

Ecosystem-based assessment of biodiversity associated with eastern hemlock forests

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The eastern hemlock (*Tsuga canadensis*) is a shade-tolerant, late-successional conifer that provides a unique cover type in the eastern forest (Rogers 1978). Eastern hemlock stands are highly valued at Delaware Water Gap National Recreation Area (New Jersey and Pennsylvania—fig. 1) and Shenandoah National Park (Virginia) because of their aesthetic, recreational, and ecological qualities. Personnel and cooperators from Delaware Water Gap and Shenandoah have conducted ecological studies in hemlock stands and identified numerous species of plants and wildlife, some of which are sensitive species, within this unique forest habitat (Sciascia and Pehek 1995, Battles et al. 1996). For example, Blackburnian warblers (*Dendroica fusca*) and water shrews (*Sorex palustris*) are closely associated with hemlock stands (Benzinger 1994, Sciascia and Pehek 1995). At Shenandoah National Park, some populations of the federally endangered Shenandoah salamander (*Plethodon shenandoah*) occur in dense hemlock stands (Mitchell 1991, Watson et al. 1994). Moreover, plant species such as painted trillium (*Trillium undulatum*) grow primarily under the canopy of hemlock stands (Radford et al. 1968).

The aesthetic, recreational, and ecological values of hemlock stands at Delaware Water Gap and Shenandoah are threatened by the hemlock woolly adelgid (*Adelges tsuga* Annand; HWA), an exotic insect pest that attacks and can kill eastern hemlock trees (McClure 1991—fig. 2, page 38). The hemlock woolly adelgid was first detected in Shenandoah in the winter of 1988 and now infests all eastern hemlock stands at that park causing significant mortality of hemlock trees (Watson et al. 1994). Resource managers at Delaware Water Gap learned in 1989 that hemlock stands were infested with the insect (Evans 1995).

The biodiversity associated with hemlock stands could be at risk if the current trend of HWA infestation and resulting mortal-

ity continues. The National Park Service endeavors to protect and maintain the natural heritage of its lands, particularly under the threat of an invasive exotic species such as the adelgid. Baseline information on the biotic components of hemlock ecosystems is fundamental to the protection and restoration of biodiversity and to the maintenance of ecosystem dynamics in hemlock stands at both Delaware Water Gap and Shenandoah.

The Pennsylvania State University (Penn State) and the Biological Resources Division (BRD) of the U.S. Geological Survey in cooperation with the National Park Service have conducted research to assess the biodiversity associated with hemlock and complementary paired hardwood ecosystems at the two parks (Ross et al. 1996, Yahner et al. 1996). The goals of this project were to: (1) assemble and synthesize existing information on terrestrial floral and faunal diversity at both parks; (2) develop and establish study site design for forest stands at both parks; (3) develop and standardize specified field protocols and procedures for a biodiversity inventory in hemlock and complementary hardwood ecosystems at both parks; (4) conduct aquatic biodiversity sampling in hemlock and complementary paired hardwood ecosystems at Delaware Water Gap; and (5) conduct terrestrial biodiversity sampling in a hemlock and a complementary hardwood stand at Shenandoah National Park. Aquatic research, similar to that being conducted at Delaware Water Gap, is not being conducted at Shenandoah primarily because hemlock stands at Shenandoah tend to be small and exist as very narrow strips along stream corridors. The effects of hemlock on aquatic biodiversity, therefore, may be difficult to ascertain because the non-hemlock com-



Figure 1. Eastern hemlock (*Tsuga canadensis*) ravine at Hornbeck Hollow, Delaware Water Gap National Recreation Area, Pennsylvania.

ponents of the forest contribute a much larger proportion of the leaf litter inputs entering the stream.

Biodiversity database

To meet the first objective, we compiled information from existing reports, publications, museums, and databases (including NP Flora/Fauna) on terrestrial floral and faunal biodiversity found in and around the two parks (Mahan 1997a, 1997b). Biodiversity information was integrated with existing data in a newly created computerized database using Microsoft Access (termed the Biodiversity Database). Biodiversity information was collected for amphibians, reptiles, birds, mammals, vascular and nonvascular plants, and invertebrates. The database significantly enhances the information available on terrestrial biodiversity in and around the two parks. Furthermore, NP Flora/Fauna contains little to no information on invertebrates present in either park. The Biodiversity Database, however, contains over 8,000 and 1,500 species of invertebrates that potentially could be located at Delaware Water

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Gap and Shenandoah, respectively. The Biodiversity Database was installed at both parks in 1997.

Selection of forest stands

To meet the second objective, BRD researchers developed a landscape analysis methodology to select forest stands for conducting biodiversity inventories (Smith et al. 1996). Stand boundaries at both parks were defined using forest cover-type maps provided by resource managers at each park (Myers and Irish 1981, Teeter 1988). Geographic Information System (GIS) methods were used to tabulate landscape attributes of hemlock stands. Hemlock stands were clustered into three topographic types based on their landscape attributes generated from a 1:24,000 digital elevation model (USGS topography) (Smith et al. 1996). Landscape attributes used for classifying and clustering hemlock stands included: elevation, percent slope, aspect, and terrain shape (Smith et al. 1996). Hemlock stands in each topographic type were then paired with hardwood forest stands using multivariate distance based on similar landscape attributes. Potential study stands were visited at Delaware Water Gap and Shenandoah to check the appropriateness of using the proposed methodology to stratify stands based on topographic type. Fourteen and seven pairs of hemlock and hardwood forest stands were selected as potential study sites at Delaware Water Gap and Shenandoah, respectively (Mahan 1997c, 1997d).

Biodiversity inventories: protocol manual

For the third objective, a manual that details standardized field protocols for inventorying terrestrial and aquatic flora and fauna was prepared (Mahan et al. 1998). Protocols for terrestrial floral and faunal inventories were standardized and developed by researchers at Penn State. Protocols for aquatic sampling were standardized and developed by researchers from the USGS Biological Resources Division (Ross et al. 1996). The protocol manual was reviewed by resource managers at Delaware Water Gap and Shenandoah and researchers associated with the Smithsonian Institution's Monitoring and Assessment of Biodiversity Program (see Dallmeier 1992).

Aquatic biodiversity inventories at Delaware Water Gap

To obtain the necessary information on the aquatic components of biodiversity (objective 4), macroinvertebrate and fish assemblages were sampled in stream reaches within 14 hemlock and paired hardwood stands at Delaware Water Gap during 1997. Aquatic macroinvertebrates and fish were sampled during April and July, respectively. Sampling events were timed to maximize resident species diversity (Ross et al. 1996). Length of stream reaches sampled were proportional to stream width and reflected existing landscape variation (Ross et al. 1996). Macroinvertebrate and fish samples were collected from a variety of microhabitats within stream reaches in each stand. Streams draining hemlock forests at Delaware Water Gap contained approximately 37% more taxa of aquatic invertebrates than streams draining hardwood stands (Snyder et al. 1999). In addition, streams draining hemlock forests supported more predatory invertebrates than stream draining hardwood stands. Finally, brook trout (*Salvelinus fontinalis*) were more likely to occur in streams draining hemlock forests (Snyder et al. 1999).

Terrestrial biodiversity inventories at Shenandoah

To obtain the necessary information on terrestrial flora and fauna (objective 5), a biodiversity profile inventory (plot-based sampling) using numerous sampling protocols was conducted in conjunction with more extensive sampling across a larger area (stand-based sampling). The terrestrial biodiversity profile inventory was conducted during 1997 at one hemlock stand (Limberlost) and a complementary paired hardwood stand (Matthew's Arm) in Shenandoah National Park. The biodiversity profile inventory included intensive sampling for terrestrial plants, vertebrates, and invertebrates from the forest soil to the forest canopy within a 20 m x 20 m plot. Although preliminary results suggest that hardwood forests are more biologically diverse than hemlock forests at Shenandoah, hemlock forests do seem to have unique species composition and structure. For example, many families of terrestrial invertebrates were only found in the hemlock stand (Sullivan et al. 1998). Several families of flies that depend on decaying organic matter and fungi were more abundant in



Figure 2 (above). Eastern hemlocks at Thornton Gap, Shenandoah National Park, have died as a result of hemlock woolly adelgid infestation. Note the gap created in the forest canopy by the dead hemlock.

the hemlock forest. Furthermore, orb-weaving spiders, a group of spiders that requires open habitat structure, were more abundant in the hemlock forest. Individuals of the bark lice family Peripsocidae, and the millipede family Parajulidae, also were more abundant in the hemlock than the hardwood forest at Shenandoah. Red-backed salamanders (*Plethodon cinereus*), which feed on large detritivorous invertebrates, such as millepedes, were significantly more abundant in the hemlock forest. Finally, southern red-backed voles (*Clethrionomys gapperi*), a fungivorous small mammal species, appear to be more abundant in the hemlock forest at Shenandoah.

Hemlock stands at Shenandoah National Park and Delaware Water Gap National Recreation Area support unique assemblages of terrestrial and aquatic species that contribute significantly to the biodiversity of the mid-Atlantic's predominantly hardwood landscape. Loss of hemlock ecosystems due to infestation by the hemlock woolly adelgid may result in significant losses of biodiversity especially in unique invertebrate assemblages. These baseline data on the biotic components of hemlock ecosystems is fundamental to the protec-

tion, maintenance, and restoration of hemlock ecosystems threatened by the hemlock woolly adelgid. **5**

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