Notes On The Geology And Meteorology of Sites Infected With White-Nose Syndrome Before July 2010 in the Southeastern United States

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Abstract: Since 2006, numerous bat colonies in North America have experienced unusually high incidences of mortality. In these colonies, bats are infected by a white fungus named Geomyces destructans, which has been observed on bat muzzles, noses, ears, and (or) wings. Although it is not exactly certain how and why these bats are dying, this condition has been named white-nose syndrome (WNS). WNS appears to have spread from an initial infection site at a cave in New York, and was first identified south of Pennsylvania during January 2009. By the end of June 2010, 41 infected sites had been identified in the states of West Virginia, Maryland, Delaware, Virginia, and Tennessee. Most of these sites are natural caves in limestone of either Cambrian-Ordovician age or Silurian-Devonian age. Published air temperature values in these WNS-infected caves range from -3.3 to 15.6 °C, and humidity measurements range from 68 to 100 %.

INTRODUCTION
In 2006 and 2007, unusually great numbers of emaciated bats and dead bats were discovered in several caves in Schoharie County, New York (Blehert et al., 2009). Studies of these bats revealed no obvious disease-causing parasites, no viral pathogens, and no unusual bacteriological problems, although some of these bats were characterized by a notable decrease in body fat. In addition, many of these bats exhibited erratic behavior such as shifting roost locations closer to cave entrances, emerging from hibernation out-of-season, and flying outside during the daytime. Furthermore, the bats were characterized by the presence of a white fungus growing on their muzzles, noses, ears, and (or) wings. This condition was named white-nose syndrome (WNS), and the sites in North America where this condition has appeared have experienced unusually high incidences of bat mortality.

The white fungus associated with WNS is a newly identified fungus named Geomyces destructans that has spores with a distinctive and unusual hook shape (Gargas et al., 2009). Until recently, G. destructans had been identified only at the WNS-infected sites in North America (Blehert et al., 2009). However, in March 2009 G. destructans was identified on a bat near Périgueux, France (Puechmaille et al., 2010). Subsequently the fungus has been identified at other sites in Europe, and it is now thought that the fungus was present in Europe prior to its appearance in North America (Wibbelt et al., 2010; Martinková et al., 2010). In contrast with the sites in North America, the occurrences of G. destructans in Europe do not appear to be associated with unusually high incidences of bat mortality.

In North America, Geomyces destructans is seen on sick bats but not on healthy bats. The fungus invades living skin tissue of bats, but does not typically cause inflammation or an immune response (Meteyer et al., 2009; Reichard and Kunz, 2009). At present, nine species of bat are known to have been infected with the fungus in North America. Blehert et al. (2009) and Turner and Reeder (2009) list the following six bat species that have been infected with the fungus: (1) the big brown bat (Eptesicus fuscus); (2) the eastern small-footed bat (Myotis leibii); (3) the little brown bat (Myotis lucifugus); (4) the northern long-eared bat (Myotis septentrionalis); (5) the Indiana bat (Myotis sodalis); and (6) the eastern pipistrelle bat or tricolored bat (Perimyotis subflavus). In addition, the U.S. Geological Survey (USGS) National Wildlife Health Center (www.nwrc.usgs.gov/publications/wildlife_health_bullets/WHB_10_04.jsp) indicates that the fungus has been identified on the gray bat (Myotis grisescens) and the cave myotis (Myotis velifer), and a news release by the Virginia Department of Conservation and Recreation (www.dgif.virginia.gov/news/release.asp?id=261) indicates that the fungus has been identified on the southeastern myotis (Myotis austroriparius). Other than attacking skin tissue, it is not yet known if the fungus affects bats in other ways and it is not known if the fungus affects other animals besides bats. In fact, it is not yet known whether G. destructans is the primary cause of the unusual bat mortality in North America or whether the fungus is simply a secondary infection. However, at the time of this writing, all isolates of G. destructans in North America have been genetically identical within the marker genes examined. This observation suggests that the fungus in North America probably disseminated from a point source.

There is great interest in understanding how WNS has spread in the past and concern about where and how WNS might spread in the future. However, WNS has been difficult to study because of the lack of a publicly available list of infected sites, and because of the paucity of detailed scientific data from caves and other infected sites in the United States. An analysis of environmental parameters associated with sites infected with WNS in the eastern United States before September 2009 has revealed that the infection occurs over a wide range of geographical, geological, and meteorological conditions (Swezey and Garrity, in press). In addition, preliminary studies suggest that the Geomyces destructans fungus may be transmitted from bat to bat, and that the fungus may also be transmitted as an unwanted hitchhiker upon humans, clothing, and caving gear (Sleeman, 2009; Turner and Reeder, 2009). Studies by Blehert et al. (2009) have shown that G. destructans prefers cold temperatures for growth, that optimal temperatures for fungus growth are between 5 and 10 °C (41 and 50 °F), and that the fungus does not grow at temperatures greater than approximately 20 °C (68 °F). Anecdotal field evidence suggests that the fungus may prefer relatively high humidity, although no laboratory studies on this topic have been published yet.

In order to improve understanding of the parameters associated with WNS, this paper presents a chronology of events regarding where and when Geomyces destructans was identified in the southeastern United States prior to July 2010 (Table 1, Fig. 1). In this paper, the southeastern United States is defined as the region south of the Commonwealth of Pennsylvania and east of the Mississippi River. Each WNS-infected site in this region is described below, with brief notes about the stratigraphic setting and meteorological conditions. It is hoped that the information presented below will inform and clarify the debate about WNS, and lead to greater understanding of environmental parameters associated with WNS.

SITES INFECTED WITH WNS IN THE SOUTHEASTERN UNITED STATES
Bats infected with the Geomyces destructans fungus were first photo-documented on 16 February 2006 in a cave that is connected to Howe Caverns, which are commercial caverns in Schoharie County, New York (Blehert et al., 2009). Since then, G. destructans has spread rapidly among bats in the eastern North America, making its first appearance in Pennsylvania (Lackawanna County, Luzerne County, and Mifflin County) during the winter 2008-2009 bat hibernation season (Swezey and Garrity, in press). During the time interval from January through March 2009, the fungus also appeared in Bath and Giles Counties, Virginia (Breathing Cave, Clover Hollow Cave) and in Pendleton County, West Virginia (Hamilton Cave, Trout Cave, Cave Mountain Cave). From April through August 2009, the
fungus was identified in three additional caves in Virginia (including the commercial Endless Caverns) and one additional cave in West Virginia. From September through December 2009, the fungus was identified in one additional cave in Virginia. From January through March 2010, the fungus was identified in five additional caves in Virginia, 13 in West Virginia, one in Maryland (Grieses Cave), and three in Tennessee (Worley’s Cave, Grinstaff Cave, and the commercial Dunbar Cave). From April through June 2010, the fungus was identified in two new caves in Virginia, and three new caves in Tennessee. Also during this time interval, bats tested positive for the Geomyces destructans fungus at two (non-cave) sites in New Castle County (Delaware) and at Pocahontas State Park in Chesterfield County (Virginia).

Each known site of WNS infection in the southeastern United States prior to July 2010 is described below (in chronological order), with brief notes about the geologic setting and meteorological conditions. Each site description also gives information regarding how that site was determined to be infected. This information is provided because many different white fungi may grow on bats, and some bats that are infected with Geomyces destructans do not display the white fungus in a manner that is visually striking and obvious to the casual observer. In other words, laboratory analyses may be necessary to provide definite confirmation of an infection by Geomyces destructans. Likewise, it is important to realize that the dates given below may not be the dates of initial infection (again, because some bats may be infected by Geomyces destructans, and not display the obvious white fungus).

A. JANUARY 2009 THROUGH MARCH 2009 (BAT HIBERNATION SEASON)

During these three months, white-nose syndrome was first identified in the southeastern United States. Specifically, WNS was detected at five sites south of the Commonwealth of Pennsylvania. Three of these sites are caves in West Virginia (Hamilton Cave, Trout Cave, Cave Mountain Cave) and two of these sites are caves in Virginia (Breathing Cave, Clover Hollow Cave).

**Hamilton Cave, Pendleton County, WV (Site 1 on Fig. 1)**


_Stratigraphy:_ Silurian-Devonian Helderberg Group (Davies, 1965; Palmer, 1975; Dyas, 1977; Medville, 2000a; Dasher, 2001). The front part of the cave is a maze of passages that have developed at the contact of the Devonian New Creek Limestone of the Helderberg Group and the overlying Devonian Corriganville Limestone of the Helderberg Group, whereas the back part of the cave consists of northeast-trending passages (without well-developed maze morphologies) that have developed primarily in the New Creek Limestone.

_Cave Meteorology:_ Dyroff (1977) published an account of a one-day study (April 10, 1977), which found that the air flowed consistently out of the cave during the morning and afternoon, and that the average air temperature inside the cave was 53 °F (11.7 °C). Hoke (2009a,b) reported that air always flows out of the cave during the winter, and that data loggers just inside the cave entrance recorded air temperatures that ranged from 55 °F (12.8 °C) at the beginning of winter to 51.5 °F (10.8 °C) at the end of winter.

**WNS Infection Reported January 2009:** Dasher (2009b, 2010b), Hoke (2009a,b), Stihler (2009, 2010a), and the U.S. Geological Survey (USGS) National Wildlife Health Center (Quarterly Mortality Reports, 2009, Quarter 1). Note that all of the Quarterly Mortality Reports of the USGS National Wildlife Health Center (NWHC) are available online at www.nwhc.usgs.gov/publications/quarterly_reports/.

**Trout Cave, Pendleton County, WV (Site 2 on Fig. 1)**


_Stratigraphy:_ Silurian-Devonian Helderberg Group, in most places at the contact between the New Creek Limestone and the overlying Corriganville Limestone (Haas, 1961; Davies, 1965; Palmer, 1975; Medville, 2000b; Dasher, 2001). However, Swezey (2003) noted that at least one location (the “Square Room”) extends from the Corriganville Limestone into the overlying Lower Devonian Shriver Chert of the Helderberg Group.

_Cave Meteorology:_ Davies (1965) reported air temperatures of approximately 12 °C, Hoke (2001) reported air temperatures ranging from 44 to 48.1 °F (6.7 to 8.9 °C), and Swezey et al. (2004) reported air temperatures ranging from 6 to 13 °C and relative humidity ranging from 81 to 92 %. In addition, Dyroff (1977) published an account of a one-day study (April 10, 1977), which found that during the morning when the outside air temperature was 32 °F (0 °C), air flowed into the cave along the bottom of the cave passage and air flowed out of the cave along the top of the cave passage. In that study, the mean air temperature was 48 °F (8.9 °C) approximately 500 feet inside the cave, although the air temperature near the ceiling was several degrees warmer than the air temperature near the floor. During the afternoon when the outside air temperature was 55 °F (12.8 °C), the air currents reversed so that warm air flowed in along the top of the cave passage and cooler air flowed out along the bottom of the cave passage. Despite this reversal in flow directions, the mean air temperature inside the cave remained at 48 °F (8.9 °C).

**WNS Infection Reported January 2009:** Dasher (2009b, 2010b), Stihler (2010a), and the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

**Cave Mountain Cave, Pendleton County, WV (Site 3 on Fig. 1)**


_Stratigraphy:_ Silurian-Devonian Helderberg Group (Davies, 1965; Dyas, 1976a,b; Dasher, 2001; Swezey and Dulong, 2010). A northwest-trending fault is present about 200 feet inside the main entrance of the cave. On the south side of this fault (i.e., between the cave entrance and the fault), the cave passages have developed within the Keyser Limestone of the Helderberg Group. On the north side of this fault, the cave passages have developed along the contact between the New Creek Limestone and the overlying Corriganville Limestone of the Helderberg Group.

_Cave Meteorology:_ No published data.

**WNS Infection Reported February 2009:** Dasher (2009b, 2010b), Stihler (2009, 2010a), and the West Virginia Division of Natural Resources (www.fws.gov/northeast/whitenose/WVPRESSRelease13Feb09.pdf).

**Breathing Cave, Bath County, VA (Site 4 on Fig. 1)**


_Stratigraphy:_ The cave is located within the Upper Silurian-Lower Devonian Keyser Limestone of the Helderberg Group (Deike, 1960a,b; Douglas, 1964; Holsinger, 1975; White and Hess, 1982; Clemmer, 2005). Within the Keyser Limestone, the cave is confined almost entirely to a 77-foot thick unit of shaly limestone between two 12-foot thick beds of sandstone, which have been named informally the upper Breathing sandstone and the lower Breathing sandstone. These sandstone beds are tongues of the Upper Silurian Clifton Forge Sandstone, which interfingers with the Keyser Limestone.

_Cave Meteorology:_ Faust (1947) published early descriptions of oscillating air flow (the “Breathing Phenomenon”) at Breathing Cave. Cournoyer (1954) published measurements taken during a 1.5 hour interval on January 9, 1954 that revealed air temperatures ranging from 26 to 33 °F (-3.3 to 11.1 °C), atmospheric pressure ranging from approximately 1002 to 1003 millibars, and 5 episodes of air flowing into the cave and then out of the cave at speeds attaining approximately 350 feet per minute. Cournoyer (1956) also published a subsequent set of measurements (taken at four locations during a 1.5 hour interval on December 10, 1955) that revealed air temperatures ranging from 33 to 51 °F (0.6 to 10.6 °C). Finally, Moore (1958) stated that air temperature in the cave is approximately

NSS NEWS, February 2011
52 °F (11.1 °C) throughout the year. 

WNS Infection Reported February 2009: Dasher (2009b), Lambert (2009), the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome-recommendations.pdf), and the Virginia Department of Game and Inland Fisheries (www.dgif.virginia.gov/news/release.asp?id=214). In addition, a WNS infection in Bath County (VA) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

Clover Hollow Cave, Giles County, VA (Site 5 on Fig. 1)


Stratigraphy: Upper Ordovician limestone (Douglas, 1964; Sluzarski, 1972; Saunders, 1974; Holsinger, 1975; Saunders et al., 1981; Orndorff, 1995). The cave entrance is located near the contact between the Upper Ordovician Witten Limestone and the overlying Upper Ordovician Moccasin Formation.

Cave Meteorology: No published data.

WNS Infection Reported March 2009: Dasher (2009b), Youngbaer (2009), the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome-recommendations.pdf), and the Virginia Department of Game and Inland Fisheries (www.dgif.virginia.gov/news/release.asp?id=214). In addition, a WNS infection in Giles County (VA) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

B. APRIL 2009 THROUGH SEPTEMBER 2009 (BAT NON-HIBERNATION SEASON)

During these six months, white-nose syndrome was detected at four sites in the southeastern United States. One of these sites is a cave in West Virginia (Salt peter Cave) and three of these sites are caves in Virginia (Hancock Cave, Newberry-Bane Cave, Endless Caverns).

Salt peter Cave, Pendleton County, WV (Site 6 on Fig. 1)


Stratigraphy: Lower Devonian Corriganville Limestone of the Helderberg Group (Davies, 1965; Dasher, 2001).

Cave Meteorology: No published data.


Hancock Cave, Smyth County, VA (Site 7 on Fig. 1)

Cave Map: None published.

Stratigraphy: Upper Ordovician limestone on the northwest flank of Walker Mountain.

Newberry-Bane Cave, Bland County, VA (Site 8 on Fig. 1)


Stratigraphy: Limestone of the Upper Ordovician Witten Formation and the overlying Upper Ordovician Witten Limestone (Douglas, 1964; Holsinger, 1975; Wright, 1982, 1995; Zokaites, 1995a; Schwartz et al., 2009).

Cave Meteorology: Air temperatures range from 7.0 to 11 °C (Brack et al., 2005).


Endless Caverns [commercial caverns], Rockingham County, VA (Site 9 on Fig. 1)

Cave Map: Map dated 1966 in Holsinger (1975).

Stratigraphy: Middle Ordovician limestone. The commercial part of the caverns is located in the Middle Ordovician New Market Limestone (Douglas, 1964; Holsinger, 1975; Hubbard, 1995; Jones, 1999, 2009). Beyond the commercial part, the main passages have developed along the contact of the New Market Limestone and the overlying Middle Ordovician Lincolnshire Limestone. In a few areas, the caverns extend above the Lincolnshire Limestone and into the overlying Middle Ordovician Edinburg Formation, which lies immediately below the Upper Ordovician Martinsburg Formation.

Cave Meteorology: Reeds (1925) stated that the air temperature is 56 °F (13.3 °C).


C. OCTOBER 2009 THROUGH MARCH 2010 (BAT HIBERNATION SEASON)

During these six months, white-nose syndrome was detected at 26 sites in the southeastern United States. Seven of these sites are caves in Virginia (Tawney’s Cave, Coon Cave, Stonley Cave, Pig Hole Cave, Starnes Cave, Newcastle Murder Hole, Shires Saltpetre Cave), three of these sites are caves in Tennessee (Worley’s Cave, Grindstaff Cave, Dunbar Cave), one of these sites is a cave in Maryland (Grieses Cave), and 13 of these sites are caves in West Virginia (Hellhole Cave, Cassell Cave, Friars Hole Cave, Snedesgars Cave, Norman Cave, Patton Cave, Carpenters Pit, Sites Cave, Short Cave, Sinnett Cave, Dyers Cave, Scott Hollow Cave, Caldwell Cave).

Tawney’s Cave, Giles County, VA (Site 10 on Fig. 1)


Stratigraphy: Ordovician Elway Limestone (Holsinger, 1975; Saunders et al., 1981). This unit lies above the Lower Ordovician Knox Group and below the Middle Ordovician Witten Limestone.

Cave Meteorology: No published data.

WNS Infection Reported November 2009: Dasher (2010a). In addition, a WNS infection in Giles County (Virginia) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Coon Cave, Bland County, VA (Site 11 on Fig. 1)


Stratigraphy: Middle Ordovician Witten Limestone.

Cave Meteorology: No published data.

WNS Infection Reported February 2010: Youngbaer (2010), although the cave was named incorrectly as “Coon Hollow Cave, Virginia.”

Stonley Cave (Divides Cave), Tazewell County, VA (Site 12 on Fig. 1)

Cave Map: None published.

Stratigraphy: Cambrian-Ordovician Knox Group.

Cave Meteorology: No published data.

WNS Infection Reported February 2010: Suspected infection reported by members of the Front Royal Grotto of the National Speleological Society (reported online at www.frontroyal.varegion.org/news.html).

Worley’s Cave (Morrell Cave, Morrill Cave), Sullivan County, TN (Site 13 on Fig. 1)

Cave Map: Map dated 1956 in Barr (1961), and an undated map in Matthews (2009).

Stratigraphy: Cambrian-Ordovician Knox Group (Barr, 1961).

Cave Meteorology: No published data.

**Grindstaff Cave, Carter County, TN** (Site 14 on Fig. 1)
- **Cave Map:** Map dated 1981 in Adams (1983).
- **Stratigraphy:** Cambrian Shady Dolomite (Barr, 1961).
- **Cave Meteorology:** No published data.

**WNS Infection Reported February or March 2010:** Dasher (2010b), and the Tennessee Department of Environment and Conservation (http://news.tennesseeanytime.org/node/5127).

**Shires Saltpetre Cave, Craig County, VA** (Site 16 on Fig. 1)
- **Cave Map:** Map dated 1995 in Zokaites (1995b).
- **Stratigraphy:** Ordovician Moccasin Formation and underlying Ordovician limestone (Douglas, 1964), probably the Upper Ordovician Witten Limestone.
- **Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Wil Orndorff (reported online at www.frontroyal.varegion.org/news.html).

**Newcastle Murder Hole, Craig County, VA** (Site 17 on Fig. 1)
- **Cave Map:** Map dated 1995 in Zokaites (1995b), and an undated line-plot of the cave in Schwartz et al. (2009).
- **Stratigraphy:** Cambrian Maryville Limestone (Holsinger, 1975).
- **Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Wil Orndorff (reported online at www.frontroyal.varegion.org/news.html).

**Shires Saltpetre Cave, Craig County, VA** (Site 18 on Fig. 1)
- **Cave Map:** None published.
- **Stratigraphy:** Ordovician Witten Limestone.
- **Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Wil Orndorff (reported online at www.frontroyal.varegion.org/news.html).

**Greises Cave, Allegany County, MD** (Site 19 on Fig. 1)
- **Cave Map:** Map dated 1962 in Franz and Slifer (1971).
- **Stratigraphy:** Silurian Tonoloway Limestone (Franz and Slifer, 1971).
- **Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010a,b). In addition, the Maryland Department of Natural Resources confirmed WNS-infection at a cave near Cumberland, Maryland (www.dnr.state.md.us/dnrnews/pressrelease2010/031810.asp). Also, WNS infection near Cumberland (MD) was reported in USGS National Wildlife Health Bulletin 2010-02 (www.nwhc.usgs.gov/publications/wildlife_health_bulletins/WHB_2010_02_WNS.pdf).

**Dunbar Cave [commercial cave] (Dunbar-Woodard Cave System), Montgomery County, TN** (Site 20 on Fig. 1)
- **Stratigraphy:** Mississippian St. Louis Limestone (Barr, 1961). Geer (1980) stated that the cave has developed along the contact between the Mississippian Warsaw Limestone and the overlying St. Louis Limestone.
- **Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b). In addition, an undated map of the cave has developed in the Patton Limestone and Sinks Grove Limestone of the Greenbrier Limestone (Greenbrier Group).

**Cassell Cave, Pocahontas County, WV** (Site 22 on Fig. 1)
- **Cave Map:** Map dated 2009 in Zimmerman (2009).
- **Stratigraphy:** Mississippian Greenbrier Limestone (Davies, 1965; Duncan et al., 1967; Dasher, 2000). Dasher (2000) stated that the cave has developed in the Patton Limestone and Sinks Grove Limestone of the Greenbrier Limestone (Greenbrier Group).

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010a,b).

**Friars Hole Cave, Friars Hole Cave Preserve, Greenbrier and Pocahontas Counties, WV** (Site 23 on Fig. 1)
- **Cave Map:** Friars Hole Cave is part of the greater series of connected caves that include Rubber Chicken Cave, Snedegars Cave, Crookshank Cave, and Canadian Hole. A 1977 map of this greater cave system may be found in Anonymous (1977), and an undated map of the Friars Hole Cave System may be found in Storrick (1992). An undated line-plot of the cave may be found in Dasher and Medville (2009).

**WNS Infection Reported March 2010:** Wil Orndorff (2010), Dasher (2010a,b), Stihler (2010a,b), Youngbaer (2010), and the West Virginia Division of Natural Resources (www.wdnr.gov/2010news/10news031.shtml).

**Snedegars Cave (Snedegars-Crookshank Cave System), Pocahontas and Greenbrier Counties, WV** (Site 24 on Fig. 1)
- **Cave Map:** Snedegars Cave is part of the greater series of connected caves that include Rubber Chicken Cave, Friars Hole Cave, Crookshank Cave, and Canadian Hole. A 1977 map of this greater cave system may be found in Anonymous (1977). In contrast, Kouts and Brace (2001) reported that average air temperature in the cave is approximately 47 °F (8.3 °C), and Schlecht (1940) reported that air temperature in the cave was approximately 0 °C (32 °F) during the evening of December 30, 1939.

**WNS Infection Reported March 2010:** Anonymous (2010), Dasher (2010b), Stihler (2010a,b), Youngbaer (2010), and the West Virginia Division of Natural Resources (www.wdnr.gov/2010news/10news031.shtml).
map of this cave system around the Snedegars Staircase Entrance may be found in Medville (1978) and an undated map of Snedegars Cave may be found in Storrick (1992).

**Stratigraphy:** Mississippian Greenbrier Limestone (Davies, 1965; Medville, 1979).

**Cave Meteorology:** Davies (1965) reported that the air temperature in Snedegars Cave is approximately 48 °F (8.9 °C) whereas Anonymous (1942) reported air temperatures ranging from 50 to 60 °F (10.0 to 15.6 °C) on July 26, 1941.

**WNS Infection Reported March 2010:** Dasher (2010b), Stihler (2010a,b), and reported online by Peter Youngbaer at www.forums.caves.org/viewtopic.php?f=58&p=84299.

### Norman Cave (Bone-Norman Cave System), Greenbrier County, WV

(Site 25 on Fig. 1)

**Cave Map:** Undated map in Handley (1995).

**Stratigraphy:** Mississippian Greenbrier Limestone (Davies, 1965).

**Cave Meteorology:** The upper levels of the cave are dry, and the lowest level contains an active stream (Davis and Maus, 1968).

**WNS Infection Reported March 2010:** Dasher (2010b), Pearson (2010), and Stihler (2010a,b).

### Patton Cave, Monroe County, WV

(Site 26 on Fig. 1)

**Cave Map:** Map dated 1969 in Hempel (1975), and an undated line-plot of cave on topographic map in Balfour (1987).

**Stratigraphy:** Middle Ordovician limestone (Davies, 1965; Whittemore, 1965).

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b), Pearson (2010), and Stihler (2010a,b).

### Carpenters Pit (Carpenters Pit-Swago Pit Cave System), Pocahontas County, WV

(Site 27 on Fig. 1)

**Cave Map:** Various maps (dated 1982 to 1992) of the greater cave system in Storrick (1992).

**Stratigraphy:** Mississippian Greenbrier Limestone (White and Dunn, 1957; Davies, 1965; Storrick, 1992).

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b), Pearson (2010), and Stihler (2010a,b).

### Sites Cave, Pendleton County, WV

(Site 28 on Fig. 1)


**Stratigraphy:** Davies (1965) and Anderson (1981) stated that the cave is in the Silurian Tonoloway Limestone, whereas Dasher (2001) stated that the cave is in the Silurian-Devonian Helberg Group.

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010a,b).

### Short Cave, Pendleton County, WV

(Site 29 on Fig. 1)

**Cave Map:** Undated map in Dasher (2001).

**Stratigraphy:** Silurian-Devonian Helberg Group (Dasher, 2001).

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b).

### Sinnett Cave (Sinnett-Thorn Mountain Cave System), Pendleton County, WV

(Site 30 on Fig. 1)

**Cave Map:** Map dated 1997 in Dasher (2001).

**Stratigraphy:** Silurian-Devonian Helberg Group (Dasher, 1965; Swezey, Piatak et al., 2004).

**Cave Meteorology:** The presence of oscillating air flow (the “Breathing Phenomenon”) at Sinnett Cave was postulated by Schmidt (1958). This phenomenon was later confirmed by Plummer (1969), who documented one resonance frequency of 28.9 mHz (approximately 35 seconds per “breathing” cycle) and another resonance frequency of 90.2 mHz (approximately 11 seconds per “breathing” cycle). Swezey, Piatak et al. (2004) reported air temperature ranging from 44 to 60 °F (6.7 to 15.6 °C), and relative humidity ranging from 66 to 88%.

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010a,b).

### Dyers Cave, Hardy County, WV

(Site 31 on Fig. 1)

**Cave Map:** None published.

**Stratigraphy:** Silurian Tonoloway Limestone (Davies, 1965; Speece, 1983).

**Cave Meteorology:** About 100 feet from the entrance, large icicles have been known to form and to persist until the end of July (Speece, 1983).

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010a,b).

### Scott Hollow Cave, Monroe County, WV

(Site 32 on Fig. 1)

**Cave Map:** Undated map in Swchweny (1990), and a map dated 1994 in Dore (1995). The 1994 map shows one area of the cave in great detail, but the undated map shows more detail for the rest of the cave system. Other detailed but undated maps of selected portions of the cave in Sasowsky and Bishop (2006) and Bishop et al. (2009).

**Stratigraphy:** Mississippian Greenbrier Limestone (Dore, 1990, 1995). Much of the cave has formed in the Hillsdale Limestone of the Greenbrier Group, at the contact of the Hillsdale Limestone and the underlying Maccrady Shale (Norris, 1992; Dore, 1995; Check et al., 2006; Sasowsky and Bishop, 2006; Bishop et al., 2009).

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010b).

**Caldwell Cave, Mercer County, WV**

(Site 33 on Fig. 1)


**Stratigraphy:** Middle Ordovician limestone (Davies, 1965; Balfour, 1993).

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010:** Dasher (2010b) and Stihler (2010a,b).

### White Oak Blowhole Cave

(Blowhole Cave, Whiteoak Sink Cave), Blount County, TN

(Site 34 on Fig. 1)

**Cave Map:** Map dated 1996 in Smith (1996) and Matthews (2008).

**Stratigraphy:** Cambrian-Ordovician Knox Group (Barr, 1961).

**Cave Meteorology:** No published data.

**WNS Infection Reported March 2010 or April 2010:** Dasher (2010b). In addition, WNS infection at White Oak Blowhole Cave (TN) was reported by the National Park Service (www.nps.gov/grsm/parknews/wns-press-release.htm) and in USGS NWHC Wildlife Health Bulletin #2010-03 (www.nwhc.usgs.gov/publications/wildlife_health_bulletins/WHB_10_03.jsp).

**Camps Gulf Cave, Van Buren County, TN**

(Site 35 on Fig. 1)

**Cave Map:** None published.

**Stratigraphy:** Barr (1961) stated that the cave is in the Mississippian Ste. Genevieve Limestone and Gasper Limestone, whereas Palmer (2009) stated that the cave is in the Mississippian Monticule and Bangor Limestones.

**Cave Meteorology:** No published data.


**D. APRIL 2010 THROUGH JUNE 2010 (BAT NON-HIBERNATION SEASON)**

During these three months, white-nose syndrome was detected at three sites in the southeastern United States. Two of these sites are caves in Virginia (Hupman’s Saltpeter Cave, Starr Chapel Saltpeter Cave), and one of these sites is a cave in Tennessee (East Fork Saltpeter Cave). In addition, a bat was confirmed to be positive for the *Geomyces destructans* fungus at a park in Virginia (Pocahontas State Park), and bats were confirmed to be positive for the
fungus at two summer roost sites in Delaware.

Hupman's Saltpeter Cave, Highland County, VA  
(Site 36 on Fig. 1)

Cave Map: Map dated 1949 in Douglas (1964) and map dated 1959 in Deike (1960a).

Stratigraphy: Silurian-Devonian Helderberg Group.

Cave Meteorology: No published data.

WNS Infection Reported April 2010: Wil Orndorff (reported online at www.frontroyal.varegion.org/news.html) and Rick Lambert in the Highland County [Virginia] Cave Survey Report for May 15, 2010 (personal email communication, May 2010).

Starr Chapel Saltpeter Cave, Bath County, VA  
(Site 37 on Fig. 1)


Cave Meteorology: No published data.


Summer roost site #1 in New Castle County, DE  
(Site 38 on Fig. 1)

Note: Bats at two summer roost sites in New Castle County (Delaware) were confirmed to be positive for the *G. destructans* fungus.

WNS Infection Reported April 2010: Niederriter (2010a,b).

Summer roost site #2 in New Castle County, DE  
(Site 39 on Fig. 1):

Note: Bats at two summer roost sites in New Castle County (Delaware) were confirmed to be positive for the *G. destructans* fungus.

WNS Infection Reported April 2010: Niederriter (2010a,b).

East Fork Saltpeter Cave, Fentress County, TN  
(Site 40 on Fig. 1)

Cave Map: None published.

Stratigraphy: Mississippian Monteagle Limestone (Sasowsky et al., 1995).

Cave Meteorology: No published data.


Pochahontas State Park, Chesterfield County, VA (Site 41 on Fig. 1)

Note: A bat in Pochahontas State Park (Virginia) was confirmed to be positive for the *G. destructans* fungus.


**DISCUSSION AND CONCLUSIONS**

Prior to July 2010, 41 WNS-infected sites were identified in the southeastern United States. In order of abundance, these infected sites are natural caves in carbonate rock (except for the one bat confirmed to be positive for the *G. destructans* fungus at a park in Pennsylvania), and the bats that were confirmed to be positive for the fungus at two summer roost sites in Delaware.

In summary, many questions still remain about the nature and origin of WNS. A total of 41 WNS-infected sites were identified in the southeastern United States prior to July 2010, and these sites are located on both sides of the Appalachian Mountains. Most of these WNS-infected sites are natural caves in limestone of Cambrian-Ordovician age, Silurian-Devonian age, or Mississippian age. Meteorological data from the infected caves are sparse, but published air temperature values in these caves range from -3.3 to 15.6 °C, and humidity measurements range from 68 to 100 %. Although much of the available meteorological data are single measurements taken on only one day, most of the air temperature values are within the range of 5 to 10 °C (41 to 50 °F) that is reported as being optimal for growth of *Geomyces destructans* (Blehert et al., 2009).

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This manuscript benefited from reviews by U.S. Geological Survey geologists David Weary and John Repetski.

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NSS NEWS, February 2011 21
Figure 1. Map showing the locations of sites infected with white-nose syndrome (WNS) and cave-bearing carbonate strata in the eastern United States before July 2010. Sites are numbered in the approximate order in which WNS infection was detected, and the key to location numbers is given in the first column of Table 1. Geological data were derived from the U.S. Geological Survey (USGS) Mineral Resources On-Line Spatial Data, which are available online at http://tin.er.usgs.gov/geology/state/. Counties that contain WNS-infected sites north of Maryland and west of Tennessee are identified on a map by Cal Butchkoski of the Pennsylvania Game Commission, available online at www.portal.state.pa.us/portal/server.pt/gateway/PTARGS_0_2_112129_9109_615025_43/http%3B/pubcontent.state.pa.us/publishedcontent/publish/marketsites/game_commission/content/wildlife/wildlife_diseases/white_nose_syndrome/images/wnsmap.jpg. Additional details regarding some of these WNS-infected sites may be found in Swezey and Garrity (in press).
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<tr>
<th>Site #</th>
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<th>Location</th>
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<th>Stratigraphic Name</th>
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Table 1. List of sites infected with WNS in the eastern United States before July 2010. Column 1 = Site number on Figure 1; Column 2 = Infected site name; Column 3 = State; Column 4 = County; Column 5 = Stratigraphic age; Column 6 = Stratigraphic name; Column 7 = Elevation in meters above sea level; Column 8 = Elevation in feet above sea level; Column 9 = Month that the WNS infection was first identified; Column 10 = Year that the WNS infection was first identified. Ls. = Limestone or Limestones. See text for sources of data.
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