



(Photo: Al Hicks, NY Dept. of Env. Conservation)



## USDA Forest Service Science Strategy for Protecting Bats From White-Nose Syndrome

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### Executive Summary

White-nose syndrome (WNS), a fungal disease caused by *Pseudogymnoascus destructans* (*P. destructans*), first observed in the U.S. in 2006, has killed millions of bats in the U.S. and Canada, and continues to spread. Bats provide important ecosystem services, including consuming billions of insects that affect forests and agricultural crops and providing significant economic benefits to society. Recognizing the importance of bats to forest ecosystems, Forest Service Research and Development (USFS R&D) proposes a strategy based on integrated disease management to address WNS and to reduce its impacts on North American bats.

WNS is proving to be one of the most significant diseases ever to affect wildlife in North America. The diagnostic symptoms of WNS have been observed in seven species of bats (big brown bat, little brown bat, gray bat, eastern small-footed bat, northern long-eared bat, Indiana bat, and tri-colored bat) with mortality occurring in all species except gray bat. *P. destructans* has been found on five additional species. Mass mortality and significant population declines have been found primarily in the little brown bat, northern long-eared bat, Indiana bat, and tri-colored bat, with mortality rates of 95 percent or more observed in some bat species. First observed in North American bats in 2006 near Albany, New York, WNS has since spread to 26 U.S. states and five Canadian provinces, as far west as Oklahoma and as far south as Alabama, Georgia and Mississippi. A recent model suggests that WNS will eventually spread across the entire U.S.

Bats are important to healthy forest and agricultural ecosystems; 43 of the 47 bat species found in the U.S. feed on insects. Consumption of night-time flying insects represents significant economic benefits in terms of pest-control services and reduced costs for commercial pesticides. In the tropics, subtropics, and southwestern U.S. deserts, bats are important pollinators of many plants, including commercially important species such as agave.

The combined known ranges of two of the affected species—little brown bat and tri-colored bat—encompass more than 180 million acres of National Forest System lands. If WNS continues to spread unchecked, there could be significant impacts to forest health across the country.

The Forest Service has identified WNS as a strategic priority, and is directing available funds to address this disease, but more resources are needed. It is critical that USFS R&D continue efforts regarding managing all aspects of the disease, as well as determining how bats use forested landscapes. National forest managers need to continue restoring healthy, resilient ecosystems, using the best available science to provide bats the best possible opportunity to survive the effects of WNS.

The proposed strategy uses the integrated disease management concept, which considers the relationships among the host, pathogen, and environmental conditions needed for disease to occur, as the guiding principle for addressing WNS in bats. The desired outcome of the strategy is to sustain functional WNS-affected bat populations through time across multiple landscapes through the scientific applications proposed in the strategy.

## Overview

White-nose syndrome (WNS) is a newly emergent fungal disease caused by *Pseudogymnoascus destructans* (*P. destructans*). It is believed to be one of the most significant diseases to affect wildlife in North America. Diagnostic symptoms of WNS have been found in seven species of bats (big brown bat, little brown bat, gray bat, eastern small-footed bat, northern long-eared bat, Indiana bat, and tri-colored bat). *P. destructans* has been found on five additional species (eastern red bat, southeastern myotis, silver-haired bat, Rafinesque's big-eared bat, and Virginia big-eared bat), but no individuals of these species have been observed with clinical or histopathological signs of the WNS disease. Mass mortality and significant population declines have been found primarily in the little brown bat, northern long-eared bat, Indiana bat, and tri-colored bat (Turner et al. 2011). Mortality rates of 95 percent or more have been observed in some bat species (Turner et al. 2011). In 2012, the U.S. Fish and Wildlife Service estimated that 5.7 to 6.7 million bats died from WNS since 2006, but this estimate does not include mortality that has occurred since 2012 in the southeastern and midwestern regions.

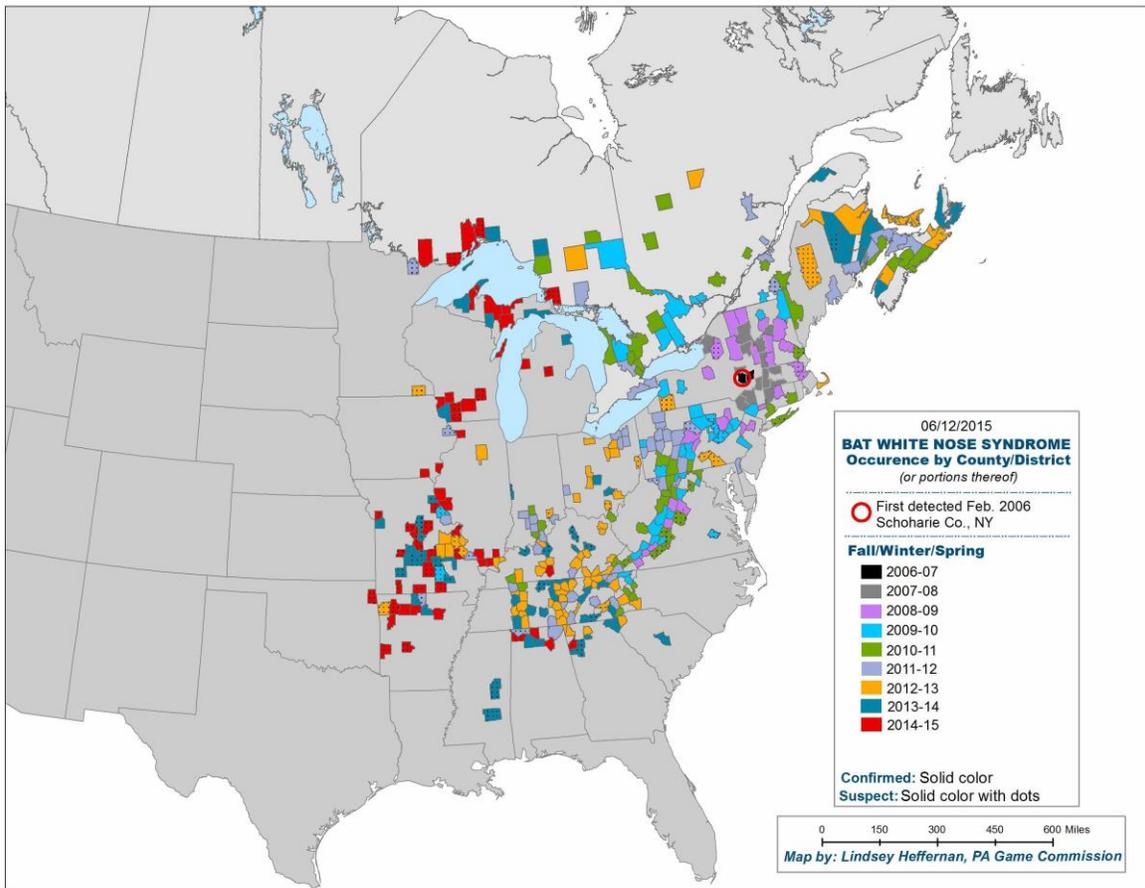
*P. destructans* is a cold-loving fungus originating from Europe or Asia that lives in cave environments. During the winter, when bats are in hibernation, *P. destructans* penetrates the epidermis of the bat's wing membrane tissue; invades underlying connective tissues, hair follicles, and sebaceous glands; and causes severe tissue degradation (Blehert et al. 2009, Gargas et al. 2009, Meteyer et al. 2009). The disease likely causes a loss of homeostasis (a water balance deficit) through the disruption of

physiological processes (Cryan et al. 2010). Affected individuals awaken frequently during hibernation and move from warmer cave interiors to colder regions near the cave entrance, depleting stored energy reserves which eventually causes death (Reeder et al. 2012). Bats in Europe have responded to WNS via reductions in population levels and other behavioral, genetic, and physiological adaptations. Natural controls of WNS in European bats have not yet been identified, however, there is some possibility natural biological controls such as bacteria may be inhibiting disease development from *P. destructans* in bats native to that part of the world.



**Figure 1:** Bat affected with white-nose syndrome. (Photo: Al Hicks, NY Dept. of Env. Conservation)

WNS was first observed in North American bats in the winter of 2006 near Albany, New York, and has since spread to 26 U.S. states and five Canadian provinces (Figure 2). WNS has been documented as far west as Oklahoma and as far south as Alabama, Georgia and Mississippi. A recent model suggests that WNS will eventually spread across the entire U.S. (Maher et al. 2012) and cave climatological data suggests sufficient microclimates exist for growth of the fungus throughout North America (Perry 2013).



**Figure 2:** Map showing current distribution of WNS (Map: Lindsey Heffernan, PA Game Commission)

Bats are important to healthy forest and agricultural ecosystems and provide many benefits to humans (Kunz et al. 2011). Forty-three of the 47 bat species found in the U.S. feed on insects; consumption of night-time flying insects represents significant economic benefits in terms of pest-control and reduced costs for commercial pesticides. For example, bats reduced the need for 32,046 kg (70,649 pounds) of insecticide and reduced damage to 131,385 kg (289,654 pounds) of cotton per year in an eight-county region of Texas (López-Hoffman et al. 2014).

In the tropics and subtropics, and southwestern U.S. deserts, bats are important pollinators of many plants, including commercially important species such as agave. Additional economic benefits provided by bats include bat-viewing during evening emergence at many caves throughout the Southwest. Tourism associated with bat-viewing has been estimated to contribute \$6.5 million annually to some local economies (Bagstad and Wiederholt 2013). Bats also serve as models in studies of aging and senescence (Brunet and Rossinni and Austad 2004), and for modeling aerodynamics, particularly in the design of small flying robots or drones (Lentink 2014).

When considering WNS and bat conservation and restoration, one must look at multiple scales, from the individual stand to the landscape. Little brown bat and tri-colored bat are two wide-ranging species that have experienced significant mortality from WNS. The combined known ranges of these species encompass more than 180 million acres of National Forest System lands. If WNS continues to spread unchecked, there could be significant impacts to forest health across the country. Bat conservation in the WNS era requires a two-pronged approach. USFS R&D must continue their efforts regarding managing all aspects of the disease, as well as determining how bats use forested landscapes. National forest managers can apply the best available science to ensure forests can provide the necessary requirements for bats to survive the effects of WNS.

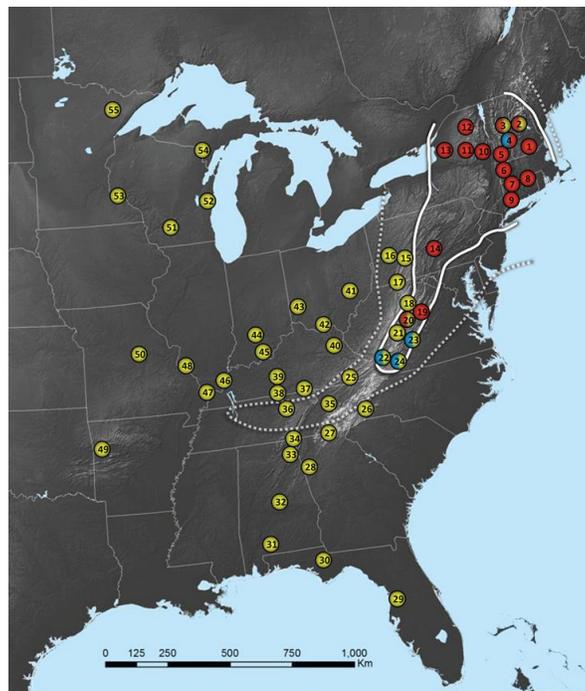
All of the bat species affected by WNS are strongly associated with forests during the summer season and hibernate in caves that are often located in forested areas. The basic needs of bats in forests are known, at least generally (Lacki et al. 2007). Many bat species need large snags for roosting. However, not all species affected by WNS require large snags; for instance, tricolored bats are foliage-roosting in forests during summer. Bats need access to freshwater. Forest edges and forest gaps are hot spots of bat foraging activity (Hein et al. 2009, Morris et al 2010). In terms of habitat management, thinning dense forest stands generally benefits foraging habitat (Hayes and Loeb 2007). Perry et al. (2007) found that thinning forests provided improved habitat for roosting for most species as well. Research to understand the impacts of fire on bats is limited, but there is information that demonstrates the benefits of prescribed fire in creating snags and other niches important to a wide variety of wildlife, including bats.

There is evidence to suggest that populations of some forest-associated bat species were stable to increasing prior to the onset of WNS (Frick et al. 2010, Langwing et al. 2012, Thogmartin et al. 2012), although population numbers for some species like tri-colored bats is limited. This suggests that at the broadest scales (eco-region, region), forest management practices in the late 20<sup>th</sup> and early 21<sup>st</sup> century have generally been compatible with bat conservation. It has been speculated that forest management activities around caves or mines could alter microclimatic conditions of hibernacula, but such concepts have not been rigorously evaluated (Hayes and Loeb 2007). In particular, the effectiveness of management concepts such as habitat buffers that extend for varying distances beyond the hibernacula have not been evaluated. Research needs to be conducted regarding the effectiveness of these buffers and other forest management concepts prior to their use as management tools.



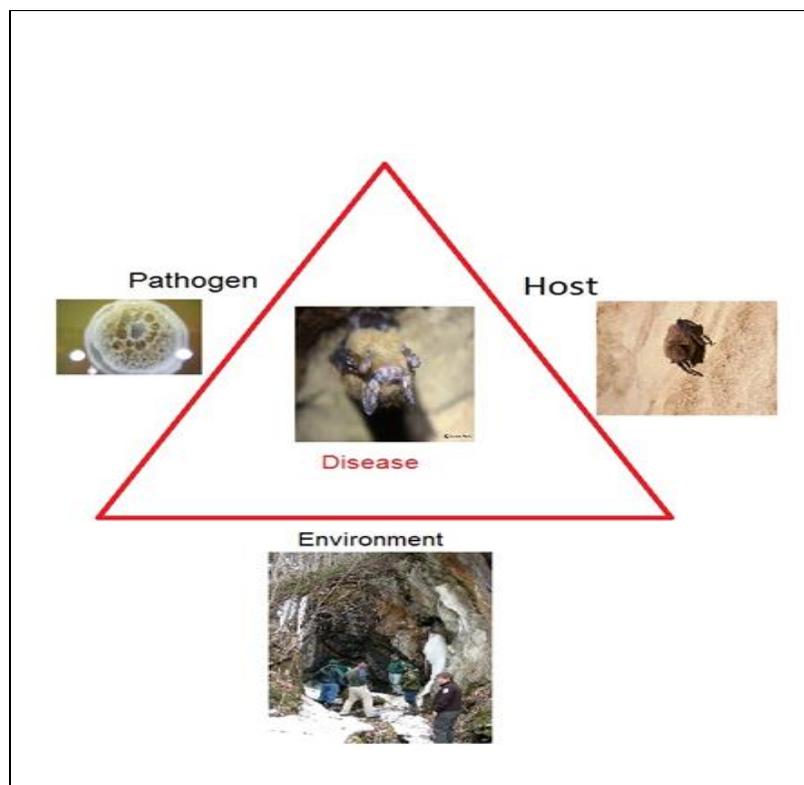
**Figure 3:** The fungus *Pseudogymnoascus destructans* (Photo: U.S. Forest Service).

*P. destructans* is readily propagated in lab settings (Figure 3). The name of the *P. destructans* fungus was changed in 2013 based on a better understanding of taxonomic placement with other fungi. It is not closely related to other fungal pathogens of mammals. Occurrence of *P. destructans* in cave environments tracks the advancing spread of WNS from its origin in the Northeast to its current distribution across the U.S. (Figure 4).



**Figure 4:** Map showing the origin and spread of *P. destructans* in the U.S. (From: J.M. Lorch, et. al. 2013)

Disease is an interactive process involving a susceptible host, a virulent pathogen, and an environment conducive to pathogen transmission. Integrated Disease Management (IDM) is a concept that considers the relationships among the host, pathogen, and environmental conditions needed for disease to occur, in order to develop mitigation options. The disease triangle (Figure 5) provides a visual way of understanding these relationships. The term environment in the disease management context encompasses the various abiotic (e.g., moisture, temperature, substrate) and biotic components affecting the interaction between host, pathogen, and environment. Without the contribution of each of the three sides of the triangle, the disease interaction cannot occur. Reducing the susceptibility of the host, the pathogenicity of the pathogen, or environmental conditions conducive for pathogen survival and growth can independently limit disease occurrence, but managing collectively under an IDM plan results in synergistic benefits.



**Figure 5: Integrated Disease Management triangle.** (Photos: U.S. Forest Service)

The disease triangle concept provides a useful framework for considering disease control strategies, since different strategies are aimed at different components of the triangle. For example, immunization reduces host susceptibility, antimicrobials may kill the pathogen, and quarantine can eliminate the environmental conditions that bring host and pathogen together. The disease triangle is especially useful for analyzing diseases of plants and animals in wild lands and other natural habitats, where localized environmental conditions play a critical role in pathogen survival as well as exposure of the host to the pathogen. WNS as it affects bats in North America should be viewed in this context.

## The Role of U.S. Forest Service Research and Development (USFS R&D)

The U.S. Forest Service is concerned with conserving bat populations, because bats are a vital component of forest biodiversity and are major predators of forest defoliating insects and agricultural pests. The potential for WNS to spread to bats in the western U.S. and Canadian provinces remains unknown, but is a cause for concern due to the recent expansion of *P. destructans* as far as west as Oklahoma. Having spread across the national forests from the Northeast to the Midwestern states, this deadly fungus is now threatening bat populations on dozens more national forests in the South and the West. State agencies are concerned about the potential impacts to state and private forests. Forest management practices may be curtailed if these bat species become endangered. The U.S. Fish and Wildlife Service recently listed the northern long-eared bat as a federal threatened species. Other bat species may become listed as threatened or endangered as WNS takes its toll. Since the majority of bat species in the U.S. use forests or trees to meet their ecological needs, the Forest Service has a special responsibility to provide for their protection in the face of WNS.

National forest managers have implemented a number of actions to help respond to the WNS disease problem, including closing caves where spread of the fungus by humans poses a concern, conducting inventories of bat populations, and assessing the presence of WNS in caves. Research scientists have identified disinfection protocols to minimize the spread of the fungus by humans, and have initiated experimental treatments of bats to reduce the impact of WNS once bats are affected. Monitoring of hibernacula has shown that after the third year of fungal establishment population declines in bat species can be dramatic, often over 95 percent. Early detection and treatment is essential. With the rapid rate of spread of *P. destructans* and the WNS disease, it is imperative that we employ available expertise towards managing the fungal pathogen in the hibernacula environments and on bats, with additional goals of reducing the threat of bat declines in areas not yet infected, and recovering already collapsed populations of bats in affected areas. Collaboration among research scientists and managers is essential, as treatments need to be tested in field settings.

The Forest Service has identified WNS as a strategic priority, and is directing available funds to address this disease. USFS R&D has committed more to WNS disease management research than any other entity, and is on the cusp of making the most progress. Our National Forests are working with state and private interests to reduce the human transmission of WNS through the cooperative management of caves, karst features, and abandoned mines where bats congregate. USFS R&D can play a pivotal role in developing solutions to protect bats through integrated disease management research; however, more funding is required to address the critical research needs identified. Time is of the essence in finding solutions to protect bats, and additional research is urgently needed.

## Accomplishments since 2012

USFS R&D developed a science strategy to address WNS in August 2012. Since that time, much has been learned about the disease. R&D is currently testing the use of “gene silencing” on *P. destructans*, a recent technology that is showing promise as a disease-fighting tool. Short-wave ultraviolet light is

showing promise as a mechanism for reducing activity of the fungus on the bats. E-nose technology has been successful in other applications for detecting fungus and holds promise for early detection of *P. destructans* in cave settings. Also, use of native soil bacteria has shown the potential to slow the growth of the WNS fungus. Diseased bats treated with volatile organic compounds produced by the bacteria have shown improved health and survival in the laboratory, and two States collaborated in conducting field tests during the 2014-2015 Winter. A summary of USFS R&D research accomplishments since 2012 is provided below. Current research priorities are described in subsequent sections of this strategy.

1. Completed first *in vivo* demonstration of a successful disease management tool (2014, Amelon and Cornelison in draft).
2. Completed toxicological evaluations of the soil-associated, Gram-positive bacterium *Rhodococcus rhodochrous* DAP96253, demonstrating no detectable toxicological effects on honey bees (*Apis mellifera*), whiteleg shrimp (*Penaeus vannamei*), Chinese house crickets (*Acheta domestica*), and torpid and euthermic bats (*Myotis lucifugus*, and *Perimyotis subflavus*). This bacterium has demonstrated tremendous potential as a biological control agent of WNS. (Cornelison et al. 2014).
3. Evaluated *in vitro* potential for collateral impacts on hibernacula-associated mycoflora with favorable results. Multiple species of North American hibernacula associated fungi representing significant taxonomic diversity were screened for their susceptibility to *R. rhodochrous* with preliminary results indicating that non-target effects of this treatment are minimal and not anticipated to have long term ecological effects in treated environments.
4. Began field trials in Missouri and Kentucky with *R. rhodococcus* (2<sup>nd</sup> group to move a biological control into the field).
5. Began *ex vivo* trials on bats with varying degrees of infection to identify optimal treatment regimens based on WNS disease progression.
6. Began a study evaluating survival and changes in body condition of hibernating bats prior to and after the natural introduction of WNS at the edge of the disease range.
7. Began evaluating immune system of little brown bats at a genetic level to identify where disease resistant individuals may exist, and to determine whether that resistance is related to naturally occurring skin microbiota of bats, which may slow *P. destructans* growth, comparing bats from pre- and post WNS affected areas.
8. Began evaluating seasonal movement patterns (functional connectivity between winter and summer habitat) using landscape genetic approaches integrated with local-scale acoustic monitoring.
9. Began evaluating habitat use around hibernacula during spring emergence.

## The National Strategy

The USFS R&D national strategy for addressing WNS in bats is comprised of the following desired outcome, goals, guiding principle, and integrated disease management research.

### Desired Outcome

The ultimate desired outcome is to sustain functional WNS-affected bat populations over time across

landscapes through application of science-based IDM methods provided through implementation of the following USFS R&D science strategy.

### Goals of this Strategy

- A. Minimize WNS disease-induced population declines through research and applied science aimed at understanding how to provide the greatest potential for survival and recovery at the population level for each bat species affected, and
- B. Provide coordinated research leadership towards identifying approaches that will perpetuate long-term, stable and functional/viable bat populations in the presence of *P. destructans*.

### Guiding Principle

WNS is a fungal disease that requires an integrated disease management (IDM) solution.

### Integrated Disease Management

Research must be directed at all three facets of the IDM triangle:

1. **Host:** Evaluation of host genetics, ecology, and demographics (survival and fitness) as they relate to disease impacts and response at the individual and landscape level.
2. **Pathogen:** Evaluation of pathogen genetics, ecology and microbial control (biological, chemical and physical).
3. **Environment:** Evaluation of pathogen and host interactions within the environment (at multiple scales).

The intent of this strategy is to guide USFS R&D priorities and resources to help in the conservation and recovery of bats. The strategy focuses on the three facets of integrated disease management and on technology transfer. Priority research is identified in the next sections.

**Host: Evaluation of host genetics, ecology, and demographics (survival and fitness) as they relate to disease impacts and response at the individual and landscape level**

Multiple bat species are hosts of WNS. While there are differences in ecology, behavior, sociality, and movement patterns among bat species, there are also many commonalities in disease manifestation and outcomes. Most bat species are considered panmictic, meaning that interbreeding occurs within and between individuals from different U.S. geographic regions, at least at evolutionary time scales. Populations display spatial variation in genetic structure that can be used to identify movement patterns and determine how movement patterns may be linked to landscape and environmental features (Manel

et al. 2003). Bats are regional migrants moving between winter and summer habitats. They hibernate in winter and use a variety of habitats during spring, summer, and autumn. Even in widely distributed species, hibernation areas can include individuals from many surrounding breeding populations, and maternity colonies can show variations in population structure implying seasonal migration and dispersal by females, which should be considered as possible factors in the spread of WNS (Dixon 2011). In addition, population structure may exist at the landscape level even though regionally connected; scale of movement patterns is important (Burns et al. 2014).

Population spatial structure may transition from continuous to fragmented as the WNS disease spreads, and movement patterns may shift. Information on bat movement patterns and connectivity both demographically and genetically at multiple scales will be crucial in restoring populations to a continuous distribution (Burns et al. 2014). If bat movement patterns are known, conservation efforts can focus on keeping remnant populations functionally connected. How bats move about the landscape in various geographic scales, and routes or pathways, are important questions to answer in order to predict subsequent spread of WNS and determine appropriate methods to reduce disease transmission.

Fitness metrics and survival probabilities of impacted and non-impacted populations need to be determined. The bat's body condition before, during, and after arousal from hibernation is important to understand, especially as it relates to environmental conditions and survival following infection with WNS. Questions remain in regards to bat physiology and disease development, response, and recovery. Early detection tools will help managers buy time as research is conducted to answer these questions.

### **Research Objectives**

These are currently the most important research objectives as related to the bat species affected by WNS:

1. Determine specifically where bats become infected and when pathogen transmission happens. Understanding the timing of infection is critical. This is the most important research question, because all IDM is based on this understanding.
2. Assess bat physiology in relation to *P. destructans* disease development, response, and recovery. Evaluate the importance of lipid levels over time. Evaluate modes of mortality.
3. Evaluate the efficacy of disease treatments to reduce the impact of WNS, and bat response to treatments both during hibernation and post-emergence.
4. Evaluate bat movement across the landscape throughout the year at multiple scales, including timing, distance and direction of movements, hot spots of bat congregation (e.g., swarming sites), and use of particular habitat types or elements during each season.

5. Evaluate diet and the importance of particular habitat variables on survival and fitness.
6. Evaluate bat population dynamics and response in relation to disease progression. Conduct long-term systematic quantitative studies to develop fitness estimates, model disease spread/association dynamics, and integrate available datasets.
7. Evaluate changes in bat reproductive success including maintenance of critical mass within maternity colonies, relative to infection history.

### **Pathogen: Evaluation of pathogen genetics, ecology, and biological control**

The severity of the WNS disease on bat species in North America will likely require that strategies using different mechanisms of control are developed and tested as soon as possible to support an integrated disease management (IDM) program. The use of genetic techniques to modify or suppress pathogen virulence, biological methods to inhibit growth or reduce reproductive capabilities of the pathogen, and physical methods of pathogen suppression might be used to help reduce the devastating effects of WNS on susceptible bat hosts and populations. Additional research is needed on mechanisms for attacking weaknesses in *P. destructans* and providing either additive or synergistic suppressive controls of its activities, colonization, and reproduction.

#### **Pathogen genetics**

Fungal diseases present unique challenges to control efforts as they are typically capable of surviving, and potentially amplifying, in host-free environments. This trait accentuates disease associated population declines, since pathogen abundance does not diminish when host populations are significantly reduced. Accordingly, environmental reservoirs must be targeted for control efforts against the WNS fungal pathogen once reservoirs of fungal inoculum are identified and understood. To this end, evaluating the potential of *P. destructans* to amplify in host-free environments is a crucial need in order to identify inoculum reservoirs that could potentially influence disease management strategies. Additionally, *P. destructans* has been shown to inhabit a relatively narrow spectrum of environmental conditions (temperature, humidity, etc.), indicating that environmental manipulation may have some potential success as a control method.

#### **Biology/Ecology**

A better understanding of the biology, life history, genetics, virulence, reproductive stages, and geographical origin of the WNS pathogen would greatly facilitate research efforts to find weaknesses in the pathogen's life cycle and growth or survival stages susceptible to attack by new effective disease-suppression alternatives. Elucidation of key pathogen growth and propagation requirements and limitations or constraints for initiating pathogenesis in bats could help scientists identify the best methods, locations, and timing for the application of direct control measures.

#### **Bio-control**

In bats infected with WNS, skin infections likely persist over multiple years even though symptoms may diminish during times of greater bat activity and associated increases in host immunity responses.

Temporary reductions in pathogen inoculum in the surface layers of the skin by applications of non-replicating (non-biological) control methods may be reversed by re-infections by *P. destructans* or by re-colonization of shallow layers by inoculum that remains viable in deeper skin layers (protected from surface disease-suppression treatments). Because of this, effective biological control agents, used singly or in combination with other control methods, are potentially the most effective strategies for providing long-term control of the WNS pathogen. Due to the resident, replicating microbial biological control agents should be better capable of having suppressive effects on *P. destructans* as long as it remains present in the host, potentially even during periods of reduced pathogen activity.

### **Early detection**

Reliable disease-detection methods that could provide a means of early detection of cave infestations and bat infections would facilitate rapid, timely, and more effective implementation of disease-control strategies before *P. destructans* has the opportunity to become established in the cave environment or in resident bat populations. E-nose technology has proven successful in the detection of fungi in other situations, and may be a successful option for use in early detection of *P. destructans*. This will be particularly true as the disease spreads westward across the U.S. and north into Canada.

### **Disease-suppression implementation**

The combination of disease suppression methods developed and used to control WNS in bats in the U.S. will likely require different modifications geographically based on differences in several key variables. Some of the key variables include differences in environmental conditions, bat species, bat behavior, intra-cave biotic components and interactions, duration of seasons, state regulation limitations, and growth requirements of host species, pathogen, and bio-control agents. For example, differences in environmental conditions in northern versus southern caves could affect bat behavior and activity for different bat species across seasons, bat susceptibility to infection, and effectiveness of bio-control agents in the presence of different resident microbes present on bat species and in cave environments. These factors will likely require modifications in control methods in different regions in terms of timing and/or composition. Additional research will be needed to work out modifications in disease-suppression methods in different regions affected by WNS to assure that control methods are effective wherever they are applied.

### **Research Objectives**

These are currently the most important research objectives as it relates to the pathogen, *P. destructans*:

1. Explore more rapid, accurate, and sensitive methods for detecting the pathogen on the host and in the environment, especially on-site detection.
2. Develop and evaluate the efficacy of disease-suppression treatments to reduce spore (inoculum) loads on the host species including biological, chemical, and physical (contact and contact-independent).
3. Develop integrated control strategies and treatment applications at operational scales.

4. Characterize the biology, life histories, and origin of *P. destructans* and related species. Include assessment of relationships between virulence and sexual vs. asexual reproductive cycles of pathogen development. Evaluate mechanism(s) of fungal cell entry and proliferation in the host.
5. Understand infectious dose and virulence as it relates to infection and disease development caused by American strains of the WNS pathogen in affected native bat species.

### **Environment: Evaluation of pathogen & host interactions within the environment (at multiple scales)**

Effective conservation of bats in the presence of WNS requires information on the interactions of bat species with the environment at both local- and landscape-scales. The specific environmental conditions in cave hibernacula that may enhance or suppress pathogen growth and survival of bats under varying microclimates are unknown. Treatment of bats or their hibernacula with biological or chemical agents that reduce the inoculum or growth of *P. destructans* may enhance bat survival and lead to stabilized populations, although unforeseen effects on other biota in cave ecosystems are possible and should be evaluated. The effectiveness of treatments also may vary depending on the physical and climatic properties of each hibernacula and factors such as hibernacula microclimate, size and complexity, *P. destructans* spore loads on individual bats and in the hibernacula, and the presence of other cave biota. Alternative locations for hibernation that are more easily treated without jeopardizing coexisting organisms may offer refugia to bats and allow greater survival of individuals and persistence of populations. Meanwhile, treatment options for controlling the spread of *P. destructans* in the environment are critically needed.

### **Research Objectives**

These are currently the most important research objectives related to the environments where bats are being affected by *P. destructans* in North America:

1. Evaluate the efficacy of treatments on reducing spore loads in the cave setting, and effects on non-target species.
2. Evaluate how hibernation conditions (e.g. temperature, moisture) affect bat survival and recovery. Understand relationship of habitat condition and bat physiology, particularly during emergence and swarming.
3. Evaluate the influence of environmental conditions on treatment options.
4. Evaluate the influence of compounding environmental stressors (natural and anthropogenic) on bat survival and recovery.
5. Evaluate potential refugia for bats (i.e. artificial hibernacula, bunkers or laboratory recovery facilities) to increase potential for survival.
6. Evaluate the potential cascading effects of the loss of bat species to ecosystem services, ecological processes, and ecosystem health in forest, grassland, and cave ecosystems.

## Communications, Partnerships, and Technology Transfer

Spanning all the priorities in this strategy is the need to share research results with managers for application in the field. In particular, managers need tools for early detection of WNS, treatment of infected cave environments, and prevention of the spread of the disease. They also need knowledge of how bats are using habitats near hibernation sites, particularly in spring and fall, in order to properly design management actions that improve bat habitat. With the rapid rate of spread of WNS across the country, it is essential to get tools into managers' hands as soon as possible. Application of ecological principles and best available science for identifying and prioritizing treatment options at the landscape scale is important. Since *P. destructans* does not recognize administrative boundaries, it is essential that managers work together to implement strategies for minimizing the impact of the disease. Close collaboration between research and management creates the best opportunities for success.

Internal communication can be used to raise awareness among Forest Service employees and help them incorporate practices sensitive to bat conservation in their management activities. Communication with other agencies will foster relationships and partnerships both nationally and internationally, while communication with the public will convey the magnitude and urgency of this issue. In all aspects of the strategy, the Forest Service can increase effectiveness by building on its existing efforts and those of its cooperators and partners.

There are existing communication efforts that could be enhanced. USFS R&D scientists should assist National Forest System managers in developing robust monitoring methods for WNS such as the North American Bat Monitoring Program (NABat). R&D scientists actively participate in national committees on WNS led by the U.S. Fish and Wildlife Service, and this has proven a good avenue for networking and information sharing. Continued investments of Forest Service scientists' time into efforts that allow for integration of R&D research accomplishments and capabilities for the purposes of conserving bats on National Forest lands as well as state and private lands is needed. These efforts to develop and implement a national strategy to address WNS efforts have been supported by Bat Conservation International, the Animal Welfare League, The Nature Conservancy and others. Additional partnership opportunities should be explored.

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