Managing the spread of *Pseudogymnoascus Destructans* and conserving Bats threatened by White-Nose Syndrome in North America

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Bats in North America face numerous challenges, including habitat loss, climate change, environmental contamination, and energy development, but none is as immediate a threat to multiple species as white-nose syndrome, a fungal disease that is responsible for unparalleled rapid declines in bat populations. White-nose syndrome (WNS) was unknown to science before discovery in New York in January 2007 (Blehert *et al*. 2009). Since that time the disease has spread to at least 26 states and five Canadian provinces, and the fungus causing the disease, *Pseudogymnoascus destructans* (*Pd,* Lorch *et al.* 2011), has been documented in three additional states: Minnesota, Mississippi, and Oklahoma (see current map: www.WhiteNoseSyndrome.org). Genetic analyses indicate the fungus is likely not native to North America and that human activity may have led to its introduction. *P. destructans* may have originated in Europe where the fungus has been detected on 13 bat species, 11 of which have been confirmed with WNS based on our current case definitions. There have been no documented deaths of European bats from WNS, however.

From what appears to be a single point of introduction to North America, *Pd* has spread rapidly, propagated largely by bat-to-bat or bat-to-environment-to-bat contact. Human-mediated transmission also may have contributed to the spread based on the potential for the fungus to be carried between caves on clothing or personal gear (USGS 2009), the ability of the fungus to remain viable for long durations in the absence of bat hosts (Lorch *et al*. 2013, Hoyt *et al*. 2014), and conspicuous longer distance jumps to heavily visited caves before detection at large bat hibernacula close by. The fungus infects torpid bats resulting in physiological and behavioral impacts, often leading to mortality. Population declines exceeding 90% have been documented in affected hibernacula during winter surveys (Turner *et al.* 2011), and corroborated by estimates of colony size and activity during summer. The international response to the disease has been rapid, and has resulted in considerable advances in our understanding of the pathogen and the disease to the extent that we are beginning to see progress in the development of potential tools and strategies designed to better manage *Pd* and the impacts of WNS on bats.

In the United States, WNS research, management, and conservation activities are coordinated through a common collaborative strategy outlined in: *A National Plan for Assisting States, Federal Agencies and Tribes in Managing White-Nose Syndrome in Bats* (USFWS 2011). The U.S. national plan is mirrored in Canada by a sister plan: *A National Plan to Manage White-Nose Syndrome in Bats in Canada* (CWHC 2015). Despite the advances made in our understanding of the mechanics of this epizootic, including pathology, transmission, dynamics, and ecological requirements of *Pd*, the best tools currently available are still those

Table 1. Bat species on which white-nose syndrome (WNS) has been confirmed based on approved case definitions, or on which at least one individual has tested positive for *Pseudogymnoascus destructans* (*Pd*) using molecular identification techniques

	Positive for WNS	***Pd* Present**
North America		
	Big brown bat (*Eptesicus fuscus*)[1]	Eastern red bat (*Lasiurus borealis*)[2]
	Eastern small-footed bat (*Myotis leibii*)	Southeastern bat (*M. austroriparius*)
	Gray bat (*M. grisescens*) ***endangered**	Silver-haired bat (*Lasionycteris noctivagans*)[2]
	Indiana bat (*M. sodalis*) ***endangered**	Rafinesque's big-eared bat (*Corynorhinus rafinesquii*)[2]
	Little brown bat (*M. lucifugus*)[1]	Virginia Big-Eared Bat (*C. townsendii virginianus*) ***endangered**
	Northern long-eared bat (*M. septentrionalis*)[1] ***threatened**	
	Tri-colored bat (*Perimyotis subflavus*)[1]	
Europe		
	Greater mouse-eared bat (*M. myotis*)[3]	Whiskered bat (*M. mystacinus*)[5]
	Daubenton's bat (*M. daubentonii*)[4]	Lesser mouse-eared bat (*M. oxygnathus*)[6]
	Bechstein's bat (*M. bechsteinii*)[4]	
	Natterer's bat (*M. nattereri*)[4]	
	Brandt's bat (*M. brandtii*)[4]	
	Geoffroy's bat (*M. emarginatus*)[4]	
	Pond bat (*M. dasycneme*)[4]	
	Northern bat (*E. nilssonii*)[4]	
	Barbastelle (*Barbastellus barbastellus*)[4]	
	Brown long-eared bat (*Plecotus auritus*)[4]	
	Lesser horseshoe bat (*Rhinolophus hipposideros*)[4]	
1 - Blehert et al. 2009; 2 - Bernard et al. 2015; 3 - Pikula et al. 2012; 4 - Zukal et al. 2014; 5 - Martinkova et al. 2010; 6 - Wibbelt et al. 2010		

that reduce the risks of human-mediated transmission of the pathogen and reduce disturbance to bats during hibernation.

In North America, seven bat species have been confirmed with WNS, and five additional species have been detected carrying *Pd* (Table 1). *P. destructans* is a psychrophilic (cold-loving) fungus that grows best in cool, wet conditions (growth range between ~ 1 and 19°C, Verant *et al*. 2012). Such conditions are common for caves and mines across the continent (Perry 2013), and hibernating bats in every state may be found using these same cool and humid conditions. Like most fungi, *Pd* produces spores and hyphae (filamentous

Table 2. Evidence and supporting publications or sources providing evidence that human actions may contribute to the spread of *Pseudogymnoascus destructans* (*Pd*) and affect survival of bats affected by white-nose syndrome (WNS).

Evidence	**Supporting publications and reports**
Pd can persist and grow in the absence of bats.	Lindner et al., 2011; Lorch et al., 2012; Lorch et al., 2013; Peuchmaille et al., 2011a; Reynolds et al. 2015
Spores of *Pd* can remain viable outside of subterranean environments.	Puechmaille et al., 2011b; Hoyt et al. 2014
Spores of *Pd* can cling to clothing and footwear and can be inadvertently transported out of contaminated sites.	J. Okoniewski, unpublished data; H. Barton, unpublished data; USGS - National Wildlife Health Center, unpublished data
Pd may be present on bats or in bat roosts without being visibly detectable.	Dobony et al., 2011; Langwig et al., 2015
Spread of *Pd* may be slowed by geographic or biological barriers to bat movements that may not be barriers to human movement.	Miller-Butterworth et al., 2014
Repeated and/or prolonged human disturbance during hibernation is detrimental to bats, especially bats already stressed by WNS.	Boyles and Willis, 2009; McCracken, 1989; Mohr, 1972; Reeder et al., 2012; Thomas, 1995; Tuttle, 1979
If done correctly, current decontamination procedures have a high probability of significantly reducing the risk of spreading viable *Pd*.	Shelley et al., 2013

vegetative growth), and is capable of asexual reproduction through spores and hyphal fragmentation. The spores can persist for extended periods in suboptimal conditions, including wide temperature and humidity ranges (Lorch *et al.* 2013). Fungal material can adhere to substrate, fur, hair, clothing, shoes, etc. (collectively referred to as "fomites"), and thus, can be moved large distances by bats, humans, or other carriers. As a consequence, human visitation to caves and mines increases the risk of contributing to the spread of WNS to uncontaminated areas through inadvertent transport of *Pd*. The containment strategies developed for WNS include: 1) cleaning and treating (hereafter, decontamination) of gear, clothing, footwear, and any other surfaces that might have been exposed to *Pd* and may subsequently come in contact with hibernating bats or their habitats, and 2) the reduction or prevention of opportunities for people to encounter, transport, and transfer *Pd* spores or vegetative structures to bats or naïve environments.

The U.S. Fish and Wildlife Service developed guidance for decontamination procedures (Decontamination Protocol, 2008) as well as recommendations for regulation or restriction of human activities likely to pose a risk for spreading *Pd* (Cave Advisory, 2009). These documents were developed in consultation with state and federal partners that would later join together formally under the collaborative national response plan. The national plan provided further support for the importance of containment strategies for managing infectious agents, and describes the ways in which universal precautions are implemented to reduce incidence of disease by preventing infections and breaking chains of transmission. The Decontamination Protocol has been revised regularly in response to research results that further our understanding of the compounds and procedures known to effectively kill spores of *Pd* (e.g., Shelley *et al.* 2013), and to include a wider variety of applications. The Cave Advisory has also been reviewed regularly, and has been the focus of considerable discussion within the WNS response community, but had not been formally revised until recently (revision under final review). While some have questioned the risks associated with human-mediated spread of *Pd*, the weight of scientific evidence in support of these protocols and recommendations continues to grow (Table 2). Additionally, members of the WNS Steering Committee have agreed to endorse the most recent versions of the two documents as national guidance, so they now represent an agreed upon set of recommendations from state, federal, and tribal agencies engaged in the national response. Updated versions of the National Decontamination Protocol and National Recommendations for Managing Access to Subterranean Bat Roosts (replacing the Cave Advisory) will be released in coming months.

Dedication and commitment of the many individuals, institutions, and government agencies who have engaged in this issue and lent their support has produced both great progress in our understanding of WNS and ability to respond to it, and significant contributions to broader scientific advancement. Healthy bat populations contribute to strong ecosystems and provide beneficial ecosystem services, thus our efforts to control and reduce the impacts of WNS on North American bats is of the highest priority.

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