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* Contents organized for archiving by: Stefanie Rose (LRB) (August 2013)

WHITE-NOSE SYNDROME MANAGEMENT:
Report on Structured Decision Making Initiative

October 2009[1]

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EXECUTIVE SUMMARY

Decision Problem: This report describes an analysis undertaken to assist state and federal natural resources managers in addressing the following question: What management measures should be taken this year within a given area to control the spread and minimize the effects of white-nose syndrome (WNS) on hibernating bats at the individual and population levels? The answer depends upon specific characteristics of the bat species, the hibernacula, and the syndrome itself, all of which could vary across the geographic extent of WNS and change over time. It also depends on a large number of agency and societal judgments concerning how to balance disease management against other objectives.

Decision Process: Structured decision making (SDM) was used to address the decision problem. The SDM process included identification of the fundamental objectives of decision makers for WNS management, development of management alternatives, formal expert elicitation methods to predict the consequences of management alternatives, multi-criteria decision analysis to identify a recommended alternative, and expected value of information methods to conduct sensitivity analyses. This analysis was carried out through a process of iterative prototyping, alternating development with review and feedback; in that spirit, this report is as much a starting point for future work as it is an end point in itself.

Spatial Framework: White-nose syndrome is an emergent and rapidly spreading phenomenon, thus the dynamics of the disease differ over space, and the appropriate management strategies may differ over space as well. For this reason, we subdivided the WNS range into three distinct areas (Fig. 1 in the report), including the area where the syndrome is most prevalent (Area 1), the area that has a matrix of affected and unaffected sites (Area 2), and the area that is not known to be currently affected but which is susceptible to spread of the disease (Area 3). Owing to time constraints, the decision process could only be developed for one of the three areas. Participants in a May 2009 workshop selected Area 3 as the part of the range most in need of management recommendations supported by a structured process. The prototype for Area 3, developed between June and August 2009, is explained below.

Area 3 Prototype: We structured the Area 3 prototype as a multi-criteria decision analysis that focused on the tradeoffs among six fundamental objectives. Twenty-three management alternatives were considered. The management alternatives consisted of portfolios of strategies applied in each of three cave profiles within Area 3. The strategies themselves were combinations of multiple individual actions.

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The consequences of the management alternatives to achievement of the objectives were predicted through expert elicitation, and the weights for the different objectives were elicited from the decision-makers (through their proxies). Quantitative analysis of these results provided recommended actions, as well as an understanding of the importance of resolving various uncertainties.

Geographic area
Area 3 encompasses sites that are uninfected to date but are susceptible to infection in the near future. The boundary of this area is delineated as being >250 miles from the nearest site of infection. Management for this area is predicated on the notion that effective strategies need to focus on containing any novel occurrences of WNS.

Profiles
Area 3 hibernacula were categorized into three broadly defined profiles, based on the observation that management actions may need to be customized to the condition of the site. <u>Affected sites</u> include any cave or mine within Area 3 that is newly affected by WNS, as shown by confirmation of the *Geomyces* fungus on either the bats or in the cave/mine. <u>Unaffected caves near an affected site</u> include all Area 3 caves or mines within 75 miles of any affected site, indicating a greater susceptibility to becoming infected with WNS through transmission from the affected site. <u>Unaffected caves far from the affected site</u> include all Area 3 caves or mines more than 75 miles from the affected site, indicating less susceptibility to becoming infected with WNS through transmission from the affected site

Fundamental Objectives
Six fundamental objectives were identified that express the most important considerations of the decision makers in proposing management relative to WNS in Area 3. The conflict among these objectives is one of the challenges in this decision context. The fundamental objectives are:

1. Prevent the spread of WNS within Area 3, either by preventing entry of the disease into the area or by eradicating the disease from the free-flying bat population.
2. Avoid unacceptable risks to endemic cave-obligate biota resulting from WNS or management strategies directed at WNS.
3. Minimize public health risks from management strategies related to WNS and from moribund bats.
4. Minimize restrictions on the affected public and land managers in Area 3.
5. Minimize the total number of bats directly killed as a result of management strategies taken in Area 3 in a given year.
6. Provide research opportunities to accelerate the search for solutions to manage this disease, by maximizing the use of Area 3 as a source of control animals and sites.

Management Alternatives
Twenty-three management alternatives were developed for Area 3 (Tables 5-6). Each alternative consists of three management strategies (one per profile) chosen from a set of 11 management strategies. The strategies range from taking no action in any of the caves within a profile, to restricting human access to various degrees, to seasonal restrictions in bat access to the caves, to more aggressive measures designed to treat the disease (such as fungicide treatment or preventive bat eradication).

Consequences Prediction and Analysis
Expert elicitation was used to predict the consequences of each management alternative in terms of each of the six Area 3 objectives. When these predicted consequences were summarized (Table 7), the tradeoffs became apparent—no one management alternative excels on all 6 objectives.

To determine how the decision makers wished to balance tradeoffs among the objectives, a weight for each objective was elicited from the proxy decision makers. All the proxies ranked Objective 1 (control spread of WNS) highest or a very close second, and on average, the second highest ranked objective was Objective 2 (avoid impact to cave-obligate biota). The third-ranked objective, based on the average weights, was Objective 3 (minimize public health risks). The other objectives fell farther behind, with Objective 4 (minimize regulatory burden) having the lowest average weight. There was not, however, a close consensus among the decision makers' proxies regarding how to weight the objectives. Since these different weightings expressed legitimate differences in policy judgment, they were carried forward in the analysis to represent uncertainty about the weights on the objectives.

To complete the tradeoff analysis, the weights on the objectives were combined with the predicted consequences to derive weighted scores for each management alternative (Table 9). Using the weighted scores, the four best-performing alternatives focused on restricting access to caves. The best-performing alternative (Alternative 10) called for restricting access at all caves in Area 3 to research and commercial purposes only and, if a cave in Area 3 becomes affected with WNS, restricting access at all caves within 75 miles to research only, and not allowing any access at the affected cave(s). The next three best-performing alternatives (Alternatives 7-9) differed in whether research access was allowed at the affected cave(s) or not, and whether commercial access was allowed at the caves far from the affected cave(s). Choice among these four alternatives is affected by how much weight is given to Objectives 2 (cave-obligate biota), 4 (regulatory burden), and 6 (research opportunity). The worst-performing management alternative (Alternative 21) called for preventive eradication of bats in all caves within 75 miles of an affected cave. Although this alternative had the highest predicted performance on Objective 1 (prevent spread of disease), it performed poorly on all other objectives. Overall, the aggressive management alternatives (like eradication or fungicide) performed relatively poorly, because the costs of more aggressive treatment outweighed the potential benefits, in large part because the costs were more certain than the benefits.

The different weightings on the objectives represent legitimate value judgments by different decision makers, and they lead to different decisions. Focused dialogue among decision makers about how to balance the different objectives will be needed in order to identify a single preferred management approach.

Recommended Area 3 Alternative: For the 2009 migration and winter season, this analysis suggests implementing Alternative 10 in Area 3. This involves confining access at all Area 3 sites to commercial and research uses only. Further, if WNS is detected this winter, then any affected sites would be closed to all access (including research), and sites within 75 miles of any affected sites would be closed to all access except research. In addition, it is recommended that partial access (for commercial and research uses only) be continued in Areas 1 and 2. It is important to note that Alternatives 7-9, which differ from Alternative 10 only in how much access to allow at any affected site and at sites far from an affected site, scored nearly the same.

This analysis is only meant to aid the decision makers in understanding the current state of knowledge and the tradeoffs inherent in the problem, not limit their discretion in exercising their responsibilities. At this point, the decision makers need to select an alternative, either from among those presented here, or from other permutations they might deem appropriate. Selection of any of alternatives 7, 8, or 10 is easily supported by the analysis herein. Selection of other alternatives would require supplemental rationale to maintain transparency.

Research Needs: Nearly all of the decision makers, through their proxies, identified Objective 1 (preventing the spread of WNS in Area 3) as the most important objective. The measurable attribute for this objective was also the most difficult to quantify. This suggests that a high priority for research is the development of quantitative, predictive models for disease dynamics as a function of management actions. This need applies beyond Area 3; for Areas 1 and 2, it is important to be able to predict the effect of management actions on other aspects of disease dynamics (e.g., mortality and development of resistance). Predictive models based on empirical evidence would be of tremendous value.

Next Steps:

Seek Agreement on the Objective Weighting among the Decision Makers

In the tradeoff analysis, the weights placed on objectives drove the outcomes, which varied substantially depending on whether averaged or individual weights were used. This is a clarion call for collaboration among the multiple decision makers involved in this decision. The preferred alternative should reflect the collective values of decision makers, which can only be achieved by either calculating a composite of individual values (through averaging of weights, for instance) or achieving consensus values through negotiation among decision makers. Focused dialogue among decision makers about how to balance the different objectives will be needed in order to identify a single preferred management approach.

Development of Area 3 User Guide

Following the choice of a management recommendation by the decision makers, a brief guide for site-specific implementation of the preferred management alternative will be prepared by the WNS SDM working group. This guide will (1) provide additional detail for the management actions comprising the alternative, (2) suggest measures for addressing the tactical considerations such as those listed on page 17 of this report, and (3) summarize WNS surveillance and monitoring protocols that are under development.

Application of the Area 3 Decision Framework to Areas 1 and 2, and Beyond

The original intent was to develop a unified approach across the range and the likely area of spread of WNS. Due to time constraints, we focused on 1 of the 3 identified geographical areas. The next steps, therefore, are to complete the SDM process for Areas 1 and 2 and to combine all area-specific analyses to yield suggestions for managing WNS across the range.

Adaptive Management Considerations

The analysis described in this report is based on the information, however coarse, that could be assembled in a short time-frame. The uncertainty about disease dynamics and the impacts of various management actions, however, is very large and greatly affects the recommended alternative. Nonetheless, the repeated nature of the management decision provides a valuable opportunity: an adaptive framework can allow decision-makers to make the best decision each year, conditional on the available information, while simultaneously pursuing understanding that should enhance future decision making. We recommend that a formal adaptive management framework be developed over the next year.

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ACKNOWLEDGMENTS

This report draws upon the expertise and contributions of numerous individuals concerned about the heightening crisis of white-nose syndrome (WNS) and its effects on eastern bat populations. Several biologists contributed to the report itself, and due credit goes to Mike Armstrong, Jeremy Coleman, Robyn Niver, Lori Pruitt, and Susi von Oettingen for their excellent assistance in defining the biological and management context within which WNS management decisions must be made. These endangered species biologists, along with the following federal and state biologists and wildlife managers, also provided indispensable information and professional judgment throughout the WNS structured decision-making process: Kevin Castle, Paul Cryan, Scott Darling, Barb Douglas, Al Hicks, Scott Johnson, David Redell, Rick Reynolds, Brooke Slack, Craig Stihler, and Greg Turner.

An analysis like this, driven by the urgency of the situation and undertaken before empirical data have accumulated, must rely on expert judgment in the face of uncertainty. Much appreciation is owed to the following experts who took the time and endured the hurdles of predicting the effects of alternative WNS management approaches on native bat species, other cave biota, and people: Tom Aley, Danny Brass, Rick Clawson, Keith Dunlap, Brock Fenton, Janet Foley, Mark Ford, John Hayes, Brian Laniewicz, Julian Lewis, Susan Loeb, Gary McCracken, Mo Salman, Jeff Wimsatt, National Wildlife Health Center staff, and workshop participants Mike Armstrong, Scott Johnson, Lori Pruitt, David Redell, and Susi von Oettingen. We also thank to Kevin Castle, Drew Tyre, and Terry Walshe for careful and critical review of this report.

INTRODUCTION

The Decision Problem and Why this SDM Process was Initiated

In March 2009, the U.S. Fish and Wildlife Service (USFWS) and various State wildlife agencies, in cooperation with the U.S. Geological Survey and National Park Service, embarked upon a collaborative effort to address the following problem: *What management measures should be taken this year and within a given area to control the spread and minimize the effects of white-nose syndrome (WNS) – a novel disease with extraordinary consequences to native bat populations – on hibernating bats at the individual and population levels?* The solution depends upon population and site characteristics and the syndrome itself, all of which could vary geographically and temporally. It also depends on a large number of agency and societal judgments concerning how to balance disease management against other objectives.

The effort to resolve this problem was initiated in the face of substantial debate among involved scientists and policy specialists about appropriate management responses to the syndrome. In order to develop management recommendations, the USFWS and state wildlife agencies requested a structured, transparent decision process to aid them in determining the appropriate response to WNS.

The recommendations ultimately issued by USFWS and the state wildlife agencies will be provided to landowners and land managers for consideration in their own implementation planning. This report describes the results of a decision analysis meant to aid the USFWS and states in designing these recommendations. This report identifies management alternatives, thought to be near-optimal (within the limits posed by significant data gaps and contrasting preferences and priorities) in terms of meeting wildlife conservation objectives, that center on the suite of actions that should be taken to control WNS, where control of WNS includes both reducing the effects of the syndrome and slowing the spread of the disease, while accounting for other objectives relevant to the shared responsibilities of the states and USFWS.

Challenges Influencing the Process and Outcomes

White-nose syndrome management decision making is fraught with challenges. While the research community works toward a better understanding of WNS and its effects, wildlife managers have an urgent need to select management actions that stand the best chance of stemming WNS over the upcoming hibernation season and beyond. This requires decisions that entail substantial uncertainty about projected management outcomes, compounded by the serious risk associated with each potential management approach, including taking no action. Issues raised by stakeholders, such as cave access, management of listed species, wildlife protection, and compatibility with other land management objectives, pose an additional challenge to WNS decision making.

In effect, this is an urgent, high risk, multiple-objective decision involving evaluation of alternative courses of action under uncertainty. While the decision-makers cannot control the uncertainties, and thus, can only partially control the outcomes, they can control the decision process. A structured process for making decisions allows transparency and the opportunity for explicit deliberation. Beyond that, the other tool for sound decision-making in the face of uncertainty is adaptive management. The management recommendations resulting from this SDM process should be revisited over time with the understanding that an important aspect of WNS management is to use information garnered from actions taken early as a means of improving the effectiveness of future actions.

Suggested Role of SDM in Current and Future WNS Management

The decision framework described herein examines the consequences of and tradeoffs among various management alternatives to determine how well each alternative is expected to achieve objectives set by decision makers. This framework should continue to be useful for decisions that focus on containing and minimizing the deleterious effects of WNS. It does so by identifying a preferred, state-dependent management strategy that can be adapted over time and by geographic location based on specific circumstances and emerging information. The details of the framework, its development, and the resulting management recommendations for the coming hibernation season follow.

DECISION CONTEXT

In order to make meaningful and rational decisions for WNS management, it is necessary to understand the context within which those decisions must be made, including both the scientific and human dimensions of the problem.

Ecological Context

White-nose syndrome is a malady of unknown origin that is killing cave-dwelling bats in unprecedented numbers in the northeastern U.S. and is rapidly spreading. The most obvious clinical sign of WNS is the presence of a white fungus on the face, wing, or tail membranes of many, but not all, affected animals. Behavioral changes, characterized by a general shift of bats from traditional winter roosts to colder areas or to roosts unusually close to hibernacula entrances, also signal WNS affliction. Bats showing clinical signs of WNS appear to be generally unresponsive to human activity in the hibernaculum and may even fail to rouse from torpor when handled. Bats at affected sites are regularly observed flying across the mid-winter landscape, and, on occasion, carcasses of little brown bats by the hundreds to thousands have been found in and around affected hibernacula. Infected animals appear to be dying as a result of depleted fat reserves, and mortalities are observed months before bats would be expected to emerge from hibernation.

White-nose syndrome was first reported at four sites in eastern New York in the winter of 2006-2007, with subsequent documentation of one additional location, Howe's Cave, based on photographic evidence from February 2006. Monitoring efforts in winter-spring of 2008 revealed 38 affected hibernacula in four states (NY, VT, MA, and CT), representing a zone of impact with a radius of approximately 125 mi from the center of the initial affected sites. To date in 2009, affected sites have been discovered as far as 500 mi from the initial sites and 370 mi from the closest known affected site from 2008 (in NY). There are now over 60 hibernacula known to be affected in nine contiguous states (CT, MA, NH, NJ, NY, PA, VT, VA, and WV; updated information on WNS is being maintained on the Service's Region 5 WNS webpage at http://www.fws.gov/northeast/white_nose.html), and because hibernating bats can travel over 90 mi between summer territories and hibernacula, the population-level impacts of WNS extend beyond these state boundaries when summer ranges are considered.

Since 2007, cumulative mortality rates have exceeded 90% of pre-WNS bat populations at some of the large hibernacula in New York and New England, including high-priority Indiana bat sites. Mortality rates (primarily of little brown bats) have ranged from 81% to over 97% at four study sites over two years (2007 and 2008) (Hicks et al. 2008). Sites more recently affected appear to be following the same trend.

Six species of cave-wintering bats are currently known to be affected by WNS: Indiana bats (*Myotis sodalis)*, little brown bats *(M. lucifugus)*, northern long-eared bats (*M. septentrionalis*), tricolored bats (formerly eastern pipistrelle, *Peryimyotis subflavus*), eastern small-footed bats (*Myotis leibii*), and big brown bats (*Eptesicus fuscus*) – essentially all of the cave bats within the current known range of WNS. Of these species, little brown bats are the most heavily affected by WNS. The federally listed Indiana bat has also suffered considerable losses due to WNS, and WNS has been found in caves used by the federally listed Virginia big-eared bat (*Corynorhinus townsendii virginianus*).

WNS now threatens to move into areas that contain some of the largest cave bat populations in the world. Fifteen species, including the six species already known to be affected, are identified as vulnerable to WNS. This includes, along with the bats listed above, the federally listed gray bat (*Myotis grisescens*), the southeastern myotis *(M. austroriparius*), eastern big-eared bat (*Corynorhinus rafinesquii macrotis*), Rafinesque's big-eared bat *(C. rafinesquii*), red bat (*Lasiurus borealis*), silver-haired bat (*Lasionycteris noctivagans*), hoary bat (*Lasiurus cinereus*), and evening bat *(Nycticelus humeralis*). The four latter bat species do not hibernate in caves but will join in fall swarms at cave entrances (although silver-haired bats have been found hibernating in caves, mines, and railroad tunnels). It is worth noting that all 15 bat species found in the Northeast and Southeast – species that are thus vulnerable to WNS, are identified as state Species of Greatest Conservation Need (SGCN). The effects of WNS on vulnerable bat species are discussed in more detail below.

Indiana bat: All known Indiana bat hibernacula in NY, VT, and NJ (except for a newly discovered site, Bull Mine, in NY) have been documented with WNS, although surveys conducted in 2009 of most other Indiana bat hibernacula across the range found no signs of WNS or any suspicious declines in abundance (A. King, USFWS, pers. comm.).

Northeast Indiana bat population estimates between 2001 and 2007 showed an average increase of 21% between each biennial survey. In sharp contrast, surveys conducted at hibernacula within Region 5 during early 2009 (post-WNS) estimated the population at 49,464 Indiana bats, a 30% decrease from the 2007 estimate, presumably a direct result of WNS-related mortality and possibly a conservative estimate of the mortality associated with WNS. From a broader perspective, this represents a loss of approximately 5.3% of the estimated 2009 total population for the species.

Impacts to Indiana bats vary among affected hibernacula. Photographic surveys of NY Indiana bat hibernacula conducted in March 2008 for comparison with the 2006-2007 counts showed, for example, that Indiana bat numbers and roosting locations appeared normal at both Barton Hill and

Williams Hotel (A. Hicks, pers. comm.), while preliminary analyses indicate that in 2008 there were approximately 600-800 fewer individuals at Glen Park Cave than there were in 2006-2007, a drop in abundance of 30-40%. A more drastic decline was observed at Haile's Cave, where no Indiana bats were observed in 2007, 2008, or 2009, despite having been observed in every survey since 1981 at levels typically in the range of 250-700 animals (Hicks and Newman 2007; A. Hicks, pers. comm.). Lastly, late winter counts in 2008 at Williams Preserve and Williams Lake were down by 92%-99% compared to 2006-2007 mid-winter surveys. Count data collected during the 2009 survey at this site, conducted in February, showed that Indiana bat abundance was slightly lower than recorded in April 2008 (A. Hicks, pers. comm.).

In summary, WNS has now been documented in nine states, and the degree of impact to bats varies greatly by site and species. Based on observations of continued mass-mortality at several sites, loss of Indiana bats is expected to continue in currently affected areas and to spread to other portions of this bat's range. A preliminary assessment of the rangewide genetic structure of the Indiana bat (based on mitochondrial DNA) suggested that genetic variance among samples was best explained by dividing sampled hibernacula (n=13) into four separately defined population groups: Midwest, Appalachia, Northeast 1, and Northeast 2 (USFWS 2007:26). The populations designated as Northeast 1 and Northeast 2 are now severely affected by WNS and could be lost completely in the near future. At least one hibernaculum in each of the other groups is also affected. Implications of WNS-related mortality of Indiana bats to the genetic health of the species are not known, but there is legitimate cause for concern.

<u>Virginia big-eared bat</u>
The rangewide population of the Virginia big-eared bat (VBEB) consists of four distinct subpopulations, each of which inhabits a small number of caves in a small geographic area, e.g., seven caves in northeastern West Virginia support approximately 60% of the known hibernating VBEB population and 77% of the known maternity population. These caves, including all five caves designated as critical habitat under the ESA, are located within a few miles of each other. In February 2009, four caves within the area harbored bats with early signs of WNS, including one maternity cave designated as critical habitat and one smaller VBEB hibernaculum. Because VBEB in this area mix together and move among caves on a seasonal basis, WNS has the potential to quickly spread through this population. As of 2007, there were only three known VBEB hibernacula located outside of West Virginia; these caves supported more than 200 hibernating VBEB. Although the three caves are outside the known affected range for WNS, they are within approximately 40 to 180 miles of affected sites. If current rates of WNS spread continue, WNS could occur in all caves designated as critical habitat within the next year (winter 2009-2010) and could extend to the range of the remaining smaller populations within the next one to two years. Although no WNS-affected VBEB have been found to date, species that aggregate in dense clusters during hibernation, as do VBEB, have been particularly hard hit by WNS, i.e., affected hibernacula have been subject to population declines of over 90%, and the absence of data suggesting otherwise, it is prudent to assume that VBEB could experience similar mortality rates. Large-scale reductions in the overall population of VBEB are likely imminent, given (1) the current proximity of WNS to Hellhole Cave (Pendleton County, WV), which contains the largest concentration of VBEB in existence as well as nearly

13,000 Indiana bats and an estimated 150,000+ little brown bats; (2) the fact that the VBEB relies heavily on caves with average summer roosts and winter hibernacula temperatures below the 20° C maximum temperature at which the *Geomyces* fungus likely persists; (3) the expected rate of spread of WNS to the remaining outlying populations; and (4) the expected high and rapid mortality once WNS enters hibernation sites.

Gray bat: Although WNS has not yet been documented in any population of gray bat, the recent discovery of the condition in Hancock Cave, Smyth County, VA places WNS approximately 11 miles from a bachelor colony of ~2000 gray bats in the same county and approximately 22 miles from a bachelor colony of ~2000 gray bats in Russell County. Additionally, Hancock Cave is 307 miles from the closest major gray bat hibernacula (Coach, Colossal, Dixon, and Jesse James caves) in south-central KY (Edmonson County) and about 218 miles from the closest gray bat Priority 1 maternity cave (Overstreet Cave) in northeastern KY.

There is an increased risk of gray bats coming in contact with bats infected with WNS, because: (1) the species is cave-obligate with average summer roosts and winter hibernacula temperatures below the 20°C maximum temperature at which the *Geomyces* fungus likely persists; (2) the species regularly migrates from 10 to 270 mi between summer maternity sites and winter hibernacula (Tuttle 1976b; Hall and Wilson 1966), with some individuals moving as much as 428-482 mi (Tuttle 1976b; Tuttle and Kennedy 2005); and (3) the species often co-occurs at roosts with other species (Tuttle 1976a) that also migrate considerable distances between winter hibernacula and summer maternity sites. The spread of WNS to gray bats would likely be catastrophic and could result in an immediate reversal in the recovery progress that has been achieved across the range of the species.

Little brown bat: Of the cave-wintering bats in the Northeast, little brown bats appear to be the species that is most pervasively affected by WNS. New York is potentially facing extirpation of local populations of affected bats (Hicks 2008). If the 90% mortality rates seen in some affected states (e.g., New York) result in the drastic decline of little brown bat populations, insect populations – at least on a local scale – could respond to decreases in predator numbers with potential impacts to human and animal health.

Eastern small-footed and northern long-eared bats: The eastern small-footed bat and the northern long-eared bat have significant populations in the Northeast but are not often the targets of focused cave management and protection, with implications for WNS impacts. The majority of eastern-small footed bat occurrences and the largest populations of this species are in PA, NY, VA, and WV (Whidden 2005a). This species has historically been rarely observed, and there are some indications that it is declining.

The northern long-eared myotis is essentially a northern species, and although its range extends relatively far south and west, it is more common in the north and east than in the rest of its range (Caceres and Barclay 2000, Harvey 1992). Pennsylvania and neighboring states are in the core of its range and probably represent an important population center for this species (Whidden 2005b).

Other cave-obligate species: More than just bats are at risk if WNS continues to spread. The Appalachians are one the world's most important centers for cave biodiversity. Given the high degree of endemism and rarity of cave-obligate fauna (mostly invertebrates), most are species of conservation concern. Bats provide a significant input of energy and nutrients to cave ecosystems; this is particularly important to cave-obligate species, which depend entirely on allochthonous input for food. Invertebrate populations would likely be affected indirectly by whatever major impacts WNS might have on bat numbers and nutrient cycling, and directly if any species are susceptible to WNS (J. Rawlins, Carnegie Museum of Natural History, pers. comm.).

There are many cave-obligate invertebrates that could be disrupted by the change in cave environments due to WNS. Maryland lists 19 species of cave-obligate invertebrates as species of concern; likewise, PA identifies 13 invertebrate SGCN species for Pennsylvania, and there are 36 cave-associated invertebrate SGCN in states neighboring Pennsylvania. Clearly the alteration to the cave environment due to WNS can have significant impacts on these globally rare species (J. Rawlins, pers. comm.).

Despite recent advances in identification of the fungus associated with this white-nose syndrome, many unanswered questions remain about the mechanisms that are driving its spread and what is actually leading to mortality. For instance, it has not yet been determined how WNS is transmitted, although the observed spread of WNS from a single New York cave in 2006 to numerous sites throughout the Northeast by 2009 suggests that it is spread from bat-to-bat (or bat-to-hibernaculum) through direct contact. Available data suggest that a recently identified fungus (*Geomyces destructans*) is responsible, at least in part, for the impacts and mortality associated with WNS (Blehert et al. 2009). This mode of transmission is consistent with the rate of spread observed to date, based on tracking data for local bat movements and from knowledge of inter- and intraspecific bat contact at summer and fall roosting and staging sites.

Although the growth characteristics of *Geomyces* raise questions about whether bats may carry viable fungal material through the summer, and thus about the potential for infection at summer maternity colonies, it is still thought to be likely that bats are the primary vector for the spread of WNS. Another potential mode of transmission is by anthropogenic processes. Fungal spores and/or other microscopic organisms can readily attach to skin, hair, clothing, and equipment, and it is possible that such elements could remain viable for extended periods after leaving a subterranean environment. Unequivocal evidence that people have transported WNS to uninfected hibernacula is lacking; however, the sometimes discontinuous pattern of spread does suggest that something other than bat-to-bat transmission may be responsible. It has been observed that many of the recently affected sites are popular destinations for recreational users of caves and mines – in fact, the site where WNS was first photographed, Howe's Cave, is connected to one of the most visited commercial cave systems in the Northeast. Overall, the evidence, albeit anecdotal, suggests that the spread of WNS may be multifactorial.

There are also questions as to whether susceptibility varies by species within and among caves or if observed signs are expressed differentially by species. For example, New York's Department of Environmental Conservation has reported that signs of WNS may manifest differently between Indiana bats and little brown bats, even within the same site. Of a total of 1,190 bats counted from clusters containing both species, 5.5% of Indiana bats had obvious signs of facial fungus, compared to 51% of little brown bats. It is also unclear how long signs take to manifest after exposure to the causative agent(s). In January 2009, an affected juvenile little brown bat was collected at a site in Pennsylvania, indicating that the developmental period for WNS may be less than six months; however, this observation is unsubstantiated (G. Turner, Pennsylvania Game Commission, pers. comm.).

Captive inoculation trials currently underway at the National Wildlife Health Center could provide clues to the transmissibility among bats of the *Geomyces* fungus associated with WNS, as well as how long it takes for bats to exhibit signs of WNS after exposure (D. Blehert, pers. comm.). Finally, it is unclear what the long- term effects (e.g., geographic spread, mortality within affected sites) to the affected bat species will be.

Management Context

The WNS management recommendations resulting from this SDM process pertain to hibernacula used by bats in the eastern United States, and particularly to species that hibernate colonially. The primary reason that U.S. Fish and Wildlife Service initiated the SDM process for WNS is the effect of WNS on the federally listed Indiana bat, with the prospect that two additional listed species, the Virginia big-eared bat and the gray bat, will be affected. If WNS continues to cause bat mortalities at currently observed levels, additional bat species may need to be considered for listing.

State wildlife agencies are the principal front-line managers of wildlife, given their broad constitutional and statutory trustee authority for the conservation of the wildlife within their borders. In most cases, state wildlife agency authority extends to federal lands (although this may be modified somewhat by enabling legislation for some land areas, e.g., units of the National Park Service), with states managing the wildlife, and federal agencies, as landowners, managing the habitat. Although Congress has given USFWS statutory responsibility for selected conservation programs, such as endangered species and migratory birds, states retain concurrent jurisdiction for those species. Because of this shared responsibility, the legal mandates and management goals—the decision context—among the state agencies and USFWS are similar.

Other federal entities, such as the U.S. Forest Service and National Park Service, have an integral role in designing and implementing actions to address WNS within their management authorities and on their lands. Generally, they look to the USFWS and the states for guidance in determining the courses of action to take. These federal agencies, however, determine whether to accept the recommendations based on their specific, individual decision context. That is, the SDM process does not supersede the mandates and objectives of other agencies; rather, the process rests upon the objectives and legal mandates applicable to fulfilling the shared trust resources responsibilities of the states and USFWS. Other federal entities will decide whether and how to implement the management actions based on how these recommendations align with their own objectives and legal mandates, i.e., their specific decision context.

In addition to the federal entities mentioned above, there are many other stakeholders that could be affected by the recommendations that arise out of this process, including state land and wildlife management agencies, Tribal agencies, federal research agencies, international governmental agencies, academics, non-governmental organizations, public interest groups, private industry, and private landowners. Cave access for recreation, research, and commercial uses, management of state and federally listed species, wildlife protection, and compatibility with other land management objectives have all been voiced as concerns related to WNS control measures.

The WNS SDM process has been geared toward making management decisions at the strategic level. We recognize, however, that tactical considerations such as bat population size, cave structure, presence of listed species, and land ownership will influence implementation of the recommendations at specific sites.

MAY WORKSHOP

A WNS SDM workshop was held in May 2009 at the U.S. Fish and Wildlife Service National Training Center in Shepherdstown, West Virginia. The purposes for this workshop were to elicit strategic management objectives from decision makers via their proxies and to complete a rapid prototype of the entire SDM framework. Participants included proxies for the State Directors from Vermont, New York, Pennsylvania, West Virginia, Virginia, Indiana, Kentucky, and Wisconsin; proxies for the Regional Directors from USFWS Regions 3, 4 and 5; and science representatives from U.S. Geological Survey and National Park Service. This group of workshop participants became the WNS SDM working group.

From a discussion of the current state of knowledge and distribution of WNS, it was recognized that the dynamics of the disease differ over space, and hence, the appropriate management strategies may differ over space as well. Thus, a geographical aspect, defining three areas that differ significantly in the disease dynamics was incorporated into the framework (Fig. 1).

Area 1 ("Epicenter"): In this area, many of the caves are already infected and the spread of the disease has largely stabilized. As of spring 2009, this includes all areas north and east of New York and possibly the northeast corner of Pennsylvania. In this area, effective strategies likely need to focus on minimizing mortality and encouraging the survival of bat populations that are resistant to the disease.

Area 2 ("Leading Edge"): At the leading edge of the disease, there is very active transition of sites from susceptible to infected within a mosaic of many uninfected caves and many infected caves. Currently, this area includes most of Pennsylvania, New Jersey, West Virginia, Virginia, eastern Ohio, and eastern Kentucky. In this area, effective strategies likely need to focus on minimizing future spread of the disease and on decreasing mortality of infected bats.

Area 3 ("Susceptible"): In this area, all of the sites are hitherto uninfected, but there is a likely chance of infection in the near future. We defined this area as being >250 miles from the nearest known site of infection. Although the outer boundary of this area may shift based on the location of newly affected sites, for the coming hibernation season the area considered to be susceptible to WNS includes western Ohio, western Kentucky, Indiana, Michigan, Illinois, Iowa, Wisconsin, Minnesota, Missouri, Tennessee, Arkansas, Georgia, and Alabama. In this area, we suspect that effective strategies need to focus on containing any novel infection.

With this geographical structure established, the next task was to elicit fundamental objectives from proxy decision makers. The widespread and multi-jurisdictional scope of WNS dictates a single, coordinated management strategy at the broadest geographic level rather than piecemeal or *ad hoc* responses to the disease. Through working group discussions, fundamental objectives were identified for the rangewide scale as well as for each of the three geographic areas (Table 1).

We then worked through a prototype decision analysis for each of the geographic areas, integrating the management objectives, a small set of management alternatives, area-specific hibernaculum profiles, and placeholder consequence predictions. As we worked through theses prototypes, it became clear that completing the SDM process for all three geographic areas was not feasible within the time allotted. A decision was made to focus the prototyping process on a single geographic area, with the understanding that the approach developed for that area would then be applied to the other two areas, albeit more informally, in a parallel effort by workshop participants involved in management decision-making for those areas. After some discussion, the working group agreed that preventing WNS from spreading into Area 3 is the critical management focus at this time; Area 3 thus became the focus for full development of a management prototype. A contingent of the working group, primarily from Area 3 but also including some workshop participants from Areas 1 and 2, committed to working on this prototype, as detailed in the next section of this report.

AREA 3 PROTOTYPE

We structured the Area 3 prototype as a multi-criteria decision analysis that focused on the tradeoffs among six fundamental objectives. Twenty-three management alternatives were considered. The management alternatives consisted of portfolios of strategies applied in each of three profiles within Area 3. The strategies themselves were combinations of multiple individual actions. The consequences of the management alternatives relative to achieving of the objectives were predicted through expert elicitation, and the weights for the different objectives were elicited from the decision-makers (through their proxies). Quantitative analysis of these results provided recommended actions, as well as an understanding of the importance of resolving various uncertainties. The details of these components follow.

Objectives

In structured decision making, fundamental objectives form the basis for measuring the performance of various alternatives. Fundamental objectives constitute the central aims of the decision-making process, as opposed to means objectives, which are desirable because they constitute ways of achieving the fundamental objectives. The area-specific objectives are means to achieving the rangewide fundamental objectives, but also are fundamental in their own right (fundamental to the managers within the respective areas). To develop the objectives, we began at the May workshop by brainstorming, without critique, a long list of concerns that management agencies, stakeholders, and the public have about WNS and related issues. We then separated the concerns into three lists: those concerns that dealt with bats, those that dealt with biota other than bats, and those that encompassed other human concerns. For each of those lists, we identified which objectives were fundamental and which were means. Five rangewide objectives were identified and were carried forward (Table 1). With these rangewide objectives established, we then developed fundamental objectives for each of the 3 geographical areas by asking how the rangewide objectives needed to be interpreted in the context of each geographical area (Table 1). Soon after the workshop, the participants briefed their respective decision makers and specifically sought their approval for both the global and area-specific fundamental objectives. The six Area 3 fundamental objectives follow.

Objective 1: Prevent the spread of WNS in Area 3, either by preventing entry of the disease into the area, or by eradicating the disease from the free-flying bat population in Area 3 (referred to as containment). One of the primary objectives expressed by all the decision-makers is the need to stop this disease because of its impact on native bat populations. The management agencies care about maintaining the viability of bat populations as well as the historical distribution of cave-dwelling bats both across and within states. In each of the three areas, these two fundamental objectives (viability and distribution of bat populations) require a different approach. For Area 3, these two objectives were distilled into a single aim: preventing the disease from becoming established in Area 3. Given that WNS is not currently found in Area 3 (by definition of Area 3), this aim could be accomplished either by preventing the entry of the disease or by containing or eradicating the disease if it did enter Area 3.

Objective 2: Avoid unacceptable risks to endemic cave-obligate biota resulting from WNS or management strategies directed at WNS. All of the decision-makers recognize that there are costs to management actions aimed at preventing the spread of WNS. One of these costs is the potential impact on other cave-obligate biota. These impacts could occur as an unintended result of say, fungicide treatments, changes to the bat populations, or simply from human disturbance within caves and mines. Of course, there is also the risk that WNS, untreated, would greatly alter the bat populations, which, in turn, would disrupt the ecosystems in the caves. Managers fundamentally care about, and are obligated under several laws to protect, the cave-obligate biota in these ecosystems.

Objective 3: Minimize public health risks from management strategies related to WNS, from Geomyces destructans, and from moribund bats. Managers also fundamentally care about the health of human populations exposed to caves, bats, or the management treatments aimed at either of those. It is not clear that there are public health risks associated with WNS or treatments aimed at stopping WNS, but several possible avenues of public health risk have been postulated: health risk based on exposure to the management treatments (for example, a fungicide that was applied aerially or that was water-soluble and could appear in the water supply); health risk due to exposure to moribund bats affected by WNS or treatment thereof, with possible exposure to zoonotic disease; or health risk due to exposure to the *Geomyces* fungus.

Objective 4: Minimize restrictions on the affected public and land managers in Area 3. To date, most of the responses to WNS have involved restricting human access to caves and mines in various ways. These restrictions can impose a regulatory burden on the affected public, and have been the topic of significant concern among a number of stakeholder groups. All other things equal, managers would like to minimize the regulatory burden placed on the public as a result of actions taken to address WNS. Like the other potential costs, this objective needs to be traded-off against the conservation benefit of such actions.

Objective 5: Minimize the total number of bats directly killed as a result of management strategies taken in Area 3 in a given year. As noted earlier, one of the fundamental objectives of the federal and state wildlife agencies is to maintain the viability and distribution of bat populations, so upon initial consideration, it would seem that deliberate mortality should be avoided. However, some scientists have argued that prophylactic eradication of bats might be a method of preventing the spread of the disease (either by removing undetected infected individuals, or by creating a "fire-break" of sorts in the distribution of the population). The arguments that have ensued over this potential management action have been heated. Underlying this debate, we believe, is a fundamental desire not to kill bats unnecessarily; otherwise, why not try prophylactic eradication as an experimental procedure? This concern actually encompasses all possible management alternatives, not just preventive eradication—managers desire not to have to directly kill bats. This objective may be traded off against the efficacy of the treatment in stopping the spread of WNS, but this particular tradeoff can only be analyzed by recognizing this objective explicitly.

Objective 6: Provide research opportunities to accelerate the search for solutions to manage this disease, by maximizing the use of Area 3 as a source of control animals and sites. At the rangewide scale, management agencies care fundamentally about protecting natural resources and responding to other social values (like public health and regulatory burden). They are not research institutions and do not fundamentally pursue increasing our body of ecological knowledge. These agencies astutely realize, however, that increased ecological knowledge may lead to improved management outcomes, so they recognize research as a means objective. For WNS, because of the substantial uncertainty about its dynamics, modes of transmission, and susceptibility to management treatment, all the agencies see research as an imperative path toward achieving their fundamental management objectives. In Area 3, there is particular recognition that the bat populations and caves constitute a pristine control setting, as well as a source of uninfected individuals for experimental treatment. Thus, the decision-makers within Area 3 view research as a means to achieving the global fundamental objectives, and hence, view it as a fundamental objective for Area 3. Some of the management actions being considered could reduce this potential, and this opportunity cost needs to be examined against the benefits of those actions.

Note that minimizing the direct costs of implementation (e.g., construction of gates, enforcement of access restrictions, purchase and application of fungicide, etc.) was not articulated as a fundamental objective. While there was some brief discussion of this issue, at the strategic level it was not viewed as a fundamental concern, because the management agencies see these costs as part of their normal operation and are more concerned with carrying out their trust responsibilities. Further, the actions considered (see below) were viewed as being largely within the budgets of the agencies to implement. At the tactical level, when specific implementation actions are taken, these costs may be taken into account.

Profiles

Area 3 hibernacula are categorized into three broadly defined profiles, with the assumption that different management strategies may vary in their applicability among the profiles. At the strategic decision-making level, the Area 3 profiles are:

1. Affected site – the initial cave(s) or mine(s) within Area 3 to show signs of being affected by WNS, through confirmation of the *Geomyces* fungus on either the bats at the site or in the cave/mine itself. Currently there are no such sites and there might not be any in winter 2009-2010. This profile exists to describe the response in case infection occurs.

2. Near Affected site – all Area 3 caves or mines within 75 miles of any affected site. Again, no such sites exist at present, but would be defined if infection occurred within Area 3. This profile was defined because the proximity to an affected site is believed to increase the susceptibility to becoming infected with WNS. The 75-mile radius was chosen to reflect the potential distance for within-season movement of bats, based on coarse empirical data of within-season spread of WNS in Virginia from 2008 to 2009 (Rick Reynolds, Virginia Dept. of Game and Inland Fisheries, pers. comm.).

3. Far from Affected site – all Area 3 caves or mines farther than 75 miles from any affected site. These sites are believed to be less susceptible to becoming infected with WNS through transmission from the affected site. Currently, all Area 3 sites are in this profile, but that would change if WNS is discovered in Area 3 this winter.

Several other tactical-level considerations will influence implementation of a given management strategy in Area 3. These considerations, which will be addressed in a forthcoming "user guide" for landowners and land managers, include but are not necessarily limited to:

- Presence of year-round cave obligate bats
- Movement behavior of the bats
- Number of bats present
- Presence of other cave biota
- Whether the site is a cave or mine
- Whether the site is a hibernacula complex
- Number of visitors to the site
- Current accessibility for research, recreational, and/or commercial uses
- Number and size of cave/mine openings
- Size and complexity of the cave/mine
- Site microclimate
- Site hydrology
- Site ownership/acceptability of WNS management actions to the landowner

Alternatives

Development of a set of Area 3 management alternatives for analysis involved multiple steps. Each WNS management *alternative* is composed of three management *strategies* which are in turn composed of multiple management *actions*. The actions are individual management interventions that are applied at the scale of a cave. A strategy is a complete set of actions applied to all of the caves that fit a particular profile. Finally, a full management alternative describes the strategies chosen for each of the three profiles within Area 3.

The working group began by identifying all possible known or proposed management actions that could be implemented to either control the spread or minimize the effects of WNS. The resulting list of actions was grouped into nine distinct categories and organized into a strategy table (Table 2). For each category, we identified the mutually exclusive set of actions that could be selected; under the bat access category, for example, we could permanently or seasonally restrict bat access to or from a cave or mine or choose not to restrict bat access at all. After a comprehensive strategy table was developed, the working group then sorted the actions into those that were either technically feasible or unfeasible for Area 3 over the coming fall and winter (see Table 2).

With the actions identified and organized by category, we then selected a set of management strategies. A management strategy is a particular set of management actions that can be taken concurrently. Using the strategy table, a management strategy was devised by selecting an option from each category of actions; however, the combination of nine distinct action categories plus multiple options within each category led to an enormous number of permutations. To narrow the number of potential management strategies, we focused on those management actions that are most controversial or otherwise are of particular interest to decision makers, recognizing that it was important to allow the decision makers to discern the effects of implementing certain strategies. Key strategies were determined by conducting pair-wise topical comparisons (Table 3) among, for example, management strategies that allow for different levels of restricting human access. We also strived to include management strategies that are representative, but not exhaustive, of the full range of management options; that is, we sought to devise at least one strategy that represented each of the major categories of action, including bat and human access restrictions, fungicide treatments, and bat eradication actions. The outcome of these exercises was identification of 11 potential management strategies (Table 4); a narrative description of each strategy is provided in Table 5.

The final step in developing alternatives was to combine one management strategy per profile into an Area 3-wide management alternative. Again, there were a large number of options to consider, and ideally we would have constructed a model to analyze all combinations. Our time frame, however, did not accommodate building a model with the required level of complexity. We thus narrowed the possible combinations by identifying those management strategies that are applicable to each profile (Table 6); for example, as the table indicates, management strategy J is applicable only to the Affected profile, while management strategy C is applicable to all three Area 3 profiles. This resulted in a set of 23 management Area 3 alternatives to run through a decision analysis.

During the analysis, it was recognized that the outcomes in Area 3 may also be affected by management scenarios taken in Areas 1 and 2, particularly through the arrival rate of WNS to Area 3. In the analysis, we considered three possible Area 1 and 2 scenarios with regard to cave access: full access to caves in Areas 1 and 2; partial access for research and commercial uses only; and no access, except for research purposes. These 3 scenarios, in combination with the 23 Area 3 management alternatives, resulted in consideration of 69 management alternatives in total. For most of the objectives, consideration of the 23 Area 3 alternatives was all that was relevant, but for Objectives 1 and 5, all 69 permutations needed to be considered.

Measurable Attributes for the Fundamental Objectives

As stated above, the fundamental objectives form the basis for measuring the performance of various alternatives. To ensure that a decision is made in accordance with the fundamental interests of the decision maker, measurable attributes that represent the objective are defined, and it is these attributes by which alternatives can be assessed in a systematic way. The measurable attributes for Area 3 fundamental objectives follow.

Objective 1: Prevent the spread of WNS in Area 3, either by preventing entry of the disease into the area, or by eradicating the disease from the free-flying bat population in Area 3 (referred to as containment). To measure the potential spread of the disease as a function of the proposed management alternatives, we evaluated the probability of WNS presence in Area 3 in the next year ($t+1$) given absence of the disease in the previous year ($t-1$), using the model shown in Figure 2.

Note that absence of the disease in the previous year is part of the definition of Area 3. Because we are talking about decisions made prior to the winter of year t, the presence or absence of the disease in year t is not known, and could be influenced by the decision made. The desired probability can be decomposed into two component probabilities, the probability of arrival and establishment of the disease in Area 3 (a) and the probability of containment conditional upon arrival of the disease (c).

Presence in year $t+1$ can arise in one of three ways: arrival in year t, successful containment, but re-arrival in year $t+1$; arrival in year t with unsuccessful containment; or no arrival in year t but arrival in year $t+1$. Thus,

$$\text{P(WNS presence at } t+1 \mid \text{absence at } t-1) = a^2c + a(1-c) + (1-a)a. \qquad (1)$$

The probability of arrival and establishment (a) is, in turn, the product of two probabilities: the probability of WNS leaving Area 1 or 2 and being transported to somewhere in Area 3, but not necessarily to a cave, either by humans or bats (a_1); and the probability of WNS establishing itself in a cave in Area 3, conditional on having already been transported to Area 3 (a_2). Thus, $a = a_1 \times a_2$.

This model for spread of the disease makes several assumptions. First, it assumes fairly low rates of arrival, where only one affected cave is likely. For higher rates of arrival where multiple caves could be newly affected in a single year, a more sophisticated structure might be needed, such as a Poisson process that could account for more than one arrival. This might be a possible extension for future model development. Second, it assumes that the arrival rates at time t and $t+1$ are identical, that is, the arrival rates this year and next year are the same. We've used this as a first approximation, but in truth, the arrival rate will probably be higher in subsequent years, as the disease spreads further. Third, the containment process expressed in the parameter c implicitly includes a detection process as well, that is, it is more accurately described as the product of the probability of detecting an infection and being able to do contain it.

Objective 2: Avoid unacceptable risks to endemic cave-obligate biota resulting from WNS or management strategies directed at WNS. To measure this risk, we evaluated the probability of unacceptable impacts to any endemic cave-obligate biota. This objective contains two implicit pieces: the probability of impact and the magnitude of impact. The magnitude is handled by identifying a threshold magnitude of impact (acceptable vs. unacceptable), but otherwise not distinguishing different magnitudes. The measurable attribute, then, is the probability of any impacts exceeding the threshold (unacceptable) level. We defined an "unacceptable level of impact" as a "75% population reduction in any species in any one cave, or 25% population reduction of any one species across sites within any state." This definition of "unacceptable" is not legally mandated or cast in stone. Indeed, any number of other variations could have been used, without changing the outcome of the analysis. What is important is that three things are coupled: the definition of "unacceptable", the predicted risk associated with it (from the expert elicitation, below), and the weight placed on this objective (from the weighting exercise, below). A different definition of "unacceptable" could result in different projected risks and different weights on this objective; but the combined effect should remain the same.

Objective 3: Minimize public health risks from management strategies related to WNS, from Geomyces destructans, and from moribund bats. To measure this risk, we evaluated the probability that at least one person would be exposed and have an adverse response to chemical treatments, the *Geomyces* fungus itself, or to moribund bats, as a direct or indirect result of the management actions taken. We defined an adverse human health impact as a condition that leads a person to seek out medical attention either for an acute or chronic condition. Bins (0%, 0-5%, 5-15%, 15-30%, 30-70%, 70-100%, 100%) were used to define the probability that at least one person will have an adverse response for each pathway of risk (treatments, fungus, and bats).

Objective 4: Minimize restrictions on the affected public and land managers in Area 3. To measure this objective, we constructed a scale that described the degree of restriction in terms of the economic impact and the loss of recreational opportunities. A management alternative received 0 pts on this scale if the alternative imposes no restrictions on the affected public or land managers in Area 3; 1 point if the alternative imposes a minor loss of recreational opportunities; 2 points if the alternative imposes a major loss of recreational opportunities across Area 3 or a minor economic impact (less than $100,000 per year across Area 3); and 3 points if the alternative imposes a major economic loss that exceeds $100,000 per year across Area 3. A minor loss of recreational opportunity occurs when some caves are closed, but alternative caves that allow recreational access are available within a reasonable radius (<150-200 miles) of the closed caves. A major loss of recreational opportunity occurs when all caves within 150 miles of any closed cave are also closed to recreational access. A radius of 150 miles was defined as reasonable because it represents a drive of about 3 hours, something that is not a tremendous burden to those seeking recreation.

Objective 5: Minimize the total number of bats directly killed as a result of management strategies taken in Area 3 in a given year. To measure this objective, we evaluated the expected number of bats that would be directly killed as a part of management strategies taken in Area 3 in a given year. As with Objective 1, we felt this was a complicated enough attribute that we built a small model of factors affecting it, and elicited some of the parameters from the experts. To build up this measurable attribute, we multiplied the *proportion* of bats killed by a particular strategy, the expected number of caves treated with that strategy, and the average population size of bats in a cave in Area 3. We focused only on bats killed in the affected and near-affected profiles, rather than all of Area 3, for two reasons: first, the only management strategies taken in the far-from-affected profile were strategies that restricted human access, not strategies that involved direct treatment of bats; and second, we did not have an estimate of the total number of caves and mines in Area 3, so we could not calculate the number of caves in the far-from-affected profile. Thus, we estimated the expected number of bats killed as

$$E\left[B(i)\right]=\sum_{p=1}^{2}c_p(i)\cdot q\left(s_p(i)\right)\cdot n \qquad (2)$$

where i represents the management alternative ($i = 1, 2,\ldots,23$ for each scenario), p is the profile ($p = 1$ for the affected profile, $p = 2$ for the near-affected profile), $c_p(i)$ is the expected number of caves in profile p under management alternative i, $q(s)$ is the proportion of bats in a cave killed under strategy s, $s_p(i)$ is the strategy taken in profile p under alternative i (thus, $s_2(12)$ = "E", because alternative 12 calls for taking strategy E in the near-affected profile), and n is the average number of bats in a cave in Area 3.

We predicted the expected number of affected caves, $c_1(i)$ from the arrival rate (a) of white-nose syndrome that was estimated as part of Objective 1. We assumed that the number of caves affected with WNS in Area 3 in year t follows a Poisson distribution with rate parameter λ. We interpreted the probability of arrival as the probability that at least one cave would be affected, that is,

$$a = p\left(X \geq 1\right) = 1 - p\left(X = 0\right) = 1 - e^{-\lambda}. \qquad (3)$$

Because the rate parameter of a Poisson distribution is also the expected value, we could solve equation (3) for λ to find the expected number of affected caves. Thus,

$$c_1(i) = -\ln\left(1 - a_i\right) \qquad (4)$$

where a_i is the arrival rate associated with management alternative i (from the elicitation for Objective 1). Based on conversations with bat experts in Kentucky and Indiana, we then assumed that there are 25 near-affected caves for each affected cave, that is, we assumed that for any given cave, there are, on average 25 caves within 75 miles of it (L. Pruitt, M. Armstrong, pers. comm.).

It is likely that a better empirical estimate of this quantity can be developed, but we feel this is certainly within the right order of magnitude. Thus,

$$c_2(i) = 25c_1(i) = -25\ln(1-a_i). \tag{5}$$

Finally, we assumed that the average number of bats in a cave in Area 3 is 1000 (n = 1000). We do not yet have an empirical estimate for this quantity but we believe the results of this analysis are not strongly sensitive to this assumption, because the same fixed average was applied across all management alternatives. Had we left this part of the calculation out, our results would have been expressed as a proportion of bats within affected and near-affected caves. We felt that an absolute scale was easier for the managers to understand, however, and the experts consulted felt that the average size chosen was correct within an order of magnitude. In the future, a more detailed analysis could incorporate empirical estimates for this quantity, as well as the variation in bat population size across caves, which might also be a very relevant consideration.

Objective 6: Provide research opportunities to accelerate the search for solutions to manage this disease, by maximizing the use of Area 3 as a source of control animals and sites. To measure this objective, we constructed a scale that described the degree of opportunity for research in Area 3. A management alternative receives 2 points if the alternative allows unfettered access *for researchers* to caves and bats, where otherwise allowed by law and the landowners; 1 point if the alternative allows limited access for research purposes, at least at a substantial subset of uninfected sites in Area 3, where there are enough bats to support limited take for research purposes; and 0 points if the alternative severely curtails access for research purposes, across Area 3, so that there is limited to no opportunity to advance the state of knowledge of the disease through research.

Consequences and Tradeoff Analysis

Description of the analytical framework

The Area 3 decision analysis consisted of evaluating 23 management alternatives against six objectives, then identifying which alternative best achieves the decision makers' fundamental objectives. In multiple-objective decision problems like this, it is rare to find an alternative that performs best on all objectives; it is much more typical to find that different alternatives perform more or less well against different objectives – the challenge in making the decision is thus to manage the tradeoffs among objectives. There are several methods for this sort of analysis; we used the Simple Multi-Attribute Rating Technique (SMART, Goodwin and Wright 2004). In this method, once the objectives, measurable attributes, and alternatives have been identified there are three analytical steps: (1) predicting the consequences of each alternative against each objective, (2) establishing weights on the objectives that reflect the values of the decision-makers, and (3) conducting the tradeoff analysis. The procedures and findings of each of these three steps are described below.

Predicting consequences

Expert elicitation was used to predict the consequences of each alternative in terms of each of the six Area 3 objectives. Although this is a scientific exercise that ideally would be done in a quantitative modeling framework supported by empirical evidence, the novelty of this situation, the lack of data, and the short time-frame to conduct the analysis precluded building of formal predictive models. Instead, we directly elicited predictions from experts. There is a substantial literature supporting the use of expert elicitation, with evaluation of the various methods (e.g., Keeney and Winterfeldt 1989, Cleaves 1994, Ayyub 2001, Cooke and Goossens 2004, Ouchi 2004, Garthwaite et al. 2005, Martin et al. 2005, MacMillan and Marshall 2006).

In general, expert elicitations can be conducted either one-on-one or as a group, and through face-to-face, telephone, or electronic media. With multiple experts and a high degree of uncertainty, the preferred method is to elicit input in a workshop forum; however, this option was not logistically feasible for the WNS decision. Instead, the elicitation process was conducted via email. Members of the working group approached the experts to request their participation. Following this initial contact, each expert was sent a brief overview of the project along with instructions pertaining to the specific input requested of them (Appendix 1). In completing the exercises, the experts were asked to provide expert judgment based on their knowledge and experience. Once submitted, the experts' predictions were compiled and averaged to obtain a single composite score for each predicted consequence. Two of the advantages of this method of elicitation are that the experts' responses are independent, and the multiple responses provide a collective measure of uncertainty about the consequence in question. Thus, the individual predictions were recorded and used to quantify uncertainty, which was then considered in sensitivity analyses.

Six expert teams were assembled, one for each fundamental objective. To select experts, the WNS working group nominated individuals who could provide subject-matter expertise based on academic studies or experience. The first objective required experts with knowledge of the transmission dynamics of WNS as function of management actions. The second required knowledge of risks posed to other cave fauna from management actions. For the third objective, knowledge of human health risks with regard to (a) *Geomyces destructans*, (b) possible treatments, and (c) diseased bats was required. The fourth objective required knowledge of cave use for various purposes in order to evaluate the level of restrictions posed by the various alternatives. The fifth objective required knowledge of the life history of cave-dwelling bats and how bats would be directly affected by management actions, while the sixth objective required knowledge of how the management actions might impede research to resolve key uncertainties about WNS dynamics. Overall, 56 experts were contacted, and of these, 19 were able to complete the predictive tasks asked of them: three experts responded for objectives 1, 2 and 4; two experts for objective 3; four for objective 6; and six for objective 5. Following is an explanation of the input we received from these experts.

It is very important to note that the experts were *not* asked to rate or rank the alternatives in terms of which one should be preferred. Such a ranking requires integration of both scientific and policy considerations. Rather, the experts were only asked to score the scientific aspects of the problem, and further, any single expert was only asked to score one or two small scientific pieces of the problem. In other words, experts were asked to predict the consequences of each management alternative relative to the specific objectives that apply to their expertise. In this way, experts were only asked for responses in their area of expertise, and they were not asked to make any policy or value judgments.

Objective 1. For the first objective (Prevent the spread of WNS within Area 3, either by preventing entry of the disease into the area or by eradicating the disease from the free-flying bat population in Area 3), the focus of the elicitation was on how the management alternatives will affect the three probabilities: a_1, a_2, and c, with a_1 being the probability of WNS leaving Area 1 or 2 and being transported to somewhere in Area 3, but not necessarily to a cave, either by humans or bats; a_2 being the probability of WNS establishing itself in a cave in Area 3, conditional on having already been transported to Area 3; and c being the probability of containment conditional upon arrival of the disease. Each step of eliciting expert input regarding these components is described below.

Component (a_1). Presumably, a_1 is only affected by actions taken in Area 1 ("Epicenter") and Area 2 ("Leading Edge"). For instance, cave closures in Areas 1 and 2 could reduce the probability of arrival by reducing the human-cave vector, because fewer scientists, cavers, and/or tourists would transport the disease out of the affected areas. It is also possible that other types of management actions could prevent the arrival of the disease in Area 3 by preventing diseased bats from leaving Areas 1 and 2. Based on these premises, we asked experts to evaluate a_1, the probability of WNS leaving Area 1 or 2 and arriving in Area 3, under three scenarios:

a) no cave or mine closures in Areas 1 and 2,
b) partial cave and mine closures in Areas 1 and 2 (the current situation, in which access is allowed for commercial or research purposes only), and
c) all caves and mines in Areas 1 and 2 closed for all purposes, except research.

Component (a_2). We also presumed that a_2 is only affected by actions taken in Area 3. Thus, cave closures in Area 3 might reduce the probability of establishment even if the disease is brought out of Areas 1 and 2, because it would not be allowed to enter a cave in Area 3. Other actions in Area 3 that could reduce the probability of establishment of the disease include cave-closures to bats, prophylactic fungicide, or, potentially, vaccination. We asked the experts to evaluate a_2 (the probability of WNS establishment in a cave in Area 3), conditional on the disease already having been transported to Area 3, for each of the 23 management alternatives.

Component (c). Conditional on the presence of WNS in an Area 3 cave, what is the probability that the disease will not spread beyond that cave, as a function of a given management alternative? Containment does not require eradication of the disease but rather precluding the disease from free-flying bat transmission. To judge the probability of containment, the focus has to be on actions taken within Area 3, and these actions will likely be reactive, i.e., if the disease is detected in year t in a particular cave, that cave now becomes part of a different profile ("affected site"). In such a case, actions might be taken at either the infection site or in neighboring caves to contain the spread of the disease. For this exercise, we asked experts to evaluate c, the probability of WNS containment within a cave in Area 3, as a function of the 23 management alternatives.

From each expert's estimates of a_1, a_2, and c, we calculated 69 different probabilities of spread (based on 23 Area 3 management alternatives times 3 different spread scenarios from Areas 1 and 2). None of the experts thought that a_1 would differ between the partial and full closure scenarios in Areas 1 and 2, although some experts felt that a_1 would be greater if there were to be no cave/mine closures in Areas 1 and 2. The net effect of an increase in a_1 is an across-the-board increase in the probability of spread. For simplicity, we only show the results for the partial closure in Areas 1 and 2 in Table 7 (see Objective 1 in the table).

Although there was substantial uncertainty in the estimates of the probability of spread for all the alternatives, the mean responses from the experts did not show large differences among the alternatives (Table 7). The most effective alternatives were predicted to be those that involved eradication of bats (Alternatives 21-23), with a mean probability of spread of 0.68; the least effective were those with limited to no closure of caves (Alternatives 1-4), with a mean probability of spread of 0.88. It cannot be emphasized enough that the uncertainty is high; indeed, some experts felt that none of these treatments would be effective at reducing spread, while others felt that the risk of spread could be greatly reduced. The mean estimates in Table 7 do not provide a definitive answer so much as a starting point for future evaluation. But for decision makers evaluating their options in the short term, this expresses the current state of knowledge.

One of the intermediate variables calculated from this elicitation was the probability of arrival of WNS in Area 3 this year ($a = a_1 \times a_2$). For management alternatives 5-10, three experts provided enough input to calculate this probability; it ranged from 0.28 to 0.90 (average 0.504) under the partial and full closure scenarios for Areas 1 & 2, and 0.49 to 0.90 (average 0.645) under the open access scenario for Areas 1 & 2.

Objective 2. For the second objective (Avoid unacceptable risks to endemic cave-obligate biota resulting from WNS or management strategies directed at WNS), we asked experts for the probabilities of unacceptable impacts to cave biota as a function of the 23 management alternatives for Area 3. Experts needed only identify a probability bin, i.e., 0%, 0-5%, 5-15%, 15-30%, 30-70%, 70-100%, 100%.

The experts felt that all of the management alternatives carried a high probability of causing unacceptable impacts to cave-obligate biota (see Objective 2 in Table 7). The lowest-performing alternatives were those that involved taking intrusive actions within the caves (Alternatives 11-23), which were assessed to have 100% likelihood of unacceptable impacts. The best alternatives were those that completely restricted access to affected caves in Area 3 (Alternatives 9-10), although the experts predicted that even these would have a high probability of impact (61%). Based on the rationales provided by the experts, they were considering both the direct effects of treatment on cave-obligate biota as well as the indirect effects that a change in bat community due to WNS would have on the cave ecology. Thus, to some extent, the experts conflated Objectives 1 and 2, evaluating simultaneously whether a treatment would help reduce the spread of the disease and thus reduce the effect on the bat population and the cave ecosystem.

Note that a time horizon for the definition of unacceptable impact was not provided, so some of the variation in the responses from the experts could have been due to differing assumptions about the time frame of interest. Future articulation of this objective should clarify this point.

Objective 3. For the third objective (Minimize public health risks from management strategies related to WNS and from moribund bats), the experts were asked to assess the probability of public health impact (in bins: 0%, 0-5%, 5-15%, 15-30%, 30-70%, 70-100%, 100%) for each of the 23 management alternatives and for each of the three pathways of risk (treatments, fungus, and bats). To calculate the overall metric, the probability that at least one person will have an adverse response was calculated for each pathway, and the maximum over pathways was taken.

None of the experts queried felt comfortable estimating the probability of adverse health risk from the management treatments (such as fungicide), so the results are based only two of the three pathways, i.e., exposure to the fungus, and exposure to moribund bats. In general, the probabilities of adverse health risks to at least one person were low (less than 10%; see Objective 3 in Table 7). In almost all cases, the greater risk was seen to be coming from exposure to moribund bats rather than to the *Geomyces* fungus itself, and the risk was largely a function of how much access there was to caves with high bat densities. The management alternatives that allowed either free access or specialized access by cavers (Alternatives 1, 2, 5, and 6) had the higher estimated risks (6.25%), while the rest of the alternatives had a lower risk (2.5%).

The causal pathways that might give rise to human health risk are complicated. For instance, one concern that exists is the possibility of WNS spreading to commercial caves with large bat populations, thus increasing the exposure of the public to many moribund bats, some of which might carry some other disease of concern to humans. As with some of the other measurable attributes, it may have been difficult for the experts to separate out the direct impact of management alternatives on an attribute from indirect impacts via a change in disease status. That is, to the extent that a management alternative affects the spread of the disease in bats, it might thus also affect the health impacts to humans. We could not determine whether this dynamic was fully considered in the elicitation. In addition, there is concern about the potential human health effects from the management treatments (particularly fungicides); because we were not able to evaluate these risks, the results of this elicitation did not provide a full assessment of Objective 3. With limited responses from the experts and incomplete coverage of all the issues, the uncertainty associated with this objective was likely underestimated.

Objective 4. With regard to the fourth objective (Minimize restrictions on the affected public and land managers in Area 3), the experts were fairly consistent in their scoring (see Objective 4 in Table 7). Alternative 1, which allows full access to all caves and mines, scored the best, with all experts agreeing this posed no restrictions on the public. Management alternatives 5, 7, and 9, which prohibit commercial access across the entirety of Area 3, performed the worst, with all experts agreeing that this constituted the highest level of restriction.

Objective 5. For the fifth objective (Minimize the total number of bats directly killed as a result of management strategies taken in Area 3 in a given year), we asked the experts to estimate the proportion of bats in a cave that would be directly killed as a result of the application of a particular management strategy in a given year. This proved to be a difficult parameter to elicit from the experts, because it was difficult for them, as it was for the experts who evaluated objective 2, to separate direct effects associated with the treatments from the indirect effects due to WNS. Initially, most of the experts considered the mortality rate to be very high for all management alternatives because they felt that eventually the disease would affect the population and a very high proportion of bats would die, especially if no management action was taken. We thus clarified the question to the experts, explaining that we were considering the spread of the disease in another objective, and the purpose of this elicitation was to understand how many bats would be killed in the first year as a direct result of the management treatment. We only included expert responses that reflected an understanding of the question being posed. The best performing alternatives were Alternatives 9 and 10, with an expected mortality level of 448 under the Area 1 and 2 partial closure scenario (see Objective 5 in Table 7). In these alternatives, no action is being taken that directly affects bats, and there is significant restriction in access to affected and near-affected caves. Direct mortality was higher in Alternatives 1-8, because although no action is being taken that directly affects bats, the increased access leads to disturbance that can reduce the survival rate of hibernating bats. The more invasive treatments (Alternatives 11-23) resulted in much higher mortality estimates, because a higher proportion of bats were likely to be killed in each cave that received treatment. The lowest-performing alternative was Alternative 21, in which bats are eradicated from affected and near-affected caves, with an expected mortality level of 23,350 bats in one year. It is important to note that this says only that many bats would be directly killed by a management action; it does not account for bat mortality due to the fungus.

Objective 6. The experts consulted were fairly consistent in their scoring of the measurable attribute for the sixth objective (Provide research opportunities to accelerate the search for solutions to manage this disease, by maximizing the use of Area 3 as a source of control animals and sites) (see Objective 6 in Table 7). In general, the experts felt that research opportunities would not be seriously curtailed by any of the management alternatives. A handful of alternatives (2, 7, 8, 12, 14, 16, and 17) received full marks, indicating that all the experts felt that research would continue unfettered under those alternatives. The lowest-performing alternatives, with an average score of 1.50, were those in which fairly aggressive action would be taken in both affected and near-affected caves (Alternatives 18, 19, 21-23), perhaps because the direct mortality in those caves and the specific treatment procedures would preclude some research access and opportunity.

Swing weighting process and results

Having generated a consequence table (Table 7) that described the predicted outcomes associated with the different management alternatives against the six objectives, we then needed to discover how the decision makers wished to balance the tradeoffs against each other. To do this, we elicited a weight for each objective. This is a policy judgment rather than a scientific endeavor, and the weights should reflect the values of the decision makers. Because it was not possible to schedule a meeting with all the decision makers to do this, we worked with their proxies, who were already familiar with the process and could provide representative feedback (in some cases, proxies discussed input with their decision makers beforehand).

We elicited objective weights using a method known as swing weighting. We asked the proxies to compare seven hypothetical management alternatives, one (the baseline) that achieved the worst score on all six objectives, and six more that each achieved the best score on one objective but worst scores on the other five. In making the comparison, the decision makers had to consider both the intrinsic importance of the objective as well as how consequential the "swing" between the worst and best score for each objective was to them. These alternatives were ranked independently by each proxy decision maker. Each alternative was then given a score between 0 and 100; 100 points were given to the highest-ranked alternative and 0 points to the baseline, with the remainder falling in between. From the scores, a set of weights was calculated for each decision maker by standardizing the scores for each objective to sum to 1 (Table 8). Noting that there were three proxies from FWS Region 5, their scores were averaged before being averaged with the others, so that Region 5 had the same influence in the outcome as the other states and regions (each of which had only one proxy). All the decision makers ranked Objective 1 (reduce the spread of WNS) highest (or very nearly so, VA ranked it a close second), so the average weight was highest for Objective 1 (0.295, Table 8). On average, the second highest weighted objective was Objective 2 (minimizing impact to cave-obligate biota), with a weight of 0.193. The third highest weighted objective was Objective 3 (minimum public health impacts), with an average weight of 0.179. The other objectives fell further behind, with Objective 4 (minimize restrictions on the public) having the lowest average weight at 0.090. It should be emphasized again that these weights reflect both the objective and the range over which it varied (that range is shown in Table 9).

There were fairly strong differences in the weights elicited from the different decision makers. We performed a principal components analysis to identify the patterns in the weights given to the six objectives. The first two principal components explained 65.1% of the variation in the weights across decision makers. Based on these two principal components, we chose three decision makers whose value judgments bracketed those of the other decision makers (see the highlighted rows in Table 8). One of the proxies from FWS R5 put a very high weight on Objective 1 and relatively little weight on any other objective; this represented a view that we need to focus on minimizing the spread of the disease at almost any cost, and can tolerate direct bat mortality and restrictions in access in doing so. The proxy for Kentucky, in contrast, put a fairly even weight on all the objectives, and, in particular, expressing a view that although we wish to slow the spread of the disease, we cannot allow too much direct bat mortality, regulatory burden, or ecosystem impact in doing so. The proxy for Pennsylvania put high weight on the first three objectives (reducing spread, reducing impact to cave ecosystems, and minimizing adverse public health risks), while putting low weight on the remaining objectives (regulatory burden, direct bat mortality, and research opportunity). The weightings from the remaining decision-makers all fell within a range bounded by these three weightings so these three were carried forward in the analysis to represent uncertainty about the weights on the objectives.

Overall results

To complete the multiple-objective decision analysis, the weights on the objectives were combined with the consequence table to derive weighted scores for each management alternative (see Table 9). First, the scores of the alternatives for each objective were normalized to a 0-1 scale, using the same best and worst case values presented in the swing weighting. For instance, for Objective 3, the range of values considered in the swing weighting for the probability of adverse human impact was 0 to 0.15. The scores for this objective (see Table 8) were re-scaled so that a score of 0 (best case) would have a normalized score of 1.0 and a score of 0.15 (worst case) would have a normalized score of 0.0. The advantage of normalizing is that it puts all scores on a comparable scale.

These normalized scores were then averaged across objectives, using the weights from the swing weighting elicitation, to derive a single composite score for each alternative. The composite score (the "Weighted Score" in Table 9) represents an integrated evaluation of a particular management alternative, one that balances the tradeoffs among objectives in a manner that should reflect the values of the decision maker.

Using the averaged weights on the objectives, the best performing alternative is Alternative 10, with Alternatives 7-9 performing almost as well (see Table 9 and Figure 3A). These alternatives focus on restricting access; this management action achieves a relatively good performance in terms of the predicted spread of the disease while performing very well on four other objectives (cave biota, human health, bat mortality, and research). Using average weights, the worst performing management alternative is Alternative 21, because of the predicted very high bat mortality, adverse impacts on cave biota, and loss of research opportunity. Alternative 21 does have the highest predicted performance on Objective 1, but this is offset by very negative performances on the other objectives. With regard to the other management alternatives (see Figure 3A), the aggressive management alternatives (Alternatives 11-23) perform relatively poorly, primarily because the uncertainty about whether they will be effective in containing the disease undermines their predicted benefit, so predicted adverse impacts carry the day. This tendency is more pronounced when aggressive treatments are applied to a greater number of caves (compare, for instance, Alternatives 15-17). Alternative 15 performs quite poorly because the in-situ fungicide and bat exclusion management actions (strategy I) are applied to both affected and near-affected caves, resulting in more severe adverse impacts, like direct bat mortality. In Alternatives 16 and 17, only the affected caves receive the most aggressive treatment, while near-affected caves receive more moderate treatment, and adverse impacts are reduced without apparent loss of control of the disease.

It is important to note, however, that the best performing alternative is not robust to uncertainty in the weights on the objectives. When the boundary weights, rather than average weights, are used, quite different alternatives emerge as high-performers. For the bound 1 weights (as expressed by FWS R5 FO2; see Figure 3B), Alternative 14 (in-situ fungicide at affected sites) performs best and Alternative 1 (no action) performs worst. For the bound 2 weights (Pennsylvania; see Figure 3C), the best performing alternative is Alternative 10, the same as with the average weights, but the worst performing alternative is Alternative 5 (access for recreation and research only). For the bound 3 weights (Kentucky; see Figure 3D), the best performing alternative is Alternative 1 (no action), while the worst performing alternative is Alternative 21 (bat eradication).

During review of a draft of this analysis by the decision-makers, several decision-makers questioned the weight given to Objective 3 (public health), wondering why it was weighted so heavily when there was no documented risk and the estimated risks were quite low. First, note that the weight reflects how much the decision makers would care about a change in probability of adverse human impact from 0.0 to 0.15, not how likely they think that impact is. Second, the actual range of probabilities was even smaller, between 0.025 and 0.0625 across alternatives (Table 7). Third, sensitivity analysis on this single weight reveals that the preferred alternative is not sensitive to even moderate changes in the weight on Objective 3, for the average weights as well as the boundary weights. Under the average objective weights, the weight for Objective 3 would have to be dropped to about a third of its current value, in order to change the preferred alternative from 10 to 2. Under all three boundary objective weights, the weight on Objective 3 can be dropped to 0 and the preferred alternative does not change.

On the other hand, the preferred alternatives are particularly sensitive to the weights on Objectives 2 and 6. Starting with the average weights, raising the weight on Objective 6 from 0.118 to 0.135, while dropping the weight on Objective 2 from 0.193 to 0.176, is enough to change the preferred alternative from 10 (F-E-C) to 8 (E-E-C). This underscores the point that the performances of alternatives 7-10 under the average weights are very close (Fig. 3A); subtle changes in the weights on the objectives are enough to shift the preference among these alternatives.

The point is that the various weightings (i.e., average and boundary weights, and even more subtle changes) represent different, legitimate values judgments by different decision makers, and they lead to different decisions. Continued focused dialogue among the decision makers regarding how they wish to balance the different objectives will be needed now and in future years.

The preceding results (Table 9 and Fig. 3) are for the scenario in which there is only partial access to caves in Areas 1 & 2; the qualitative results, however, are not sensitive to the scenario in Areas 1 & 2. If full access is allowed to caves in Areas 1 & 2, alternative 10 is still the preferred option in Area 3. The composite scores change (to reflect the higher probability of spread of the disease), but the rankings of all the alternatives remain the same.

Management Recommendations for Area 3

Preferred alternative

For the 2009 migration and winter season, this analysis suggests implementing alternative 10 in Area 3. This involves confining access at all Area 3 sites to commercial and research uses only. Further, if WNS is detected this winter, then any affected sites would be closed to all access (including research), and sites within 75 miles of any affected sites would be closed to all access except research. In addition, it is recommended that partial access (for commercial and research uses only) be continued in Areas 1 and 2.

Based on the expert elicitation, if alternative 10 is implemented in Area 3 and partial access (or full closure) is implemented in Areas 1 and 2, the probability of arrival of WNS in Area 3 this winter is 0.50, that is, there are even odds that the management alternatives for the affected and near-affected profiles would have to be applied. If open access is allowed in Areas 1 and 2, the estimated probability of arrival of WNS in Area 3 increases to 0.65.

Objective 1 (preventing the spread) was the highest ranking objective. Alternatives 21-23 (eradication options) are the best performing management options on Objective 1, but performed the worst on Objectives 2 (cave biota) and 6 (research opportunity) and poorly on Objective 5 (killing bats). So, in the end, the eradication management options, although best in terms of preventing the spread of the disease, performed poorly when taking account of all the objectives. Conversely, the top-ranking alternatives (restricting access, alternatives 7-10) ranked third on performance for Objective 1, but were superior on Objectives 2 (cave biota), 3 (public health) and 5 (killing bats), with alternative 10 being the top-ranked alternative. In the long term, this is not likely to be the full solution to disease management, but in the short term the potential costs of more aggressive treatment (like fungicide or culling) outweigh the potential benefits, in large part because the costs (e.g., impacts to cave biota) of such treatments are believed more certain than the benefits (e.g., decreasing the likelihood of WNS spreading to Area 3). This management strategy needs to be coupled with research to verify the underlying assumptions (e.g., humans are an important transmission vector) and explore more direct methods for control of the disease (see Research section below for further discussion).

During briefings, several decision makers questioned why excluding research in affected areas was included in the top-ranked alternative. Alternative 10 is favored over alternative 8 (which is the same as alternative 10 except it allows research access) only by Objective 2 (cave biota), that is, the slight nod is given to alternative 10 because the removal of research access would mean less harm to the cave-obligate biota. A very slight change in the weights on Objectives 2 and 6, however, tips the favor toward alternative 8. In fact, alternatives 7, 8, and 10 are all essentially tied in score (Fig. 3A), very subtle changes in the weights on the different objectives can lead to favoring any of those three alternatives. Increasing the importance of research over cave-biota favors alternatives 7 and 8 over 10; increasing the importance of cave-biota over regulatory burden favors alternative 7 over 8 and 10.

Application of management recommendations in the short term

This analysis is only meant to aid the decision makers in understanding the current state of knowledge and the tradeoffs inherent in the problem; it is not meant to limit the discretion of the decision makers in exercising their responsibilities. At this point, the decision makers need to select an alternative, either from among those presented here, or from other permutations they might deem appropriate. Selection of any of alternatives 7, 8, or 10 is easily supported by the analysis herein; selection of other alternatives would require supplemental rationale; to maintain transparency, the decision makers should describe where this analysis erred.

As soon as a preferred management alternative is identified by decision makers, the components of that management alternative, i.e., the individual management actions and strategies comprising the Area 3-wide alternative, can be structured into a set of succinct management recommendations to be included in a user guide. These recommendations will be targeted to the upcoming bat migration/hibernation season and will include a monitoring component to allow for refinement as the results of management efforts become available.

RESEARCH NEEDS EMANATING FROM THE SDM PROCESS

Sensitivity Analysis: Expected Value of Information

Sensitivity analysis, broadly speaking, seeks to understand how the outcomes of a predictive endeavor are affected by uncertainty in the input parameters. For decision analytic applications, the best measure of sensitivity is the expected value of information (Felli and Hazen 1998, 1999). The expected value of perfect information (EVPI) measures the expected improvement in management performance if all of the uncertainty could be resolved before the decision was made over the case where the decision has to be made in the face of uncertainty (Yokota and Thompson 2004). It is valuable because it measures the consequences of the uncertainty *to the decision-maker*. For example, there may be a lot of uncertainty underlying the predictions for a particular decision, but the choice of the optimal action might not be affected by that uncertainty; in that case, the value of information would be 0, because resolution of the uncertainty would not change what the decision-maker would do, so would not change the expected management performance.

We examined the expected value of perfect information for the WNS analysis, focusing on uncertainty as expressed by the set of experts queried for their judgments. That is, we viewed the responses of each expert as alternative hypotheses about the effects of the actions on the measurable attributes, and asked which uncertainty was most important to resolve. Consider first the case when we use the average objective weights. The uncertainty expressed by the experts is consequential: depending on which expert's responses are used on each measurable attribute, alternatives 2, 3, 4, 7, 8, 9, or 10 might all be favored, so the uncertainty matters to the decision-makers, in the choice of the recommended action and hence, in the expected management performance. The expected value of perfect information is 0.062; that is, by fully resolving uncertainty before making a decision, the expected composite score would be increased by 0.062 (relative to an expected composite score in the face of uncertainty of 0.534, so about a 12% increase in performance across objectives). We then looked at which measurable attributes are contributing the most to the value of information, using a technique called the expected value of perfect X information (EVPXI, Yokota and Thompson 2004). That is, if uncertainty could be resolved in just one measurable attribute, how much would it increase the expected performance? Fully resolving uncertainty about objective 1 (spread of the disease) has an EVPXI of 0.014, which is 22% of the EVPI. What this means is that uncertainty expressed by the experts who evaluated objective 1 constitutes 22% of the total effect of uncertainty on expected performance. Resolution of uncertainty about objective 2 (cave-obligate biota) would increase expected performance 74% as much as resolution of all the uncertainty. For objectives 3-6, the corresponding values are 14%, 4%, 0%, and 15%. Thus, if were to choose a single measurable attribute to analyze more carefully, it would be the impact of the actions on cave-obligate biota besides bats. Interestingly, note that objective 5 (number of bats directly killed) has an EVPXI of 0. This means that, while there is large uncertainty about exactly how many bats would be killed under particular actions, that uncertainty, at least as expressed by the experts surveyed, is not consequential to the choice of action.

Like the recommended action itself, the expected value of perfect information is quite sensitive to the weights put on the objectives. Under bound 1 weights, the uncertainty expressed by the experts could lead to any of alternatives 1, 2, 3, 4, 5, 7, 8, 9, 10, 12, 14, or 23 being selected as optimal; this set is quite a bit larger than the corresponding list for the average weights. But, the EVPI is 0.022, approximately one-third of what it was under the average weight setting. That is, the value of information is lower if we use the bound 1 weights than if we use the average weights. Under bound 2 weights, the set of alternatives that might be favored is the same as for the average weights, and the EVPI is similar, 0.0709. Under bound 3 weights, uncertainty could lead to choosing alternatives 1, 2, 3, 7, 8, 9, 10, or 12, and the EVPI is 0.025. The point here is that the value-based policy uncertainty, as expressed by the alternative weights on the objectives, is at least as important to the decision, and perhaps quite a bit more so, than the scientific uncertainty, at least as expressed by the range of responses from the scientific experts consulted.

There is one more value of information calculation we can perform. We can ask which *alternative*, if taken this year, would be most informative in resolving uncertainty that was relevant to deciding what to do in subsequent years. Using a technique called the expected value of sample information (EVSI, Yokota and Thompson 2004), we asked which alternatives would recover the largest portion of the expected value of perfect information, assuming that the composite response could be measured with some degree of precision. Interestingly, for the average objective weights, alternatives 2, 3, 4, 7, 8, 9, and 10 (the same set that has high expected performance under the average objective weights) were the most informative actions; with alternative 7 being the most informative action of all, under all levels of monitoring precision examined. That is, the expected performance is highest for alternative 10 (F-E-C), but the expected learning is highest for alternative 7 (E-E-E). It is also worth noting that when the composite response can be monitored with perfect precision, the expected value of sample information for alternative 7 is also the expected value of perfect information, but by the time the standard deviation of the observed response increases to 0.1 (~15% CV), the expected value of sample information drops to about 25% of the EVPI. That is, to learn directly from observed management responses requires the ability to monitor the responses fairly precisely.

The expected value of sample information, not surprisingly, depends on the weights on the objectives. For the bound 1 weights, alternatives 13, 15, and 20 are the most informative actions, over a fairly wide range of observational error. For the bound 2 weights, alternatives 7 and 8 are most informative. And for the bound 3 weights, alternatives 2, 5, 8, and 20-23 are most informative, although the information provided by these alternatives decreases very quickly with increasing error in the monitoring program.

In summary, the greatest source of uncertainty that affects the recommended alternatives in this analysis is the set of weights placed on the objectives, that is, the policy determinations that govern how to trade competing objectives against each other. Of the scientific uncertainty, it appears that uncertainty in the response of Objectives 2 (cave-obligate biota) and 1 (spread of WNS) to the alternatives are most important to resolve in identifying the preferred course of action. Some of this uncertainty could be resolved simply by monitoring the outcomes of ongoing management and comparing those outcomes to the predictions contained herein; luckily, the most informative actions are also the ones that have the highest expected performance, so we do not have to trade short-term management performance to accelerate learning.

The primary limitation to the conclusions from the expected value of information analysis is that it assumes that all of the relevant uncertainty is contained in the alternative responses of the experts. Several points greatly undermine this assumption. First and foremost, we did not structure the expert elicitations specifically to ask about uncertainty. Had we done so, the experts might have indicated a greater degree of uncertainty than captured by the range of their responses. Second, we only had a small sample of experts for each of the objectives (only 3 experts for three of the objectives); the outliers in a group can sometimes be the most insightful in establishing the range of uncertainty, and with a small number of experts, we might not have gotten these insights. Thus, we should only use the current analysis of the expected value of information as a rough guide. Expressing the full degree of uncertainty then analyzing it with the methods presented herein is the first step in developing a formal adaptive management program for WNS.

Research Needs Specific to Area 3

Nearly all of the decision makers, through their proxies, identified Objective 1 (preventing the spread of WNS in Area 3) as the most important objective. The measurable attribute for this objective was also the most difficult to quantify. This suggests that a very high priority for research is the development of quantitative, predictive models for disease dynamics as a function of management actions. This modeling work needs to be deeply couched in the management context of the decision makers; we hope that the preliminary framework described herein can provide valuable guidance as well as a starting point for such modeling work. This need applies beyond Area 3; for Areas 1 and 2, it is important to be able to predict the effect of management actions on other aspects of disease dynamics (mortality, and development of resistance). Quantitative, predictive models, ideally based on empirical evidence, would be of tremendous value.

Clearly, development of such predictive models requires more information about the transmission pathways of the disease, and how management actions might disrupt those pathways. The research to produce this information will have both biological and engineering components: biological to understand what techniques could be used to combat the disease (e.g., efficacy of existing fungicides); engineering to understand how those techniques could be applied on the scale necessary to have an effect.

It is interesting to note that the alternatives that ranked highest under many objective weighting scenarios and over much of the scientific uncertainty all focused on restricting human access as the primary management strategy. Thus, the preferred alternative and other high ranked ones are largely predicated on the hypothesis that an important mode of transmission of WNS is cave-to-cave via a human vector. Notably, however, the value of information analysis did not identify strategies based on other transmission pathways as being important to pursue to resolve uncertainty. These conclusions may be an artifact of how we performed the expert elicitation, and may reflect some status quo bias. We did not ask the experts (particularly those consulted for Objective 1) to articulate different views based on the transmission pathway. Such work to specifically build models around fundamentally different hypotheses regarding transmission would be of tremendous value in identifying fruitful avenues of research that might improve management. Such work would be the foundation of an adaptive management strategy for WNS.

Effects of WNS and/or management treatments for the disease on obligate cave biota (Objective 2) constitute another topic that is ripe for research, and one that was identified by the sensitivity analysis as being most valuable to improving management results in the face of uncertainty. The measurable attribute for this objective was vague about the particular biota of importance. Clarification of this point would allow a more focused analysis of the risks posed by various treatments.

NEXT STEPS

Seek Agreement on the Objective Weighting among the Decision Makers

In the tradeoff analysis, the weights placed on objectives drove the outcomes. As Figure 3 indicates, outcomes varied substantially depending on whether averaged or individual weights were used. This is a clarion call for collaboration among the multiple decision makers involved in this decision. The preferred alternative should reflect the collective values of decision makers, which can only be achieved by either calculating a composite of individual values (through averaging of weights, for instance) or achieving consensus values through negotiation among decision makers. Focused dialogue among decision makers about how to balance the different objectives will be needed in order to identify a single preferred management approach.

Development of Area 3 User Guide

Following the choice of a management recommendation by the decision makers, a brief guide for site-specific implementation of the preferred management alternative will be prepared by the WNS SDM working group. This guide will (1) provide additional detail for the management actions comprising the alternative, (2) suggest measures for addressing the tactical considerations such as those listed on page 17 of this report, and (3) summarize WNS surveillance and monitoring protocols that are under development.

Application of the Area 3 Decision Framework to Areas 1 and 2, and Beyond

The original intent was to develop a unified approach across the range and likely area of spread of WNS. Due to time constraints, we focused on one of the three identified geographical areas. The next steps, therefore, are to complete the SDM process for Areas 1 and 2 and to combine all area-specific analyses to yield suggestions for managing WNS across the range. The decision framework developed for the Area 3 prototype can serve as an initial framework for analysis of Areas 1 and 2. The following elements of the decision framework will need to be adjusted to account for the different status of affected sites and bat populations in each of these areas: cave/mine profiles, management objectives, management alternatives, and predicted consequences. The weights assigned to the management objectives by decision makers in these areas may also vary from those assigned by Area 3 decision makers.

Key Considerations in Moving Forward

- A critical consideration in moving forward is how to incorporate adaptive management into the decision framework in order to make beneficial adjustments for future management efforts. The first step is to articulate and analyze the current uncertainty. From that, the components of a rigorous monitoring program, designed specifically to improve management of WNS by reducing the relevant uncertainty, can be articulated.

- Determining how the decision framework can best be applied to Areas 1 and 2, both substantively and logistically, should be considered as soon as possible.

- The role of decision makers and their proxies in future WNS decision-making should be clarified. It would be helpful to be explicit about: (1) which decisions will be delegated to lower management and staff levels, and (2) the level of decision-maker support for continuing the SDM process for WNS management.

- Finally, the role of this process within the full network of white-nose syndrome research, planning, and management efforts among federal and state agencies and non-governmental organizations should be considered. For instance, various states are developing surveillance and monitoring protocols, and the SDM framework could both contribute to and benefit from these efforts.

- Future iterations of this analysis can build on the framework presented here. For example, these results and the insights gained from the sensitivity analyses could be used to eliminate poor-performing alternatives and craft novel alternatives; the structure of the measurable attributes could be used to motivate particular research tasks to take the place of expert judgment; and the divergence in objective weights could be use to focus deliberation among decision makers.

Adaptive Management Applied to This Problem

The analysis described in this report is predicated on the need for the management agencies to make decisions in the immediate future for implementation this coming hibernation season, and is based on the information, however coarse, that could be assembled in a short time frame. The uncertainty about the disease dynamics and the impacts of various management actions, however, is very large, and greatly affects the recommended alternative. But, the repeated nature of the management decision provides a valuable opportunity: an adaptive framework can allow decision-makers to make the best decision each year, conditional on the available information, while simultaneously pursuing understanding that should enhance future decision making. That is, the research needs can be embedded formally in the management framework. As new methods are proposed to combat this disease, they will need to be tested *in situ* to determine their efficacy. The results of those experimental applications can be used to revise the predicted consequences of the alternatives, and the decision analysis can be updated to reflect the new understanding. In this way, the recommended management actions can evolve as new information becomes available. In the analysis herein, we've treated research opportunity as a fundamental objective (Objective 6), rather than a means objective; a more sophisticated treatment would recognize this as a means objective, and ask whether actions that facilitated (or constrained) learning improve management outcomes in the long-run. We recommend that a formal adaptive management framework be developed over the next year.

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TABLES AND FIGURES

Table 1. List of fundamental objectives developed for the rangewide and area-wide scales

Fundamental Objectives	
Rangewide Objectives	• Maintain viability of all bat species (prevent extinction of any species due to WNS effects). • Maintain a representative distribution of all bat species (prevent reduction in species' distributions due to WNS effects) • Avoid unacceptable impacts to cave-obligate biota • Avoid unacceptable public health risks due to WNS treatment actions, exposure to moribund bats, and due to direct effects of the fungus • Maintain credibility of the agencies by minimizing regulatory burden, ensuring public understanding of the issue, and using credible science to inform decisions
Area 1 Objectives	• Increase rate of resistance • Improve survival of the remaining bats • Minimize adverse effects of treatment on cave fauna • Avoid public health risks from treatment (e.g., water quality, contact with treatment) • Provide research opportunities (this is a means to the global fundamental objectives)
Area 2 Objectives	• Slow the rate of infection • Improve survival of the remaining bats • Maintain representative distribution of species across the region • Minimize adverse effects on non-bat species, (including effect of treatment on cave fauna, and effects on scavenger populations through rabies spread, etc.) • Avoid public health risks from treatment and from moribund bats (rabies) • Provide research opportunities (means to global fundamental objectives), specifically as a source of lab animals.
Area 3 Objectives	• Maintain viability of all bat species primarily through preventing/delaying infection to avoid change in abundance • Maintain current distribution of all bat species through preventing/delaying infection to avoid change in distribution due to WNS • Avoid unacceptable impacts to cave-obligate biota • Avoid unacceptable public health risks from treatment, moribund bats (rabies), and the fungus • Maintain credibility of the agencies by minimizing regulatory burden, ensuring public understanding of the issue, and using credible science to inform decisions • Provide research opportunities (means to global fundamental objectives), specifically as source of control animals and sites

Table 2. Strategy table for WNS treatments at caves/mines within Area 3. Each column includes a mutually-exclusive set of specific options for a general category of action. "Cave" refers to both caves and mines. Lighter text indicates actions that are not technically feasible for this coming fall and winter.

Bat-related Cave/Mine Closures	Decontamination Procedures	Gear Dedication	Human-related Cave Closures	Human-related Closure Duration	Cave Treatment	Alternative Habitats[1]	Provide Food in Cave	Bat Eradication	In-situ Bat Treatment[2]	Ex-situ Bat Treatment[3]	Duration of Captivity
restrict bat access [4]	yes	yes	close for all uses	year-round	fungicides	create in new place	yes	eradicate remaining bats	fungicides	capture & treat w/fungicides	indefinite
seasonally restrict bat access	no	no	recreational access only	hibernation season only	biocontrol agents	create within a cave	no	eradicate bats w/ clinical signs	biocontrol agents	capture & treat w/ biocontrol agents	multiple seasons
do not restrict bat access			research access only	active season only	infrared treatments	no alternative habitat		eradicate no bats	inoculation vaccination	capture all bats & inoculate	one season
			commercial access only	no closure	modifications of cave/mine environment				restrict movement of affected bats	capture all & do not treat	one week
			recreational and research access only		ultraviolet treatments				place unaffected bats in alternate space	capture all & nourish	
			recreational and commercial access only		no treatment				no treatment	capture all fungicide & nourish	
			research and commercial access only							no treatment	
			allow all uses								

[1] Create new roosting space
[2] Capture both affected and unaffected bats to extent possible
[3] Capture all bats, remove from cave/mine and treat.
[4] Prevent access and from cave/mine indefinitely

Table 3. Pairwise comparisons used to discern the effects of particular management actions

Pairwise comparisons to understand the effect of:	Strategies to compare			
Decontamination	A	B		
Access level	B	C	D	E
Seasonal bat exclusion	E	G		
Seasonal bat exclusion with fungicide	H	I		
In-situ/cave fungicide	E	H		
In-situ/cave fungicide with exclusion	G	I		
Ex-situ fungicide	G	J	(I)	
Eradication	G	K		

Table 4. Final set of management strategies selected for developing management alternatives for Area 3

Strategy	Bat-related Cave Closures	Decontamination Procedures	Gear dedication	Human-related Cave Closures	Duration	Cave Treatment	Alternate Habitats	Provide Food in Cave	Preventive Bat Eradication	In-situ Bat Treatment	Ex-situ Bat Treatment	Duration of Captivity
A	No	No	No	Allow all uses	N/A	No	No	No	None	No	No	N/A
B	No	Yes	Yes	Allow all uses	N/A	No	No	No	None	No	No	N/A
C	No	Yes	Yes	Res/comm access	Year-round	No	No	No	None	No	No	N/A
D	No	Yes	Yes	Res/rec access	Year-round	No	No	No	None	No	No	N/A
E	No	Yes	Yes	Research access	Year-round	No	No	No	None	No	No	N/A
F	No	Yes	Yes	Closed all	Year-round	No	No	No	None	No	No	N/A
G	Seasonal	Yes	Yes	Research access	Year-round	No	No	No	None	No	No	N/A
H	No	Yes	Yes	Research access	Year-round	Fungicide	No	No	None	Fungicide	No	N/A
I	Seasonal	Yes	Yes	Research access	Year-round	Fungicide	No	No	None	Fungicide	No	N/A
J	Seasonal	Yes	Yes	Research access	Year-round	Fungicide	No	No	None	No	Fungicide & nourish	1-wk
K	Seasonal	Yes	Yes	Research access	Year-round	No	No	No	Eradicate all	No	No	N/A

Table 5. Narrative description of selected management strategies

Strategy A (No Action) Explicitly chooses to forego any management actions, including actions that are currently being undertaken. In particular, this strategy allows full access to all sites, and does not require decontamination protocols or use of dedicated gear.
Strategy B (Full Access) Allows full, year-round access for research, recreational, and commercial uses. Differs from No Action only insofar as it includes taking measures to minimize the risk of spread by following recommended decontamination protocols as well as restricting the use of gear to dedicated sites, i.e., not using gear at multiple caves/mines.
Strategy C (Research and Commercial Access) Suggests that research and commercial access can be allowed if appropriate decontamination and gear dedication procedures are implemented. Prohibits non-commercial recreation access to caves/mines. The restrictions are year-round, not seasonal. No other management actions (e.g., bat access restrictions, cave treatments, or bat treatments) are included in this strategy.
Strategy D (Research and Recreational Access) Research and recreational access are allowed if appropriate decontamination and gear dedication procedures are implemented. Prohibits commercial use of caves/mines. The restrictions are year-round, not seasonal. No other management actions are included in this strategy.
Strategy E (Research Access) Allows research access only, if appropriate decontamination and gear dedication procedures are implemented. Prohibits commercial and non-commercial recreational use of caves/mines. The restrictions are year-round, and no other actions are included in this strategy.
Strategy F (Full Closure) Prohibits all types of human access year-round at caves/mines to which it is applied. If full, year-round closures are implemented, decontamination and gear dedication procedures are not needed, unless the need for emergency access arises, in which case those procedures would be followed. No other management actions are included in this strategy.
Strategy G (Seasonal bat access restrictions) Focuses on preventing within-season cave-to-cave movement of bats. Also includes decontamination procedures, gear dedication, and year-round research-only access. The access restriction will entail sealing the cave/mine entrance(s) in such a way to prevent ingress or egress of bats for the duration of the hibernation period. For affected caves, the intent is to confine all bats within the cave to prevent dispersal; those that survive may leave at the end of the hibernation period. For sites near affected sites, the intent is to prevent diseased bats from entering the cave in mid-winter. (Note that there are many sites for which it may be nearly impossible to seal the cave; local considerations would affect implementation of this strategy.)
Strategy H (Cave and bat in-situ fungicide) This strategy focuses on fungicide treatment. As with Strategy E, this strategy includes appropriate decontamination and gear dedication procedures and access for research only. It differs from Strategy E in providing both cave and in-situ bat fungicide treatments. In-situ treatment means to treat and keep bats at the cave/mine. The intent, therefore, is to treat both the cave and bats present with a fungicide.
Strategy I (Bat in-situ fungicide and exclusion) Similar to Strategy H, with the exception of adding the management action of restricting bat movement in and out of caves during the hibernation period (in the manner of Strategy G).
Strategy J (Bat ex-situ treatment) Similar to Strategy I except for replacing the in-situ fungicide treatment with an ex-situ fungicide and nourishment action. The purpose of this strategy is to treat the cave while removing bats from the wild and bringing them into captivity to treat with fungicides and nourish. Captivity duration is one week.
Strategy K (Eradicate bats) To the set of actions described under strategy G, this strategy adds bat eradication. In caves that receive this strategy, the intent would be enter during hibernation and euthanize all bats in the cave, by whatever means are suitable, taking into account the local site characteristics. For affected caves, the purpose of the strategy would be to kill diseased bats and so prevent them from spreading the disease elsewhere. For sites near affected caves, the purpose would be to kill any infected bats that might have gone undetected, and to remove a source of susceptible animals that could have been infected.

Table 6. Final set of Area 3 management alternatives selected for analysis

	Area 3 Profiles		
	Affected Site	Near Affected Sites	Far from Affected Sites
Management Alternative	Strategy	Strategy	Strategy
1	A	A	A
2	B	B	B
3	C	C	C
4	C	C	B
5	D	D	D
6	D	D	B
7	E	E	E
8	E	E	C
9	F	E	E
10	F	E	C
11	G	G	C
12	G	E	C
13	H	H	C
14	H	E	C
15	I	I	C
16	I	H	C
17	I	E	C
18	J	I	C
19	J	G	C
20	J	E	C
21	K	K	C
22	K	H	C
23	K	E	C

Table 7. White-nose syndrome management consequences table for Area 3. The mean (min-max) response for each alternative is shown for each objective. Within each column, the best performing alternatives (based on means) are marked in yellow and the worst performing alternatives are marked in pink. The range shown for each response reflects the uncertainty expressed by the group of experts consulted. These results are for the scenario in which only commercial and research access to caves and mines is allowed in Areas 1 and 2 (i.e., partial closures).

Area 3 Portfolio of Strategies				Response (Mean, Min-Max)					
	Profile								
Mgmt Altern.	Affected	Near Affected	Far From Affected	Obj 1: Prob. of spread	Obj 2: Prob. of impact to cave biota	Obj 3: Prob. adverse human impact	Obj 4: Restrictions on public	Obj 5: Direct bat mortality	Obj 6: Research opportunity
1	A	A	A	0.880 (0.392-0.990)	92.5 (85.0-100.0)	0.0625 (0.025-0.100)	0.00 (0-0)	1252 (0-3339)	1.75 (1.0-2.0)
2	B	B	B	0.880 (0.340-0.990)	75.0 (50.0-100.0)	0.0625 (0.025-0.100)	0.67 (0-1)	1252 (0-3339)	2.00 (2.0-2.0)
3	C	C	C	0.880 (0.340-0.990)	75.0 (50.0-100.0)	0.0250 (0.025-0.025)	1.67 (1-2)	1252 (0-3339)	1.75 (1.0-2.0)
4	C	C	B	0.880 (0.340-0.990)	75.0 (50.0-100.0)	0.0250 (0.025-0.025)	1.33 (1-2)	1252 (0-3339)	1.75 (1.0-2.0)
5	D	D	D	0.760 (0.340-0.990)	100.0 (100.0-100.0)	0.0625 (0.025-0.100)	3.00 (3-3)	931 (0-2484)	1.75 (1.0-2.0)
6	D	D	B	0.760 (0.340-0.990)	100.0 (100.0-100.0)	0.0625 (0.025-0.100)	2.67 (2-3)	931 (0-2484)	1.75 (1.0-2.0)
7	E	E	E	0.760 (0.340-0.990)	68.1 (36.3-100.0)	0.0250 (0.025-0.025)	3.00 (3-3)	466 (0-621)	2.00 (2.0-2.0)
8	E	E	C	0.760 (0.340-0.990)	75.0 (50.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	466 (0-621)	2.00 (2.0-2.0)
9	F	E	E	0.760 (0.340-0.990)	60.6 (36.3-85.0)	0.0250 (0.025-0.025)	3.00 (3-3)	448 (0-597)	1.63 (1.0-2.0)
10	F	E	C	0.760 (0.340-0.990)	60.6 (36.3-85.0)	0.0250 (0.025-0.025)	2.33 (2-3)	448 (0-597)	1.63 (1.0-2.0)
11	G	G	C	0.760 (0.241-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	8818 (2484-21113)	1.88 (1.5-2.0)
12	G	E	C	0.760 (0.032-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	787 (478-1409)	2.00 (2.0-2.0)
13	H	H	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	7700 (2484-12419)	1.75 (1.0-2.0)
14	H	E	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	744 (215-1075)	2.00 (2.0-2.0)
15	I	I	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	12543 (2484-21113)	1.75 (1.0-2.0)
16	I	H	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	7886 (2484-12754)	2.00 (2.0-2.0)
17	I	E	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	930 (543-1409)	2.00 (2.0-2.0)
18	J	I	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	12672 (2866-21113)	1.50 (1.0-2.0)
19	J	G	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	9090 (2866-21113)	1.50 (1.0-2.0)
20	J	E	C	0.707 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	1059 (812-1409)	1.75 (1.0-2.0)
21	K	K	C	0.680 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	23348 (21113-24838)	1.50 (0.0-2.0)
22	K	H	C	0.680 (0.039-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	8302 (3344-12754)	1.50 (0.0-2.0)
23	K	E	C	0.680 (0.369-0.990)	100.0 (100.0-100.0)	0.0250 (0.025-0.025)	2.33 (2-3)	1346 (955-1552)	1.50 (0.0-2.0)

Table 8. Swing weighting elicitation for WNS management in Area 3. Each row shows the weights given to each objective by a particular decision-maker (in most cases through their proxy or proxies). The three responses from within FWS Region 5 themselves were averaged before being averaged with the rest of the weights, to give equal influence. The three sets of weights marked in green represent the weightings that bound all the other weightings, based on an analysis of the first two principal components of the weights. These boundary weightings are analyzed separately in the decision analysis (Table 9).

Decision-maker	**Source**	**Obj 1**	**Obj 2**	**Obj 3**	**Obj 4**	**Obj 5**	**Obj 6**
FWS R3		0.341	0.198	0.205	0.137	0.085	0.034
FWS R4		0.286	0.200	0.043	0.086	0.243	0.143
FWS R5	Avg	0.347	0.157	0.210	0.082	0.069	0.134
	FO 1	*0.222*	*0.210*	*0.247*	*0.025*	*0.099*	*0.198*
[redacted]							
	FO 3	*0.278*	*0.208*	*0.222*	*0.167*	*0.056*	*0.069*
Indiana		0.260	0.195	0.234	0.039	0.247	0.026
[redacted]							
Vermont		0.364	0.218	0.255	0.055	0.073	0.036
Virginia		0.231	0.186	0.233	0.023	0.140	0.186
West Virginia		0.345	0.155	0.121	0.138	0.069	0.172
Wisconsin		0.217	0.196	0.174	0.130	0.087	0.196
Average		**0.295**	**0.193**	**0.179**	**0.090**	**0.124**	**0.118**

Table 9. Multiple-objective decision analysis for white-nose syndrome management alternatives, Area 3. Each objective is normalized to a 0-1 scale on which higher scores reflect better performance (the best and worst performing alternatives are shown in yellow and pink, respectively). The normalized scores are then weighted by the weights calculated from the swing weighting (Table 7) to produce a weighted score. In addition to the primary analysis with the average weights, this table includes a sensitivity analysis that calculates weighted scores for three boundary weighting schemes. All results are for the scenario in which only commercial and research access to caves and mines is allowed in Areas 1 and 2 (i.e., partial closures).

Area 3 Portfolio of Strategies				Normalized Responses							Weighted Score		
	Profile												
Management Alternative	Affected	Near Affected	Far From Affected	Obj 1	Obj 2	Obj 3	Obj 4	Obj 5	Obj 6	Weighted Score (avg)	Bound 1	Bound 2	Bound 3
1	A	A	A	0.120	0.075	0.583	1.000	0.950	0.875	0.466	0.387	0.306	0.631
2	B	B	B	0.120	0.250	0.583	0.778	0.950	1.000	0.495	0.402	0.367	0.629
3	C	C	C	0.120	0.250	0.833	0.444	0.950	0.875	0.495	0.407	0.417	0.556
4	C	C	B	0.120	0.250	0.833	0.556	0.950	0.875	0.505	0.413	0.418	0.578
5	D	D	D	0.240	0.000	0.583	0.000	0.963	0.875	0.398	0.395	0.306	0.455
6	D	D	B	0.240	0.000	0.583	0.111	0.963	0.875	0.408	0.401	0.307	0.477
7	E	E	E	0.240	0.319	0.833	0.000	0.981	1.000	0.522	0.470	0.480	0.533
8	E	E	C	0.240	0.250	0.833	0.222	0.981	1.000	0.528	0.479	0.462	0.569
9	F	E	E	0.240	0.394	0.833	0.000	0.982	0.813	0.514	0.449	0.488	0.509
10	F	E	C	0.240	0.394	0.833	0.222	0.982	0.813	0.534	0.461	0.492	0.553
11	G	G	C	0.240	0.000	0.833	0.222	0.647	0.938	0.431	0.439	0.379	0.455
12	G	E	C	0.240	0.000	0.833	0.222	0.969	1.000	0.479	0.464	0.385	0.537
13	H	H	C	0.293	0.000	0.833	0.222	0.692	0.875	0.445	0.461	0.391	0.466
14	H	E	C	0.293	0.000	0.833	0.222	0.970	1.000	0.494	0.493	0.402	0.549
15	I	I	C	0.293	0.000	0.833	0.222	0.498	0.875	0.421	0.451	0.390	0.423
16	I	H	C	0.293	0.000	0.833	0.222	0.685	1.000	0.459	0.477	0.401	0.486
17	I	E	C	0.293	0.000	0.833	0.222	0.963	1.000	0.493	0.493	0.402	0.548
18	J	I	C	0.293	0.000	0.833	0.222	0.493	0.750	0.406	0.433	0.380	0.400
19	J	G	C	0.293	0.000	0.833	0.222	0.636	0.750	0.423	0.441	0.380	0.432
20	J	E	C	0.293	0.000	0.833	0.222	0.958	0.875	0.478	0.475	0.392	0.525
21	K	K	C	0.320	0.000	0.833	0.222	0.066	0.750	0.361	0.425	0.388	0.312
22	K	H	C	0.320	0.000	0.833	0.222	0.668	0.750	0.435	0.458	0.390	0.445
23	K	E	C	0.320	0.000	0.833	0.222	0.946	0.750	0.470	0.473	0.391	0.507
Normalized scale: Worst Case				1	100	0.15	3	25000	0				
Normalized scale: Best Case				0	0	0	0	0	2				
Weight (avg)				0.295	0.193	0.179	0.090	0.124	0.118				

Weight (bound 1)	0.541	0.054	0.162	0.054	0.054	0.135
Weight (bound 2)	0.327	0.310	0.261	0.016	0.003	0.082
Weight (bound 3)	0.233	0.116	0.058	0.198	0.221	0.174

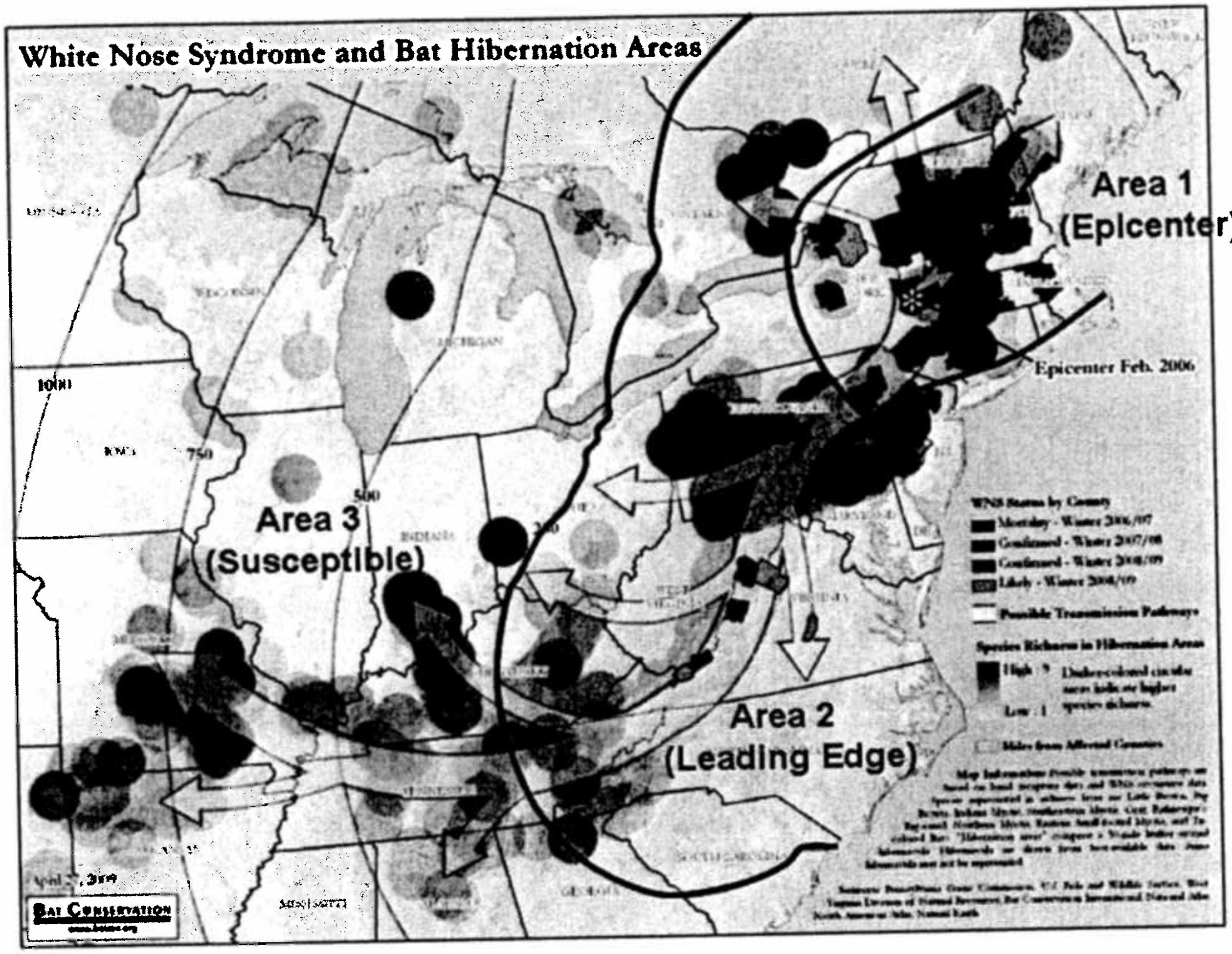

Figure 1. White-nose syndrome geographic areas. These areas are defined based on the spread and dynamics of the disease. For fall 2009, the areas are based on the status of the disease at the end of the previous winter. The boundaries of the areas will very likely move in future years.

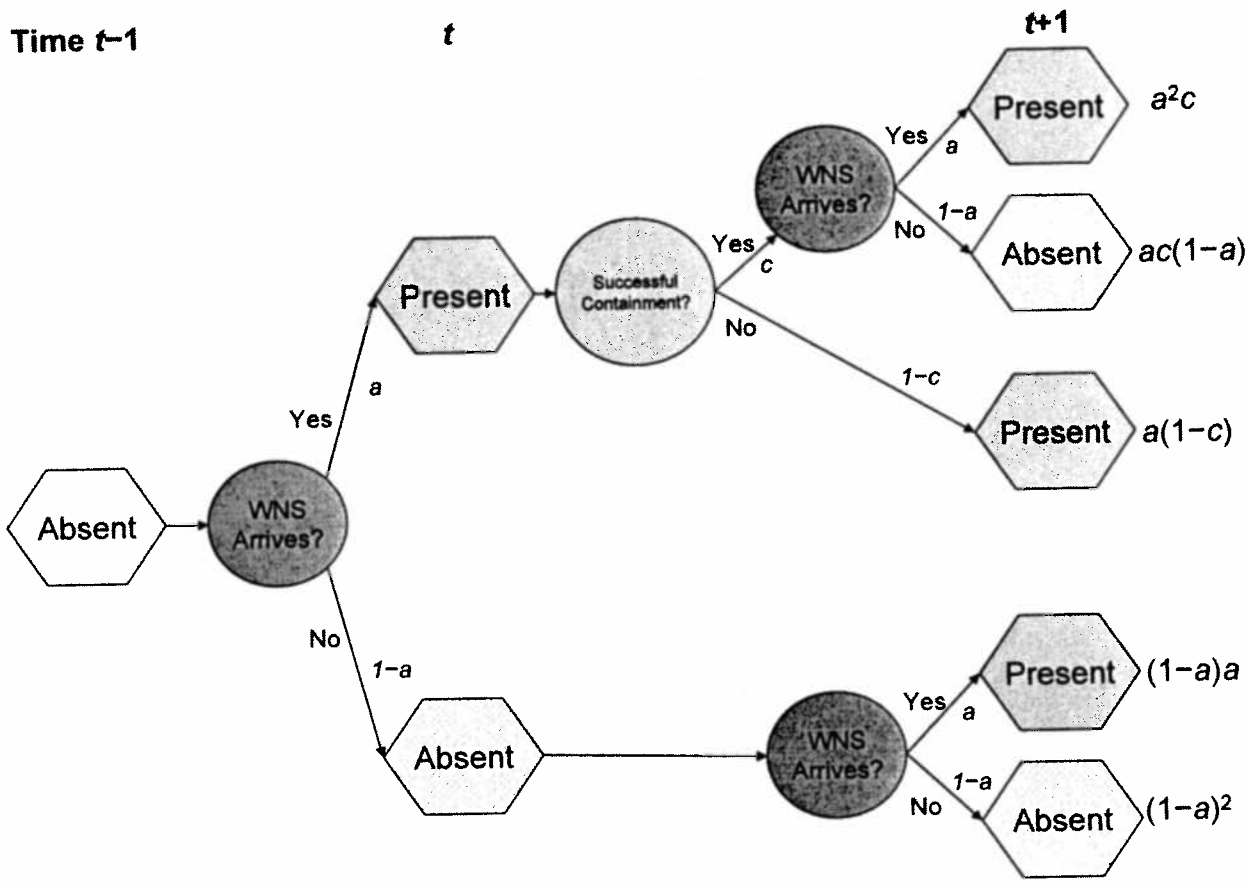

Figure 2. Probability of presence of WNS in Area 3 in year t+1, conditional on absence of the disease in year t−1. The outcome is affected by two probabilities: the probability of arrival and establishment (a) and the probability of containment (c).

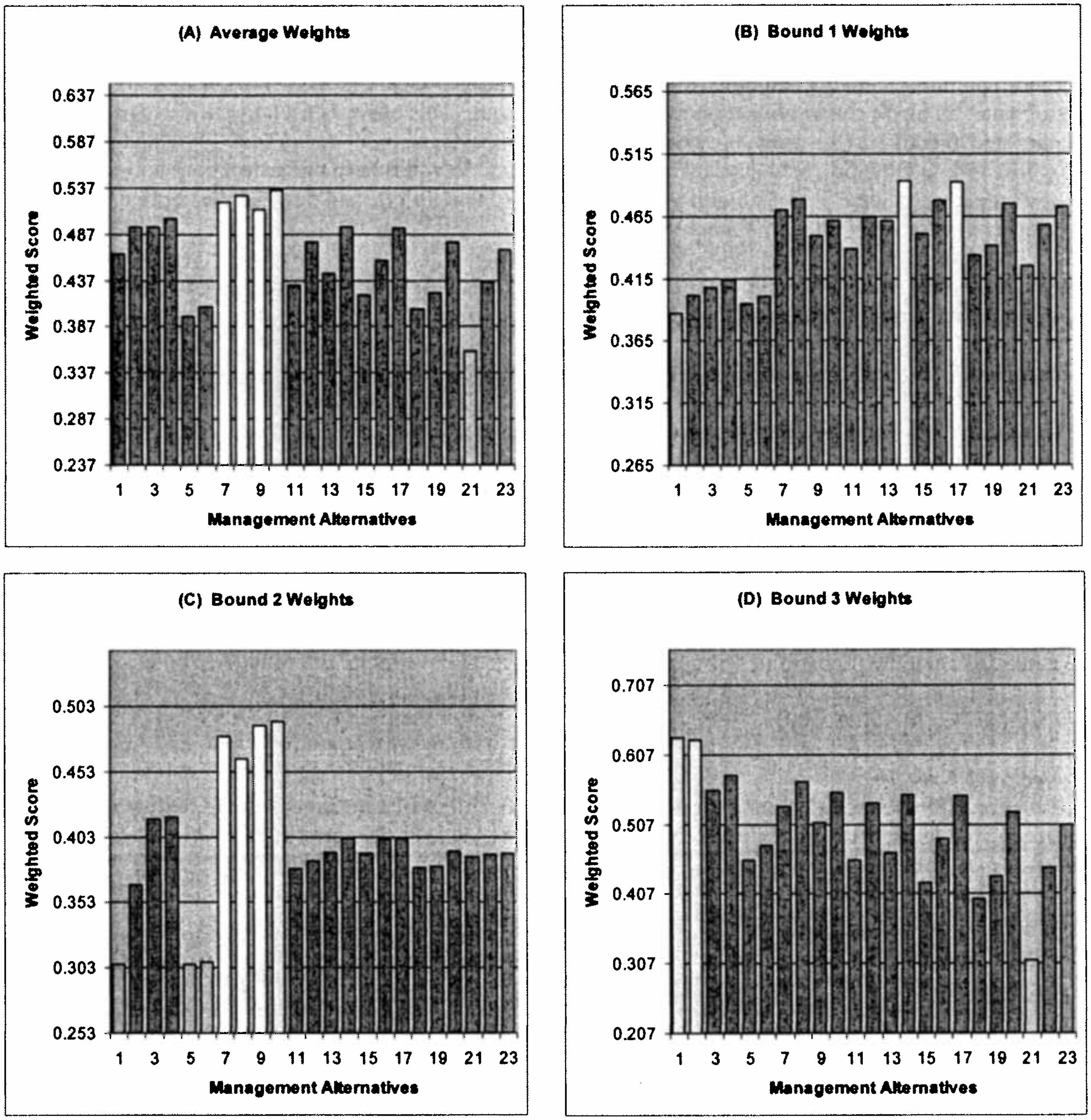

Figure 3. Weighted scores for the 23 white-nose syndrome management alternatives, Area 3, under four sets of objective weightings: (a) average weights across decision-makers; (b) boundary weighting 1, which heavily favors preventing the spread of the disease; (c) boundary weighting 2, which puts almost no weight on minimizing restrictions on the public or on minimizing direct bat mortality; and (d) boundary weighting 3, which puts fairly equal weight on all objectives.

APPENDIX 1: SAMPLE EXPERT ELICITATION INSTRUCTIONS

Expert judgments were elicited by email, after initial contact to ascertain the willingness of the expert to participate. A blank expert elicitation form is shown below. This one was used to elicit expert beliefs regarding Objective 2 (the probability of unacceptable impacts to any endemic cave-obligate biota in response to implementing management alternatives 1 -23). In addition to the instructions and form shown below, the experts were provided with a brief overview of the project, and detailed descriptions of the management alternatives (as in Tables 4-6).

Objective 2 Narrative: Avoid unacceptable risks to endemic cave-obligate cave biota resulting from WNS or management strategies directed at WNS.

Measurable attribute: the probability of unacceptable impacts to any endemic cave-obligate biota.

This objective contains two implicit pieces: the probability of impact and the magnitude of impact. The magnitude is handled by identifying a threshold magnitude of impact (acceptable vs. unacceptable), but otherwise not distinguishing different magnitudes. The measurable attribute, then, is the probability of any impacts exceeding the threshold (unacceptable) level.

We define an "unacceptable level of impact" as a "75% population reduction in any species in any one cave, or 25% population reduction of any one species across sites within any state."

We need to elicit the probabilities of unacceptable impacts to cave biota as a function of the 23 portfolios of management strategies in Area 3. Experts need only identify a probability bin: 0%, 0-5%, 5-15%, 15-30%, 30-70%, 70-100%, 100%.

Objective 2 Exercise:
Instructions: Please provide your expert belief on the probability of a management alternative resulting in unacceptable impacts to any endemic cave-obligate species. Insert the corresponding bin letter into cells G29-51 (see Table A-1). Refer to the Management Alternative & Definitions worksheets for descriptions of Management Alternatives.

Terms:

Affected Profile= Caves or mines where bats with clinical signs of WNS, particularly white facial fungus, are observed.

Near Affected Profile= All caves or mines presumed to be unaffected that are within 75 miles of an affected site.

Far from Affected Profile= All caves or mines or mines presumed to be unaffected that are located farther than 75 miles

Probability Bins:

a	0 %	b	0-5 %	c	5-15 %
d	15-30 %	e	30-70 %	f	70-100 %
g	100%				

Table A-1. Blank expert elicitation form for the measurable attribute associated with Objective 2. This table was provided in an Excel spreadsheet for direct entry.

	Management Strategy			Expert Belief	
Management Alternative	**Affected Profile**	**Near Affected Profile**	**Far from Affected Profile**	**p(unacceptable impact to cave-obligate biota)**	**Rationale**
1	A	A	A		
2	B	B	B		
3	C	C	C		
4	C	C	B		
5	D	D	D		
6	D	D	B		
7	E	E	E		
8	E	E	C		
...	F	E	E		
23	K	E	C		