Wildlife Health AUSTRALIA


Photo: Terry Reardon


Photo: Marvin Moriarty/USFWS

White-nose Syndrome Response Guidelines

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1. Introduction

1.1. Purpose and Scope

This document is intended to aid response agencies in the event of a detection of the fungus *Pseudogymnoascus destructans* or the disease white-nose syndrome (WNS) in Australia. Prevention and preparedness activities are additionally outlined in Appendix 1.

This document covers infection with *P. destructans*, the fungus causing white-nose syndrome. It provides an overview of the disease, expected consequences and options for action.

1.2. Development

The policy recommendations in this document were developed by Wildlife Health Australia (WHA) in consultation with stakeholder groups. The consultation process included a workshop held by Wildlife Health Australia and Animal Health Australia in October 2016, which brought key stakeholders and response agencies together to consider the options for responding to white-nose syndrome in Australia. Participants included representatives from Commonwealth and State government agencies for agriculture and environment, Animal Health Australia, WHA, biosecurity emergency management experts, bat ecology experts from the Australasian Bat Society, and university wildlife disease experts and epidemiologists. This document was updated in January 2026 to incorporate the latest scientific information and update the format.

Funding for the development of these guidelines was provided by the Australian Government Department of Agriculture, Forestry and Fisheries.

1.3. Other documentation

This document should be read and implemented in conjunction with:

- WHA fact sheet on white-nose syndrome
- WHA Guidelines on how to report a suspect case of WNS
- WHA Guidelines on sample submission for WNS exclusion testing
- WHA Biosecurity Guidelines for bat research in Australian caves

Further information on WNS is also available from the Australian Government[a] and the North American White-Nose Syndrome Response Team.[b] A detailed risk assessment and summary of WNS as it relates to the Australian situation is available online [1].

1.4. Disease-specific training

Video resources on collecting skin swabs and biopsies for WNS surveillance, environmental sampling and the use of UV-light to screen for the growth of *P. destructans* are available from the USGS National Wildlife Health Center.[c]

[a] https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/animal/white-nose-syndrome
[b] https://www.whitenosesyndrome.org
[c] https://www.usgs.gov/centers/nwhc/science/white-nose-syndrome

2. Nature of the disease

2.1. Disease status

White-nose syndrome is a **nationally notifiable disease** and must be reported to the relevant state or territory agency. Guidelines on what to look for and how to report a suspect case are available online: [WHA How to Report a Suspect Case of WNS.]

White-nose syndrome is listed among the 'higher risk' diseases of concern on Australia's **National Priority List of Exotic Environmental Pests, Weeds and Diseases**.[a]

A WNS outbreak could be considered under the *National Environmental Biosecurity Response Agreement* (NEBRA), which sets out emergency response arrangements, including cost-sharing arrangements, for responding to biosecurity incidents that primarily impact the environment and/or social amenity and where the response is for the public good.[b]

The World Organisation for Animal Health (WOAH) does not include WNS on its list of notifiable diseases, however it is included in the list of non-WOAH-listed diseases affecting wild animals, which are selected for monitoring by the WOAH's Working Group on wildlife diseases.[c]

2.2. Aetiology

White-nose syndrome is caused by the fungus *Pseudogymnoascus destructans* (previously named *Geomyces destructans*). *P. destructans* is a psychrophilic (cold growing) fungus that thrives at temperatures below 15°C and ceases to grow above 20°C (but see *Persistence of the agent* for more detailed information). While descended from soil-decomposing fungi in caves, the fungus has evolved to specifically grow on the skin of bats during winter hibernation [2].

Recent analysis has revealed the existence of two distinct clades or species, known as Pd-1 and Pd-2, which exhibit a degree of host specialisation but are both capable of causing WNS [3].
The genome sequence of both species is available online.[d]

P. destructans appears to have been present in Europe and Asia for a long time and has been found in over 25 countries. While Pd-1 is dominant in Europe, it is absent from Asia, where only Pd-2 has been found. Across Eurasia, both strains may cause skin pathology in bats, but no apparent mass mortalities as seen in North America [4, 5]. It appears that the pathogen currently spreading through North America is a single clonal strain of Pd-1, likely originating from western Ukraine [3]. As Pd-2 has not yet been found in North America, the virulence of this strain in naïve species is currently unknown.

[a] https://www.agriculture.gov.au/biosecurity-trade/policy/environmental/priority-list#native-animal-diseases
[b] https://www.agriculture.gov.au/biosecurity-trade/policy/emergency/nebra
[c] https://www.woah.org/en/what-we-do/animal-health-and-welfare/animal-diseases/?_tax_diseases=non-listed-affecting-wildlife
[d] https://www.ncbi.nlm.nih.gov/bioproject/?term=PRJNA862744

2.3. Susceptible species

2.3.1. Insectivorous bats

Twelve bat species in North America and 31 species in Europe and Asia have been identified with WNS (as of November 2025), with fungus detected on additional bat species but without signs of disease.[a] The affected North American species are from the genera *Eptesicus, Myotis* and *Perimyotis,* and in Europe and Asia from *Miniopterus, Myotis, Eptesicus, Barbastella, Plecotus* and *Rhinolophus.*

There are many insectivorous bat species (also known as microbats) in Australia, including some in the same genera as affected species in North America and Europe (see Table 1 below). These small bats are nocturnal, roost during the day and leave the roost around dusk to forage, using echolocation to navigate and find insect prey. Numerous microbat species live in caves, which can range from small splits or crevices through to extensive caverns, as well as mines that are abandoned or irregularly used. During temperate winters bats enter periods of torpor or hibernation to conserve energy when insect prey is scarce, reducing their metabolic activity and lowering their body temperature to be close to the ambient temperature in the roost [6].

Species most likely to be impacted are those that roost and hibernate in caves where the year-round temperature is maintained below 20°C, in regions with severe winters with limited free water and/or prey availability, and in species that tend to cluster together in large numbers.

While the susceptibility of Australian bat species to WNS is not known, *P. destructans* is not species-specific. Therefore, all Australian bat species inhabiting caves with a climate suitable for *P. destructans* growth should be considered potentially susceptible to the disease. Several reviews of cave-dwelling Australian species likely to encounter the pathogen and develop WNS in the event of an incursion have been undertaken [7-10].

[a] https://www.whitenosesyndrome.org/impacted-bats

Table 1. Australian insectivorous bat species predicted to be susceptible to WNS.

	Species name	Common name	Distribution[a]	Conservation status	Species range overlap[+]
Miniopterus	*Miniopterus orianae bassanii*	Southern bent-wing bat	SA, VIC	Critically endangered (federally)	100 %
	Miniopterus orianae oceanensis	Eastern bent-wing bat	NSW, QLD, SA, VIC	Critically endangered (VIC) Vulnerable (NSW)	68 %
	Miniopterus australis	Little bent-wing bat	QLD, NSW	Vulnerable (NSW)	32 %
Chalinolobus	*Chalinolobus dwyeri*	Large-eared pied bat	NSW, QLD	Endangered (federally)	86 %
	*Chalinolobus morio**	Chocolate wattled bat	All states	Not listed	85 %
Rhinolophus	*Rhinolophus megaphyllus*	Eastern horseshoe bat	NSW, QLD, VIC	Vulnerable (QLD, VIC)	56 %
Myotis	*Myotis macropus*	Large-footed myotis	All states except SA	Vulnerable (NSW)	55 %
Vespadelus	*Vespadelus troughtoni*	Eastern cave bat	QLD, NSW	Vulnerable (NSW)	43 %
	Vespadelus finlaysoni	Finlayson's cave bat	NT, SA, WA	Not listed	2 %

* Primarily tree-roosting with a cave roosting population occurring in the Nullarbor Plain region

[+] Percentage of species range overlapping with projected spread of *P. destructans* (Turbill and Welbergen 2020)

[a] https://www.ausbats.org.au/batmap.html

2.3.1.1. *Factors affecting susceptibility*

Differences in species susceptibility to WNS are not completely understood, however there are host factors that are known to affect susceptibility:

- Species (and individuals within species) with a higher body mass are inherently less affected, as their size allows them to store more fat reserves for overwinter survival [11].
- Females generally exhibit higher infection rates and greater disease severity than males, leading in some species to population shifts toward a male-biased sex ratio [12].
- Species roosting in larger clusters are more likely to develop WNS as *P. destructans* is transmitted via bat-to-bat contact [13].
- Bats hibernating in more humid, warmer caves (within the temperature range that allows *P. destructans* to thrive) are also more susceptible, as these conditions promote fungal growth and elevate the minimum ambient temperature, limiting how much bats can lower their body temperature during hibernation and thereby reducing the efficiency of energy conservation [14]. Species preferring aboveground hibernacula such as bridges or culverts are less likely to develop WNS [15].
- The skin/ wing microbiome of species less affected by WNS may have protective properties [16].

Susceptible species also appear to respond to infection with an immune reaction that results in excessive inflammation, which contributes to increased arousal from hibernation and utilisation of fat reserves [17].

Bats in Europe and Asia appear to be able to tolerate the fungus so that *P. destructans* does not cause mass mortalities [18]. This is likely to be due to a combination of factors including ecological behaviour, fungal loads and immune response [19, 20]. Fifteen years after the first introduction of *P. destructans* to North America, those bat populations that have survived have begun to show adaptive change including dampened immune responses and increased overwintering survival [21].

2.3.2. Domestic animals and other wildlife

Australia's megabats including the flying-foxes (*Pteropus* spp.) do not hibernate and are thus not susceptible to WNS. No other animal species are known to be susceptible to WNS.

2.3.3. Humans

No human health risk from WNS has been identified. However, there are other health and safety risks associated with working with bats (see *Workplace health and safety*).

2.4. World distribution and occurrence in Australia

White-nose syndrome was first recognised in North America in New York state in 2006. Since then, it has spread through the USA and Canada, with WNS confirmed in 40 states and 9 Canadian provinces as of November 2025.[a] The fungus has also been found in other states without the disease.

In the USA, *P. destructans* was first found in a commercial tourist cave and was likely introduced by humans via clothing or equipment (fomites) contaminated with *P. destructans* spores. In March 2016, the fungus was detected for the first time in the western USA, in Washington State, more than 2,000 km from the westernmost detection prior to that time. While it is not known how this spread occurred, human

[a] https://www.whitenosesyndrome.org/where-is-white-nose-syndrome

activity is a possible explanation. Current models predict that WNS is likely to spread throughout the entire continental USA by 2030 [22].

P. destructans has been found in over 25 countries in Europe and Asia, without the mass mortalities observed in North America [4, 5].

As of November 2025, *P. destructans* has not been identified in Australia. WNS has been excluded in a small number of suspect cases in Australian bats. Some targeted surveillance has been conducted for *P. destructans* in Victoria and South Australia [23], however large-scale systematic surveillance of high-risk areas has not been conducted.

2.5. Epidemiology

2.5.1. Infection and transmission

White-nose syndrome is a disease of hibernating bats, as it occurs when the body temperature drops low enough to allow the fungal pathogen to grow on the skin. Immune responses are also suppressed during hibernation, allowing *P. destructans* to invade the skin.

Based on North American experience, sites may test positive for *P. destructans* about two years before clinical disease is observed in local bats [22]. Once established, the disease follows a seasonal pattern, with first signs of skin lesions seen in autumn. However, significant mortalities do not occur until mid-winter, approximately 83-120 days after bats enter hibernation, and peak in late winter [24]. On the skin of torpid bats, *P. destructans* enters a phase of enhanced growth, and vast amounts of conidia are shed [25]. By the end of winter, prevalence of *P. destructans* on bats at an affected site approaches 100%. As bats come out of hibernation their metabolic activity increases, and their body temperature rises. Along with higher ambient temperature, this results in surviving bats clearing the infection from the skin after winter [26]. However, *P. destructans* has also been detected on individual bats during summer [27] (see also *Persistence of the agent*), including the fur of tree-roosting bats, which may serve as vectors for the spread of the pathogen [28].

Transmission of *P. destructans* occurs via contact with contaminated cave substrate and direct contact between infected bats. Although larger clusters of bats facilitate faster disease spreads, due to caves acting as a natural reservoir for *P. destructans*, transmission of the fungus to a susceptible bat is not entirely density dependent. Airborne transmission has not been demonstrated. Ectoparasites have been considered as possible vectors of *P. destructans* [29]. In Europe most of the pathogen's natural movement occurs within sites indicating that any spread to novel locations is most likely human-mediated [30]. However, in North America, seasonal movement of bats between caves has been shown to contribute to dispersal of *P. destructans* [31].

Due to its origins as a soil saprotroph (environmental decomposer), *P. destructans* is capable of persisting in the environment without the presence of bats, and some caves have stayed contaminated for several years after extinction of the local bat population [32] (see also *Persistence of the agent*).

A number of Australian cave-dwelling species roost in very large colonies, numbering thousands of individuals, for at least part of the year. They move between multiple caves and commonly share roosts with other bat species. The southern bent-wing bat, for example, is an obligate cave-dwelling bat that spends the winter in numerous caves and rock crevices, with over 50 known sites. During the breeding season the majority of the population congregates in three main breeding or maternity caves [33].

Bats can also travel long distances from the roost site during foraging. These factors would significantly contribute to pathogen spread upon introduction and establishment in Australia. While specific models for all species and regions at risk have not yet been developed, a recent Victorian Wildlife Disease risk assessment has rated the risk of WNS to southern bent-wing bats as "extreme", and "high" for their close relative, the eastern bent-wing bat [9].

2.5.2. Persistence of the agent

The *P. destructans* fungus grows best in cold conditions, with highest fungal loads in the wild observed between 5 - 7°C [34] and no growth above 20°C [35]. *P. destructans* conidia can remain viable for over two weeks at 37 °C, for two months at 30°C, and for nearly five months at 24°C [36]. The fungus grows best at humidity levels above 90 % but it can survive prolonged periods of low humidity [37]. *P. destructans* is capable of growth on a range of substrates including wood and soil, and can persist in guano [38]. Other possible substrates include invertebrate exoskeletons, feathers, hair, skin, and moist plant material [1].

P. destructans can persist in the environment for long periods in the absence of bats. Under laboratory conditions, *P. destructans* was cultured from dried agar plates kept at 5°C and low humidity for over 5 years [37]. In the field, live *P. destructans* was found in the sediment of a US mine that had been closed to bats for around two years [32].

The fungal spores are destroyed by submersion in hot water maintained at a temperature of 55°C for a minimum of five continuous minutes, or disinfectants such as isopropyl alcohol 50-70%, sodium hypochlorite (e.g. bleach at 8.25%) and Virkon® S. More detailed guidelines for bat research in Australian caves, including specific recommendations on disinfection of specific items are available for further reference: [WHA Biosecurity guidelines for bat research in caves in Australia].

A specific WNS decontamination protocol has been developed in North America and is regularly updated, containing guidelines on product use and suggested procedures: National White-Nose Syndrome Decontamination Protocol.[a]

2.6. Diagnostic criteria

2.6.1. Clinical signs, presentation and pathology

Clinical signs of WNS include:[b]

- Presence of white or grey powdery fungus on muzzle, face, wing membranes
- Wing damage, e.g. membrane thinning, depigmented areas, flaky appearance, holes
- Emaciation, dehydration
- Aberrant behaviour such as flying during the day or increased arousal/activity during a period of torpor or hibernation.
- Mass mortality

The physiological process by which WNS causes mortality is not fully known. It appears that wing damage caused by the fungus during hibernation results in increased evaporative water loss with subsequent dehydration and electrolyte imbalance, causing the bats to wake from hibernation more frequently,

[a] https://www.whitenosesyndrome.org/_files/ugd/18444a_809d5f1c71f6483cb771de0728cab6cb.pdf
[b] For photos of affected bats, see: https://www.usgs.gov/centers/nwhc/science/white-nose-syndrome?qt-science_center_objects=7#multimedia

which depletes the fat reserves that are needed to survive over winter [39]. Dead bats are thus found dehydrated and emaciated. The bats also exhibit a misdirected and energetically costly immune response [17, 40].

Fungal growth on the wing membrane of affected bats may be visible under UV-light, showing a characteristic yellow-orange fluorescence.

Histological changes in the skin include characteristic cup-like erosions of the epidermis or ulceration, with no or minimal evidence of inflammation, and branching septate fungal hyphae and distinctive asymmetrically curved conidia [41].

Diagnosis of clinical WNS in an individual bat requires both detection of *P. destructans* and characteristic histopathology of skin lesions.

2.6.2. Differential diagnosis

Differential diagnoses for WNS include other causes of mass mortality in cave-dwelling microbats (e.g. unusual weather events, acute toxicity). The overgrowth of saprophytic fungi on dead bats may appear as a white powdery material. Differential diagnoses for skin lesions on microbats include bacterial dermatitis, skin infection with other fungi (especially *Trichophyton spp.*), and mite infestation.

Another *Pseudogymnoascus* species, *P. roseus*, is present in Australia but is not known to be pathogenic to bats [23].

2.6.3. Laboratory tests

Available tests for *P. destructans* include molecular assays such as real-time PCR [42], sequencing and fungal culture. Fungal culture can help distinguish Pd-1 and Pd-2, as the two strains exhibit distinct colouration on nutrient agar [3]. *P. destructans* must further be distinguished from other fungal species in the same or closely related genera, which may occur in cave environments [43]. Testing for *P. destructans* can be conducted at the CSIRO Australian Animal Health Laboratory (CSIRO-ACDP) in Geelong.

Ancillary tests such as UVA light on wing membranes have lower sensitivity and specificity, and while they may be helpful in WNS-endemic areas, they are not recommended for confirmation or exclusion of WNS.[a] Other molecular tools, such as field-usable rt-PCR and LAMPs have been developed, and may be useful for future pathogen screening [44, 45].

2.6.4. Samples for laboratory testing

Only people who are experienced bat handlers, wearing appropriate protection and are rabies-vaccinated should handle bats. Members of the public should instead be advised to contact a local wildlife rehabilitation organisation or veterinarian if they find an injured or sick bat. For information on personal protective equipment and decontamination, see the WHA National Guidelines for Sample Submission – White-Nose Syndrome – Exclusion Testing and WHA Personal Protective Equipment (PPE) for Bat Handlers.

[a] USGS National Wildlife Health Center Bat White-Nose Syndrome (WNS)/Pd Surveillance Submission Guidelines https://www.usgs.gov/media/files/bat-white-nose-syndromepd-surveillance-submission-guidelines

Photographs should be taken before sample collection, as the attachment of the fungus to the bat is not robust and may be disrupted during sampling. Details to be recorded include location, date of collection, bat colony status and observations, a description of the lesion(s), body condition, and who collected the samples.

To ensure the most appropriate samples are collected and are appropriately stored during transport, where feasible the state/territory WHA Coordinator[a] or state/territory diagnostic laboratory should be contacted prior to collecting or submitting any samples. The whole carcass should be submitted where possible, to allow histopathology to be conducted and to maximise the opportunity for testing. Where this is not possible or preferable, non-lethal sampling techniques include biopsy of wing membrane or skin, and swab of affected area. For more detailed information, see the WHA National Guidelines for Sample Submission – White-Nose Syndrome – Exclusion Testing. Samples should initially be sent to the state or territory diagnostic laboratory, from which they may be forwarded by the laboratory to CSIRO-ACDP for emergency disease testing.

Biosafety guidelines for working with *P. destructans* in the laboratory have been developed by the USGS National Wildlife Health Center.[b]

2.7. Treatment and vaccination

2.7.1. Treatment and vaccination of affected bats

Antifungal drugs frequently used to treat fungal infections in veterinary medicine (e.g. voriconazole) should not be used as they have been shown to be harmful to bats [46]. While no specific treatment is currently being used in North America, several avenues are being explored.

An oral vaccine is being tested, and its use as a paste or aerosol could facilitate hibernaculum-wide use [47]. However, as antibodies may not be fully protective against WNS [48] and antibody dynamics following vaccination are not yet known, other proposed treatments involve modulating the immune response in susceptible species [17].

Probiotics are being investigated, with varying success, based on the identification of antifungal organisms within the microbiome of species that are resistant or tolerant to WNS [49, 50].

Bats may recover from WNS and clear the fungus if supported through the winter period. Moribund individuals brought into captivity and provided with warmth and additional food can fully recover within a month. However, bats can remain infectious for up to 70 days [51].

At the population level, bats can be passively supported by increasing foraging opportunities outside hibernacula in pre-winter and spring e.g. using UV lures to attract insects [52]. However, these could also repel some bat species and may not be appropriate in all contexts [53].

2.7.2. Environmental treatment

While treatment of individual bats can be complicated by logistics, cave treatments to reduce fungal loads have been considered as an alternative/ addition to mitigating the impacts of *P. destructans*.

[a] https://wildlifehealthaustralia.com.au/Incidents/WHA-Coordinator-Contacts
[b] https://www.usgs.gov/media/files/biosafety-measures-working-p-destructans-laboratory

Volatile organic compounds produced by soil microbes or those found on the wing membranes of species persisting with *P. destructans* have been trialled to assess reduction of fungal load during bat absence over summer in hibernacula [54-56]. While effective in laboratory trials, field assessments proved to be complicated and to date, there is no strong evidence for the use of volatile organic compounds in improving disease outcomes [57].

Since *P. destructans* is highly sensitive to UV light, UV-disinfection of caves has been proposed as a method to decontaminate caves in the absence of bats [58].

Considerations for long-term treatment of affected caves/ caves at risk of *P. destructans* incursion include alteration of cave microclimates via environmental modification (e.g. creating additional entrances to draw in cold air). Efforts are generally geared towards cooling hibernacula down to a lower temperature, which slows fungal growth and enables bats to enter deeper torpor, thereby preserving more energy [59, 60]. It has been noted, however, that WNS-infected bats do not always choose these locations even when available [61]. There are also inherent difficulties of manipulating the complex spatio-temporal temperature and humidity gradients present in natural caves, and variability of cave temperatures due to weather and season conditions need to be considered [60]. It has been suggested that environmental modification should focus on creating large spatial microclimate gradients within hibernacula, that vary as little as possible throughout winter [60].

3. Implications for Australia

3.1. Manner and risk of introduction to Australia

Accidental introduction of *P. destructans* via human-mediated transport of contaminated fomites such as clothing, footwear or equipment is the most likely source of pathogen introduction to Australia.

While surveys of the general public are lacking, a 2017 survey of the international speleological community highlighted the need for more targeted education to inform specific interest groups. Many respondents, especially those from Europe, were uncertain about the disease status in certain regions or failed to follow decontamination protocols despite being aware of them. Nonetheless, the survey revealed a generally strong willingness within this community to help prevent the spread of WNS [62].

Potential activities to prevent introduction of *P. destructans* into Australia are outlined in Appendix 1.

3.2. Environmental impact

White-nose syndrome has had a significant impact on bat populations in North America, with millions of bats estimated to have died due to the disease. Due to the significant threat that WNS may pose to native bats if introduced, WNS is listed among the 'higher risk' diseases of concern on the Australian Department of Agriculture, Fisheries and Forestry's National Priority List of Exotic Environmental Pests, Weeds and Diseases.[a] Insectivorous microbats perform an important ecological role. The loss of these bats would significantly affect other parts of the ecosystem such as invertebrates within cave environments.

Although Australia's temperate climate may moderate the impact of WNS and reduce the likelihood of large-scale mortality events, recent work suggests that bat populations in warmer southern regions may be more susceptible than previously thought [10]. For threatened species, such as the critically endangered southern bent-wing bat, the addition of a disease like WNS to the other threatening processes could have a significant impact on its survival [7]. In addition, WNS has the potential to cause long-term shifts in both species' composition and overall ecosystem structure. Female bats tend to be disproportionately affected compared to males, resulting in altered sex ratios within populations. Even in the absence of mortality, infection can impair reproductive fitness in females [63], creating the potential for long-term impacts that may exacerbate conservation threats for species.

As seen after large-scale die-offs in North America, WNS may affect community composition in an ecosystem, including non-cave-dwelling migratory bats not usually affected by the disease [64]. Persisting species may expand their distribution; such range expansions do not necessarily coincide with a broadening of dietary niches, meaning their ecological roles may not fully replace those of species lost to WNS [65].

[a] https://www.agriculture.gov.au/biosecurity-trade/policy/environmental/priority-list#native-animal-diseases

3.3. Economic impact

Although not well defined, there are potential consequences for agriculture due to the loss of insect pest control. The economic value insect-eating bats provide to the Australian cotton industry alone is valued at AUS$63.6 million annually [66].

There may also be a negative impact on tourism. Naracoorte Caves World Heritage Area, for example, is a popular tourist site that includes a Bat Observation Centre for viewing the southern bent-wing bat colony. Annual visitor numbers are in excess of 70,000, and the direct economic benefit of the site has been estimated at $17.6 million [67].

In the USA, damages within the agricultural sector following the arrival of WNS in a county (due to crop loss and an increased need for insecticide use) amounted to a cumulative total of approximately US$29.9 billion between 2006 and 2019. The increase in use of pesticides could have further flow-on impacts on environmental and human health.

3.4. Social and cultural impact

The local decline or extinction of bat species affected by WNS may have socio-cultural impacts. Communities of people value native Australian wildlife highly, as demonstrated by the fact that the southern bent-wing bat was voted Australian Mammal of the Year in 2022 from 370 other species.[a]

Bats have cultural significance for some First Nations peoples, featuring in Dreaming stories and as a totem.

[a] https://www.scimex.org/newsfeed/southern-bent-wing-bat-takes-the-glory-as-2022-mammal-of-the-year

4. Policy and Rationale

4.1. Introduction

The consequence of WNS in Australian microbats is potentially serious. The disease has had a significant impact on bat populations in North America, with millions of bats estimated to have died due to the disease. While the susceptibility of Australian bat populations is not known, the disease is of concern for southern cave-dwelling species, including the critically endangered southern bent-wing bat. Insectivorous microbats perform an important ecological role, and economic consequences for agriculture could occur due to the loss of insect pest control.

The WHA Emergency Wildlife Disease Response Guidelines provide a high-level document for guiding the management of an emergency wildlife disease response in Australian native animals.

4.2. Summary of policy recommendations

The recommended policy is to:

1. eradicate WNS if a single site or area is affected, unless other factors suggest this is not feasible; or
2. contain the disease if eradication is not feasible i.e. prevent or slow the spread of WNS into new areas, control the disease within affected areas, and protect high value populations such as threatened or high-risk species.

The policy can be achieved by a combination of strategies including *(high priority activities in bold)*:

1. **Identification and engagement of stakeholders**
2. **Disease surveillance**
3. **Biosecurity and decontamination**
4. **Conservation activities**
5. **Cave management**
6. **Public awareness: Education and communication**
7. Epidemiological assessment
8. Supportive treatment of infected bats
9. Environmental modification
10. Depopulation (culling) *(only in specific circumstances)*

Other management options are not currently available but may eventuate from overseas research:

11. Chemical or biological treatment of infected bats
12. Vaccination
13. Environmental treatment to reduce fungal load

4.3. Case definition

The definition of a case is a confirmed laboratory detection of *P. destructans,* either on a bat or in an environmental sample.

Any detection of *P. destructans* in Australia is considered sufficient to trigger a response as described in these guidelines, regardless of the presence or absence of clinical disease, or whether the fungus is detected on a bat or in an environmental sample such as a cave wall, sediment or soil. Clinical disease may not manifest immediately. Experience in North America shows that sites may test positive for *P. destructans* about two years before clinical disease is observed in bats [22].

If *P. destructans* is detected in Australia, revised or subsequent case definitions may be developed. As a reference, the case definition and diagnostic categories for WNS in the USA are available from the USGS National Wildlife Health Center website.[a]

4.4. Nature and extent of response

The aim of the response will differ depending on how widespread the disease is at the time of detection, and the area and species affected. The initial aim may be for eradication, with regular reassessment as further epidemiological information is obtained. The likely rate and extent of spread of WNS through caves in southern Australia once the pathogen is established is not known. However, based on the North American experience, precautionary response activities should be considered for cave-dwelling bat populations likely to be at risk in other geographic areas, including in other jurisdictions [7].

1. Eradication: May be feasible if the incursion is detected at an early stage, for example when only a single cave or site is affected, however the outbreak may be well advanced by the time of detection. Mortalities of bats in caves can easily go undetected as human disturbance of hibernating bats is discouraged, and any carcasses may be decomposed or scavenged before they are observed.

2. Containment: If multiple sites are affected, the focus will shift to containment i.e. prevention or slowing of spread of WNS into new areas, control of the disease within affected areas, and protection of high value populations such as threatened or high-risk species.

Stand-down of the response will occur when it is determined that a coordinated response beyond business-as-usual activities is no longer needed. This may occur if WNS has been eradicated, or eradication is no longer considered feasible. Additional information on the stand-down of EAD responses can be found in the AUSVETPLAN management manual Control centres management (Part 1).

Further consideration regarding the spatio-temporal extent of the response:

1. Timing: WNS is a seasonal disease, only affecting bats during the winter hibernation period. Significant disease only manifests well into winter, with mortality occurring around 120 days after bats enter hibernation [24] (see *Epidemiology*). If the pathogen is detected after a recent introduction, outside the hibernation period, or during the first three months of hibernation, the effects may not be seen until a later time.

[a] https://www.usgs.gov/centers/nwhc/science/white-nose-syndrome

2. Species variability: Variable species susceptibility has been seen in North America and appears to be associated with differences in ecology and behaviour (see *Susceptible species*). The pathogen may be first detected in a species with low susceptibility to the disease but still pose a threat to other Australian bat species that may have higher susceptibility.

4.5. Roles and responsibilities

4.5.1. Lead agency

The lead agency for the response will be defined by the legislation in each state/territory, and it is worth noting that responsibilities for wildlife may involve multiple agencies. The response arrangements including roles and responsibilities for disease outbreaks in wildlife are described in greater detail in the WHA Emergency Wildlife Disease Response Guidelines.

In the event that the response is managed under NEBRA, roles and responsibilities under the NEBRA are outlined in the Agreement. There is a requirement to report nationally within 24 hours to enact a NEBRA response.[a] Advice on reporting suspect cases of WNS is provided in Appendix 1.

4.5.2. Stakeholders

Any significant wildlife disease event will draw community and media attention and may generate emotive responses. Stakeholders for a disease event like WNS are a diverse group with different perspectives, interests and concerns. Because of this, stakeholders should be identified and engaged as a prevention, preparedness and early response activity. Consultation with stakeholders is critical to ensure compliance with response measures such as closing caves to human access, and biosecurity and decontamination procedures. Experts in (Australian) bat ecology, immunology, wildlife disease and epidemiology should be consulted for technical advice throughout a response. These experts may be situated within government agencies, universities or special interest groups such as the Australasian Bat Society.

Wildlife Health Australia is a key stakeholder that can assist with communication and coordination where needed.

Stakeholders will vary depending on the situation and location, but may include the following:

- Commonwealth agriculture, environment, and health agencies (including the Environmental Biosecurity Office, Office of the Threatened Species Commissioner, and the Department of Health, Disability and Ageing).
- State agriculture, environment, and health agencies, including Chief Veterinary Officers, WHA State/Territory Coordinators and Environment Representatives
- Local government
- Wildlife Health Australia
- Species Recovery Teams (where appropriate)
- Australasian Bat Society[b]

[a] https://www.agriculture.gov.au/biosecurity-trade/policy/emergency/nebra
[b] A non-profit organisation with the primary aim of promoting the conservation of all Australasian bats http://ausbats.org.au

- Australasian Cave and Karst Management Association[a]
- Australian Speleological Federation[b]
- Local Indigenous groups
- Other/local caving groups
- Tourism Australia
- National Parks staff and volunteers
- Bat carers
- Universities/researchers
- Private landholders with caves on or near their land
- Mine owners and managers
- Local conservation groups
- Interested members of the public.

4.6. Workplace health and safety

No human health risk from WNS has been identified. However, there is a risk of exposure to other diseases such as Australian bat lyssavirus (ABLV) through handling bats. Bats should only be handled by trained people who have current rabies immunity[c] and using appropriate personal protective equipment (PPE).

In the event of a bat bite, scratch or other significant contact, first aid should be applied immediately and urgent medical attention sought (even if the person is vaccinated as further booster doses of rabies vaccine are required). This includes where contact has occurred between the saliva or neural tissue of a bat and the mucous membranes (eyes, nose and mouth) or non-intact skin of a person. For further information see public health and biosecurity guidelines.[d,e,f,g] Any communications to the public should include strong advice not to handle bats, but instead to contact a local wildlife care organisation or veterinarian if a sick, injured or orphaned bat is found.

Another infectious disease risk associated with visiting bat caves is histoplasmosis. This disease is caused by the fungus *Histoplasma capsulatum*, which is found in soil with high organic content and bird and bat droppings e.g. in bat caves. Human infection occurs from inhaling fungal spores when contaminated soil, dust or guano is disturbed (e.g. for sample collection). People who are immunosuppressed are at increased risk of serious illness. While exposure is not common, it is more frequent in New South Wales and Queensland. Wherever *H. capsulatum* may occur, a properly fitted particulate respirator should be

[a] A professional association for all those responsible for, or interested in, planning and management of limestone landscapes and caves in the Australasian region and beyond http://www.ackma.org

[b] A national body representing caving clubs, and representing Australia in the International Union of Speleology, with a primary objective of protecting the cave and karst environment of Australia http://www.caves.org.au

[c] Australian Technical Advisory Group on Immunisation. Australian Immunisation Handbook – Rabies and other lyssviruses https://immunisationhandbook.health.gov.au/contents/vaccine-preventable-diseases/rabies-and-other-lyssaviruses

[d] Department of Health. Rabies Virus and Other Lyssavirus (Including Australian Bat Lyssavirus) Exposures and Infections. CDNA National Guidelines for Public Health Units https://www.cdc.gov.au/resources/publications/rabies-and-other-lyssavirus-cdna-national-guidelines-public-health-units

[e] https://www.worksafe.qld.gov.au/__data/assets/pdf_file/0021/18345/lyssavirus-handling-bats.pdf and https://www.worksafe.qld.gov.au/resources/videos/films/safe-bat-handling

[f] Wildlife Health Australia National Wildlife Biosecurity Guidelines https://www.wildlifehealthaustralia.com.au/Portals/0/ResourceCentre/BiosecurityMgmt/National_Wildlife_Biosecurity_Guidelines.pdf

[g] Australian Veterinary Association Guidelines for Veterinary Personal Biosecurity https://www.ava.com.au/library-journals-and-resources/ava-other-resources/veterinary-personal-biosecurity/

worn.[a,b] There are also physical risks associated with accessing and working in a cave environment. Cave safety guidelines are available from the Australian Speleological Federation.[c]

Health and safety risks associated with hazardous chemicals used for disinfecting equipment need to be managed. Refer to the safety data sheet of the product for more information.

4.7. Strategies for control and eradication

4.7.1. Identification and engagement of stakeholders

Engagement with stakeholders at all stages of the response is a high priority and should be context-relevant.

It is crucial that stakeholders be involved as early as possible in a response. As well as providing technical advice, these groups may provide a source of experienced, vaccinated volunteers to assist with surveillance and response activities if required and appropriate. Engagement with stakeholders such as bat researchers, carers and cavers will help facilitate cooperation with controls such as cave closures and adherence to biosecurity protocols. They may also be a good source of local information.

4.7.2. Disease surveillance

Surveillance to determine the extent of the disease is a high priority.
Surveillance will:

- Provide information to assist and refine the epidemiological assessment
- Monitor disease spread including tracing back and forward
- Determine the susceptibility of Australian microbats to WNS
- Identify potentially susceptible species and populations.
- Assist with decision-making for management activities
- Monitor the effectiveness of the response.

General surveillance networks can be established and existing networks utilised or strengthened to detect new cases and locations. Relying on opportunistic observation of sick or dead bats is unlikely to be sufficient, as small numbers of bat deaths are not uncommon under normal conditions, rats in caves remove carcasses, many bats hibernate in unknown locations, and disturbance of hibernating bats by people entering caves is discouraged.

A coordinated and consistent targeted disease surveillance program should be established in affected and non-affected areas, guided by the findings of the epidemiological assessment. Monitoring for sick and dead bats will be most useful from mid to late winter, i.e. July to September, but monitoring of surrounding caves to determine the extent of spread of the pathogen can occur at any time of year through environmental sampling and sampling of bats (trapping at the mouth of the cave or sampling bats on walls). Standardised protocols for sampling of bats and the environment are recommended (see WHA Guidelines on sample submission for WNS exclusion testing), as well as coordinated collection and management of surveillance data.

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[a] http://conditions.health.qld.gov.au/HealthCondition/condition/14/92/76/Histoplasmosis
[b] https://www.cdc.gov/histoplasmosis/?CDC_AAref_Val=https://www.cdc.gov/fungal/diseases/histoplasmosis/
[c] ASF Safety Guidelines http://www.caves.org.au/administration/codes-and-standards/send/8-codes-and-standards/15-safety-guidelines

Sampling techniques should be optimised to prevent transmission of disease e.g. to minimise physical contact of bats within harp traps, bats can be removed individually shortly after trapping. Harp-traps and other equipment should also be decontaminated after a site visit, and, if possible, site-specific equipment should be used (see *Biosecurity and decontamination*).

While non-destructive sampling techniques are useful, it may be necessary to euthanise a small number of bats to confirm the diagnosis (only after obtaining the necessary approvals or licencing as required for the jurisdiction).

Rapid diagnosis and processing of samples will be critical for surveillance activities. Depending on the extent of the outbreak, it may be necessary to develop capacity at laboratories other than CSIRO-ACDP, such as state/territory government laboratories.

Some of the other unique challenges associated with WNS surveillance that should be considered include:

- Resourcing - people who are vaccinated and experienced in bat handling, and sufficient equipment to prevent contamination of uninfected sites. Stakeholder groups may be a source of volunteers and/or equipment
- Health and safety issues - working in caves and with bats
- Biosecurity – fungal spores are spread by fomites, and rigorous decontamination procedures are required.

4.7.3. Biosecurity and decontamination

Biosecurity is a high priority given that fungal spores can be spread on fomites and humans have been implicated in the spread of WNS in North America.

Biosecurity is critical to prevent inadvertent transfer of *P. destructans* on clothes, equipment, vehicles and other fomites. Biosecurity and decontamination will be particularly critical for surveillance teams. Protocols should provide recommendations on PPE, movement between sites and decontamination. Training in the use of PPE, biosecurity principles and decontamination procedures should be provided to people visiting sites.

For guidance on minimising the risk of spread of disease in caves, including detailed guidance on decontamination of equipment, see the US National White-Nose Syndrome Decontamination Protocol,[a] which is regularly updated and contains guidelines on product use and suggested procedures, and the WHA Biosecurity guidelines for bat research in caves in Australia. As an overview:

- Equipment that is disposable or can be effectively decontaminated should be selected whenever possible. The impact of treatment on equipment should be considered.
- The first step in decontamination is cleaning, to remove all dirt and debris.
- The preferred treatment (after cleaning) is submersion in hot water, maintaining a temperature of at least 55°C for a minimum of 5 continuous minutes.
- Equipment that cannot be immersed in water can be treated with an appropriate disinfectant, as outlined in the above protocol and guidelines e.g. isopropyl alcohol (50–70%), sodium hypochlorite or bleach (8.25%), Virkon® S, and disinfectant wipes containing 70% isopropyl alcohol or quaternary ammonium compounds (e.g., Clorox®).

[a] https://www.whitenosesyndrome.org/_files/ugd/18444a_809d5f1c71f6483cb771de0728cab6cb.pdf

Site-specific protocols will need to be developed by the responding agency for management of equipment, vehicles and waste material. This includes field equipment such as clothing, footwear, caving equipment (harnesses, ropes, helmets, backpacks), trapping and sampling equipment, gloves, cameras and other electronics, torches, containers, bags and vehicles (inside and out). For example, the South Australian Department for Environment and Water (DEW) has developed a WNS biosecurity policy and procedure for activities such as research and recreational caving (where it is managed by DEW) and DEW-managed sites including Naracoorte caves, which serves as a breeding site for the critically endangered southern bent-wing bat. Off-site areas such as laboratories, veterinary / wildlife hospitals, offices or homes also need to be considered. For general information, refer also to the *AUSVETPLAN Operational Procedures Manual on Decontamination*.[a]

Careful planning of site visits for surveillance and other activities is required. Ideally, site-dedicated equipment (clothing, footwear, research and caving equipment) will be used. Where this is not feasible, separate sets of equipment may be maintained for known infected and other 'clean' sites. 'Clean' equipment must be stored separately, without any contact with potentially contaminated equipment, and infected sites should only be visited after those which are believed to be uninfected. For a detailed example of decision-making for biosecurity including a flow chart for movement of equipment, see the US *National White-Nose Syndrome Decontamination Protocol*.**Error! Bookmark not defined.**

Individual response plans may be developed for some caves. Examples from North America show a range of approaches to biosecurity where caves have remained open, from decontamination of visitor's shoes through to a full change of clothes before entry (see *Cave management*). Some American states have developed flow charts to assist in decision making, and certification documents for cave visitors (e.g. *White-Nose Syndrome Response Plan - Mammoth Cave National Park, Appendix C p21*).[b]

As well as the prevention of human-mediated spread of disease between sites, biosecurity protocols should be developed to prevent bat-to-bat spread during capture and handling in the field. Trapping of bats (e.g. harp traps) often results in individuals from different species coming into contact. A moratorium on trapping of bats for research may be considered to help prevent disease transmission through this method. Detailed biosecurity protocols will also be needed for off-site situations such as veterinary care, bat rehabilitation, captive facilities, research facilities and laboratories. This would include appropriate isolation and management of individual bats, and the use of hygiene, PPE and disinfection to prevent any spread of the pathogen. Guidelines for carers have been developed in the UK and are available online.[c] For general advice on biosecurity, see the WHA National Wildlife Biosecurity Guidelines.

Education and communication through stakeholder groups and the media will be critical to ensure that biosecurity messages reach people working with bats, cavers, and members of the public (see *Public awareness: Education and Communication*).

4.7.4. Conservation activities

Conservation activities are a high priority, to protect bat populations affected by WNS, particularly for threatened species.

[a] Animal Health Australia (2024). Operational procedures manual: Decontamination (Version 5.1). Australian Veterinary Emergency Plan (AUSVETPLAN), Edition 5, Canberra, ACT https://animalhealthaustralia.com.au/ausvetplan/
[b] https://parkplanning.nps.gov/projectHome.cfm?ProjectID=31851
[c] https://www.bats.org.uk/about-bats/threats-to-bats/white-nose-syndrome/information-for-bat-workers

Activities to mitigate the impact of WNS on bat populations include:

- Mitigation of other threatening processes and sources of morbidity and mortality that could compound the impact of WNS.
- Reducing stress to hibernating bats e.g. closing caves to visitor access and reducing disturbance by researchers.
- Protection and restoration of bat habitat and food sources to support bat populations.
- Assessing the risk to bat species from WNS and listing species as threatened, as necessary.
- Captive management e.g. captive breeding for insurance populations, maintaining bats in captivity during winter. Captive breeding provides an opportunity to re-establish wild populations, however, is only likely to be useful if the disease situation changes i.e. if suitable disease-free sites are identified and can be maintained, if the disease can be eradicated, or if vaccines become available.
- See also *Supportive treatment of infected bats* and *Environmental modification*.

4.7.5. Cave management

4.7.5.1. *Closure of caves to human access - Quarantine*

Restricting human access to caves is a high priority given that fungal spores can be spread on fomites. Humans have been implicated in the spread of WNS in North America.

Closing caves (and mines) to human access is a key step in preventing human-mediated spread of WNS. Closures may be temporary or permanent, depending on the situation and likely impact. Widespread temporary closure of all caves in a region may also be considered at the time of first detection, until the situation is better understood, analogous to a standstill imposed during an outbreak of livestock disease. As well as preventing disease spread, closing caves protects diseased bats from further disturbance by human visitors. An alternative to full closure is to restrict access through a permit or approval process. Where a decision is made not to close a cave, a biosecurity plan should be developed (see *Biosecurity and decontamination*).

Different approaches and approvals for cave closures may be required depending on the type of land e.g. public, private, National Park, Commonwealth etc. Closure of popular caves to human access may not be readily accepted by the public, cavers or cave managers and there is a potential loss of income from tourism for some caves, so consultation with stakeholders will be critical in ensuring compliance.

Officially closing a cave to deter people from entering can be done using signs, tape, fencing, etc (see also *Public awareness: Education and communication*). Physical closure methods that prevent human access but allow continued access by bats have been used for various purposes overseas but are unlikely to be feasible for most at-risk Australian bat species.

If the *P. destructans* pathogen is detected in a cave where no bats are dwelling, the cave could be sealed off to prevent bat and human access, and surveillance conducted in the surrounding area to monitor the situation.

4.7.5.2. *Show caves*

Caves with regular human access should be assessed for the risk of introduction of *P. destructans*, using criteria such as bat use of the site, number and type of visitors expected and tour type (unrestricted access, crawling tour, walking tour, etc.), and appropriate mitigations should be implemented.

Specific recommendations for show cave management[a] have been developed in North America and include a flow-chart for management recommendations and a user-friendly risk assessment worksheet for site operators.

4.7.6. Public awareness: Education and communication

Education and communication are a high priority in order to promote early detection by encouraging rapid reporting of suspect cases, prevent further spread of the disease, improve compliance with response actions, and support affected bat populations by avoiding disturbance during hibernation.

Effective communication to the public will:

- Inform them of the situation
- Provide information about the potential significance to biodiversity
- Provide information about planned response actions
- Provide advice on what to look for and how to report (see WHA How to Report a Suspect Case of White-Nose Syndrome)
- Ask for their assistance in complying with response measures such as cave closures.

Human health messages should be included to allay fears of a potential human health risk from WNS, but to remind the public that bats should not be handled due to the risk of other diseases. Balanced communication is important to avoid contributing to negative public perceptions of bats, which can lead to persecution (see the WHA Flying-foxes and Microbats: A Public Health Communication Guide for Government Media Teams for guidance and talking points). Messages may be shared through media releases, social media, on websites (e.g. government agencies, parks, special interest groups - see *Stakeholders*), at park entrances, through permit application processes, and directly to private landholders. Tailored messages can be prepared to target particular stakeholder groups e.g. educating cavers on the importance of decontamination procedures and the reason for cave closures; raising awareness of the signs of WNS among people who come in contact with bats; informing landholders with caves or mines on their land. Messages should also highlight the risk of spreading *P. destructans* from Australia to other parts of the world where this pathogen has not been found.

Examples of messaging in and around caves, including those open to visitors, are available online.[a]

4.7.7. Epidemiological assessment

An immediate assessment of the epidemiological situation should be undertaken, including aspects such as seasonality, species, ecology, geographical range, human access and activity, transmission pathways,

[a] White-nose Syndrome Disease Management Working Group. 2019. WNS show cave guidance: recommended practices to reduce risks of people spreading the fungus *Pseudogymnoascus destructans* (p 15). https://s3.us-west-2.amazonaws.com/prod-is-cms-assets/wns/prod/920cf500-0c6e-11ea-a154-67ca1cde5e5d-FINAL-WNS-Show_cave_guidance_11122019.pdf

etc. Ongoing monitoring of the epidemiological situation will help to determine whether the response is effective or if a change of approach is required.

A general assessment of the risk that WNS poses to southern bent-wing bats in Victoria has recently been undertaken [9] and can serve as an example for similar efforts in the future as more data on Australian bat ecology becomes available.

4.7.8. Supportive treatment of infected bats

Specific chemical or biological treatments are currently not available. An alternative is to provide supportive therapy to assist bats to recover from the disease and clear the fungus by bringing bats into captivity, raising their body temperature and providing food [68]; see *Treatment and vaccination of affected bats*). Recovered bats could then be released after winter. This is unlikely to be feasible for large numbers of bats but may still be a useful option for threatened species or an important colony. While it is unclear how long Australian species could harbour the fungus once infected, bats suffering from WNS in North America have generally tested positive for up to 70 days after being brought into captivity, and this extended timeframe would need to be considered.

After bringing the bats into captivity, the infected cave could be physically closed to any access by bats, humans or other animals to prevent re-infection from the environment. Environmental treatment of the cave to remove the fungus may be considered, and suitable methods may involve volatile organic compounds, UV-treatment, or modification of cave microclimates (see *Environmental treatment*).

4.7.9. Environmental modification

Environmental modification is directed at reducing growth and/or transmission of *P. destructans* or supporting infected bats to reduce the impact of disease.

Temperature and humidity

Environmental modification of temperature and humidity is considered to have potential as a long-term solution, and these methods have been used in some instances in the USA [59]. Options include manipulation of the temperature and/or humidity around hibernating bats by physically altering the cave entrance, restricting access of bats to some areas of a cave, or by creating ‘thermal refugia’ or localised warm areas where bats can retreat during periods of arousal from hibernation.

However, these modifications will not be feasible for all sites. There are also possible unintended consequences on other species within caves, unknown impacts on hibernation patterns, and the risk of deterring bats from the site (see *Environmental treatment*).

Food and water

Provision of supplemental food and water during winter has been suggested to reduce starvation and dehydration resulting from WNS, however bats may not learn to take supplemental food and feeding bats during hibernation may result in physiological problems [69].

An alternative is to alter the environment to provide water and food around caves in vulnerable areas e.g. establish crops to accumulate insects and establish wetlands. This could be done proactively to support at-risk populations ahead of a disease front. UV-lures outside of caves may also be considered as a practical approach in the pre- or post-winter timeframe, attracting more prey insects to specific bat hibernacula. Pilot studies of this approach are encouraged, as some bat species may be repelled by the use of UV-lights [53].

4.7.10. Depopulation (Culling)

Culling of bats is only considered an appropriate response in very specific circumstances and must be conducted humanely with appropriate permits or licences. It presents logistic challenges.

Culling is only considered an appropriate response in very specific circumstances, where eradication is considered feasible e.g. where WNS is detected soon after introduction and it is certain that only one site is infected. In this case generalised culling (total culling of the bat colony) and physical sealing of the cave could be considered, however total culling of a colony is likely to be logistically difficult as bats rouse periodically and fly during hibernation and are known to move between adjacent sites. Approval for culling would need to be obtained, including an exemption under the EPBC Act if it is a listed threatened species, and any state/territory approvals according to relevant legislation.[a] If culling is to be undertaken, animal welfare must be considered and only best-practice, humane methods used. Selection of the best method will depend on the particular circumstances and must take into account current recommendations for euthanasia of animals.[b]

In all other situations culling is not recommended. Depopulation of wild animals for disease control has generally not been found to be effective, and in some cases may even exacerbate the disease by encouraging dispersal of surviving animals and creating vacant niches for other animals to enter. Culling may also impact threatened species or populations, and result in significant negative reaction by stakeholders and the public.

Targeted culling to remove infected individuals is generally not recommended for management of WNS for a variety of reasons, including that bats are highly mobile animals, there are high contact rates within colonies, individuals with resistance to the disease may be removed, and there is already a high prevalence of infection early in the hibernation period [69-71]. Culling has no impact on *P. destructans* in the environment as the fungus can persist in the absence of bats, and modelling has shown that generalised culling does not improve the long-term survival of a colony [71].

An alternative to culling where only one or two locations are infected and a relatively small number of bats are affected, is to bring the bats into captivity to recover, and physically close the cave (see *Supportive treatment of infected bats*).

4.8. Management options in development

The management options listed below are not currently available, however the situation may change as research progresses, and these options can then be incorporated into a response.

[a] http://www.environment.gov.au/epbc/what-is-protected; http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl
[b] AVMA Guidelines for the Euthanasia of Animals https://www.avma.org/KB/Policies/Pages/Euthanasia-Guidelines.aspx

4.8.1. Chemical or biological treatment of infected bats

There are a number of challenges in achieving effective treatment for WNS:

- Treatment of bats leaves the environment infected, so if treatment offers only short-term protection, re-infection is likely.
- The proportion of the population that needs to be treated to achieve success may not be known.
- The disturbance associated with treatment (or the treatment itself) may have an impact on hibernating bats.
- The effects of the treatment on other species and cave ecology may not be known.

While chemical and biological treatments for infected bats are under development, there are no scalable treatments that have been fully validated or widely accepted. Delivery of treatments on a broad scale presents logistic difficulties, particularly if repeated treatments are necessary. Options could include fogging, with the disadvantage of potentially affecting other microbial cave flora, or hand delivery, which would only be feasible for a small number of bats. Treatment of individual bats may be a more viable option for bats in care or captivity, or for genetically valuable animals.

While initial work demonstrated that *P. destructans* is susceptible to several antifungal drugs e.g. voriconazole and amphotericin B [72, 73], some have shown to be harmful to bats and their effects on the ecosystem are unclear, and therefore should not be used on bats.

Further research is underway overseas, for example:

- Probiotic bacteria: Certain bacteria naturally occurring within the microbiome of resistant or tolerant bat species have been isolated and have been considered for direct topical treatment of affected bats. Examples of reagents successfully used in field trials include *Pseudomonas fluorescens* [49].

- Use of volatile organic compounds: Instead of the bacteria themselves, fungistatic compounds they produce have been isolated from bat wing and soil microbes for use as gaseous compounds. The benefit is the ability to be used in aerosolised form. However, field trials show mixed results, ranging from no clear benefit [57] to an apparent increase in *P. destructans* growth [50].

- Immune-modulating therapeutics: Since immune dysregulation and resulting sepsis are postulated to contribute significantly to mortality in WNS-susceptible species, agents that inhibit these inflammatory processes have been suggested as treatment options [17].

4.8.2. Vaccination

Vaccination against WNS and other methods of increasing immunity are the subject of research in North America, despite the challenge of weakened immune response during hibernation. Challenges of administering a vaccine are similar to those outlined above for treatment. A safe and practical vaccine could be used to establish immune populations, reduce susceptibility to infection and disease, and reduce or prevent transmission. An oral vaccine candidate is currently being tested in the USA and shows early promise, with future plans of delivery as a paste or in aerosolised form [47].

4.8.3. Environmental treatment to reduce fungal load

Research is underway overseas to find suitable chemical treatments that can be applied to the surfaces or interior of a cave or mine to kill the fungus causing WNS, but an accepted environmental treatment option is not currently available (see also *Environmental treatment*).

Challenges of environmental treatment include:

- Treatment may affect the health of bats and other cave-dwelling species.
- Treatment is likely to affect the cave microflora, with potential ecological impacts.
- Not all hibernation sites may be known, access to caves and mines may be restricted, and the size and complexity of many caves and mines will make coverage difficult.
- Bat-to-bat transmission will not be affected.

Despite these challenges, environmental treatment could be useful in particular situations e.g. for hibernation sites for significant populations, for single sites in conjunction with treatment of bats, or where only one site is affected and eradication is possible, such that the benefit outweighs the potential ecological effects.

Appendix 1: Prevention and preparedness activities

A number of activities can be undertaken prior to an incursion of WNS to reduce the risk of introduction of the disease and to better prepare the country for an effective response.

1. Prevention of introduction

Pre- and post-border activities to prevent entry of WNS into Australia include alerts to quarantine staff, development of Australia-specific information for decontamination, asking incoming visitors about cave visits overseas, an education campaign for overseas visitors and Australians returning from overseas,[a] and information maintained on websites such as Commonwealth & state/territory government agencies, Wildlife Health Australia, and caver and bat interest groups.

2. Development of laboratory diagnostic capacity

Testing for *P. destructans* is available at CSIRO-ACDP, but not currently at state/territory government laboratories. It is important to maintain laboratory capacity to confirm and respond to an event, including ongoing development of laboratory tests and monitoring overseas developments in diagnostics. Exclusion testing of suspect cases assists in maintaining diagnostic capacity.

3. Surveillance and early detection

The likelihood of early detection of a WNS incursion can be improved by:

- Awareness campaigns for recognising and reporting suspect cases (see below)
- Advising veterinarians on appropriate sample submission for suspect cases (see WHA Guidelines on sample submission for WNS exclusion testing).
- Targeted surveillance in caves considered as high risk for point of entry (sampling of cave environment +/- bats)
- Provision of sample kits, protocols and training to field researchers, rangers, etc. for swabbing cave walls.

Targeted education and training will help ensure that suspect WNS cases are reported and receive the appropriate response. The initial observation of a suspect case could be from a range of sources. The visible presence of the fungus or clinical disease e.g. skin lesions, sick/dead bats could be detected and reported by a bat ecology or disease researcher, environmental manager, cave manager or staff, caver, bat carer, veterinarian, landowner or another member of the public. Advice on recognition and reporting of suspect WNS cases is provided in WHA How to Report a Suspect Case of White-Nose Syndrome. Recommended reporting is through one of the following: the state/territory WHA Coordinator[b], the Emergency Animal Disease (EAD) Hotline (1800 675 888), a local veterinarian, or WHA. Other potential reporting routes could include a park ranger, state/territory Environment agency, veterinary hospital or university. As reports may be made to the EAD Hotline, information on the significance of WNS, how it might present and what response is required should be provided to those taking hotline calls.

[a] http://agriculture.gov.au/pests-diseases-weeds/animal/white-nose-syndrome
[b] https://wildlifehealthaustralia.com.au/Incidents/WHA-Coordinator-Contacts

4. Stakeholder engagement and communication

Stakeholders for a disease event such as WNS involving bats and caves will be a diverse group, and wildlife issues in general can draw significant attention from the media and the public. Identifying and engaging with stakeholders prior to any outbreak of WNS will help prevent introduction of the disease and improve the chance of early detection of an outbreak. Established relationships will also assist with an effective response (see *Stakeholders*). A communication plan can be developed in consultation with stakeholders, ready for deployment at the start of a response.

5. Risk assessment and response plan preparation

Risk assessment and planning for specific sites or bat populations will help to identify mitigation activities. Preparation of site-specific response plans is recommended in advance of an incursion.

6. Conservation initiatives

Activities supporting vulnerable bat populations and mitigating threatening processes may help reduce the impact of WNS if it is introduced. Where appropriate, WNS should be included as a potential threat in recovery plans for threatened bat species.

7. Research to inform risk and response

Identification of key knowledge gaps and facilitation of research are considered a high priority to inform prevention and response activities. These response guidelines should be reviewed regularly to take account of new findings from research in Australia and overseas.

A formal process to identify research priorities has not been undertaken, however significant knowledge gaps were identified during the risk assessment process [7, 8]. Some of these gaps are being addressed as part of an Australian Research Council-funded project[a] and through the Southern Bent-wing Bat Recovery Team[b], as outlined below.

- Temperature and humidity in Australian caves: Recent analysis of larger datasets with higher-resolution temperature information for caves in south-east Australia has expanded the expected range of *P. destructans* if introduced [10]. Research on cave climatic conditions has been conducted on behalf of the Southern Bent-Wing Bat Recovery Team[b], and in earlier work on bent-wing bat maternity caves [74, 75]. Caves in south-east South Australia are also monitored by paleo/karst researchers.

- Body temperature of Australian bats during torpor/ hibernation: Research into the winter ecology of eastern bent-wing bats has shown that populations hibernating in colder caves are very similar to species that have declined due to WNS in North America [76]. Similar work is underway for southern bent-wing bats, but further work is needed on other species at risk.

- Susceptibility of Australian microbats to WNS: Cell culture models have been created from eastern bent-wing bat wing tissue for future *in vitro* studies of host response to *P. destructans* [77]. Further work is needed to understand differences in susceptibility among Australian species.

[a] https://www.batslab.org/white-nose-syndrome.html
[b] https://www.swifft.net.au/cb_pages/team_southern_bent-wing_bat_-_recovery_team.php

- Ecosystem services attributable to insectivorous bats and their economic importance to agriculture in Australia: The importance of bats for the cotton industry has been assessed [66]. Further research would increase the knowledge base of the importance of bats to agriculture more broadly.

- Fungal species present in Australian cave environments: Further surveillance is needed for *P. destructans* and to assess which fungal species are present in south-east Australian caves.

- Population and ecology of at-risk bat species: Regular population monitoring is being undertaken at southern bent-wing bat and eastern bent-wing bat roosts in temperate Australia[a,b] [78]. There are a number of studies on southern bent-wing bat survivorship [79, 80] and ecology [81, 82], but more information and intensive population monitoring are required for other at-risk species.

[a] https://www.swifft.net.au/cb_pages/team_southern_bent-wing_bat_-_recovery_team.php
[b] Arthur Rylah Institute unpublished data

Glossary

For up-to-date definitions of standard AUSVETPLAN terms, see the AUSVETPLAN Glossary.

Term	Definition
AUSVETPLAN	Australian Veterinary Emergency Plan. A series of response plans that describe the proposed Australian approach to an emergency animal disease incident. The documents provide guidance based on sound analysis, linking policy, strategies, implementation, coordination and emergency-management plans.
Biosecurity	The management of risks to the economy, the environment and the community, of pests and diseases entering, emerging, establishing or spreading.
Captive breeding	Bringing wild animals into captivity e.g. to rear animals for reintroduction into the wild for the purpose of conservation. *See also* Insurance population.
Decontamination	Includes all stages of cleaning and disinfection.
Depopulation	The removal of a host population from a particular area to control or prevent the spread of disease.
Disinfectant	A chemical used to destroy disease agents outside a living animal.
Emergency animal disease	A disease that is (a) exotic to Australia or (b) a variant of an endemic disease or (c) a serious infectious disease of unknown or uncertain cause or (d) a severe outbreak of a known endemic disease, and that is considered to be of national significance with serious social or trade implications. *See also* Endemic animal disease, Exotic animal disease.
Emergency Animal Disease Hotline	24-hour freecall service for reporting suspected incidences of exotic diseases — 1800 675 888.
Endemic animal disease	A disease affecting animals (which may include humans) that is known to occur in Australia. *See also* Emergency animal disease, Exotic animal disease.
Epidemiological investigation	An investigation to identify and qualify the risk factors associated with the disease.
Epidemiology	The study of disease in populations and of factors that determine its occurrence.
Exotic animal disease	A disease affecting animals (which may include humans) that does not normally occur in Australia. *See also* Emergency animal disease, Endemic animal disease.
Fomites	Inanimate objects (e.g. boots, clothing, equipment, instruments, vehicles, crates, packaging) that can carry an infectious disease agent and may spread the disease through mechanical transmission.

Hibernation or torpor	Reduction in metabolic activity and lowering of body temperature by an animal in order to conserve energy e.g. during winter when food is scarce.
Insurance population	A captive population of a wild species, designed to ensure the survival of the species. *See also* Captive breeding.
Microbats	Small bats (Order Chiroptera) that are insectivorous and use echolocation to navigate and forage.
Microflora	Collective microorganisms (bacteria, fungi) in a location or ecosystem.
Microbiome	Collective microorganisms (bacteria, fungi) within a specified organism/ tissue
Monitoring	Routine collection of data for assessing the health status of a population or the level of contamination of a site for remediation purposes. *See also* Surveillance.
Polymerase chain reaction (PCR)	A method of amplifying and analysing nucleic acid (DNA or RNA) sequences that can be used to detect the presence of viral genetic material.
Prevalence	The proportion (or percentage) of animals in a particular population affected by a particular disease (or infection or positive antibody titre) at a given point in time.
Sensitivity	The proportion of truly positive units that are correctly identified as positive by a test. *See also* Specificity.
Specificity	The proportion of truly negative units that are correctly identified as negative by a test. *See also* Sensitivity.
Surveillance	A systematic program of investigation designed to establish the presence, extent or absence of a disease, or of infection or contamination with the causative organism. It includes the examination of animals for clinical signs, antibodies or the causative organism.
Susceptible animals	Animals that can be infected with a particular disease.
Vaccination	Inoculation of individuals with a vaccine to provide active immunity.
Vaccine	A substance used to stimulate immunity against one or several disease-causing agents to provide protection or to reduce the effects of the disease. A vaccine is prepared from the causative agent of a disease, its products, or a synthetic substitute, which is treated to act as an antigen without inducing the disease.
Vector	A living organism (frequently an arthropod) that transmits an infectious agent from one host to another. A biological vector is one in which the infectious agent must develop or multiply before becoming infective to a recipient host. A mechanical vector is one that transmits an infectious agent from one host to another but is not essential to the life cycle of the agent.

Wild animals	Non-domesticated animals living without captive management or control.
- Wildlife (native)	Animal species that are endemic or indigenous to the whole or parts of Australia, whether captive or non-captive.
- Feral animal	Non-domesticated animals living without captive management or control.

Abbreviations

Abbreviation	Full title
ACDP	Australian Centre for Disease Preparedness
AUSVETPLAN	Australian Veterinary Emergency Plan
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EAD	Emergency Animal Disease
NEBRA	National Environmental Biosecurity Response Agreement
PCR	Polymerase chain reaction
PPE	Personal protective equipment
WHA	Wildlife Health Australia
WNS	White-nose syndrome
WOAH	World Organisation for Animal Health

References

Documents and guidelines

WHA fact sheet EXOTIC – White-nose Syndrome

WHA How to Report a Suspect Case of White-Nose Syndrome

WHA National Guidelines for Sample Submission – White-Nose Syndrome – Exclusion Testing

White-Nose Syndrome Response Team Case Definitions

USGS National Wildlife Health Center Bat White-Nose Syndrome/Pd Surveillance Submission Guidelines

National White-Nose Syndrome Decontamination Protocol (USA)

Animal Health Australia (2024). Operational manual: Decontamination (version 5.1). Australian Veterinary Emergency Plan (AUSVETPLAN), edition 5, Canberra, ACT

USGS NWHC Biosafety Measures for Working with *P.s destructans* in the Laboratory

WHA National Wildlife Biosecurity Guidelines

Response plan examples – USA and Canada

US and Canadian national, federal and state response plans for WNS, available from https://www.whitenosesyndrome.org/resources, with particular reference to:

- U.S. Fish and Wildlife Service (2011). A National Plan for Assisting States, Federal Agencies, and Tribes in Managing White-Nose Syndrome in Bats
- Canadian Wildlife Health Cooperative (2021). A National Plan to Coordinate the Management of Bat Health in Canada
- U.S. National Park Service (2011). Mammoth Cave National Park White-Nose Syndrome Response Plan
- Michigan Department of Natural Resources and Environment (2010). White-nose Syndrome Response Plan
- Kentucky Department of Fish and Wildlife Resources (2014). Kentucky WNS Response Plan

Cited references

1. Holz P, Hufschmid J et al. (2016) Qualitative risk assessment: White-nose syndrome in bats in Australia. . Available from: https://www.wildlifehealthaustralia.com.au/ProgramsProjects/BatHealthFocusGroup.aspx#WNS

2. Popov IV, Chikindas ML et al. (2025) Genomic insights into *Streptomyces albidoflavus* SM254: tracing the putative signs of anti-*Pseudogymnoascus destructans* properties. *Brazilian Journal of Microbiology*, **56**(3): 2121-2131

3. Fischer NM, Dumville I et al. (2025) Two distinct host-specialized fungal species cause white-nose disease in bats. *Nature*, **642**(8069): 1034-1040

4. Puechmaille SJ, Wibbelt G et al. (2011) Pan-European distribution of white-nose syndrome fungus (*Geomyces destructans*) not associated with mass mortality. *PLoS ONE*, **6**(4): e19167

5. Hoyt JR, Sun K et al. (2016) Widespread bat white-nose syndrome fungus, northeastern China. *Emerging Infectious Diseases*, **22**(1): 140-142

6. Churchill S (2009) 'Asutralian Bats.' Vol. 2nd edn. (Allen & Unwin: Crow's Nest, New South Wales)

7. Holz P, Hufschmid J et al. (2019) Does the fungus causing white-nose syndrome pose a significant risk to Australian bats? *Wildlife Research*, **46**(8): 657-668

8. Turbill C and Welbergen JA (2020) Anticipating white-nose syndrome in the Southern Hemisphere: Widespread conditions favourable to *Pseudogymnoascus destructans* pose a serious risk to Australia's bat fauna. *Australian Ecology*, **45**(1): 89-96

9. Ramsey DSL, Cripps J et al. (2025) Assessing the risks of endemic and exotic diseases to Victorian terrestrial wildlife. Available from: https://www.ari.vic.gov.au/__data/assets/pdf_file/0033/758247/Technical-Report-Series-No-387-Wildlife-disease-risk-Assessing-the-risks-of-endemic-and-exotic-diseases-to-Victorian-terrestrial-wildlife.pdf

10. Wu NC, Welbergen JA et al. (2025) Vulnerability of Southern Hemisphere bats to white-nose syndrome based on global analysis of fungal host specificity and cave temperatures. *Conservation Biology*, **39**(2): e14390

11. Haase CG, Fuller NW et al. (2021) Body mass and hibernation microclimate may predict bat susceptibility to white-nose syndrome. *Ecology and Evolution*, **11**(1): 506-515

12. Kailing MJ, Hoyt JR et al. (2023) Sex-biased infections scale to population impacts for an emerging wildlife disease. *Proceedings of the Royal Society of London - Series B: Biological Sciences*, **290**(1995): 20230040

13. Frick WF, Puechmaille SJ et al. (2015) Disease alters macroecological patterns of North American bats. *Global Ecology and Biogeography*, **24**: 741-749

14. Langwig KE, Frick WF et al. (2016) Drivers of variation in species impacts for a multi-host fungal disease of bats. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **371**(1709)

15. Loeb SC, Bridges WCJ et al. (2025) Winter activity of tricolored bats in aboveground and subterranean hibernacula in the southeastern USA. *Scientific Reports*, **15**(1): 13644

16. Troitsky TS, Laine VN et al. (2023) When the host's away, the pathogen will play: the protective role of the skin microbiome during hibernation. *Animal Microbiome*, **5**(1): 66

17. Kwait RE, Eskew EA et al. (2025) Transcriptomic evidence of cytokine storm and sepsis in little brown bats exposed to white-nose syndrome. *Conservation Physiology*, **13**(1): coaf040

18. Whiting-Fawcett F, Blomberg AS et al. (2025) A Palearctic view of a bat fungal disease. *Conservation Biology*, **39**(1): e14265

19. Zukal J, Bandouchova H et al. (2016) White-nose syndrome without borders: *Pseudogymnoascus destructans* infection tolerated in Europe and Palearctic Asia but not in North America. *Scientific Reports*, **6**(1): 19829

20. Fritze M, Puechmaille SJ et al. (2021) Determinants of defence strategies of a hibernating European bat species towards the fungal pathogen *Pseudogymnoascus destructans. Developmental and Comparative Immunology*, **119**: 104017

21. Gagnon MF, Turner GG et al. (2025) Long-term trends in the extent of *Pseudogymnoascus destructans* infection in little brown myotis. *Biological Conservation*, **302**: 110954

22. Wiens AM and Thogmartin WE (2022) Gaussian process forecasts *Pseudogymnoascus destructans* will cover coterminous United States by 2030. *Ecology and Evolution*, **12**(11): e9547

23. Holz PH, Lumsden LF et al. (2018) Two subspecies of bent-winged bats (*Miniopterus orianae bassanii* and *oceanensis*) in southern Australia have diverse fungal skin flora but not *Pseudogymnoascus destructans. PLOS ONE*, **13**(10): e0204282

24. Lorch JM, Meteyer CU et al. (2011) Experimental infection of bats with *Geomyces destructans* causes white-nose syndrome. *Nature*, **480**(7377): 376-378

25. Reeder SM, Palmer JM et al. (2017) *Pseudogymnoascus destructans* transcriptome changes during white-nose syndrome infections. *Virulence*, **8**: 1695-1707

26. Langwig KE, Frick WF et al. (2015) Host and pathogen ecology drive the seasonal dynamics of a fungal disease, white-nose syndrome. *Proceedings of the Royal Society B: Biological Sciences*, **282**(1799): 20142335

27. Huebschman JJ, Hoerner SA et al. (2019) Detection of *Pseudogymnoascus destructans* on Wisconsin bats during summer. *Journal of Wildlife Diseases*, **55**(3): 673-677

28. Campbell CJ, Nelson DM et al. (2022) White-nose syndrome pathogen *Pseudogymnoascus destructans* detected in migratory tree-roosting bats. *Journal of Wildlife Diseases*, **58**(3): 652-657

29. Mustachio A and Bodri MS (2019) Can ectoparasites be implicated in the spread of *Pseudogymnoascus destructans*? *Journal of Wildlife Diseases*, **55**(3): 704-706

30. Zhelyazkova VL, Fischer NM et al. (2024) Bat white-nose disease fungus diversity in time and space. *Biodiversity Data Journal*, **12**: e109848

31. Ballmann AE, Torkelson MR et al. (2017) Dispersal Hazards of Pseudogymnoascus Destructans by Bats and Human Activity at Hibernacula in Summer. *Journal of Wildlife Diseases*, **53**(4): 725-735

32. Lorch JM, Muller LK et al. (2013) Distribution and environmental persistence of the causative agent of white-nose syndrome, *Geomyces destructans*, in bat hibernacula of the Eastern United States. *Applied and Environmental Microbiology*, **79**(4): 1293-1301

33. DELWP (2020) National recovery plan for the southern bent-wing bat *Miniopterus schreibersii bassanii*,

34. Martinkova N, Pikula J et al. (2018) Hibernation temperature-dependent *Pseudogymnoascus destructans* infection intensity in Palearctic bats. *Virulence*, **9**(1): 1734-1750

35. Verant ML, Boyles JG et al. (2012) Temperature-dependent growth of *Geomyces destructans*, the fungus that causes bat white-nose syndrome. *PLOS ONE*, **7**(9): e46280

36. Campbell LJ, Walsh DP et al. (2020) Long-term survival of *Pseudogymnoascus destructans* at elevated temperatures. *Journal of Wildlife Diseases*, **56**(2): 278-287

37. Hoyt JR, Langwig KE et al. (2015) Long-term persistence of *Pseudogymnoascus destructans*, the causative agent of white-nose syndrome, in the absence of bats. *EcoHealth*, **12**(2): 330-333

38. Urbina J, Chestnut T et al. (2021) *Pseudogymnoascus destructans* growth in wood, soil and guano substrates. *Scientific Reports*, **11**(1): 763

39. Verant ML, Meteyer CU et al. (2014) White-nose syndrome initiates a cascade of physiologic disturbances in the hibernating bat host. *BMC Physiology*, **14**(1): 10

40. Reeder DM, Frank CL et al. (2012) Frequent arousal from hibernation linked to severity of infection and mortality in bats with white-nose syndrome. *PLoS ONE*, **7**(6): e38920

41. Meteyer CU, Buckles EL et al. (2009) Histopathologic criteria to confirm white-nose syndrome in bats. *Journal of Veterinary Diagnostic Investigation*, **21**(4): 411-414

42. Muller LK, Lorch JM et al. (2013) Bat white-nose syndrome: a real-time TaqMan polymerase chain reaction test targeting the intergenic spacer region of *Geomyces destructans. Mycologia*, **105**(2): 253-259

43. Shuey MM, Drees KP et al. (2014) Highly sensitive quantitative PCR for the detection and differentiation of Pseudogymnoascus destructans and other Pseudogymnoascus species. *Applied and Environmental Microbiology*, **80**(5): 1726-1731

44. Niessen L, Fritze M et al. (2022) Development and application of loop-mediated isothermal amplification (LAMP) assays for rapid diagnosis of the bat white-nose disease fungus *Pseudogymnoascus destructans. Mycopathologia*, **187**(5-6): 547-565

45. Greening SS, Haman K et al. (2024) Validation of a field-portable, handheld real-time PCR system for detecting *Pseudogymnoascus destructans*, the causative agent of white-nose syndrome in bats. *Journal of Wildlife Diseases*, **60**(2): 298-305

46. Reeder DM, Ghannoum MA et al. (2010) Treatments for White Nose Syndrome. Available from: https://rcngrants.org/sites/default/files/final_reports/2010-01%20FINAL%20grant%20report.pdf

47. Rocke TE, Kingstad-Bakke B et al. (2019) Virally-vectored vaccine candidates against white-nose syndrome induce anti-fungal immune response in little brown bats (*Myotis lucifugus*). *Scientific Reports*, **9**(1): 6788

48. Johnson JS, Reeder DM et al. (2015) Antibodies to *Pseudogymnoascus destructans* are not sufficient for protection against white-nose syndrome. *Ecology and Evolution*, **5**(11): 2203-2214

49. Hoyt JR, Langwig KE et al. (2019) Field trial of a probiotic bacteria to protect bats from white-nose syndrome. *Scientific Reports*, **9**(1): 9158

50. Hooper S and Amelon S (2023) Contact-independent exposure to *Rhodococcus rhodochrous* DAP96253 volatiles does not improve the survival rate of *Myotis lucifugus* (little brown bats) affected by White-nose Syndrome. *PeerJ*, **11**: e15782

51. Meteyer CU, Valent M et al. (2011) Recovery of little brown bats (*Myotis lucifugus*) from natural infection with *Geomyces destructan*s, white-nose syndrome. *Journal of Wildlife Diseases*, **47**(3): 618-626

52. Frick WF, Dzal YA et al. (2023) Bats increased foraging activity at experimental prey patches near hibernacula. *Ecological Solutions and Evidence*, **4**(1): e12217

53. Freeze SR, Deeley SM et al. (2025) The bat signal: An ultraviolet light lure to increase acoustic detection of bats. *Animals*, **15**(16): 21

54. Micalizzi EW and Smith ML (2020) Volatile organic compounds kill the white-nose syndrome fungus, *Pseudogymnoascus destructans*, in hibernaculum sediment. *Canadian Journal of Microbiology*, **66**(10): 593-599

55. Korn VL, Pennerman KK et al. (2021) Trans-2-hexenal downregulates several pathogenicity genes of *Pseudogymnoascus destructans*, the causative agent of white-nose syndrome in bats. *Journal of Industrial Microbiology and Biotechnology*, **48**(9-10): 23

56. Lu Y, Zhu Y et al. (2025) Antifungal mechanism of ketone volatile organic compounds against *Pseudogymnoascus destructans. Virulence*, **16**(1): 2569627

57. Gabriel KT, McDonald AG et al. (2022) Development of a multi-year white-nose syndrome mitigation strategy using antifungal volatile organic compounds. *PLoS ONE*, **17**(12): e0278603

58. Kwait R, Kerwin K et al. (2022) Whole-room ultraviolet sanitization as a method for the site-level treatment of *Pseudogymnoascus destructans. Conservation Science and Practice*, **4**(5): e623

59. Turner GG, Sewall BJ et al. (2022) Cooling of bat hibernacula to mitigate white-nose syndrome. *Conservation Biology*, **36**(2): e13803

60. Boyles JG, Brack Jr V et al. (2023) Balancing costs and benefits of managing hibernacula of cavernicolous bats. *Mammal Review*, **53**(3): 133-142

61. Hopkins SR, Hoyt JR et al. (2021) Continued preference for suboptimal habitat reduces bat survival with white-nose syndrome. *Nature communications*, **12**(1): 166

62. Salleh S, Cox-Witton K et al. (2020) Caver knowledge and biosecurity attitudes towards white-nose syndrome and implications for global spread. *Ecohealth*, **17**(4): 487-497

63. Johnson C, Brown DJ et al. (2021) Long-term changes in occurrence, relative abundance, and reproductive fitness of bat species in relation to arrival of White-nose Syndrome in West Virginia, USA. *Ecology and Evolution*, **11**(18): 12453-12467

64. Mallinger EC, Goodwin KR et al. (2023) Species-specific responses to white-nose syndrome in the Great Lakes region. *Ecology and Evolution*, **13**(7): e10267

65. Wray AK, Gratton C et al. (2022) Disease-related population declines in bats demonstrate non-exchangeability in generalist predators. *Ecology and Evolution*, **12**(6): e8978

66. Kolkert H, Smith R et al. (2021) Insectivorous bats provide significant economic value to the Australian cotton industry. *Ecosystem Services*, **49**: 101280

67. National Parks and Wildlife Service South Australia (2020) Value of South Australia's National Parks and Reserves. Study 1: Economic contribution of nature-based tourism in parks summary report. Available from: https://data.environment.sa.gov.au/Content/Publications/Economic-value-of-SAs-Parks-Summary-Report.pdf

68. Fuller NW, McGuire LP et al. (2020) Disease recovery in bats affected by white-nose syndrome. *Journal of Experimental Biology*, **223**(Pt 6): 23

69. Foley J, Clifford D et al. (2011) Investigating and managing the rapid emergence of white-nose syndrome, a novel, fatal, infectious disease of hibernating bats. *Conservation Biology*, **25**(2): 223-31

70. Hallam TG and McCracken GF (2011) Management of the panzootic white-nose syndrome through culling of bats. *Conservation Biology*, **25**(1): 189-94

71. Meyer AD, Stevens DF et al. (2016) Predicting bat colony survival under controls targeting multiple transmission routes of white-nose syndrome. *Journal of Theoretical Biology*, **409**: 60-69

72. Chaturvedi S, Rajkumar SS et al. (2011) Antifungal testing and high-throughput screening of compound library against *Geomyces destructans*, the etiologic agent of geomycosis (WNS) in bats. *PLoS One*, **6**(3): e17032

73. Beekman CN, Meckler L et al. (2018) *Galleria mellonella* as an insect model for *P. destructans*, the cause of White-nose Syndrome in bats. *PLoS One*, **13**(9): e0201915

74. Baudinette R, Wells R et al. (1994) Microclimatic conditions in maternity caves of the bent-wing bat, Miniopterus schreibersii: an attempted restoration of a former maternity site. *Wildlife Research*, **21**(6): 607-619

75. Dwyer P and Hamilton-Smith E (1965) Breeding caves and maternity colonies of the bent-winged bat in south-eastern Australia. *Helictite*, **4**(1): 3-21

76. Villada-Cadavid T, Wu NC et al. (2025) Winter torpor and body mass patterns of a cave-roosting bat in cool and warm climates. *Oecologia*, **207**(12): 193

77. Langguth A, Brannelly LA et al. (2025) Deriving fibroblast cell lines from wing-punch biopsies of Australian eastern bent-winged bats (*Miniopterus orianae oceanensis). PeerJ*, **13**: e20222

78. Mills D (2021) Summer and autumn activity patterns of the eastern bent-wing bat (Miniopterus orianae oceanensis) at a large maternity site in southern New South Wales1. *Australian Journal of Zoology*, **68**(6): 332-345

79. van Harten E, Lawrence R et al. (2022) Seasonal population dynamics and movement patterns of a critically endangered, cave-dwelling bat, *Miniopterus orianae bassanii. Wildlife Research*, **49**(7): 646-658, 13

80. van Harten E, Lawrence R et al. (2022) Novel passive detection approach reveals low breeding season survival and apparent lactation cost in a critically endangered cave bat. *Scientific Reports*, **12**(1): 7390

81. Bail NJ, Lumsden LF et al. (2025) Emergence and Return Times in a Colonial, Cave-Dwelling Bat: Age and Sex Differences Driven by Reproductive Cycle. *Ecology and Evolution*, **15**(5): e71281

82. Bush A, Lumsden L et al. (2025) Flight height patterns of a critically endangered insectivorous bat, impacted by wind turbine collision. *bioRxiv*: 2025.05.23.655017