the 1980s are currently being used in ways beyond their original collection purposes (e.g. Black et al., 2008; Hart et al., 2010; Pederson et al., in review) suggesting that new collections will serve science for decades to come. Finally, hemlock is likely not the last species to go functionally extinct. A community-based effort at collection could serve as a model for archiving physical, digital, and graphic records from tree species threatened with extinction in the near future (e.g. ash).

V The Hemlock Legacy Project (HeLP): a community-based science initiative

We hope to inspire tree-ring scientists from across eastern North America to collect tree-ring samples from old-growth hemlock before the HWA renders them useless. Here we present a list of possible sites (Table 1), a recommended sampling design for collections, and evidence that it is still possible to sample many old-growth stands and gain climatic and disturbance information even if trees are already infested with HWA. Experienced scientists can assist in this data collection effort by: (1) updating existing collections; (2) making collections at old-growth sites that have not been sampled previously; and (3) helping identify new locations to sample. Scientists and interested citizens who would like to get involved, but who have more limited experience, should contact the authors or visit the HeLP website (www.geo.wvu.edu/hemlocklegacy) for more information.

1 Update existing collections

Many collections of hemlock made in the 1980s could provide important information on response to climate change, nitrogen deposition, and other recent phenomena in eastern North America if those collections were updated with the subsequent ~30 years of annual growth since their original collection. For example, updated collections could be calibrated against ~30 years of additional climate data, yielding better validated reconstructions. To identify collections to update, scientists can search the holdings of the ITRDB and contact resource managers and citizen scientists to locate existing collections suitable for updating in their area. Initial announcements and discussion of this project have been met with enthusiasm, several volunteers, and identification of imperiled sites in the southern Appalachian Mountains (Figure 3; Table 1). Two collections, Savage Gulf and Mohonk Preserve, were updated by the Lamont-Doherty Earth Observatory Tree Ring Lab and Pederson et al. (2009) in 2008. By updating Savage Gulf, Pederson et al. (2009) increased tree replication during the 1600s nearly fourfold.

2 New sites

We have identified 29 new sites that have the potential to yield long records of climate and disturbance (Figure 1) and recommend that citizens and scientists sample them. One new collection in West Virginia has yielded a new climate record (1707–2007) and one of the oldest known hemlock (> 515 yrs) (M. Merrill and A. Hessl, unpublished data). Hemlock has historically had limited economic value (Godman and Lancaster, 1990), so many remnant old-growth stands survived 18th- and 19th-century logging. The best locations to find old-growth hemlock in the southern end of its range are in deep gorges, ravines, or other geomorphic formations that make access difficult. Areas that have low productivity, steep slopes or little soil development often have old trees (Stahle and Chaney, 1994). Again, resource managers and citizen scientists may be the best sources of information about unsampled old-growth stands.

3 Methods: new collections

We encourage scientists to use a standard protocol at all sites to ensure data quality and compatibility. For sites already infested with

Table 1. Hemlock tree-ring sites listed in the ITRDB (International Tree Ring Data Bank) that could be updated, and new, previously unsampled, sites likely containing old-growth hemlock.

Site	Latitude (°)	Longitude (°)	State/Province	Type
Bee Branch Gorge	34.33	−87.84	AL	New
Amicalola	35.57	−84.23	GA	New
Tight Hollow	37.00	−83.00	KY	New
Mammoth Cave National Park	37.00	−86.00	KY	New
Henry Wright Preserve	35.07	−83.24	NC	New
Bluff Mountain	36.39	−81.57	NC	New
Floodwood Drive	44.33	−74.38	NY	New
Green Lakes State Park	43.41	−75.97	NY	New
Letchworth State Park	42.66	−77.97	NY	New
Cook Forest State Park	41.00	−79.00	PA	New
Heart's Content	42.00	−79.00	PA	New
Jenkins Woods	41.90	−76.47	PA	New
Smoky Mountains	35.68	−83.54	TN/NC	New
Skidmore Watershed	38.52	−79.18	VA	New
Cathedral State Park	39.00	−79.50	WV	New
Gauley River	NA	NA	WV	New
Panther Knob	38.50	−79.50	WV	New
WVU Forest	39.00	−79.70	WV	New
Brushy Canyon	34.29	−87.27	AL	New
Great Mtn Forest	41.98	−73.26	CT	New
Sage's Ravine	42.05	−73.43	CT	New
Beaver Creek Wilderness	36.88	−84.43	KY	New
Dunbar Brook	42.71	−72.95	MA	New
Guilder Pond	42.11	−73.44	MA	New
Roaring Brook	42.64	−72.23	MA	New
Loon Lake	46.12	−89.18	MI	Update
Presque Isle River	46.43	−89.58	MI	Update
Salt Point	46.28	−84.52	MI	Update
Dotson Knob	35.81	−81.99	NC	New
Kelsey Tract	35.05	−83.11	NC	Update
Mirror Lake	35.07	−83.21	NC	New
Gibb's Brook	44.13	−71.24	NH	Update
Bowater-Mersey	44.49	−64.00	NS	Update
Adirondack Mountain Reserve	44.08	−73.47	NY	Update
Pack Forest	43.33	−73.48	NY	Update
Roaring Brook Keene Valley	44.08	−73.45	NY	Update
Six Miles Creek	42.43	−76.48	NY	New
Spruce Glen	41.46	−74.11	NY	Update
Alan Seeger Natural Area	40.40	−77.42	PA	Update
Dingman's Falls State Park	41.13	−74.55	PA	Update
East Branch Swamp	41.20	−77.43	PA	Update
Hemlocks Natural Area	40.14	−77.39	PA	Update
Tionesta Natural Area	41.45	−78.58	PA	Update
Reviere du Moulin	46.38	−71.53	QU	Update
Savage Gulf	35.27	−85.34	TN	Update
Hemlock Cove - Sunset Field	37.30	−79.31	VA	Update
Limberlost	38.54	−78.35	VA	New
Ramseys Draft Recollection	38.20	−79.20	VA	Update
Bass Lake Peninsula	45.06	−88.53	WI	Update

HWA, meet with land managers or owners and estimate the date of initial infestation. At each site, identify the oldest trees in each stand (Pederson, 2010; Stahle, 1996; Stahle and Chaney, 1994; Swetnam and Brown, 1992) and core a minimum of 20 of these trees (minimum two cores per tree). In addition to standard increment cores, at least one large diameter (12 mm) core should be taken from five trees with the longest record and soundest wood at each site, if possible. Hemlock cores tend to fall apart during collection and large diameter samples can minimize this problem. In addition, large samples will allow for multiple chemical analyses. Complete cross-sections of 10 or more snags, stumps, or logs could be sampled with a chainsaw opportunistically at each site, particularly at those sites where the HWA has already caused widespread mortality. Be sure to collect geographic coordinates of each site and, if possible, each tree sampled.

4 Vegetation and age structure sampling

In order to develop estimates of productivity and make these collections useful to a wider group of researchers, we encourage scientists to collect vegetation from fixed-area plots and age structure data in each sampled stand. This information is currently not available for hemlock collections in the ITRDB and is therefore particularly important for chronologies that researchers plan to update. We encourage researchers to follow the vegetative sampling procedure of D'Amato et al. (2008), which makes a tradeoff in sampling a large number of plots with getting an estimate of forest structure and composition. Establish 3–5 0.04 ha plots along transects through the central portion of each stand. Record species and diameter and core every tree $\geq$ 1.37 m tall and $\geq$ 10 cm diameter at breast height (DBH, 1.37 m). Ideally, investigators would record the dominant understory vegetation, slope, aspect of each plot, and as many environmental conditions as possible so that the structure of these forests can be captured before they are lost. All age and vegetation data should be uploaded to VegBank (http://vegbank.org/vegbank/index.jsp) upon completion of your work or publication.

5 Tree-ring archiving

Scientists and students can record ring-width measurements, including earlywood and latewood, and store these data in standard format. If possible, scientists should scan each core or cross-section using a high-resolution 4000 dpi scanner suitable for analysis in WinDENDRO (Regent Instruments, Inc, Quebec City, Canada) or other image analysis software. This extra step will make a wider range of data analysis possible virtually. Data can be archived in each lab using Tellervo (Brewer, 2012) or other tree-ring archival software, and measurements can be archived and made public on the ITRDB. If scientists cannot maintain a physical archive for their samples, please contact the authors.

6 How to get involved

We have proposed a large project that is subcontinental in scale and is beyond the scope of any single researcher or institution. To succeed, many individuals must get involved. Regardless of background, there are many ways people can contribute to HeLP. First, the collections suggested here can easily be incorporated into laboratory exercises for advanced high school and undergraduate classes. University courses or activity groups could contribute with the investigation of one stand. By contributing data to a large project, students would have the opportunity to network beyond the classroom. Second, there are many citizen scientist groups, birding groups, environmental organizations, etc., that are able to explore local forests more than today's typical college professor or researcher. A significant potential contribution for these groups to HeLP is to find new sites for study and participate in collections.[1]

Figure 3. Scenes of hemlock. Top two pictures are previously undescribed old-growth forests in western North Carolina (photos courtesy of W. Blozan). The two sites above contain old, drought-sensitive trees (virtually no soil development) and represent ideal new sites to sample. The spike-top on the tree in the top-left photo is a sign of great age. The middle left picture is of an old hemlock in the Pigeon Wilderness, New York, with decay in the outer portions of the log (photo: N. Pederson). The middle right picture is looking into the eastern portion of Savage Gulf, Tennessee, home to an old-growth forest with hemlock dating to the early 1600s (photo: N. Pederson). This forest was treated in 2012 for HWA (W. Blozan, personal communication). The bottom photo shows K. Tackett emerging into a recently discovered old hemlock forest on Cold Hill, Kentucky (photo: N. Pederson). (See colour version of this figure online).

VI Conclusion

As exotic forest pathogens continue to affect forests globally, scientists, forest managers, and interested citizens will need to actively collect and archive biological samples from species threatened with real and functional extinction. With large numbers of scientists and citizen scientists working regionally and globally, it may be possible to preserve the natural archive present not just in eastern hemlock but other tree species threatened with significant losses across their range (e.g. ash, beech, etc.). Hemlock has yielded great insights into eastern forest dynamics and eastern climate, but likely holds more secrets yet to be discovered by a new generation of scientists. There is limited time to collect samples from infested forests and preserve data for the next generation of researchers and students.

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Note

1. Please visit the project website (www.geo.wvu.edu/hemlocklegacy) or contact the authors of this paper for more information. We also ask that people interested in participating share the project's web pages with social media outlets such as Facebook, Twitter, blogs, community billboards.

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