US Forest Service Research and Development (USFS R/D) National Science Strategy on White Nose Syndrome (WNS)

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Executive Summary

White nose syndrome (WNS) is among the most devastating wildlife crises in recent history with up to 6 million bats already lost to this disease *(http://www.fws.gov/whitenosesyndrome/).* Recently, Congressional language directed US Department of Agriculture Forest Service to "*. . prioritize research related to White Nose Syndrome as well as inventory and monitoring of bat resources on Forest Service lands*". In response to this emerging infectious disease (EID) and Congressional directive, we have

evaluated the science leadership role of USFS R/D in addressing this threat at the local, state, national and international levels. We believe a strategic approach using our scientific, management and collaborative resources provides the best outlook to make progress against this disease.

To that end, a multidisciplinary team of scientists from across USFS Research Stations and the Washington Office developed this *USFS R/D National Science Strategy on White Nose Syndrome*. The overarching goal of this National Strategy is: "*Effective and efficient use of Forest Service science capabilities to address white nose syndrome and to support bat conservation and management"*. This strategy proposes to shift the focus of WNS activities from surveillance for clinical disease to focusing on the desired endpoint for bat conservation and recovery, that is - *the perpetuation of viable bat populations,* even if *G. destructans* becomes enzootic in North America. Efforts must continue to slow the westward progression of this disease; however, as with many other invasive species, total eradication may be an unrealistic goal. Our focus must shift to how can we minimize exposure of uninfected animals to the pathogen, maximize survival of bats that are exposed to the pathogen and minimizing the survival and fitness of the pathogen.

A strategic USFS response to this disease is a large and significant undertaking. USFS has been a key partner in the development of the *National Plan for Assisting States, Federal Agencies, and Tribes in Managing White-Nose Syndrome in Bats* (*National WNS Plan)*, a document prepared jointly by the U.S. Departments of the Interior, Agriculture, and Defense, along with the Association of Fish and Wildlife Agencies. Additionally USFS has been engaged in WNS management and science response since the beginning of the WNS outbreak in 2006.

This strategy identifies those next steps USFS R/D needs to take to accomplish conservation of viable bat populations in the presence of *Geomyces destructans*. This document is not intended to be an all-encompassing strategy, rather to identify a strategic direction for research efforts spanning Forest Service programs. The strategy begins with a short description of the magnitude of the problem, characterizing the complexity of this disease and describes the Forest Service's unique ability to make a difference nationally, including the agency's:

- Broad existing authorities and responsibilities assigned to the Chief of the Forest Service for management of approximately 20% of forest habitats in the nation.
- An "in-house" research branch focusing on research to guide management actions. Expertise in mycology, pathology, bat ecology, genetics, entomology, and many other disciplines.

- A network of 80 experimental forests providing places for long-term science and management studies in major vegetation types of the 195 million acres of public land administered by the Forest Service.
- Well established presence across the country and around the world including relationships with agencies in every state and territory as well as colleges and universities.

This national strategy encompasses six priorities:

- Quantification and enhancement of bat population status, survival, and fitness
- Evaluation of host biological treatments
- Evaluation of pathogen genetics, ecology and biological control
- Evaluation of environmental refugia
- Quantification of ecological and economic impacts
- Risk assessments for targeted management

Each program priority includes a list of strategic actions. The need for communication, partnerships and collaboration is identified. An additional need is for a strategy for "managing the science" including an Implementation Strategy that describes information on scientists with required skills, details on ongoing research projects and projects that could be completed with additional funding. Managing the science will encompass coordinated, cooperative research utilizing strengths from each Research Station in collaboration with National Forest Systems. The implementation plan will include input from an extended team of scientists and administrators.

List of Preparers

Sybill Amelon, Research Wildlife Biologist, USDA Forest Service, Northern Research Station
Robert T. Brooks, Research Wildlife Biologist, USDA Forest Service, Northern Research Station
Jessie Glaeser, Research Plant Pathologist, USDA Forest Service, Northern Research Station
Megan Friggens, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station
Daniel Lindner, Research Plant Pathologist, USDA Forest Service, Northern Research Station
Susan C. Loeb, Research Ecologist, USDA Forest Service, Southern Research Station
Ann Lynch, Research Entomologist, USDA Forest Service, Rocky Mtn. Research Station
Drew Minnis, Research Botanist, USDA Forest Service, Northern Research Station
Roger Perry, Research Wildlife Biologist, USDA Forest Service, Southern Research Station
Mary M. Rowland, Acting Wildlife National Program Leader, USDA Forest Service, PNW Research Station
Monica Tomosy, US Forest Service Liaison to USGS National Climate Change and Wildlife Science Center, USDA Forest Service Research and Development
Ted Weller, Ecologist, USDA Forest Service, Pacific Southwest Research Station

Introduction

The *National Plan for Assisting States, Federal Agencies, and Tribes in Managing White-Nose Syndrome in Bats* (*National WNS Plan)*, is a document prepared jointly by the U.S. Departments of the Interior, Agriculture, and Defense, along with the Association of Fish and Wildlife Agencies. This document provides a strategic framework for the investigation and management of WNS, including key action items and the role(s) of agencies and entities involved in the continental effort. USFS has been a key partner in the development of this plan, and has been engaged in WNS management and science response since the beginning of the WNS outbreak in 2006. USFS R/D has been providing science products and partnership resources to help address the research, monitoring, management, and conservation needs.

On December 15, 2011 the Congressional Record, Volume 157, Number 193 includes the following language relative to WNS.

> USFS FY 2012 Conference Language:
>
> "The Forest Service is commended for its localized needs research and is directed to expand this research in support of project development on national forests. The Forest Service should prioritize research related to White Nose Syndrome as well as inventory and monitoring of bat resources on Forest Service lands. "

USFWS also received direction from Congress on WNS. Communication and coordination between leaders, managers, scientists, and staff of both bureaus would enhance the effectiveness of both in addressing the WNS crisis.

> USFWS FY 2012 Conference Language:
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> "The conferees direct the Service to fund white nose syndrome research and response activities at no less than $4,000,000 from within Recovery. Funds should be used to:
>
> 1) Increase research capacity to fund basic and applied research to stop the spread of the disease;
> 2) Provide funding for States to implement response activities;
> 3) Increase FWS capacity for surveillance, monitoring, and coordination activities.
>
> The conferees expect these activities to be coordinated with other Federal partners."

In response to this EID and the National WNS Plan, we have evaluated the science leadership role of USFS R/D in addressing this threat at the local, state, national and international levels. We believe a strategic approach using our scientific, management and collaborative resources provides the best outlook to make progress against this disease.

To that end, a multidisciplinary team of scientists, specialists and managers across FS Research Stations and the Washington Office developed this *USFS R/D National Science Strategy on White Nose Syndrome*. This document is not intended to be an all-encompassing strategy, rather to identify a strategic direction for research efforts spanning Forest Service programs. This strategy proposes to shift the focus of WNS activities from surveillance of clinical disease advances to focusing on the desired endpoint for bat conservation and recovery, that is - *the perpetuation of viable bat populations* even in the presence of *G. destructans*.

Research and Development's Role

Forest Service R/D has several unique characteristics that position it to play a primary role in helping to find a solution to this disease. The Forest Service conducts research, scientific collaboration, and scientific reviews to fill priority information gaps. In addition to more than 500 research scientists, there are thousands of specialists in forest entomology, forest mycology and pathology, invasive species experts, soil scientists, wildlife biologists and ecologists in the National Forest System. Specialized research centers representing Mycology, Climate Change, and Biological Control development and production contribute to the unique capabilities of USFS R/D. Biological Control research and production laboratories - the FS Quarantine Laboratory at Ansonia, Connecticut (CT) and the FS Northern Research Station Laboratory at Hamden CT - are located near the epicenter of WNS. These and other genetic science facilities across the country are capable of conducting both bat and fungus research using state of the art molecular equipment.

Besides the uniquely pertinent areas of expertise, established partnerships position USFS R/D for success. Forest Service responsibilities extend across the country with forests and grasslands in 44 states and working relationships with State Wildlife and State Forestry Departments across the country. The USFS R/D has working relationships with other agencies within US Department of Agriculture (USDA), other governmental departments and tribal organizations including: Agricultural Research Service (ARS), Animal and Plant Health Inspection Service (APHIS) and the U.S. Geologic Survey (USGS). Additionally, USFS R/D has already formed extensive collaborative research with colleges and universities throughout the U.S. The Forest Service has a long history of providing scientific information

to states and territories to handle natural resource problems. The Forest Service is also uniquely able to address issues of management concern, especially as it regards management of National Forests and Grasslands, and has a well-established record of using research to support on-the-ground adaptive management practices. Under the leadership of the Director of Resource Use Sciences, USFS R/D is uniquely capable and prepared to provide leadership in this natural resource problem. In the remainder of this document, we summarize strategic approaches of USFS R/D to contribute to this objective and to address Congressional direction.

Background

Bats have important roles in many ecosystems and provide economic benefit as predators of nocturnal agricultural and forest insects (Boyles et al. 2011). Declining populations of this diverse mammalian group have been a concern of resource management and conservation agencies worldwide for several decades [40 Code of Federal Regulations - CFR 17590 17591, April 21, 1975; 40 CFR 58308 58312 December 16, 1975; (Hutson et al. 2001, Kunz and Racey 1998)]. The reasons for these declines include: direct persecution, habitat loss, roost disturbance at hibernacula and maternity sites, environmental contaminants (Hutson et al. 2001), wind turbines (Kunz et al. 2007), climate change (Rebelo et al. 2010) and since 2006, a disease epidemic known as white nose syndrome (WNS) (Brooks 2011, Dzal et al. 2010, Frick et al. 2010). This emerging infectious disease (EID) is associated with the fungal pathogen *Geomyces destructans* (Gargas et al. 2009). If *G. destructans* is found to affect all hibernating bat species, then losses from this disease alone may threaten up to 60% of U.S. bat species.

Fungi are ubiquitous in the environment and have important roles in ecosystems as recyclers of nutrients, decomposers of organic materials and as root-associates that promote plant health. Only approximately 0.3% of the currently identified fungal species have pathogenic relationships with animals and plants – the vast majority of these affect plants (Blanco and Garcia 2008, Erjavec et al. 2009). Pathogenic fungi are associated with a variety of diseases in animals ranging from acute self-limiting pulmonary infections and cutaneous lesions in immunocompetant individuals, to systemic inflammatory disease and often fatal infections in individuals with compromised immune systems. Fungi that infect insects have received considerable attention as possible biological control agents (Shah and Pell 2003), but the ecology of most fungal species is poorly known (Hesketh et al. 2010). Prior to the past 2-3 decades, incidence of invasive fungal disease in vertebrate animals was relatively rare.

In the past 2 decades, fungal pathogens have increased as major causes of disease in wild and domestic animals. Examples include chytridiomycosis affecting amphibians (Briggs et al. 2010), aspergillosis and histoplasmosis observed in birds and mammals (Blanco and Garcia 2011), moniliasis in

birds (Johnson et al. 2011), cryptococcosis in mammals (Burek 2008), and most recently white nose syndrome (geomycosis caused by *Geomyces destructans*) in bats (Chaturvedi and Chaturvedi 2011). EID's of wildlife are of concern to conservation and land management due to their ability to deplete population sizes, hinder the recovery of rare species, impact ecological services and necessitate management actions that may impact the environment.

Bat populations in the northeastern U.S. have sustained unprecedented mortality since WNS was first observed in Howe's cave in New York in 2006. Recent estimates suggest death of 5.7 – 6.7 million bats (USFWS press release January 2012) from at least 6 bat species, including the endangered Indiana bat (*Myotis sodalis*). Mortality rates in affected hibernacula generally exceed 75% and have been documented as high as 97% (Blehert et al., 2009). The pattern of rapid spread of WNS and extensive local host population declines following infection is characteristic of an introduced, virulent pathogen dispersing through a naïve population.

Many aspects of the complex interactions involving *G. destructans*, the cave environment, and bat mortality remain unclear. For clarity, we refer to "infection" as the occurrence of a fungal microbe in association with a host, whereas "disease" indicates a state where the host-fungus interactions result in sufficient host damage for clinical manifestations to become apparent. Recent research has centered on *G. destructans* as the causative agent of the skin infection that is a hallmark of WNS pathology (Lorch et al. 2011, Meteyer et al. 2009). To date, *G .destructans* is the only consistently identified contributor to this disease. Histological tests of infected bats from WNS-positive sites confirm cutaneous fungal infection in 90% (n=117) of necropsies (Blehert et al., 2009). Furthermore, growing fungal hyphal tips of *G. destructans* are able to fill hair follicles and sebaceous glands, penetrate into the noncorneal layers of the bat epidermis, and invade regional tissues causing significant damage (Blehert et al., 2009; Meteyer et al., 2009). Asexual spores, termed "conidia," are a distinguishing feature of *G. destructans,* and have been identified from fungi cultured from WNS-affected bats (Blehert et al., 2009; Meteyer et al., 2009). Despite this feature, it is still difficult to rapidly and accurately detect *G. destructans* because of the considerable diversity of genetically similar but non-pathogenic fungi associated with bats and their environments (e.g. cave soils) (Lindner et al. 2010); which has slowed many investigations centered around the spread of WNS.

The relationships between infection and disease are frequently dynamic in nature, centering on the equilibrium that can be achieved between the resistance and tolerance mechanism of the host, and the infectivity and virulence mechanisms of the pathogen. Emerging diseases, such as WNS, typically cause a high degree of pathogenicity and mortality in susceptible host populations because the hosts are immunologically naïve with little or no resistance or tolerance to the introduced disease. Normally, this

type of infection is self-limiting because the large scale losses in host populations adversely affect both the pathogen's ability to reproduce and its chances of gaining access to new susceptible hosts. This situation creates severe selective pressure for the pathogen to become less pathogenic over time. However, given the rate of spread and degree of species affected by WNS, it is unlikely that we will detect this influence in *G. destructans* before widespread and devastating losses have occurred in North American bat populations. In addition, *G. destructans* is able to persist within the hibernacula where conditions are within the range of growth of the pathogen (Lindner et al., 2010). The role of the hibernacula as a reservoir further reduces the selective pressure on *G. destructans* because the disadvantage of host elimination becomes less important for this pathogen's survival.

A host will develop resistance over time to infections by organisms that cause harm, but this process can take long periods of time and this mechanism may be reduced in bats. Due to the unique aspects of hibernation in bats, their immune systems are essentially compromised during the winter, when they hibernate to conserve energy. This represents a severe limitation to the normal mammalian host defense response and reduces the likelihood that bats will develop the ability to resist infection.

Current and Future Paradigms

Response priorities for bat species threatened by WNS are currently structured around surveillance for clinical disease and preventing pathogen spread to unexposed populations through cave closures or equipment decontamination. Our examination of other EID's suggests, in most cases, local elimination of harmful or invasive microorganisms is at best a short term solution because of the continued risk of re-introduction (DeLiberto, APHIS, personal communication). Genetic evidence indicates several bat species have admixed populations (Amelon 2011, Turmelle et al. 2011) indicating mixing of individuals over fairly large areas. Bat species and individuals interact and breed at hibernacula across their ranges in the eastern US. Recent research results suggest that hibernacula may serve as environmental reservoirs (Lindner et al. 2010). If bats are mixing across their ranges and hibernacula serve as pathogen reservoirs, it follows that spread is likely under suitable conditions. However, decontamination efforts should continue in order to slow the spread of the pathogen to western areas. Preventing disease does not necessarily require eliminating exposure to pathogens. Similarly, preventing population declines does not necessarily require eliminating disease. For example, the purported identical pathogen exists in Europe without the associated high levels of mortality associated with the clinical disease (Pikula et al. 2012, Puechmaille et al. 2010).

We propose the expenditure of funds for this EID should shift from the paradigm of focusing on surveillance for clinical disease and attempting to control inevitable disease spread to focusing on the desired endpoint for bat conservation and recovery, that is - *the perpetuation of viable bat populations* even if *G. destructans* is endemic. White nose syndrome and other EID's are not strictly a wildlife issue; they are environmental issues that require interactive evaluation by diverse disciplines. For instance, while *Batrachochytrium dendrobatidis* is considered the causal agent of chytridiomycosis, additional stressors associated with pesticide exposure, species characteristics, climate change, and environmental conditions weaken host defenses and influence the disease process (Garner et al. 2009, Pounds et al. 2006). Similar results have been observed with other wildlife diseases including colony collapse in bees (Evans and Schwarz 2011). These extrinsic factors may play an important role in WNS by increasing stress levels and leaving bats less able to resist and tolerate infection (Garner et al. 2009). Therefore, WNS research needs to include expertise from many scientific disciplines to successfully identify appropriate management actions. Appropriate technology transfer will be an important part of the USFS R/D WNS strategy in order to translate research into on the ground management strategies.

The National Strategy

The overarching objectives of this strategy are a) to provide coordinated science leadership towards identifying approaches that will perpetuate viable bat populations in the presence of *G. destructans*, and b) to minimize disease-induced population declines through research aimed at understanding how to provide the greatest potential for survival and fitness at the population level. The strategy focuses on six priorities:

- **Quantification and enhancement of bat population status, survival, and fitness.**
- **Evaluation of host biological treatments.**
- **Evaluation of pathogen genetics, ecology and biological control.**
- **Evaluation of environmental refugia.**
- **Quantification of ecological and economic impacts.**
- **Risk assessments to targeted management.**

(Note: In the following sections, research activities that have been initiated by USFS R/D scientists, at least as a pilot study are marked with *. Research activities that were submitted as proposals for funding in the last FWS WNS RFP are marked with °.

Quantification and Enhancement of Bat Population Status, Survival and Fitness

Effective bat conservation requires understanding the relationships among individual bat species, their environment and humans. Land managers are repeatedly faced with evaluating complex conservation issues relative to bat populations whether these populations are currently affected by WNS or not. Providing the greatest potential for survival and fitness of bat populations will require evaluation of interactions between complex environmental and landscape factors as well as minimizing the impact of WNS on bat populations. Current research suggests that a range of summer and winter habitats are required to meet the survival needs of diverse bat populations (Weller et al. 2009). Since many questions regarding the specific habitat associations of bats and *G. destructans* are yet to be addressed, a strategy of maintaining a range of environmental conditions will provide insurance that high-quality habitats are available where bats may have an advantage over the pathogen.

Research Objectives:

- Develop quantitatively robust population survey and modeling methodologies of summer and winter populations, evaluating approaches and exploring new models. *****
    - Conduct long-term studies to provide the demographic data necessary to test models. *****
- Assess effects of habitat condition and management on population status survival and fitness. **º**
- Evaluate changes in bat reproductive success relative to infection history.
- Explore potential intervention strategies (e.g., translocation, increasing bat populations less susceptible to WNS) to improve conditions for decimated populations.
- Assess impacts from loss of genetic diversity through mortality and associated impacts of small population size, including maintenance of critical mass within maternity colonies for populations to recover.*****

Evaluation of Host Biological Treatments

Results of chytridiomycosis research suggest a single “cure-all” is an unlikely outcome when a disease affects multiple, diverse and widespread species. Therefore, evaluating diverse options for biologically based treatments provides opportunities of identifying multiple approaches to mitigating disease impacts. Protective or antagonistic microbiota may be capable of inhibiting *G. destructans*. To increase this capacity, bioaugmentation or biotherapy is a strategy to add a beneficial strain or consortium of microbiota to affected species or to their habitat for the purpose of reducing host

susceptibility to infection or disease. Usually the microorganisms applied in this strategy are already or were historically present in the habitat or on the species, rather than introducing new organisms to an already stressed system. Biostimulation is a similar strategy of adding nutrients or compounds to promote the growth of beneficial microbiota relative to potential pathogens.

Research Objectives:

- Further investigate potential antagonistic microbes and compounds naturally occurring on bats.*
- Evaluate additional environmental stressors. º
- Evaluate the influence of compounding stressors (natural and anthropogenic disturbances) on likelihood of disease manifestation. º
    - Evaluate metabolic changes/requirements for shorter hibernation periods that may be associated with climate change or geographical variation. º
- Determine critical thresholds for infection to manifest as disease.
- Determine the viability of spores and hyphae in presence of antagonists.

Evaluation of Pathogen Genetics, Ecology and Biological Control

Species within the genus Geomyces are common soil fungi and are typically not pathogenic. Very little is known about the genetics, life cycle, or species distribution of these fungi. Developing a better understanding of the pathogen is essential for understanding epidemiological data, creating effective control measures, and for developing tools for pathogen detection.

Research Objectives:

- Develop rapid, accurate, and sensitive molecular methods for detecting the pathogen on the host and in the environment, including on-site detection. *****
- Evaluate the genetic diversity of the pathogen and related species. *****
    - Characterize the life history and biology of the pathogen and related species. º
- Evaluate mechanisms of virulence between pathogenic and non-pathogenic *Geomyces*.
- Evaluate the range of pathogen survivability, with and without the presence of antagonists.
- Evaluate mechanism(s) of cell entry and proliferation.

- Evaluate the rate and quantity of inoculum development and potential loads in natural and man-made refugia. Evaluate the rate of inoculum increase and decrease in the presence and absence of bats and environmental sources.
- Identify potential natural control targets for *Geomyces* (environmental conditions, bat communities composition, latency periods). *****

Evaluation of Environmental and Climatic Refugia

Environmental conditions may suppress disease development by decreasing pathogenicity (inhibiting pathogen growth or transmission), decreasing susceptibility (allowing effective host responses), or both. Refugia, therefore, represent areas of high conservation value since they may provide alternative sites for populations at risk. Species distribution models may help to identify climatic refugia.

Research Objectives:

- Evaluate potential refugia for bats (i.e. mines, artificial hibernacula or bunkers or man-made laboratory hibernation chambers) as temporary hibernacula to increase potential survival. *****
- Evaluate range of conditions providing greatest survival for bats in refugia.
- Evaluate the range of thermal conditions at which bats are able to successfully hibernate.
- Evaluate *ex situ* colonies for bio-therapy/treatment, (nutrition, probiotics, elevated temperatures, etc). **º**

Quantification of Ecological and Economic Impacts

Estimated bat population losses and the resulting loss of potential arthropod predation may result in quantifiable increases in insect populations and, possibly, economic losses in agricultural and forest production (Boyles et al. 2011, Cleveland et al. 2006, Kalka et al. 2008, Williams-Guillén et al. 2008). Further, because bats consume a large number of biting Dipterans (i.e., mosquitoes, blackflies, and others), the loss of insectivorous bats could negatively impact recreational values and use, and threaten human and wildlife health via a potential increase in insect-borne diseases.

Research Objectives:

- Assessment of the ecological and economic impacts of the loss of nocturnal insect predators and associated indirect impacts to forestry and agriculture. *****
- Evaluate the potential cascading effects to ecological processes and ecosystem health in forest, grassland, and cave ecosystems caused by the loss of nocturnal insect predators.

Risk Assessments to Targeted Management

The spread of WNS is ongoing and management strategies must be developed for regions currently experiencing widespread losses as well as those that still anticipate disease introduction. Models are needed to predict the spatial and temporal characteristics of the spread of this disease, which would provide invaluable insight to the relationship between disease, host and environment as well as inform management actions with respect to the most efficient and effective strategies for conserving North American bat species. Many of the research targets addressed within this strategy build upon previously conducted or ongoing research activities. Current research on the spread of WNS in the Eastern U.S. can be used to parameterize models that might predict rate and direction of spread to western regions. Methods and analyses can be pursued that will allow us to identify caves and species most at risk of disease incidence. Finally, we can utilize the expertise and resources within the Forest Service to develop decision support and assessment tools to inform future research direction and help managers identify appropriate actions.

Research Objectives:

- Incorporate landscape analyses that determine spatial patterns (rate, direction, covariates) of disease emergence and spread dynamics.
- Model bat distributions.
- Model disease spread/association dynamics.
- Develop tools that help target management actions.
    - Conduct risk and vulnerability assessments.
    - Develop decision support tools that incorporate analysis of risk.

Communications Strategy

An important factor that spans all priorities is the need to clearly communicate information. Internal communication will 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. 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 collaborators and partners. It is important to assess existing efforts to determine where additional effort is needed.

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Appendix A. Team Member Contact Information

Sybill Amelon, Research Wildlife Biologist
USDA Forest Service, Northern Research Station
202 Nat. Res. Bldg.; UMC
Columbia, MO
(573) 875-5341 ext 231 (office)
samelon@fs.fed.us

Robert T. Brooks, Research Wildlife Biologist
USDA Forest Service, Northern Research Station
University of Massachusetts
Amherst, MA 01003
Tel: 413.545.1845
rtbrooks@fs.fed.us

Jessie Glaeser, Research Plant Pathologist
USDA Forest Service, Northern Research Station
One Gifford Pinchot Dr.
Madison, WI 53726
(608) 231-9215 (office)
jglaeser@fs.fed.us

Megan Friggens, Research Ecologist
USDA Forest Service, Rocky Mountain Research Station
333 Broadway SE
Albuquerque, NM 87102
Voice: 505-724-3679
meganfriggens@fs.fed.us

Daniel Lindner, Research Plant Pathologist
USDA Forest Service, Northern Research Station
One Gifford Pinchot Dr.
Madison, WI 53726
(608) 231-9511 (office)
dlindner@fs.fed.us

Susan C. Loeb, Research Ecologist
USDA Forest Service, Southern Research Station
233 Lehotsky Hall, Clemson University
Clemson, SC 29634
864-656-4865
sloeb@fs.fed.us

Ann M. Lynch, Research Entomologist
US Forest Service, Rocky Mountain Research Station
Laboratory of Tree-Ring Research
105 West Stadium
Tucson AZ 85721
520 626 9582
alynch@fs.fed.us

Drew Minnis, Research Botanist
USDA Forest Service, Northern Research Station
One Gifford Pinchot Dr.
Madison, WI 53726
(608) 231-9215416 (office)
amminnis@fs.fed.us

Roger W. Perry, Research Wildlife Biologist
USDA Forest Service, Southern Research Station
P.O. Box 1270
Hot Springs, AR 71902
501-623-1180, x 108
rperry03@fs.fed.us

Mary M. Rowland, Acting Wildlife National Program Leader, WO R&D
USDA Forest Service, PNW Research Station
La Grande Forestry & Range Sciences Lab.
1401 Gekeler Lane
La Grande, OR 97850
541-962-6582 (o)
mrowland@fs.fed.us

Monica Tomosy, US Forest Service Liaison to USGS National Climate Change and Wildlife Science Center USDA Forest Service Research and Development
Arlington, VA
703-605-5258
mstomosy@fs.fed.us

Ted Weller, Ecologist
USDA Forest Service
Pacific Southwest Research Station
1700 Bayview Drive
Arcata, CA 95521
(707) 825-2955
tweller@fs.fed.us