Title: Fungal Diseases in Wildlife: Emerging threats from Pathogenic Fungi

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Abstract

Since 1970 there has been a steady rise in infectious disease cases in wildlife and emerging fungal pathogens, even when controlling for reporting bias. Two of the more visible emerging fungal diseases-- chytridiomycosis in amphibians and white-nose syndrome in bats-- have caused unprecedented die-offs of wildlife populations around the globe, threatening biodiversity and ecosystem services. Here we clarify factors associated with fatality from fungal disease in order to shed light on the dynamics of these pathogens and their wildlife hosts and discuss how these factors can be used to advise and prioritize conservation approaches.

In a Nutshell

- White-nose syndrome and chytridiomycosis are only two of an emerging class of fungal pathogens that may pose important threats to wildlife species
- Understanding of the transmission of fungal diseases and identifying general factors that influence host mortality including natural immunosuppression, body temperature, water limitation, and behavior, can advise conservation efforts that tend to focus on either limiting transmission or reducing host mortality

- Identifying these factors will assist with assessing ongoing conservation efforts and with predicting which species may be more vulnerable to population declines as a result of fungal disease in the future

Introduction

Disease has been recognized to play an important role in the ecology of wildlife populations (e.g., Prins &Weyerhaeuser 1987), but until recent times, has thought pose a more limited extinction risk to most taxa than other threats such as habitat change, overexploitation, or invasive species (Baillie et al. 2004). In particular, the potential threat to wildlife populations of fungal pathogens – which are usually unable to cause disease in otherwise healthy individuals (Laakkonen 1999; Casadevall 2005; Fisher *et al.* 2012) – has until recently been largely ignored by conservation scientists and practitioners.

Basic theoretical models of host-pathogen dynamics have suggested disease is a limited threat to long-term host persistence because local disease populations should go extinct prior to local host populations, enabling host recovery (e.g., Anderson & May 1992). Newer models, however, have identified several conditions under which diseases can drive host and even non-host populations to extinction (e.g., de Castro & Bolker 2005). Meanwhile, emerging infectious diseases – diseases that are newly recognized, newly affecting a population, or rapidly increasing in incidence or geographic range (Daszak et al. 2000) – have been appearing at an increasing rate since 1940, even when controlling for reporting bias (Jones *et al.* 2008).

White-nose syndrome (WNS) in bat populations (Box 1) and chytridiomycosis (chytrid) in amphibians (Box 2) have caused mass mortality of wildlife host populations in recent years, threatening many species with regional extinction (Briggs et al. 2010, Frick et al. 2010, Thogmartin et al. 2013). Yet, these diseases represent only two of a large suite of emerging fungal diseases (Fisher et al. 2012) that present major threats to local and regional biodiversity, ecosystem function, and key ecosystem services (Berger *et al.* 1998; Daszak *et al.* 2001; Blehert *et al.* 2009; Frick *et al.* 2010).

Threats of fungal pathogens to wildlife populations are clearly much greater than previously thought and it is therefore important to identify viable management strategies to mitigate their threat. Our aim in this paper is to discuss potential management strategies to control the transmission of current fungal diseases and identify patterns in host mortality that can be helpful in identifying vulnerable populations for future outbreaks. Using WNS and chytrid as our primary examples, we hope to discuss the viability of proposed management strategies through a discussing the life history of both pathogen and host.

Transmission and Emergence of Fungal Pathogens

Epidemiological models demonstrate how increased heterogeneity in modes of transmission increase the ability of a disease to spread and invade new populations (Robertson, Eisenberg *et al.* 2013). Fungal diseases, have a large multitude of transmission pathways due to their possession of a resting stage in their development and their generalist nature. By analyzing the variety of modes of transmission in fungal pathogens we can better understand their pathogenicity and ability to spread globally.

The fungus responsible for WNS, *Pseudogymnoascus destructans* (Pd), (Minnis and Lindner 2013), formerly known as *Geomyces destructans* , has been discovered in soil samples taken from hibernacula as well as growing on cave-walls. This means that although the most common mode of transmission seems to be through direct contact with an infected individual, Pd could potentially be transmitted through these passive environmental vectors as well as through animal or human vectors (Lindner, Gargas et al. 2011; Puechmaille, Wibbelt et al. 2011). Chytridiomycosis is transmitted through an aquatic zoospore that, like Pd, is most commonly passed from individual to individual. However, this zoospore is also thought to possess a resting stage, allowing it to be transmitted through environmental or animal vectors (Berger et al. 2005). In other soil dwelling fungal pathogens, including Histoplasmosis and Blastomycosis, burrowing and dust-bathing can also cause spores to be released into the air where they can be inhaled and cause respiratory infection (Perez-Torres, Rosas-Rosas et al. 2009; Werner and Norton 2011).

Understanding the various transmission pathways of emerging fungal pathogens is an important step to preventing future disease emergence and for controlling the spread of existing pathogens. It is important to investigate various methods used to mitigate disease spread in order to focus conservation efforts towards transmission pathways that would be the most efficient and cost-effect methods of control.

Human-mediated Trade and Transportation

The human-mediated introduction of a novel disease to a naiive population, termed "pathogen pollution," can occur through a variety of different mechanisms including the international trade of agricultural materials, biological waste, domesticated animals, and

encroachment on wildlife populations (Daszak et al 2010). While it is impossible to measure the degree to which human migration and trade may have contributed to disease emergence in wildlife, it is thought to have played a major role in the migration of several disease outbreaks including West-Nile Virus and Mad Cow Disease (Daszak et al 2010). For fungal pathogens, human-mediated dispersal is thought to be a leading initiator of new outbreaks globally (Fisher et al. 2012). For this reason, it is important to recognize the role of human-mediated pathogen movement in the emergence of fungal pathogens and to investigate methods to control its influence.

Pd has spread rapidly throughout the eastern, southern, and Midwestern United States and eastern Canada (Fig. 3), threatening the area with a local extinction of species whose populations were previously stable or increasing (Frick *et al.* 2010). While this fungus is also widespread among many European bat species, these species are not experiencing the same declines reported in North America (Puechmaille, Frick *et al.* 2011). Some scientists hypothesize that this pattern suggests that European bats coevolved with the fungus, while North American bats have only recently been introduced to it (Puechmaille, Wibbelt et al. 2011) and suffer more severe consequences as a result of the introduction of the pathogen to a naive population (Puechmaille, Frick et al. 2011). Because no bat species migrate between Europe and America, it is likely that the introduction of the pathogen to North America was human-mediated (Wibbelt et al 2010).

The trade of amphibians for pets, research, food, or even for conservation, expands across almost all continents and involves many species that could be potential carriers for Bd (Fisher and Garner 2007). These traded populations often come into contact with wild amphibian populations, possibly bringing pathogens with them and leading to increased range of Bd infection (Fisher and Garner 2007). Additionally, because these trade practices and mass

transport of amphibians existed before the emergence of Bd, it is hypothesized that it has played a major role in its establishment as an international pandemic (Fisher and Garner 2007). Chytrid was thought to have existed as a stable endemic infection for years in Africa before cases were reported in other parts of the world (Weldon, du Preez et al. 2004), suggesting that a lack of regulations in international trade of amphibians has resulted in the pathogen infecting naïve populations (Fisher, Garner *et al*. 2009).

The pattern of human mobility on a global scale has an indisputable influence over the exposure of wildlife to novel pathogens. Scientists have begun to create models that use human transportation networks and trade routes to discover possible origins of non-native organisms that may have been introduced through human-mediated dispersal (Yemshanov, Koch *et al.* 2013). Such models may be useful in predicting high risk areas for future fungal disease outbreaks by integrating human-mediated movement of potential hosts and carriers of infectious zoospores with information on the natural history of the disease and its requirements for establishment in a given area (Fisher and Garner 2007). However, these models are limited by lack of data and precision in predicting patterns in human mobility (Yemshanov, Koch *et al.* 2013).

Legal means have also been used to control the human-mediated transmission of both WNS and chytrid. These include regulations and formal guidelines limiting human access to cave habitats and requiring cavers to decontaminate their caving gear between visits to cave environments to control WNS (Zimmerman 2009; 2011; Hallam and Federico 2012) and an increase in amphibian trade laws and screenings of amphibians transported internationally to control human-mediated spread of chytrid (Kriger and Hero 2009). Although these laws, regulations and guidelines have the potential to reduce human-mediated disease transmission

they may be costly and controversial. Therefore it is necessary to identify the more vulnerable areas or populations to make these policies more efficient and cost-effective, and to instill education and oversight that will ensure maximum compliance.

Animal to Animal Transmission

While human-mediated transportation plays a major role contributing to the movement of disease around the world, the most common mode of more localized disease spread is through direct contact between affected individuals. This can occur through social behaviors, mating, roosting behaviors, and can be influenced by migration. Unfortunately, this type of transmission is often difficult to control as it involves natural life processes that cannot be disrupted and therefore, can only be managed through treating infected individuals or reducing their numbers.

A common method to reduce animal to animal transmission rates in past wildlife diseases is through manipulating infected host population through culling. Hallam et al. (2011) determined that culling would not be an effective strategy for reducing the spread of WNS due to the fact that they can persist in the environmental without a host and due to the movement of bats between hibernacula and variety of social settings during which transmission could occur. In the case of chytrid, however, Woodhams et al. (2011) actually suggests that culling may be beneficial in reducing transmission rates, although it has yet to be proven in the field. For this reason, while culling could potentially be a viable management strategy it should be approached with caution when used to control emerging fungal diseases.

Another method of controlling direct contact transmission involves treating infected individuals directly to prevent these individuals from furthering disease spread. Such methods

include “capture and treat” techniques that involve the use of antifungal drugs, probiotics, antibiotics, or salt treatments (Fig. 7) (Woodhams and Alford 2005; Woodhams *et al.* 2007; Kriger and Hero 2009). Other management strategies for chytridiomycosis include a vaccination program and the introduction of natural predators of the Bd fungus (Woodhams, Bosch et al. 2011).

The use of antifungal drugs to treat white-nose syndrome has not been shown to be effective in treating the disease (Robbins 2012), however, research is ongoing and certain strains of biocontrol fungi (Zhang et al. Abstract) or bacteria (Cornelison CT Abstract) have been identified that may be beneficial in impeding Pd growth and may be fungicidal in the field. Additionally, a vaccination plan has been suggested as a potential strategy for increasing host immunity against Pd (Osorio 2012). While these treatment techniques have shown to reduce growth of the fungus in the lab, it is unclear whether they could be a viable large-scale management strategy for reducing animal to animal transmission.

Placing individuals at temperatures above the thermal optimum of the fungi has proven to reduce or eliminate infection in both cases of bats and amphibians (Johnson 2003 ; Geiger, Kuepfer et al. 2011). For this reason, some researchers have proposed supplying heated refuges for animals in their natural environment where they can clear infection (Johnson 2003 ; Zimmerman 2009; Woodhams *et al.* 2011). However, this method requires that animals are able to locate and travel to these thermal refuges, which may not always be possible for infected animals in a natural setting.

For all of these methods, it is necessary to further investigate how these strategies could have unwanted effects on the surrounding environment. Introducing new chemicals or bacteria may affect the microbial community that could have significant trophic effects. Individual

treatment strategies also may be costly as they require sufficient supplies and monitoring in order to ensure success.

Animal-Environment- Animal Transmission

It has been stated previously that fungal pathogens possess a resting stage that can allow them to remain dormant in their environment even in the absence of a host. There are several environmental factors that can influence the ability of this phase to persist which are necessary to identify in order to fully manage further transmission.

The growth and persistence of fungal pathogens are highly influenced by temperature and humidity. WNS mortality has been shown to be more closely associated with hibernation sites that are “warmer and wetter” (Hayman DTS et al abstract) while incidence of chytridiomycosis seems to peak during the “cool, dry season” (Woodhams and Alford 2005). Clearly these patterns vary for different diseases, however, realizing these preferred growth conditions can be useful in identifying environments which may be most likely for persistence of the pathogen.

In addition, seasonality can influence all of these factors. The prevalence of WNS shows an increase as winter progresses which can be attributed to hibernation energetics and cool winter temperatures that promote Pd growth (Puechmaille, Wibbelt et al. 2011). Symptoms of WNS such as inflammation and skin lesions tend to occur during the spring (Bouma, Carey et al. 2010). Flory et al (2012) further suggests that bats that roost in more seasonally-variable habitats are more likely to suffer from WNS mortality than those who live in habitats with a steadier

yearly climate. Incidence of chytridiomycosis was also observed to follow a seasonal pattern with most frog deaths occurring during the winter (Berger, Speare et al. 2004).

The choice of breeding location has been shown to alter the risk of infection for both bats and amphibian. Kriger and Hero (2007) suggest that amphibians breeding near permanent bodies of water are at higher risk of developing chytridiomycosis while terrestrial species of amphibians rarely develop the disease at all. WNS only affects cave-dwelling bat species and roosting location therefore plays a large role in infection risk of this disease as well (Dzal, McGuire et al. 2011).

Identifying high risk areas is important for focusing management while altering microhabitats areas may also be a viable strategy for mitigating disease transmission. An example of this involves building artificial caves and hibernacula as a possible means of controlling WNS (Gorman 2012). These caves could provide a controlled environment that could be disinfected following each hibernation cycle, eliminating the potential for passive transmission through cave walls (Gorman 2012). Such artificial roosts include bat boxes, which have documented success (Gallo M et al. abstract), or abandoned buildings like military bunkers (Aguis S et al. abstract).

Unlike bat hibernacula, most animal habitats do not consist of confined spaces that can be sanitized. For this reason it is difficult to completely remove a fungus from the surrounding environment without introducing large amounts of potentially harmful chemical treatments or fungal predators. Therefore the best way to control animal to environment to animal transmission may be to focus on treating individuals that live in areas that may be most suitable for fungal growth, something that is further is discussed in the following sections.

Recognizing Vulnerable Populations

When creating a management plan for emerging fungal diseases it is important to make sure to focus conservation on the most vulnerable populations in order to ensure maximum efficiency of resource use. Additionally, understanding which populations may be more at risk for future outbreaks could help predict fungal disease emergence by focusing monitoring of more vulnerable species and habitats. Therefore we have identified several factors that influence the vulnerability of populations to emerging fungal diseases through recognizing patterns in current emerging diseases.

Natural States of Immunosuppresion

Fungal diseases are considered to be "opportunistic" pathogens, usually requiring some type of previous injury or disease in order to cause infection in their host (Laakkonen 1999; Casadevall 2005). *Basidiobolus ranarum*, a fungal disease that also affects amphibian populations has been shown in the lab by Taylor et al. to only cause infection when the skin of the amphibian was abraded, suggesting that the fungus could only affect injured hosts (Taylor, Williams et al. 1999). However, both WNS and chytrid have been shown to cause disease in otherwise healthy individuals (Fisher et al. 2012) and it is therefore important to understand the mechanisms by which these infections occur in order to identify populations that may be more vulnerable to mortality from fungal pathogens.

During their annual winter hibernation, many North American bat species enter prolonged bouts of torpor during which their metabolism slows down, and their respiration, heart rate, and body temperature decrease in order to conserve as much energy as possible.

Hibernating bats also suppress immune function to further contribute to this energy conservation (Bouma *et al.* 2010). This immunosuppressed state typically does not lead to disease emergence because microbes are rarely able to survive at low winter temperatures. Other hibernating animals may also be at an increased risk from fungal pathogens, due to their repressed immune function and limited ability to acquire energy during this time.

Much like bats, amphibians also enter a natural immunocompromised state during metamorphosis. The transition from an aquatic larval lifestyle to an adult terrestrial one exposes the amphibian to a new set of pathogens. To compensate, amphibians must completely dismantle their previous larval immune system and reconstruct a new immune system capable of protecting it in a terrestrial environment and suited to a new adult body and lifestyle (Rollins-Smith 1998). This post-metamorphic stage is considered to be the most vulnerable life-history stage for amphibians (Rollins-Smith 1998), if infection does not occur at metamorphosis, the likelihood of disease causing death and the ability of the pathogen to persist in the population is greatly reduced (Briggs *et al.* 2005).

Temporary states of suppressed immune function are a vital part of the life history of both bats and amphibians as a means of dealing with energy limitation. Though necessary for development and survival, metamorphosis and hibernation may decrease the animal's ability to fight off infection and cause them to use excess energy, thereby increasing mortality. Recognizing that natural immunosuppressed states exist in wildlife populations and concentrating management strategies around the times, may allow us to recognize populations that may be more at risk of mortality from emerging fungal diseases.

Body Temperature

The majority of fungal species grow best at “ambient temperatures” (25-35°C) (Casadevall 2012). Many warm-blooded mammals either have a body temperature above this range or are able to raise their body temperature through a fever response to above the growth range of the fungus (Casadevall 2005; Casadevall 2012). For this reason, cold-blooded animals are usually more susceptible to fungal infection while warm-blooded or “endothermic” species are thought to be highly resistant (Casadevall 2005; Casadevall 2012). While chytridiomycosis has the advantage of affecting cold-blooded hosts (Fig. 6B), WNS affects mammals and therefore does not seem to follow this trend. An explanation for the success of Pd on a mammalian host can be explained by the hibernation energetics of bat species.

When bats experience a suppressed metabolism during hibernation, they also experience a drop in body temperature. The body temperature of hibernating bats dropped to just above the temperature of their hibernacula and overlaps substantially the growth range of Pd (Fig. 6A) (Piotrowski *et al.* 2004; Blehert *et al.* 2009; Jonasson and Willis 2012). WNS only affects cave-dwelling bats, as it is necessary for their body temperatures to reach these low levels in order for infection to occur (Dzal *et al.* 2011). Therefore both cold-blooded animals and warm-blooded species with naturally lower or more variable body temperatures, usually during hibernation, may be at a higher risk of developing an infection from fungal pathogens. Although it is an anomaly, WNS is not the only fungal pathogen that can affect mammals. Another disease, Paracoccidioides, takes advantage of the naturally lower body temperature of their host, armadillos, to invade the tissue around the cooler areas of their body and cause disease (Bagagli, Sano et al. 1998).

Despite variability in the optimal growth ranges of fungal pathogens, evidence clearly indicates that cold-blooded animals, as well as those that have naturally occurring lower or more variable body temperatures, are at higher risk of developing a fungal pathogen and are less able to fight off an infection than those with the ability to maintain their body temperature above the growth range of the fungus.

Sociality and behavioral factors

Various behaviors in wildlife host species may alter their likelihood of fatality. Bat social behaviors affect WNS transmission during roosting and the selection of hibernacula. Certain bat species will roost in "highly gregarious" and "tightly packed" aggregations which have the benefit of reducing the exposed skin surfaces of the bats, thereby reducing cutaneous evaporative water loss (Langwig *et al.* 2012). Additionally, during the summer and early autumn large numbers of individuals from various hibernating bat species exhibit a swarming behavior in order to mate (Puechmaille *et al.* 2011; Langwig *et al.* 2012). These social behaviors create opportunities for bat-to-bat transmission of fungal pathogen (Hallam and McCracken 2011). For this reason more social organisms or those that live in more crowded populations may be more vulnerable to high transmission rates.

Additional host behaviors may also alter vulnerability although they are highly pathogen-dependent. Because many fungal diseases, including WNS, Blastomycosis, and Histoplasmosis can exist outside of their host in the soil, animals that burrow, dust-bathe or live in close proximity to the soil may be at higher risk of developing infection (Bagagli et al. 1998; Laakkonen 1999). When it comes to chytridiomycosis, excessive skin shedding may also be

another adaptive mechanism used to reduce infection on the host, however, it may also be a manipulation of the host by the fungus in order to cause them to increase keratinized substrate (Woodhams, Ardipradja et al. 2007). It is important to understand the life history of these diseases in order to determine how behavioral adaptations may make a certain individual or population more vulnerable to infection.

Unaffected Species and Potential Animal Vectors

When treating infected individuals, it is important to keep in mind that there may be other animal hosts that do not suffer mortality and may persist as vectors. Several species that coexist with the pathogen may serve as reservoir hosts for infection. In both WNS and chytrid, some species or individuals are able to survive with infection and mortality has been shown to be highly species dependent (Rollins-Smith 1998; Blaustein, Romansic et al. 2005; Davidson et al 2003).

Pd has been isolated from three bat species without showing any damage in the United States (Turner 2011). Some species who have been exhibiting lower declines and therefore may be more resistant to WNS in the United States include big brown bats (*Eptesicus fuscus*), the small footed bats (*Myotis leibii*) (Turner, Reeder et al. 2011; Langwig, Frick et al. 2012) and the Indiana bat (*Myotis sodalist*) (Amelon S.K. 2012).The chytrid fungus has also been discovered to exist on or among several species of amphibians without causing the same symptoms or degree of fatality. Searle et al (2011) found variations in mortality of 6 different species of amphibians who were all exposed to Bd. Interestingly this study showed little difference in infection, only in mortality. Examples include the American bullfrog (*Lithobates catesbeianus*) which is able to

342 persist with a high level of infection from Bd without any signs of developing disease symptoms
343 (Blaustein, Gervasi et al. 2012) and the Boreal Toad (*Bufo boreas*) which thrives at a low
344 infection level with a slow population decline (Pilliod, Muths et al. 2010). Woodhams et al
345 (2007) found that even when environmental conditions and the pathogen strain are held constant,
346 the outcome of infection among species still varied. One explanation for this is differences in the
347 presence of antimicrobial skin peptides among species of amphibians, however shedding periods
348 and molting may also play a role (Woodhams, Ardipradja et al. 2007; Gammill, Fites et al.
349 2012).

350 Because of differential host mortality, maintaining biodiversity in areas where disease in
351 present may be protective against direct transmission in a similar way that herd immunity can
352 reduce disease transmission as a result of vaccaination programs. Various conservation methods
353 aimed at maintain biodiversity therefore can also have benefits towards disease control. One
354 method currently being employed to reduce the spread of chytrid, involves maintaining a group
355 of select amphibians in captivity so that these populations can be reintroduced into the wild when
356 the disease has run its course (www.amphibianark.org). While this project could play a major
357 role in maintaining amphibian biodiversity, it may not be a viable strategy for other animal
358 populations that are more expensive and difficult to keep in captivity. Additionally, in order for
359 such programs to be effective it is important to recognize which species may be more susceptible
360 to infection.
361

362 **Conclusions**
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The ability of emerging fungal pathogens to adapt and invade previously untouched ecosystems has recently caught the attention of conservation scientists and practitioners around the globe. Emerging fungal pathogens have shown the potential to cause major die-offs and local extinctions of their wildlife host populations, especially in the cases of WNS and chytrid. A reduction in the abundance and change in distribution of these species could potentially affect ecosystem function and global public health. By achieving a thorough understanding of the epidemiology and life history of emerging fungal pathogens, we may be able to discover conservation strategies that would be most efficient in delaying the progression of these diseases.

Further research in population dynamics and epidemiology of current fungal pathogens is necessary in order to find more effective and efficient methods to manage their impacts and to prevent future disease emergence. Information on factors that affect host mortality and disease transmission are crucial to evaluating possible conservation strategies and with assessing with future response strategies when dealing with infectious disease in the field.

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Box 1: White-Nose Syndrome in bats

White-nose syndrome (WNS), a disease affected hibernating bats, is caused by the pathogenic fungus *Geomyces destructans* (Pd) (Lorch *et al.* 2011), which was first documented outside of Albany, New York in 2006 (Blehert *et al.* 2009). WNS is characterized by lesions affecting the snouts, ears, and especially the wings of infected individuals (Cryan *et al.* 2010; Lorch *et al.* 2011). Pd is believed to cause abnormal arousals from hibernation, which can lead to water and energy loss and eventually death (Reeder et al. 2012). White-nose syndrome is expected to result in multiple regional extinctions of bat species in the North Eastern United States (Frick et al. 2010, Thogmartin et al. 2013).

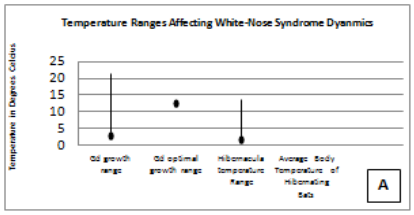
Box 2: Chytridiomycosis in amphibians

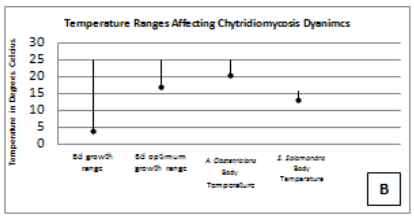
Amphibians have also suffered greatly from the recent emergence of a fungal disease, Chytridiomycosis, or chytrid. Chytrid is caused by the fungus *Batrachochytrium dendrobatidis* (*Bd)* which was first identified in 1997 and named in 1999 (Fisher *et al.* 2009). The chytrid fungus (Bd) also affects the skin of its host causing a physical disruption of the epidermis (Rosenblum *et al.* 2010) and is thought to cause death through a disruption in electrolyte transport and osmoregulatory function (Daszak et al. 2001; Voyles et al. 2007; Voyles et al. 2009; Rosenblum et al. 2010). Chytrid has been called the "worst infectious disease ever recorded among vertebrates in terms of the number of species impacted, and its propensity to drive them to extinction" (Briggs et al. 2010).

Figure 7: Distribution of White-nose Syndrome in Northeastern United States

Photograph of a blue poison dart frog (*Dendrobates azureus*) receiving treatment for chytridiomycosis with an antifungal soak. Taken at the The National Amphibian Conservation Center at the Detroit Zoo. Detroit, Michigan. July 2012.

Figure 6: Temperature Dynamics of White-Nose Syndrome and Chytridiomycosis



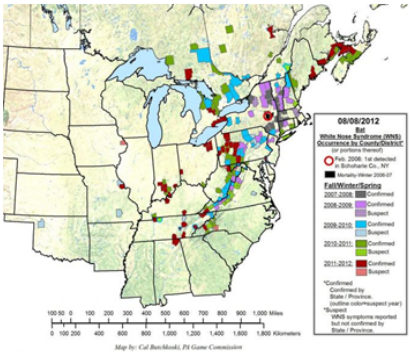


Graph A is a representation of the temperature ranges affecting the dynamics of the Gd fungus which causes white-nose syndrome. The areas where the bars overlap are the temperature ranges at which infection can occur (Verant, Boyles et al. 2012). Graph B shows a similar representation for the temperature ranges that affect the dynamics of the chytrid fungus, Bd. The graph includes the growth and optimal growth range (Blaustein, Gervasi et al. 2012) as well as two examples of amphibians that have suffered fatalities as the result of chytridiomycosis: the common midwife toad (*A. Obstetricians) (Busack 1978)* and the fire salamander (*S. Salamandra*) (Busack 1978) .

Figure 4: Global Distribution of Chytridiomycosis 2006-2011

Created with data from bd-maps.net search year= 2006, 2007, 2008, 2009, 2010 and spatialepidemiology.net. http://www.spatialepidemiology.net/user_maps/php/temp/11-29-12-22340.html

Figure 3: Distribution of White-nose Syndrome in Northeastern United States



Map from http://www.whitenosesyndrome.org/resources/map, created 8/8/12.