Exhibit No.:	
Issue(s):	Need, Renewable Energy, Reliability
Witness:	Bill Powers, P.E.
Sponsoring Party:	Neighbors United Against Ameren's Power Line
Type of Exhibit:	Surrebuttal Testimony
Case No.:	EA-2015-0146
Date Testimony Prepared:	November 16, 2015

MISSOURI PUBLIC SERVICE COMMISSION

CASE NO. EA-2015-0146

SURREBUTTAL TESTIMONY

OF

BILL POWERS, P.E.

ON BEHALF OF

NEIGHBORS UNITED AGAINST AMEREN'S POWER LINE

November 16, 2015

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I. Introduction

Q. Identify the rebuttal testimony you are addressing in your surrebuttal testimony.

A. My surrebuttal testimony addresses the rebuttal testimony of Missouri Public Service Commission ("Commission") witnesses Daniel Beck, Shawn Lange, Michael Stahlman, and Sarah Kliethermes.

II. Staff Is Incorrect to Rely on Unverified Regional Benefits of MVP Portfolio to Find that Mark Twain Line Is in Public Interest

Q. What is your overall impression of Commission witness testimony?

A. Commission staff witnesses Beck, Lange, Stahlman, and Kliethermes largely repeat claims of economic benefit described in MTEP11 and the MTEP14 Triennial Review Report for the portfolio of MVP projects as the basis for their collective finding that approval by the Commission of the Mark Twain Line is in the public interest for Ameren MO ratepayers. For example, much of Mr. Lange's rebuttal testimony consists of direct quotes from MISO documents and ATXI witnesses to justify a finding that the project is in the public interest, with little critical analysis of the MISO documents or ATXI witness information cited. The majority of the schedules included with Ms. Kliethermes' rebuttal testimony are MISO summaries of the economic benefits of the portfolio of MVP transmission projects. Although there are notable exceptions in staff rebuttal testimony to the uncritical acceptance by staff of ATXI claims of economic and grid reliability benefits, ultimately staff accept the Mark Twain Line is in the public interest because MISO says it is, regardless of whether the line can be shown to provide any unique benefits to Ameren MO ratepayers that could not be provided more inexpensively by other means.

Q. Do any of the MISO MVP documents assert that the rejection of any one element of the MVP portfolio would compromise the economic benefit of the rest of the MVP portfolio?

A. No. Nowhere does MISO state that MVP portfolio is subject to a form of domino theory, whereby if any one of the MVP projects is rejected by a state utilities commission the entire MVP portfolio will no longer be economically viable. ATXI has made no showing that the denial of the Mark Twain Line will shift the cost-benefit ratio of the remaining portfolio of MVP projects from "beneficial" to "not beneficial," or have any material impact on whether they are built or not.

Q. Does staff rebuttal testimony evaluate the Mark Twain application on its own merits, or review it as one element of a much larger whole that is located outside of Missouri?

A. As one element of a much larger whole. Commission staff rebuttal testimony asserts that approval of the Mark Twain line is in the public interest because the project is part of a portfolio of projects that was found by MISO to be cost beneficial, and the cost recovery mechanism - a MISO transmission tariff - will assure cost recovery from ratepayers.

Q. Despite this apparent deference to MISO regarding whether the project is in the public interest, do Commission staff assert that the Commission has the authority to evaluate the Mark Twain line on its own merits?

A. Yes. Ms. Kliethermes states the Commission retains the ability to reach its own conclusions, which may be different than the conclusions reached by MISO.[1] However, Ms. Kliethermes makes this observation after stating that MISO found both the MVP portfolio as a whole and the Missouri portion of the MVP portfolio to be cost beneficial,

[1] Kliethermes rebuttal testimony, p. 5, lines 1-2.

and after providing summaries of the MISO cost-benefit analyses as schedules to her rebuttal testimony.

III. Neighbors United Concurs with Staff that There Is No RPS Justification for the Mark Twain Line

Q. Does the testimony of Commission witness Beck support approval of the Mark Twain line to meet the Missouri RPS requirement?

A. No. Witness Beck states that the investor-owned utilities in Missouri can meet the RPS using renewable energy credits ("RECs"), and those RECs do not have to be associated with energy that is delivered to or generated in Missouri.[2] He also states that the current value of a REC is less than $1 per REC.[3] This REC cost compares to the cost of production from a wind farm of approximately $50 to $60 per megawatt-hour (MWh).[4]

Q. Given Ameren MO can meet the Missouri RPS with RECs, and RECs are extremely low cost, is there any RPS justification for constructing the Mark Twain Line?

A. No.

Q. If Missouri investor-owned utilities can buy very low cost RECs to meet their RPS obligations, why would these utilities locate wind generation near the Mark Twain Line or import electricity from other states over this line?

A. They would not do so.

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[2] Beck rebuttal testimony, p. 6, lines 20-23.
[3] Ibid, p. 8, lines 2-4.
[4] Powers rebuttal testimony, p. 6, lines 21-23.

IV. Neighbors United Disagrees with Staff that the Missouri Clean Power Plan May Be a Justification for the Mark Twain Line

Q. Mr. Beck offers Missouri compliance with the Missouri Clean Power Plan (CPP) as another justification for the Mark Twain Line. Does the CPP call for new transmission as a necessary element of carbon reduction?

A. No. The claim of Mr. Beck is that the Mark Twain Line would limit the effect of the uncertainty of what the Clean Power Plan will require by providing Missouri electric utilities opportunities to locate wind generation near the Mark Twain Line, by allowing Missouri electric utilities the opportunity to import renewable electricity from other states (especially other MISO states), and by allowing Missouri utilities the opportunity to export electricity from in-state sources to other states.[5]

Q. Hasn't the Commission informed EPA that it anticipates that demand-side management programs will be a major element of its CPP carbon reduction portfolio?

A. Yes. The Commission December 23, 2013 comment letter to EPA on CPP compliance strategy emphasizes demand-side management programs under the Missouri Energy and Efficiency Investment Act (MEEIA), Mo. Rev. Stat. § 393.1075.[6] Yet in its 2014 IRP, Ameren MO suspended its demand response program for the 2016-2018 period.[7] Ameren MO identified this demand response program as cost-effective in the 2011 IRP. The program would have added 100 MW of demand response by 2021.[8] The justifications offered by Ameren MO in the 2014 IRP for retrenchment of demand side management

[5] Beck rebuttal testimony, p. 9, lines 1-5.
[6] **Exhibit PE-40**, p. 2, pdf pp. 13-15.
[7] Powers rebuttal testimony, p. 31, lines 2-8.
[8] Ibid.

programs are controversial, as explained in the March 2015 rebuttal testimony of Synapse Energy Economics in proceeding EO-2015-0055 before the Commission.[9]

Q. How does 100 MW of demand response compare to the increase in imports available to Ameren MO if the Mark Twain Line is built?

A. 100 MW of demand response is more than four times the 24 MW of increased import capacity that would be provided, according to ATXI, by the Mark Twain Line.[10]

V. Neighbors United Disagrees with Staff that the Mark Twain Line Is Needed to Address Northeast Missouri Reliability Issues

Q. Does Mr. Lange imply that the Mark Twain Line is necessary to make wind power at the West Adair substation deliverable?

A. Yes.[11]

Q. Is this implication correct?

A. No.

Q. Why not?

A. Mr. Lange did not mention that the same MISO interconnect study he cites to support a position that wind power is not deliverable at the West Adair Substation also states that a $10.9 million upgrade to the Adair-Novelty 161 kV line will make 300 MW of wind power fully deliverable, as explained in my rebuttal testimony.[12]

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[9] **Exhibit PE-41**.
[10] **Exhibit PE-42**.
[11] Lange rebuttal testimony, p. 9, line 22, p. 10, line 1-8.
[12] Powers rebuttal, p. 11, lines 5-9.

Q. So should significant amounts wind power be located near the Adair Substation there is a viable upgrade to the existing 161 kV transmission system that would make this wind power fully deliverable with no cost to Ameren MO ratepayers?

A. That is correct. The $10.9 million would be paid by the wind power developer, not by Ameren MO ratepayers.[13]

Q. Did Mr. Lange assess the reasonableness of ATXI grid reliability modeling assumptions?

A. Yes and no. Mr. Lange states in his rebuttal testimony that there are no wind projects in the MISO queue for interconnection at the Adair Substation.[14] Mr. Lange correctly acknowledges that much of the Mark Twain Project may not be physically necessary if that area of Missouri is not developed with wind.[15] However, Mr. Lange does not opine whether it is reasonable for ATXI to assure there is a 300 MVA customer load on the Adair Substation when the modeled Category C event, the simultaneous loss of two of the three existing 161 kV lines connecting at the Adair Substation, takes place.[16] ATXI states the contingency event occurs under peak load conditions.[17] Almost no wind power is generated during peak load conditions, only about 6 percent of rated capacity.[18] ATXI assumes that wind power generation does not contribute to the Category C contingency.[19] The estimated peak load on the Adair Substation is approximately 64 MW at peak summer demand, not 300 MVA.[20,21] This large discrepancy between the peak substation

[13] Ibid, p. 12, lines 1-5.
[14] Lange rebuttal testimony, p. 11, lines 10-12.
[15] Ibid, p. 11, lines 7-8.
[16] **Exhibit PE-43**.
[17] Ibid.
[18] Powers rebuttal testimony, p. 23, lines 4-6.
[19] **Exhibit PE-43**.
[20] Ibid, p. 28, lines 11-15.
[21] MW is assumed to be equivalent to MVA in this rebuttal testimony.

load modeled by ATXI and the actual peak substation load is not addressed by Mr. Lange in his rebuttal testimony.

Q. Did Mr. Lange evaluate any alternatives to the Mark Twain Line to address the Category B and C contingencies that ATXI asserts will be addressed by the Mark Twain Line?

A. No. Mr. Lange simply accepts ATXI's assertion that the Mark Twain Line will address these contingency conditions and does not consider other solutions on the existing 161 kV transmission system that would be less costly to Ameren MO ratepayers. Some of these solutions are addressed in my rebuttal testimony.[22]

VI. Neighbors United Concurs with Staff that MISO and ATXI Economic Benefit Analyses Are Obsolete and Incomplete

Q. Do you agree with Mr. Lange that the economic modeling done by MISO uses old data?

A. Yes. Mr. Lange points-out in his rebuttal testimony that the studies were carried out during the mid- to late-2000's.[23]

Q. Doesn't Ms. Kliethermes also state that the ATXI witness uses old data to claim economic benefits for the Mark Twain Line?

A. Yes. Ms. Kliethermes states that the generation source(s) used by ATXI in its modeling is based on expectations held in the year 2010, and that this information it is not reflective of reality at this time.[24]

[22] Powers rebuttal testimony, pp. 24-33.
[23] Lange rebuttal testimony, p. 9, lines 12-20.
[24] Kliethermes rebuttal testimony, p. 10, lines 10-12.

Q. Does Commission witness Stahlman state that staff disagree with ATXI that the MTEP14 MVP Triennial Review should be viewed as evidence of the project's economic feasibility?

A. Yes. Mr. Stahlman states that the MTEP14 MVP Triennial Review does not isolate the cost-benefit ratio of the Mark Twain transmission project.[25]

Q. Does Mr. Stahlman point-out in his rebuttal testimony that the MTEP14 MVP Triennial Review economic analysis did not include any offsets due to restrictions in land use, for example the loss of agricultural land?

A. Yes. Mr. Stahlman states that the model, PROMOD IV, focuses on electric markets.[26]

Q. Does Mr. Stahlman recommend the Commission not use the economic development benefits analysis contained in the Direct Testimony of ATXI witness Geoffrey Hewings, Ph.D. as a basis to approve or reject the Project?

A. Yes. Mr. Stahlman states that staff understands that job creation can make it easier to "sell" a project from a public policy perspective, but fundamentally, job creation is a function of the costs of the project rather than its benefits.[27]

Q. Does Ms. Kliethermes recommend that the Commission not rely on any implications in the testimony of ATXI witness Dr. Schatzki that (1) the Project would reduce Missouri retail electric rates, or that (2) the Project would reduce environmental emissions in Missouri?

A. Yes.[28]

[25] Stahlman rebuttal testimony, p. 7, lines 7-11.
[26] Ibid, p.4, lines 10-12.
[27] Ibid. 6, lines 14-16.
[28] Kliethermes rebuttal testimony, p. 3, lines 4-6.

Q. Why does Ms. Kliethermes make this recommendation?

A. Ms. Kliethermes states that it is not suitable for projecting the impact of the Project on Missouri retail rates, or projecting the impact of the Project on the ability of the State of Missouri to comply with various emissions requirements.[29]

Q. Do staff consider the possibility that MTEP14 Triennial Review economic benefits modeling conducted for the MVP portfolio as a whole may be wrong because of the use of obsolete data and the presumption that wind power will be the predominant form of renewable energy developed to meet regional RPS targets for the foreseeable future?

A. No. Mr. Lange uncritically repeats MISO's statement that its "Value Proposition" (of the MVP portfolio) reflects that its continued efforts in regional planning enables more economic placement of wind resources in the region.[30] No staff rebuttal testimony questions whether the framework MISO presumption, that future RPS targets will be met with wind power, is still valid in the face of rapid and ongoing declines in the cost of solar power.[31] Staff takes the collective view that, although there is no specific evidence to support MISO claims of the economic benefit of the Mark Twain Line, the regional economic benefits of the MVP portfolio as a whole justify a finding that the Mark Twain Line is in the public interest of Ameren MO ratepayers.

[29] Ibid, p. 5, lines 8-10.
[30] Lange rebuttal testimony, p. 7, lines 1-4.
[31] Powers rebuttal testimony, pp. 34-41.

Q. Did staff evaluate the MISO economic benefits modeling conducted for other specific MVP transmission projects outside of Missouri to determine if the same analytical deficiencies staff identified relative to the economic benefits assertions made by ATXI for the Mark Twain Line are also present for other specific MVP transmission projects?

A. No.

Q. Is it reasonable for Commission staff to rely on economic benefit data they know to be obsolete and incomplete to opine that the Mark Twain Line is in the public interest?

A. No.

VII. Staff Does Not Address How the Mark Twain Line Route Will Be Affected by Environmental Compliance Requirements

Q. Are the conditions described in staff testimony adequate to account for the environmental compliance authorizations the Mark Twain Line must obtain?

A. No. Commission witness Dietrich states in her rebuttal testimony that, of about 3,000 written public comments received, less than 10 comments provide support for the request, and over 2,900 (are) opposed to the request.[32] Ms. Dietrich documents that a theme of the comment letters in opposition is: 1) the negative impact of the line on real estate values, 2) the presence of the line impeding farming in the project area, 3) cause deforestation, 4) restrict future land use options, and 5) tarnish rural landscapes. Despite the public concern over the project, there is no mention in staff rebuttal testimony regarding the environmental authorizations that must be obtained before the Commission finalizes its

[32] Dietrich rebuttal testimony, p. 3, lines 13-18.

order, if it chooses to approve the project, and how these authorizations may affect the location of the project right-of-way.

Q. Is staff aware that the route preferred by ATXI may cause significant negative economic impacts due to impact on agricultural lands?

A. Yes. However, staff witness Stahlman clarified in his rebuttal testimony that the MISO economic cost-benefit analysis did not include any costs associated with the loss of agricultural land.[33] Additional costs not mentioned in staff rebuttal testimony include addressing endangered Indiana bat and proposed endangered northern long-eared bat habitat degradation,[34] raptor nesting area degradation, fragmentation of woodland habitat, and degradation of spawning streams.[35] These issues may be partially mitigated by right-of-way route modifications negotiated by the U.S. Fish and Wildlife Service and the Missouri Department of Natural Resources with ATXI to limit negative impacts.[36,37]

Q. What action should be taken by the Commission, if it chooses to approve the project, to assure the final route of the Mark Twain Line causes minimum economic and environmental disruption in the project area?

A. The Commission can condition the effective date of the order approving the Mark Twain Line, if it chooses to issue such an approval, to occur after receipt by the Commission of final project approvals issued by the U.S. Fish and Wildlife Service and the Missouri Department of Natural Resources.

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[33] Stahlman rebuttal testimony, p.4, lines 10-12.
[34] **Exhibits PE-44, PE-45, PE-46, PE-47, PE-48**.
[35] Powers rebuttal testimony, p. 43, lines 6-8.
[36] **Exhibit PE-38** (Powers rebuttal testimony).
[37] **Exhibit PE-49**.

VIII. Conclusion

Q. Does this conclude your surrebuttal testimony?

A. Yes.

BEFORE THE PUBLIC SERVICE COMMISSION
OF THE STATE OF MISSOURI

In the Matter of the Application of Ameren Transmission Company of Illinois for Other Relief or, in the Alternative, a Certificate of Public Convenience and Necessity Authorizing it to Construct, Install, Own, Operate, Maintain and Otherwise Control and Manage a 345,000-volt Electric Transmission Line from Palmyra, Missouri, to the Iowa Border and Associated Substation near Kirksville, Missouri.	)	**File No. EA-2015-0146**

AFFIDAVIT OF WILLIAM E. POWERS, P.E.

STATE OF CALIFORNIA)
) ss
COUNTY OF SAN DIEGO)

William E. Powers, being first duly sworn on his oath states:

1. My name is William E. Powers and I am the principal of Powers Engineering, 4452 Park Blvd., Suite 209, San Diego, California, 92116.

2. Attached hereto and made a part hereof for all purposes is my Surebuttal testimony on behalf of Neighbors United Against Ameren's Power Line consisting of 14 pages and Schedules PE-40 THRU PE-49 prepared in written form for introduction into evidence in the above-referenced docket.

3. I hereby swear that my answers to the questions contained in the attached Surrebuttal testimony are true and correct to the best of my knowledge, information and belief.

William E. Powers, P.E.
William E. Powers, P.E.

Subscribed and sworn to before me this 16 day of November, 2015

OFFICIAL SEAL
ELYCE MARIE MARTINEZ
NOTARY PUBLIC-CALIFORNIA
COMM. NO. 1995401
SAN DIEGO COUNTY
MY COMM. EXP. OCT. 26, 2016

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December 23, 2013

The Honorable Gina McCarthy
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

Re: Missouri Public Service Commission's Comments on Section 111(d) of the Clean Air Act

Dear Administrator McCarthy:

The Missouri Public Service Commission (MoPSC), respectfully submits this letter and the attached comments to articulate its position that the Environmental Protection Agency's (EPA) guidelines, to be developed under Section 111(d) of the Clean Air Act (CAA), 42 U.S.C. § 7411, should be crafted in such a way as to allow Missouri maximum flexibility in developing performance standards that will take into account its particular circumstances.[1] The EPA's guidelines should be crafted consistent with the CAA's framework of cooperative federalism, President Barack Obama's Climate Action Plan and the President's Memorandum for the Administrator of the Environmental Protection Agency, which contemplates state primacy in developing plans to reduce carbon emissions from the power sector.

[1] In submitting these comments, the MoPSC is not offering an opinion regarding the legality of the EPA's authority to promulgate rules under Section 111(d). Further, nothing in these comments binds the MoPSC in its decisions in any future proceeding. Finally, nothing in these comments binds any other state agency.

The CAA's framework of cooperative federalism contemplates that the EPA will issue guidelines establishing a procedure, while the states will issue state implementation plans (SIPs) that define the mechanisms to meet the EPA's guidelines. The states will have the primary responsibility, through their SIPs, for determining the performance standards for satisfying the EPA's guidelines. 42 U.S.C. § 7411 (d)(1).

In directing the EPA to promulgate rules to reduce carbon emissions from existing power plants under Section 111(d) of the CAA, President Obama emphasized the necessity of involving all stakeholders, including state public service and utility commissions in crafting these guidelines. The EPA's guidelines should be developed in a way that "allow[s] the use of market based instruments, performance standards, and other regulatory flexibilities." Any such guidelines must also "ensure . . . the continued reliance on a range of energy sources and technologies." Finally, the EPA's guidelines must be "developed and implemented in a manner consistent with the provision of *reliable* and *affordable* electric power for consumers and business." *See, Memorandum on Power Sector Carbon Pollution Standards*, 2013 Daily Comp. Pres. Doc. 457 (June 25, 2013) (emphasis added).

The MoPSC, through regulation of Missouri's investor owned utilities (IOUs), ensures safe and adequate service at just and reasonable rates. The MoPSC is the state agency responsible for setting rates for the IOUs, for administering the Missouri Renewable Energy Standard (RES), Mo. Rev. Stat. § 393.1020 to 393.1030, and the Missouri Energy and Efficiency Investment Act (MEEIA), Mo. Rev. Stat. § 393.1075, as well as ensuring resource adequacy through the MoPSC's integrated resource planning process, 4 CSR 240-22.010 to 240-22.080. These comments are intended to inform the EPA regarding the composition of Missouri's IOU power generation, and the state programs that will serve to reduce carbon emissions.

Missouri's IOU's have implemented programs under the MEEIA and are adding renewable energy resources to their portfolios, in addition to retrofitting existing coal-fired power plants. These efforts have either reduced or are expected to continue to reduce greenhouse gas emissions. For instance, two Missouri IOUs' efforts under the MEEIA are expected to provide cumulative energy savings of approximately 950,000 MWhs over a three year program period, from 2013 to 2016. Since 2005, the IOUs have collectively spent in excess of $700 million on projects that reduce greenhouse gas emissions. For 2012 alone, Missouri IOUs have reduced carbon emissions by approximately 4.4 percent or 1.6 million metric tons.

The EPA's guidelines should complement and enhance the work already being done in each state. The EPA's guidelines should not frustrate or inhibit already-existing state efforts, nor inhibit future state efforts that support greenhouse gas emissions reduction. The MoPSC encourages the EPA to develop guidelines that will allow all carbon emission reducing measures

Acknowledgements

Several individuals contributed to this document. The principal authors are:
Natelle Dietrich, Director-Tariff, Safety, Economic and Engineering Analysis and Goldie Tompkins, Policy Advisor/Chief of Staff to the Chairman. Additional contributors include: Robert S. Kenney, Chairman; Stephen M. Stoll, Commissioner; Mark Hughes, Personal Advisor to Commissioner Stoll; William P. Kenney, Commissioner; Rachel Lewis, Personal Advisor to Commissioner Kenney; Daniel Y. Hall, Commissioner; Janet Wheeler, Personal Advisor; Adam McKinnie, Chief Utility Economist; Walt Cecil, Regulatory Economist; and Susan Sundermeyer, Assistant to Natelle Dietrich.

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I. Introduction

The Missouri Public Service Commission (MoPSC) has long been acutely aware of and attuned to myriad environmental regulations facing the electric power sector. To that end, in August 2011, the MoPSC opened a working docket[1] to examine the potential financial and reliability impacts on the power sector of a host of planned and potential environmental regulations. In May 2012 the MoPSC Staff issued a report of its findings. In September 2013, in anticipation of the EPA's announced plans to regulate greenhouse gases from new and existing power plants, the MoPSC instructed its staff to update its 2012 report. On December 19, 2013, the MoPSC Staff issued its updated report of its findings. All of these documents can be found in the MoPSC's Electronic Information Filing System (EFIS), at https://www.efis.psc.mo.gov.

The comments of the MoPSC demonstrate that the EPA's rules should provide Missouri maximum flexibility to develop, monitor and credit the resources that will be most effective in reducing carbon emissions. These comments contain a description of Missouri's current IOU generation mix, the IOUs' efforts that are intended to increase their renewable energy resources,[2] and the energy efficiency programs that the IOUs have implemented that will serve to reduce carbon emissions.

Like other states, many Missouri electric utilities own electric generating units that are not located in Missouri and this important geographic element should be acknowledged in the rules as it will be a factor in regional carbon emissions. Also, the lack of flexibility in developing a state implementation plan (SIP) could unnecessarily punish Missouri's utilities that have already invested in and deployed renewable energy resources and demand-side or energy efficiency programs. The EPA's proposed guidelines should allow credit for early emission reductions efforts.

II. Missouri's Regulated Electric Utilities

Missouri's four investor owned electric utilities are vertically integrated, with each utility owning and operating generation, transmission and distribution. Missouri's IOUs have transferred functional control of their transmission assets to one of two Regional Transmission Organizations (RTO): the Southwest Power Pool (SPP) or the Midcontinent Independent System Operator (MISO).

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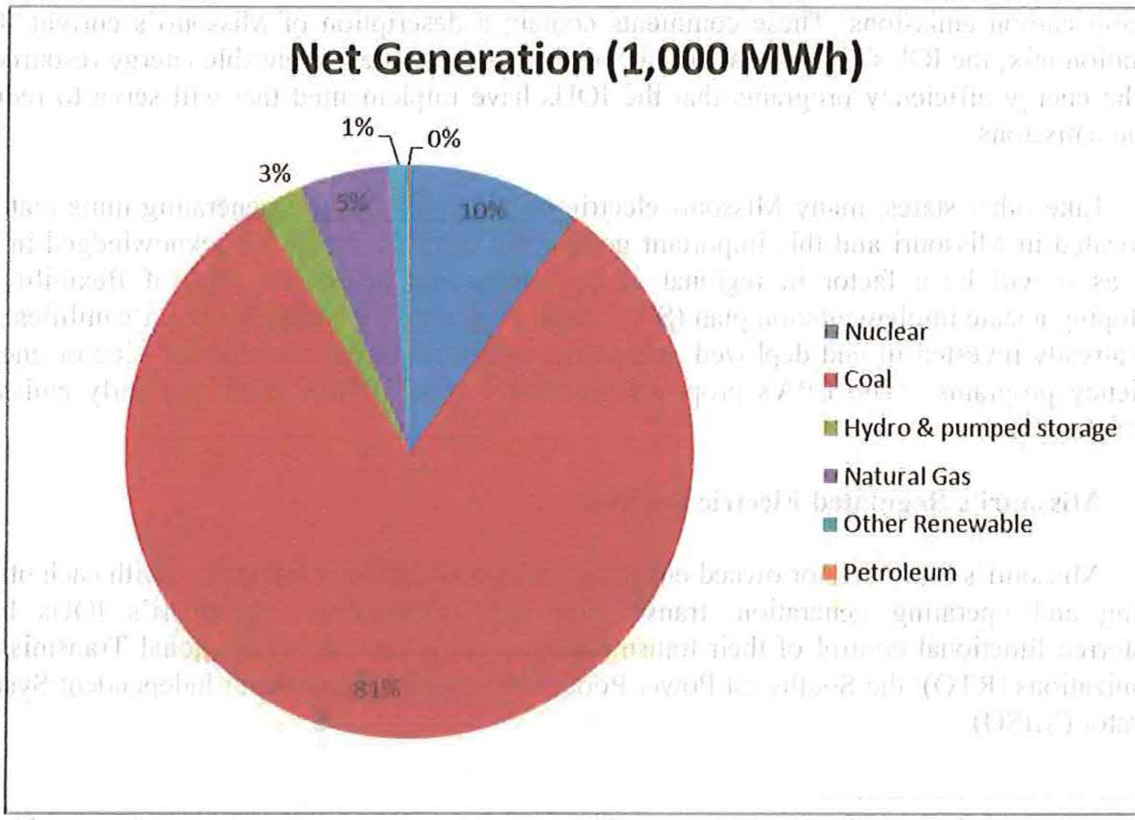
[1] *See, generally,* Docket No. EW-2012-0065, *In the Matter of an Investigation of the Cost to Missouri's Electric Utilities Resulting from Compliance with Federal Environmental Regulations,* accessible at https://www.efis.psc.mo.gov/mpsc

[2] "Renewable energy resources" is defined as electric energy produced from wind, solar thermal sources, photovoltaic cells and panels, dedicated crops grown for energy production, cellulosic agricultural residues, plant residues, methane from landfills, from agricultural operations, or from wastewater treatment, thermal depolymerization or pyrolysis for converting waste material to energy, clean and untreated wood such as pallets, hydropower (not including pumped storage) that does not require a new diversion or impoundment of water and that has a nameplate rating of ten megawatts or less, fuel cells using hydrogen produced by one of the above-named renewable energy sources, and other sources of energy not including nuclear that become available after November 4, 2008, and are certified as renewable by rule by the department. (Mo. Rev. Stat. § 393.1025)

A. Electric Utility Generation Mix in Missouri

Missouri's IOU electric generation mix is predominately coal with approximately 81 percent of production by coal-fired plants.[3] As is demonstrated below, Missouri IOUs are exploring ways to diversify their fleets through the use of natural gas, nuclear, wind, solar, hydroelectric generation and landfill gas. Additionally, Missouri's IOUs are increasing other generation substitutes, such as demand response and energy efficiency. Missouri law requires each IOU to obtain targeted renewable energy standards, which ultimately will reduce dependence on coal fired generation. The MoPSC monitors resource adequacy through an integrated resource planning process. But this process does not mandate any specific fuel choice in the IOUs' generation mix. Through its regulations, the MoPSC requires that the IOUs, on a predetermined time schedule, present their integrated resource plans to the Commission for review and stakeholder input.



[3] *See* http://www.eia.gov/state/?sid=MO&CFID=11683014&CFTOKEN=6dbebadd895da3e6-24CF265A-25B3-1C83-543A14991FD45D82&jsessionid=843010c8f48cb3de55c835f6b4a60217a62a#tabs-4

1. Investor-owned utilities
   a. Union Electric Company d/b/a Ameren Missouri (Ameren Missouri)[4]
      i. 76% Coal
      ii. 14% Nuclear
      iii. 4% Renewables[5]
      iv. 1% Gas

   b. The Empire District Electric Company, Inc. (Empire)[6]
      i. 56% Coal
      ii. 27% Gas
      iii. 16% Wind
      iv. 1% Hydropower

   c. Kansas City Power & Light and KCP&L Greater Missouri Operations[7,8]
      i. 83% Coal
      ii. 14% Nuclear
      iii. 2% Gas
      iv. 1% Wind

2. Municipal electric utilities[9,10]
   a. Coal
   b. Natural gas combined heat and power
   c. Natural gas combined cycle
   d. Wind
   e. Landfill gas
   f. Solar

3. Rural electric cooperatives[11]
   a. 75% Coal
   b. 14% Natural gas
   c. 5% Hydropower
   d. 5% Wind
   e. 1% Purchased power

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[4] "Ameren Missouri Company Overview and SMR Planning". Scott Bond, Director Nuclear Development. February 2013. http://www.researchcaucus.org/schedule/2013/25Feb2013/Bond-Ameren-MO-Presentation.pdf Page 3.

[5] Includes wind and hydropower.

[6] EDE – Environmental Update Presentation, page 6, filed October 29, 2013, EFIS Doc. No. 30, Docket No. EW-2012-0065

[7] Collectively KCP&L/GMO

[8] Great Plains Energy 2012 Annual Report, page 7. KCP&L and GMO are wholly owned direct subsidiaries of Great Plains Energy, page 6.

[9] *See* Appendix A

[10] Information on the percentage of generation mix in the municipal electric utility portfolio is not publicly available.

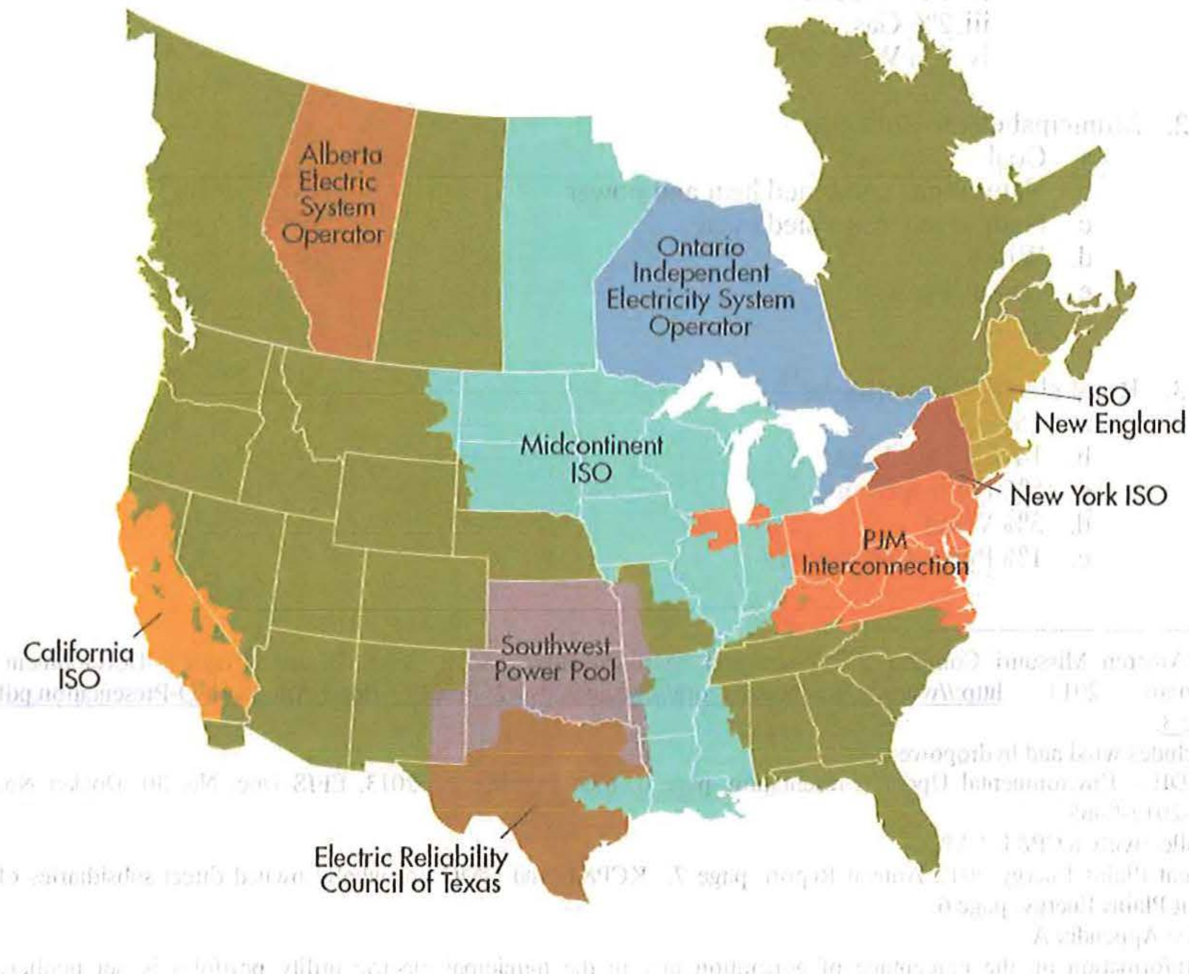
[11] Associated Electric Cooperative, Inc., 2012 Annual Report. http://www.aeci.org/docs/default-source/documents/2012-annual-report-dot-org.pdf. (Note: Associated Electric Cooperative, Inc. is part of a three-tiered system with six generation and transmission cooperatives owned by 51 distribution cooperatives in Missouri, southeast Iowa and northeast Oklahoma.)

B. Estimate of Missouri IOU Carbon Emissions

Missouri's IOUs emit approximately 48.5 million metric tons of carbon today. Other power generators in Missouri are not included in this emission estimate.

C. Regional Transmission Organizations

Missouri's IOUs participate in one of two RTOs-MISO and SPP. MISO delivers electric power across all or part of sixteen states and the Canadian province of Manitoba. SPP is responsible for ensuring reliable supplies of power and adequate transmission infrastructure in nine states. MISO participates in the next day market, while SPP's next day market is scheduled to go live in March 2014. Once both markets are operational, the dynamics of bidding power into the market will change.



MISO's modeling has identified a potential capacity shortfall of 3-7 GW as early as 2016.[12] Recognizing this potential shortfall, MISO and the Organization of MISO States (OMS)[13] jointly developed a survey to assess resource adequacy. The survey requests information on future load expectations, current resources, potential new resources, retirements, and energy efficiency/demand response programs. A zonal analysis will be presented in early 2014. When developing guidelines, the EPA should be cognizant of the fact that power flows regionally. Given that fact, states must have flexibility when they establish standards of performance for existing sources because regional solutions may be indicated. The MISO/OMS system-wide assessment will help to inform state plans.

III. Missouri Strategies to Address Carbon Emissions

Any established guidelines should provide flexibility to states to develop a SIP that establishes a performance standard based on the best system of emission reduction for that state. Over the past decade Missouri has employed a variety of strategies that either provide the framework for reducing, or actually reduce, carbon. These past and current strategies should not be ignored or preempted by stringent guidelines. A discussion follows of the strategies currently implemented in Missouri, including utility resource planning, demand-side management, renewable energy standards, energy efficiency and net metering.

A. IOU Electric Utility Resource Planning

MoPSC Rule 4 CSR 240-22.010 outlines the policy objectives for IOU electric utility resource planning. Electric utility resource planning is defined as the process by which an electric utility evaluates and chooses the appropriate mix and schedule of supply-side, demand-side, and distribution and transmission resource additions and retirements to provide the public with an adequate level, quality, and variety of end-use energy services. The planning process also includes an analysis of "special contemporary issues", or evolving new issues.

The investor-owned electric utilities are required to file with the MoPSC their resource plans every three years on April 1. The triennial filing includes, among other things, a summary of the preferred resource plan that will meet expected energy service needs for the twenty year planning horizon. The preferred resource plan must clearly show the demand-side resources and supply-side resources (both renewable and non-renewable resources), including additions and retirements for each resource type; identification of critical uncertain factors affecting the preferred resource plan; and information related to existing legal mandates and approved cost recovery mechanisms.

[12] MISO Comments, filed November 8, 2013, EFIS Doc. No. 38, Docket No. EW-2012-0065.

[13] The Organization of MISO States, Inc. is a non-profit, self-governing organization of representatives from each state with regulatory jurisdiction over entities participating in MISO. The purpose of the OMS is to coordinate regulatory oversight among the states, including recommendations to MISO, the MISO Board of Directors, the Federal Energy Regulatory Commission, other relevant government entities, and state commissions, as appropriate. (OMS Purpose Statement at http://misostates.org/)

The IOUs also file with the MoPSC, an annual update report commensurate with changing conditions since the last filing. It is the responsibility of each IOU to keep abreast of evolving electric resource planning issues and to consider and analyze those issues in a timely manner to ensure evolving regulatory, economic, financial, environmental, energy, technical or customer issues are adequately addressed in the long-term plans.

These electric resource plans are a tool that should inform any SIP. The MoPSC already has a process in place to allow Missouri IOUs and their stakeholders to analyze and employ a comprehensive strategy to resource planning, which includes the analysis of strategies to comply with environmental mandates. This tool will assist Missouri when it monitors and analyzes those measures most advantageous to reducing carbon.

B. Renewable Energy Standards Applicable to Investor Owned Utilities

Missouri's Renewable Energy Standard (RES), Mo. Rev. Stat. §§ 393.1020 to 393.1030, includes a requirement for all IOUs to generate or purchase electricity generated from renewable energy resources. The portfolio requirement provides that electricity from renewable energy resources constitutes the following portions of each electric utility's sales:

(1) No less than two percent for calendar years 2011 through 2013;
(2) No less than five percent for calendar years 2014 through 2017;
(3) No less than ten percent for calendar years 2018 through 2020; and
(4) No less than fifteen percent in each calendar year beginning in 2021.

At least two percent of each portfolio requirement is required to be derived from solar energy, unless exempted from this requirement.

A regulated utility may comply with the standard in whole or in part by purchasing renewable energy credits (RECs). Each kilowatt-hour of eligible energy generated in Missouri counts as 1.25 kilowatt-hours for purposes of compliance with the RES.[14]

State law mandates that renewable energy facilities shall not cause undue adverse air, water, or land use impacts, including impacts associated with the gathering of generation feedstocks.[15] If any amount of fossil fuel is used with renewable energy resources, only the portion of electrical output attributable to renewable energy resources can be used to fulfill the RES. Methane generated from the anaerobic digestion of farm animal waste and thermal depolymerization or pyrolysis for converting waste material to energy are renewable energy resources for purposes of the statute.[16]

[14] *See* Mo. Rev. Stat § 393.1030.1.
[15] *See* Mo. Rev. Stat § 393.1030.4.
[16] *See* Mo. Rev. Stat § 393.1030.4-5.

MoPSC Rule 4 CSR 240-20 sets the definitions, structure, operation and procedures for IOU compliance with the RES. Each IOU is required to file with the MoPSC, a RES compliance report on the status of the utility's compliance with the law.[17]

Public versions of the RES Compliance Reports for 2011 and 2012 are available on the MoPSC website.[18] *See* Appendix B for a summary of the 2012 Compliance Reports.

Mo. Rev. Stat § 393.1030 also requires each IOU to make available to its retail customers, a solar rebate for new or expanded solar electric systems sited on customers' premises, up to a maximum of twenty-five kilowatts per system measured in direct current that is confirmed operational by the electric utility.[19] Ameren Missouri, Kansas City Power & Light (KCP&L) and KCP&L Greater Missouri Operations (GMO) have solar rebate programs that will further contribute to carbon reduction.

It is critically important that any EPA guidelines not inhibit state renewable energy standards. The Missouri IOUs' annual compliance plans and reports demonstrate that efforts are being made to introduce renewables into the generation mix. Carbon emissions have been and should continue to be reduced by generation diversification through renewable energy. Future IOU RES compliance plans will provide Missouri another resource to monitor progress toward implementing those measures that it is uniquely positioned to decide will be most advantageous for meeting the carbon emission requirements in the State.

Since 2005, the IOUs have collectively spent in excess of $700 million on projects that reduce greenhouse gas emissions. For 2012 alone, Missouri IOUs have reduced carbon emissions by approximately 4.4 percent or 1.6 million metric tons.[20] The efforts of the IOUs to date demonstrate that Missouri should be provided maximum flexibility to develop, monitor and credit those resources that will be most effective in meeting goals to reduce carbon while considering the capabilities of the generation fleet within the state. Each state regulatory body is uniquely situated to monitor, review and advance the policy of carbon emissions and should retain the opportunity to manage resources and establish the state's standard of performance in a way that can meet the goals of the EPA.

C. Missouri Energy Efficiency Investment Act (MEEIA)

Mo. Rev. Stat. § 393.1075, provides:

> 3. It shall be the policy of the state to value demand-side investments equal to traditional investments in supply and delivery infrastructure and allow recovery of all reasonable and prudent costs of delivering cost-effective demand-side programs. In support of this policy, the commission shall:

[17] *See* Rule 4 CSR 240-20.80

[18] *See* http://psc.mo.gov/Electric/Renewable_Energy_Standard_Compliance_Reports

[19] *See* Mo. Rev. Stat. § 393.1030.3.

[20] These numbers are an aggregate of highly confidential, commercially sensitive data provided by the IOUs.

(1) Provide timely cost recovery for utilities;
(2) Ensure that utility financial incentives are aligned with helping customers use energy more efficiently and in a manner that sustains or enhances utility customers' incentives to use energy more efficiently; and
(3) Provide timely earnings opportunities associated with cost-effective measurable and verifiable efficiency savings.

The MoPSC is responsible for approving demand-side programs under the MEEIA with the goal of achieving all cost-effective demand-side savings. Cost recovery for MEEIA programs is not permitted unless the programs result in energy or demand savings and are beneficial to all customers in the customer class in which the programs are proposed, regardless of whether the programs are utilized by all customers.

Four MoPSC rules provide the framework to implement MEEIA, which allow IOUs to recover their costs while providing financial incentives and timely earning opportunities associated with cost-effective demand-side savings.[21] The rules address demand-side programs and set forth the requirements and procedures for filing and processing applications to approve, modify or discontinue programs. The IOUs are required to file applications to modify demand-side programs when there is a twenty percent or more variance in the total program budget or if program design changes significantly.

IOU programs must go through an evaluation, measurement and verification (EM&V) process to evaluate the utility's program delivery and oversight. The EM&V process estimates and/or verifies the estimated actual energy and demand savings, utility lost revenue, cost effectiveness and other effects of demand-side programs. The MoPSC has an independent contractor that reviews the work of each IOU EM&V contractor. Stakeholder meetings are held to review the progress of IOU demand-side programs.

Two IOUs currently have MEEIA programs that were implemented in early 2013, but it is noteworthy that energy efficiency programs existed in Missouri prior to implementation of MEEIA. Additional MEEIA filings are expected in the next few months. The utilities that have not yet filed under MEEIA offer similar energy efficiency programs.

Examples of residential MEEIA programs include: incentives paid to retail partners to discount the price on high efficiency lighting products; high efficiency water heater, window air conditioner and smart strip rebates and incentives; diagnostics/tune-ups, retrofits and replacement upgrades for air conditioners, heat pumps and cooling systems; refrigerator recycling; home energy performance assessments, direct installs and cost effective follow-up measures; incentives for construction of Energy Star® homes; and energy savings to low income qualifying customers. There are also commercial and industrial programs. The IOUs are also evaluating the appropriateness of implementing demand response programs.

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[21] *See* Rules 4 CSR 240-3.163, 4 CSR 240-3.164, 4 CSR 240-20.093 and 4 CSR 240-20.094.

Ameren Missouri MEEIA Filing[22]

Ameren Missouri's MEEIA plan is a 3-year plan that consists of 11 demand-side programs. Most programs were implemented in January 2013, and are estimated to have a cumulative annual energy savings of approximately 793,000 MWh during the third program year.

GMO MEEIA Filing[23]

GMO's MEEIA plan is a 3-year plan that consists of 15 demand-side programs. Most programs were implemented in January 2013, and are estimated to have a cumulative annual energy savings of approximately 155,000 MWh and cumulative annual capacity savings of approximately 73 MW during the third program year.

Implementation of MEEIA in Missouri has resulted in over 217.5 MWh cumulative energy savings to date.

Other Efficiency Efforts

From 2009 through 2012, the Missouri Department of Economic Development, Division of Energy[24] administered a number of energy efficiency programs in the industrial, agriculture and residential sectors using American Recovery and Reinvestment Act (ARRA) funding. The industrial and residential programs (other than low-income weatherization) were administered by the Division of Energy's implementation contractor, Shaw Environmental & Infrastructure, Inc. The programs achieved deemed energy savings of 165,873,458 kWhs, which resulted in a 138,441 metric ton reduction in carbon emissions equivalent. Verified savings totaled 155,088,969 kWhs and an annual 129,440 metric ton carbon emission equivalent reduction.[25] An additional 177,564.48 metric ton equivalent of potential carbon emission reductions were identified in energy audits for industrial customers.[26]

D. IOU Missouri Potential Studies

The MEEIA rules also provide detailed requirements for conducting current market potential studies[27] including requirements for: 1) use of primary research, 2) updating the potential study no less frequently than every four years, 3) review by stakeholders of required documentation, and 4) identification and discussion of the twenty-year baseline energy and demand forecasts. Through potential studies, IOUs and stakeholders consider the potential for generation diversification.

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[22] For information on Ameren Missouri's programs; http://www.ameren.com/sites/aue/UEfficiency/Pages/home.aspx

[23] For information on GMO's programs; http://www.kcpl.com/save-energy-and-money

[24] The Missouri Department of Economic Development, Division of Energy "assists, educates and encourages Missourians to advance the efficient use of diverse energy resources to provide for a healthier environment and to achieve greater energy security for future generations." The Division of Energy was transferred to the Missouri Department of Economic Development from the Missouri Department of Natural Resources in August 2013.

[25] Internal Report prepared by Shaw Environmental & Infrastructure, Inc., for the Missouri Department of Natural Resources – through their Division of Energy (now under the Department of Economic Development) for their Energize Missouri programs on September 2012. Page 102.

[26] *Id.* at page 11.

[27] *See* Rules 4 CSR 240-3.164(2)(A), 4 CSR 240-22.050(2)-(4).

E. IOU Net Metering (to Support Distributed Generation)

Mo. Rev. Stat. § 386.890 and MoPSC Rule 4 CSR 240-20.065 establish and implement the Net Metering and Easy Connection Act by setting forth standards for interconnection of qualified net metering units, that have a generating capacity of 100 kW or less, with the distribution systems of electric utilities. Retail electric suppliers are required to make net metering available to customer-generators on a "first-come, first-served" basis until the total rated generating capacity of net metering systems equals five percent of the utility's single-hour peak load during the previous year unless the electric suppliers' regulating or governing body increases the total rated generating capacity. The most recent IOU reports indicate generating capacity from net metering at approximately 15.4 MW, with a total estimated 3,627 MWhs received from customer-generators.

This information is useful in informing a SIP and state review of progress toward achieving carbon reductions since customer-generators provide an alternative, clean energy source to traditional electric generation. Solar panels and small wind turbines are popular sources of distributed generation through net metering. Distributed generation sources also can use natural gas-fired microturbines or reciprocating engines which use hot exhaust for space or water heating.

IV. Recognized and Anticipated Carbon Reductions

The EPA guidelines should provide the states the flexibility to recognize emission reduction efforts to date. There should be flexibility to allow utilities to acknowledge carbon reductions across their entire fleet, not just within a state. For instance, some generating facilities that serve Missouri customers are located in Kansas, Arkansas, Nebraska and Iowa. There must also be consideration and allowance for annual load growth resulting from economic development and increases to population. State growth and progress should not be impeded by stringent, inflexible guidelines.

It has been suggested, in the President's Climate Action Plan, that 2005 be considered a baseline year, from which carbon reductions would be measured. Since 2005, the IOUs have collectively spent in excess of $700 million on projects that reduce carbon emissions. For 2012 alone, Missouri IOUs have reduced carbon emissions by approximately 4.4 percent or 1.6 million metric tons.[28] These reductions should be recognized by allowing flexibility in establishing any baseline.

A. Recognized Efficiencies in Missouri's IOU Generation Fleet

Ameren Missouri has realized efficiencies through its addition of wind farms located in northeast Iowa, the Maryland Heights Renewable Energy Center, MEEIA programs, solar projects, its Callaway nuclear plant, hydro-electric generation (including generation at the Keokuk Hydro-electric Generation Station in Iowa), and its program to utilize refined coal in order to lower costs and reduce emissions.

[28] These numbers are an aggregate of highly confidential, commercially sensitive data provided by the IOUs.

Empire has completed several projects since 2005 that have either directly or indirectly reduced carbon emissions. Some examples include installation of gas temperature sensors at a coal-fired facility and 20-year wind contracts with windfarms located in Kansas. In addition to plant improvements, Empire has multiple demand-side energy efficiency programs not offered under MEEIA. According to its resource plan, Riverton units 7 and 8 have been converted from operation on coal to full operation on natural gas. The last coal was burned at Riverton in September 2012. An analysis of system losses indicated improved percentages in the amount of line losses on Empire's transmission and distribution system when compared to 2005. Empire estimates it has reduced its total metric tons of carbon by 5.5 percent since 2005.

KCP&L/GMO projects that reduce carbon emissions include the Wolf Creek nuclear generating station (located in Kansas), the Iatan Unit 2 generating facility, added wind generation through windfarm projects in Kansas, enhanced customer energy efficiency and refined coal projects. GMO has currently effective MEEIA programs and KCP&L has energy efficiency programs offered outside of MEEIA.

Not all IOU activities have been quantified to date as to the anticipated carbon reduction or associated cost of compliance, but some of the projects have reduced carbon by over 1.6 million metric tons at an estimated cost in excess of $700 million.

B. What Reductions Can Missouri's IOUs Achieve from Plants?

According to Ameren Missouri,[29] Meramec Units 1-4, which total approximately 833 MW, could be retired by 2020, but the integrated resource plan also recognizes that environmental regulations could speed up or delay the retirement.

By 2016, Empire plans a turbine retrofit at its Asbury plant[30] resulting in a 5.5 percent carbon reduction and conversion of Riverton Unit 12 from a simple cycle combustion turbine to a combined cycle unit[31] for a 24.5 percent reduction. These improvements will cost an estimated $185 to $195 million.[32]

KCP&L/GMO have planned retirements at Montrose 1 in 2016 and Montrose 2 & 3 in 2021.[33] In 2012, the Montrose Station's carbon production was approximately 2 million metric tons.[34] Sibley Units 1 and 2 are planned for retirement in 2023.[35] In 2012, the Sibley Units produced approximately 254,000 metric tons of carbon.[36]

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[29] Ameren Missouri 2013 Integrated Resource Plan Annual Update Report, Non-proprietary Version, Page 12. Case No. EO-2013-0424. March 15, 2013.
[30] The Empire District Electric Company Integrated Resource Plan Volume 1, Non-proprietary Version. Page 14. Case No. EO-2013-0547. July 1, 2013.
[31] *Id.* at pages 16-17.
[32] *See* Appendix C
[33] Kansas City Power & Light Company Integrated Resource Plan 2013 Annual Update, Non-proprietary Version, pages 7-10. Case No. EO-2013-0537. June 20, 2013.
[34] *See* Appendix D
[35] KCP&L Greater Missouri Operations Company Integrated Resource Plan 2013 Annual Update, Non-proprietary version, pages 7-10. Case No. EO-2013-0538. June 20, 2013.
[36] *See* Appendix D

KCP&L/GMO may convert Lake Road Unit 4/6 from coal to natural gas for an estimated carbon per year reduction of 196,000 metric tons.[37]

KCP&L/GMO state that since carbon capture and sequestration for coal-based generation is not yet commercially viable, the only way for KCP&L/GMO to reduce carbon in any significant manner would be to reduce coal generation. For KCP&L/GMO to sufficiently reduce generation several coal plants would need to be retired. Others would have to run on reduced generation. The estimated net cost to comply through coal reduction would be approximately $92 million, absent any increase in wholesale market prices due to regional coal plant retirements.[38]

V. Conclusion

When it comes to energy, each state is unique; each with differing energy resources, resource planning processes, and energy efficiency programs. Each state is situated differently as to what action has been taken to reduce carbon emissions; some states have had programs targeted at reducing greenhouse gas emissions in place for several years, other states have programs just underway, while others may have none. It is important that the rules are crafted in a way that will allow each state, despite its differences, to develop and implement a plan that can meet targets. A feasible plan is mindful of cost and resource adequacy and should therefore give appropriate credit for actions already taken and underway to reduce greenhouse gas emissions.

[37] *Id.*
[38] *Id.*

MPUA

Missouri Public Utility Alliance

November 20, 2013

Ms. Natelle Dietrich
Director of Tariff, Safety, Economic, and Engineering Analysis
Missouri Public Service Commission
200 Madison Street, PO Box 360
Jefferson City, MO 65102-0360

Via Email to: natelle.dietrich@psc.mo.gov

Dear Ms. Dietrich:

Thank you for your email of November 14, 2013 enquiring about the preparation of municipal utilities to comply with President's Climate Action Plan. As you aware municipal utilities are locally regulated by their elected city councils or boards of aldermen (*Relevant Electric Retail Regulatory Authorities)*. These answers are provided in the form of general information and not as a specific legal response to the information request you sent. We are pleased to try to be helpful.

It is the position of Missouri's municipal utilities that section 111(d) authorizes the United States Environmental Protection Agency to only develop guidelines for certain classes for pollutants, not specific limits. This same position was recently voiced by Rebecca Weber, EPA Region 7 Director of the Air and Waste Management Division. Whether carbon dioxide alone or as part of a related group of substances generally referred to as greenhouse gases (GHG) meet the definition for regulation under section 111(d) is, and will continue to be, the subject of judicial challenges.

To date, EPA has not **published** New Source Performance Standards for future fossil fueled power plants in the Federal Register and only recently concluded listening sessions conducted around the nation, including in Lenexa, KS, to secure public input on proposed standards for existing power plants. Without a detailed regulatory matrix of requirements, processes and timelines it is difficult to predict impacts and responses.

Missouri's municipal utilities are closely monitoring the regulatory activity. The Missouri Public Utility Alliance (MPUA) along with some larger municipal utilities have been actively engaged in discussions with senior management at the Missouri Department of Natural Resources on regulatory features that need to be included. EPA Administrator Gina McCarthy, herself a former administrator, has publically said that the agency will be seeking advice on regulatory frameworks from state environmental agencies. Additionally MPUA provided verbal and written testimony at the November public listening session in Lenexa.

Missouri's municipal utilities have a proven record of responding to the priorities of their citizen owners and are including lower emission electric energy sources where they can be cost justified. Since 2005 MPUA and its member utilities have added a windfarm, two natural gas-fired combined heat and power facilities, one combined cycle natural gas plant, one landfill gas plant, and one solar powered facility with two additional units either under construction or under contract. Additionally the coal portion of our portfolio has shifted from older less efficient plants to a fleet of plants that are among the lowest emitting plants in the nation both for CO_2 and all other regulated pollutants. All of these steps have been taken without statutory mandates at the federal or state level.

Additionally our larger utilities have demand response and energy efficiency programs. The City of Independence was recently recognized for starting a two year project to replace all of their conventional city street lights with LED lights significantly reducing power demands.

I hope this provides some background on the steps that municipalities are taking to respond to the evolving public interest in this field.

In the meantime, municipal officials and MPUA will carefully monitor development of proposed regulations on CO_2 emission from existing power plants and craft their responses once concrete targets have been established by the State of Missouri.

Thank you for the opportunity to share our viewpoints. If there are any questions, please don't hesitate to contact me at fgilzow@mpu.org or by phone at 573-445-3279.

Sincere regards,

H. Floyd Gilzow
Vice President of Governmental and Environmental Regulations
Missouri Public Utility Alliance

Summary of Missouri 2012 RES Compliance Reports

Ameren Missouri RES Compliance[1]

- Keokuk Hydro-electric Generation Station
  - o Located on the Mississippi River in Keokuk, Iowa
  - o 15 separate generators
  - o Nameplate ratings from 7.2 to 8.8 MWs
  - o Generation output for CY 2012 was 754,125 MWhs
  - o Retired 632,197 RECs to meet the non-solar RES requirements
- Pioneer Prairie Wind Farm I LLC
  - o Located in Northeast Iowa
  - o 15 year power purchase agreement
  - o 102.3 MWs of nameplate generation from 62 turbines
  - o Retired 88,023 RECs to meet the non-solar RES requirements
- Various PV solar technologies at the Ameren Missouri headquarters building
  - o Located in St. Louis, Missouri
  - o Approximately 104 kW generational output
  - o Full generational output consumed at the headquarters building representing approximately 0.4 percent of the total electric consumption at the building.
- Maryland Heights Renewable Energy Center
  - o Methane gas produced by the IESI Landfill in Maryland Heights, Missouri
  - o 3 solar 4.9 MW Mercury 50 gas turbines produce electricity
  - o Generational output for CY 2012 was 37,450 MWh
- Retired 14,698 S-RECs acquired from third party brokers[2]

The Empire District Electric Company[3]

- Elk River Windfarm, LLC (now owned by Iberdrola Renewables)
  - o Located in Butler County, KS
  - o 20-year contract
  - o 150 MW energy generated
  - o Annual generation estimated at approximately 550,000 MWhs
- Cloud County Windfarm, LLC (now owned by EDP Renewables North America, LLC)
  - o Located in Cloud County, KS
  - o 105 MW Phase 1 Meridian Way Wind Farm
  - o Annual generation estimated at approximately 330,000 MWhs
- Ozark Beach Hydroelectric Project
  - o Located in Taney County, Missouri
  - o 4 generators with individual nameplate ratings of 4 MW each
  - o Generated 57,806 MWh in 2012
  - o Retired 64,381 RECs

1 See: http://psc.mo.gov/Electric/Renewable_Energy_Standard_Compliance_Reports

2 Includes S-RECs from Western Renewable Energy Generation Information System, Ameren customers, generation from the headquarters solar installations.

3 See: http://psc.mo.gov/Electric/Renewable_Energy_Standard_Compliance_Reports

KCP&L Greater Missouri Operations Company[4]

- Gray County Wind Energy
  - Located in Montezuma, Kansas
  - Purchased power agreement
  - 157,698 MWh
- Ensign Wind
  - Located in Gray County, Kansas
  - 26,713 MWh
- St. Joseph Landfill Gas
  - Located in St. Joseph, Missouri
  - 3,000 MWh
- RECs and S-RECs
  - Retired 158,374 RECs retired to meet non-solar RES
  - Acquired 3,600 S-RECs from 3Degrees Group
  - Retired 3,232 S-RECs

Kansas City Power & Light Company[5]

- Spearville I Wind Farm
  - Located in Spearville, Kansas
  - 156,367 MWh
- Spearville II Wind Farm
  - Located in Spearville, Kansas
  - 81,904 MWh
- Paseo Solar
  - Located in Kansas City, Missouri
  - 95 MWh
- Spearville 3, LLC Wind Farm
  - Located in Spearville, Kansas
  - Purchased power agreement
  - 43,875 MWh
- Cimarron II Renewable Energy Company, LLC
  - Located in Gray County, Kansas
  - Purchased power agreement
  - 130,936 MWh
- RECs and S-RECs
  - Retired 168,182 RECs from Spearville I and II
  - Acquired 3,900 S-RECs from 3Degrees Group
  - Retired 3,433.5 S-RECs

[4] Id.
[5] Id.

Informal Discovery – Section 111(d) of the Clean Air Act

Please clearly indicate when information is highly confidential so we treat the information accordingly.

Information included in this report may not be all-inclusive, and should be considered a work in progress. Specific data can be gathered as requested and verified with additional time.

1. President Obama's Climate Action Plan identifies 2005 as the baseline year to which America should reduce its greenhouse gas emission by 17% by 2020. Does the utility agree that 2005 should be the baseline year? If not, what year should be the appropriate baseline year for comparing/measuring CO2 emissions and reductions? Please explain.

This is a complex question that is difficult to answer. In other regulations (i.e., CSAPR and CAIR) the baseline was established using three years of historic emissions data. For PSD permitting the "look back" period to determine baseline emissions includes developing an average over multiple years to account for variability in operation. The approach for determining the baseline for CO2 emissions needs to include the highest historic CO2 levels possible in order to appropriately calculate true emission reductions. Regardless of the approach taken to determine baseline CO2 emissions it would be prudent for EPA to allow credit for projects that have had an impact on reducing CO2 emissions prior to the established baseline period as these reductions of CO2 are ongoing.

The baseline period should not be later than 2005.

2. Please explain the utility's understanding of how the 17% reduction in greenhouse gas emissions by 2020 is to be measured and the understanding used throughout your answers (i.e., regional, percentage by state, percentage by specific generating source, etc.)

There is a great deal of uncertainty about the best approach to measure reductions. It is a very complex issue and becomes even more complex when one considers regional transmission organizations (RTO) and next day markets where dispatching for each electric generating unit (EGU) will be done by the respective RTO. For Empire, this new market is expected to go-live in 2014. Due to this major change in how EGUs will be dispatched the EPA should delay developing its CO2 regulation for existing units until after the next day market program has been in effect for a period of time.

In addition, conversations with EPA indicate 17% is the target for the nation, not solely the responsibility of the utilities. The reductions will impact other departments such as DOT, USDA and Department of the Interior. It is important that the solution for the reductions of one sector, such as electric vehicles for the DOT, does not become the responsibility of another sector.

Although the initial reduction will be a certain percentage for the utility sector, there must be concession within the regulation to allow for annual load growth. EPA should not implement a rule that could penalize communities for economic growth and progress.

Some mechanism must be included in the final regulation to allow credit for a company's fleet-wide CO2 reductions that take place across state lines, i.e. reductions at the Asbury plant are in Missouri, and reductions at the Riverton plant are in Kansas. The overall CO2 burden reduction for Empire should transcend state boundaries. As a result, emission requirements should be set by fleet average or some other means versus an individual unit. This would not only transcend state lines but also effectively integrate renewable energy and other efficiency gains as GHG solutions.

3. What specifically has the utility done from 2005 to date to reduce CO2 emissions? Please provide the costs associated with the measures with any and all supporting documentation, including but not limited to workpapers.

Empire has completed several projects since 2005 that have resulted in either direct or indirect reductions of CO2 emissions. These projects range from the installation of gas temperature sensors at a coal-fired facility to the execution of 20-year contracts for wind energy. In total, the costs associated with these projects are in excess of $165M. This number does not include plant improvements at our jointly-owned Iatan Power Station (see KCPL response) that include a complete turbine retrofit. .

In addition to plant improvements, Empire has multiple demand-side energy efficiency programs available to its customers in each state it serves. Also, a summary of Empire's latest "Analysis for System Losses" report indicates each year has shown improved percentages in the amount of line losses on Empire's transmission and distribution system when compared to 2005.

4. What amount of CO2 reduction has the utility realized from the actions taken in number 3 above? How was the amount of reduction determined? Please provide any and all documentation that supports the calculation, including by not limited to workpapers.

Since 2005 Empire has reduced its total tons of CO2 by 6%. More accurately, Empire's CO2 intensity (CO2lbs/KWh) has decreased by a total of 18 %. The amount of CO2 reduction gained by Empire's wind purchase power agreements and hydro generation are obvious when the CO2 intensity is considered.

5. By plant or generating source, what is the utility's CO2 emission today?

		EDE CO2 by Source tons CO2							
Year	Asbury	Riverton	Energy Center	State Line 60%	Iatan 12%	Plum Point 7.52%	Plum Point PPA	Spot Purchase	TOTAL
2012	1,447,182.2	289,070.5	57183.9	522265.12	1465288.4	371,797.7	278,758.8	233,591.54	4,665,138.2

Empire's 2012 CO2 emission profile is shown above from generation and purchased power.

6. What actions is the utility planning on taking to further reduce CO2 emissions?

Empire will implement two major efficiency projects by mid-2016 that will greatly reduce CO2 emissions in the future. These projects include a turbine retrofit at the Asbury facility and the conversion at Riverton unit 12 from a simple cycle combustion turbine to a combined cycle unit. These improvements will cost an estimated $185 to $195M.

7. What is the utility's anticipated CO_2 reduction from the actions identified in number 6 above? Please provide any and all documentation that supports the calculation, including but not limited to workpapers.

Empire estimates the turbine retrofit project at Asbury will reduce CO_2 emission rate (lbs/Gross MWh) by 6% and the conversion to combined cycle at Riverton to reduce CO_2 emission rate (lbs/Gross MWh) by an additional 27%.

8. If available, please provide the incremental costs the utility anticipates will be necessary to spend per source for each percentage of CO_2 emissions reduced up to 17% below the 2005 emission level. Please provide any and all documentation that supports the calculation, including but not limited to workpapers. If the Company has partial data up to a certain percentage, please provide what is available.

We are unable to develop this number in the time allowed, but will provide as required

9. If possible, please quantify, by facility, CO_2 emissions produced by the utility's combustion of biomass.

No information available. EDE does not combust biomass.

10. Besides installing emissions controls, using renewable energy sources or increasing demand side management, has the utility considered any other non-traditional programs to achieve credit for emission reductions (i.e., planting trees, purchasing equipment for Concentrated Animal Feeding Operations (CAFOs) to reduce methane emissions for reduction credits, etc.)

2005 – 2010, Empire participated in the Rio Bravo climate action program reforestation project in Belize.

2011-current, Empire participated in activities before and after the Joplin tornado which resulted in a concentrated tree-planting reforestation effort in the community.

Beginning in 2011, Empire partnered with other MO utilities in the Shallow Carbon Sequestration Demonstration project.

Empire has explored multiple biomass fuel options (solid-waste fuel pellets, torrified wood , nut shells, treated wood waste, etc.) and several technology options for CO_2 utilization, but none have proven to be economically feasible under current conditions.

Kansas City Power & Light and KCP&L Greater Missouri Operations Informal Discovery Response - Section 111(d) of the Clean Air Act

Please clearly indicate when information is highly confidential so we treat the information accordingly.

1. President Obama's Climate Action Plan identifies 2005 as the baseline year to which America should reduce its greenhouse gas emission by 17% by 2020. Does the utility agree that 2005 should be the baseline year? If not, what year should be the appropriate baseline year for comparing/measuring CO2 emissions and reductions? Please explain.

Response: *KCP&L and KCP&L GMO continue to review this matter and are not ready to provide a baseline recommendation. The Companies believe that state plans, and the EPA guidelines, should allow for the recognition of actions taken prior to implementation of the existing source greenhouse gas (GHG) standard. In addition, a longer baseline period (three or four years) may be sought.*

KCP&L and KCP&L GMO believe that credit should be received for changes in the composition of our generating fleets and other actions taken before the existing source GHG standards are finalized that have the effect of reducing GHG emissions associated with providing electric service (e.g., plant retirements and repowerings, investments in zero-emitting generation such as nuclear uprates, investments to comply with state renewable energy standards or to improve heat rates, etc.). In particular, EPA should ensure that its approach to best system of emission reduction allows states to include early emissions reductions activities in compliance plans.

To further complicate the recommendation, the baseline selection is also impacted by the standard of compliance. KCP&L and KCP&L GMO believe that EPA should allow states to convert a rate-based (lbs CO2/MWh) standard to a mass-based (annual tons of CO2) standard, or vice-versa, but not mandate either one. In addition, states should be allowed to consider alternatives to either a rate or mass standard which could include a technology or efficiency standard.

2. Please explain the utility's understanding of how the 17% reduction in greenhouse gas emissions by 2020 is to be measured and the understanding used throughout your answers (i.e., regional, percentage by state, percentage by specific generating source, etc.)

Response: *A representative from KCP&L and KCP&L GMO has recently met with officials from EPA Region VII on two occasions in Missouri and Kansas and asked that question. The EPA officials in attendance were unable to answer the question but requested our input. We provided the following initial response. The President's Climate Action Plan set a U.S. GHG emissions reduction goal of 17 percent below 2005 emissions by 2020. Under the Clean Air Act, this goal cannot be the technical basis for emissions guidelines. This goal, however, may be informative of EPA's thinking with respect to existing source performance standards. The Companies believe* *that the power sector should not have to make more than its equitable share of economy-wide reductions. The Companies believe that GHG reductions achieved to date should be recognized in the rule.*

3. What specifically has the utility done from 2005 to date to reduce CO2 emissions? Please provide the costs associated with the measures with any and all supporting documentation, including but not limited to workpapers.

Response: *In addition to continuing to participate in the operation of Wolf Creek Generating Station which does not emit CO2 from its generation, KCP&L and KCP&L GMO have:*

- Constructed and operate the high efficiency Iatan Unit 2 generating facility
- Added wind generation
- Enhanced customer energy efficiency

The costs associated with these measures are included in Table 1.

4. What amount of CO2 reduction has the utility realized from the actions taken in number 3 above? How was the amount of reduction determined? Please provide any and all documentation that supports the calculation, including by not limited to workpapers.

Response: *Please see attached Table 2.*

5. By plant or generating source, what is the utility's CO2 emission today?

Response: *Please see attached Table 3.*

6. What actions is the utility planning on taking to further reduce CO2 emissions?

Response: *Per the KCP&L and GMO 2013 Annual IRP Updates, over the next several years the companies may retire Montrose Station (Units 1, 2 and 3) along with Sibley Units 1 & 2. The IRP Update indicates the following retirement dates:*

Montrose 1:	*2016*
Montrose 2 and 3:	*2021*
Sibley 1 & 2:	*2023*

Lake Road Unit 4/6 may be converted from coal to natural gas.

Additional wind energy resources and DSM actions are planned, however this would not significantly reduce KCP&L and GMO CO2 production as coal generation levels would remain generally unchanged.

7. What is the utility's anticipated CO2 reduction from the actions identified in number 6 above? Please provide any and all documentation that supports the calculation, including but not limited to workpapers.

Response: *For 2012, the Montrose Station CO_2 production was approximately 2.2 million tons. Sibley Units 1 & 2 produced approximately 280,000 tons. If the CO2 emission rate of Lake Road 4/6 were cut in half due to the conversion to natural gas, an additional 216,000 tons reduction per year would be achieved.*

8. If available, please provide the incremental costs the utility anticipates will be necessary to spend per source for each percentage of CO2 emissions reduced up to 17% below the 2005 emission level. Please provide any and all documentation that supports the calculation, including but not limited to workpapers. If the Company has partial data up to a certain percentage, please provide what is available.

Response: *Given that carbon capture and sequestration for coal-based generation is not yet commercially viable, the only way to reduce CO2 in any significant quantity is to reduce coal generation.*

For KCP&L and GMO to reduce generation in sufficient quantity to meet a 17% reduction target, several coal plants would be retired. These include Montrose 1, 2 and 3, Sibley 1 and 2 and Lake Road Unit 4/6. In addition LaCygne 1 would only run during three summer months and Sibley 3 would reduce generation during the spring and fall season.

Below is the approximate annual cost for GPE customers:

Annual Production Cost Increase:	*$46.7 million (fuel, purchased power, off-system sales)*
Replacement Capacity Cost (579 MW):	*$53.1 million (annual carrying costs)*
New Capacity Firm Gas Service (579 MW):	*$28.1 million (annual costs)*
Total Cost Increase:	*$127.9 million*
Retired Plant O&M Savings:	*$36.0 million*
Net Cost Increase:	*$91.9 million*

Please note these costs do not include any impact from higher wholesale market prices (and associated impact on purchased power costs) due to regional coal plant retirements.

9. If possible, please quantify, by facility, CO2 emissions produced by the utility's combustion of biomass.

Response: *KCP&L and KCP&L GMO do not combust any biomass in their electricity generating units.*

10. Besides installing emissions controls, using renewable energy sources or increasing demand side management, has the utility considered any other non-traditional programs to achieve credit for emission reductions (i.e., planting trees, purchasing equipment for Concentrated Animal Feeding Operations (CAFOs) to reduce methane emissions for reduction credits, etc.)

Response: *No significant additional emission reductions are currently planned beyond increased renewable generation, DSM activities and potential coal plant retirements.*

Exhibit No.:	
Issue:	Ameren Missouri's 2016-2018 Energy Efficiency Plan
Witness:	Tim Woolf
Type of Exhibit:	Rebuttal Testimony
Sponsoring Party:	Sierra Club
Case No.:	EO-2015-0055
Date Testimony Prepared:	March 20, 2015

BEFORE THE PUBLIC SERVICE COMMISSION
OF THE STATE OF MISSOURI

In the Matter of Union Electric Company d/b/a	)	
Ameren Missouri's 2nd Filing to Implement	)	**File No. EO-2015-0055**
Regulatory Changes in Furtherance of Energy	)	
Efficiency as Allowed by MEEIA	)	

Rebuttal Testimony of
Tim Woolf

On Behalf of
Sierra Club

On the Topic of
Ameren Missouri's 2016-2018 Energy Efficiency Plan

March 20, 2015

Table of Contents

List of Schedules

1. INTRODUCTION AND QUALIFICATIONS

Q. Please state your name, title and employer.

A. My name is Tim Woolf. I am a Vice-President at Synapse Energy Economics, located at 485 Massachusetts Avenue, Cambridge, MA 02139.

Q. Please describe Synapse Energy Economics.

A. Synapse Energy Economics is a research and consulting firm specializing in electricity and gas industry regulation, planning and analysis. Our work covers a range of issues, including economic and technical assessments of demand-side and supply-side energy resources; energy efficiency policies and programs; integrated resource planning; electricity market modeling and assessment; renewable resource technologies and policies; and climate change strategies. Synapse works for a wide range of clients, including attorneys general, offices of consumer advocates, public utility commissions, environmental advocates, the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), U.S. Department of Justice, the Federal Trade Commission and the National Association of Regulatory Utility Commissioners. Synapse has over twenty five professional staff with extensive experience in the electricity industry.

Q. Please summarize your professional and educational experience.

A. Before joining Synapse Energy Economics, I was a commissioner at the Massachusetts Department of Public Utilities (DPU). In that capacity, I was responsible for overseeing a substantial expansion of clean energy policies, including significantly increased ratepayer-funded energy efficiency programs; an update of the DPU energy efficiency guidelines; the implementation of decoupled rates for electric and gas companies; the promulgation of net metering regulations; review and approval of smart grid pilot programs; and review and approval of long-term contracts for renewable power. I was also responsible for overseeing a variety of other dockets before the commission, including several electric and gas utility rate cases.

Prior to being a commissioner at the Massachusetts DPU, I was employed as the Vice President at Synapse Energy Economics; a Manager at Tellus Institute; the Research Director at the Association for the Conservation of Energy; a Staff Economist at the Massachusetts Department of Public Utilities; and a Policy Analyst at the Massachusetts Executive Office of Energy Resources.

I hold a Masters in Business Administration from Boston University, a Diploma in Economics from the London School of Economics, a BS in Mechanical Engineering and a BA in English from Tufts University. My resume, attached as Schedule TW-1, presents additional details of my professional and educational experience.

Q. Please describe your professional experience as it relates to energy efficiency policies and programs.

A. Energy efficiency policies and programs have been at the core of my professional career. While at the Massachusetts DPU, I played a leading role in updating the Department's energy efficiency guidelines, in reviewing and approving utility three-year energy efficiency plans, in reviewing and approving utility energy efficiency annual reports, in convening a working group on rate and bill impacts of utility energy efficiency programs, and in advocating for market rules to enable energy efficiency to participate in the New England wholesale electricity market.

I also served as a co-chair of the Working Group on Utility Motivation as part of the State Energy Efficiency Action Network, a state- and local-led effort sponsored by DOE and EPA. In that capacity, I worked with commissioners and consumer advocates from around the country to improve the regulatory policies supporting utility energy efficiency programs.

As a consultant, I have reviewed and provided recommendations concerning utility energy efficiency policies and programs throughout the U.S. and Canada, and I have testified on these issues in British Columbia, Colorado, Delaware, Florida, Kentucky, Massachusetts, Minnesota, Missouri, Nevada, Nova Scotia, Québec, and Rhode Island. My work has encompassed all aspects of energy efficiency program design and implementation, including cost-benefit analyses, avoided costs, efficiency potential studies, efficiency measure assessment, program delivery options, program budgeting, utility performance incentives and other relevant regulatory policies.

Additionally, I have been the lead technical consultant for the National Efficiency Screening Project, which is comprised of a team of experts and advocates dedicated to improving the techniques used to screen energy efficiency resources. I have also represented clients on several energy efficiency collaboratives, where policies and programs are discussed and negotiated among a variety of stakeholders, including utilities, commission staff, consumer advocates, and efficiency advocates.

I have worked for a variety of clients on energy efficiency issues, including consumer advocates, environmental advocates, regulatory commissions and other government agencies.

Q. On whose behalf are you testifying in this case?

A. I am testifying on behalf of Sierra Club.

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to present my review of Union Electric Company d/b/a Ameren Missouri's (Ameren or the Company) 2016-2018 Energy Efficiency Plan (2016-2018 Plan, Efficiency Plan, or Plan),[1] and the Company's underlying analyses, including analyses presented in Ameren's 2013 Demand Side Management Market Potential Study (Potential Study) and 2014 Integrated Resource Plan (IRP).[2]

Ameren has applied to implement its proposed 2016-2018 Energy Efficiency Plan under the Missouri Energy Efficiency Investment Act (MEEIA), which allows for the implementation of commission-approved demand-side programs with a goal of achieving all cost-effective demand-side savings.[3] I offer several recommendations for how the Plan should be improved to increase the benefits available to Ameren customers and to the

[1] In this testimony, the Plan refers to Ameren's proposed three-year program portfolio. With the exception of the proposed variance from annual demand and energy savings targets, Ameren's proposed technical resource manual (TRM) and demand-side investment mechanism (DSIM) are beyond the scope of my rebuttal testimony.
[2] Ameren's 2013 Potential Study and 2014 IRP are before the Commission in case no. EO-2015-0084.
[3] Mo. Ann. Stat. § 393.1075.

Company, including lower system costs and energy bills due to increased, cost-effective energy savings.

Q. Have you previously testified before the Missouri Public Service Commission?

A. Yes. I provided rebuttal testimony on behalf of the Missouri Office of the Public Counsel regarding Ameren Missouri's 2011 IRP in case no. EO-2011-0271.

2. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Q. Please summarize your primary conclusions.

A. In general, Ameren's 2016-2018 Plan dramatically understates the amount of cost-effective energy efficiency that is realistically achievable, and thus includes energy savings goals and budgets that are way too low. As such, the Plan does not reflect a reasonable pursuit of achieving all cost-effective demand-side savings. To put the Company's proposed Plan in perspective, the projected energy savings (0.4 percent of retail sales per year) are roughly one half of the amount of the savings in Ameren's 2013-2015 Plan (0.5 to 0.9 percent of sales), and are less than half of the reported savings for the last two program years, 2013 (0.9 percent of sales) and 2014 (1.0 percent of sales).[4]

The Company provides three reasons why the savings in its 2016-2018 Plan are so low relative to the savings in its 2013-2015 Plan: (1) the enactment of federal appliance efficiency standards (Federal Standards); (2) 2013 evaluation, measurement and verification (EM&V) measure level savings estimates; and (3) lower avoided costs. (Plan

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[4] *See* Plan at p. 16; 2014 IRP Chapter 3, Appendix A at p. 82; and Ameren's Demand-Side Program Annual Report for 2014 (2014 Annual Report), Case No. EO-2015-0210.

at p. 12). However, these three factors do not justify such a dramatic drop in efficiency savings because: (1) a large number of cost-effective efficiency opportunities remain despite the Federal Standards; (2) EM&V measure level savings estimates have little effect on the total amount of available cost-effective efficiency savings; and (3) many of the Company's programs remain highly cost-effective despite lower avoided costs.

Ameren's Efficiency Plan is based upon the analyses in the Company's Potential Study and IRP, both of which contain critical flaws that constrain efficiency resources. The Company's Potential Study significantly understates the amount of achievable efficiency savings by:

- applying customer adoption rates that do not reflect potential program participation under realistic or ideal implementation conditions;
- applying unrealistic and inappropriate program and portfolio cost estimates to determine program-level efficiency potential; and
- applying unreasonable and unrealistic artificial caps on and downward adjustments to the energy savings potential.

Ameren's 2014 IRP incorporates the results of the Potential Study and then further limits the efficiency savings by:

- excluding certain key efficiency programs, such as the Residential Home Energy Performance and Small Business Direct Install programs;
- dramatically understating the probable costs of complying with future federal greenhouse gas regulations, and not even considering the potential for energy efficiency to help offset those costs;

- modeling the two main efficiency scenarios (the realistically achievable potential (RAP), and the maximum achievable potential (MAP)) that do not represent a reasonable range of efficiency opportunities; and
- choosing the RAP portfolio for the Preferred Resource Plan, despite Ameren's finding that a resource plan that included the MAP portfolio would result in a significantly lower present value of revenue requirements (PVRR) than would a plan that included the RAP portfolio.

Ameren's Efficiency Plan, which is based upon these flawed analyses, suffers from the limitations described above. However, Ameren has many opportunities to address these shortcomings and expand its efficiency programs and savings by maintaining some programs that it plans to terminate; adding new programs that it analyzed but did not include in its Efficiency Plan; modifying existing program designs to increase customer adoption; and expanding program budgets to increase customer participation rates. Ameren should pursue these opportunities.

Q. What are the implications of Ameren proposing such low energy savings goals in its 2016-2018 Plan?

A. The implications are significant. Forgoing the opportunity to achieve additional, cost-effective energy efficiency savings will result in greater reliance on more expensive supply-side resources and lead to higher bills for customers on average.

The proposed Efficiency Plan is expected to reduce electricity costs, revenue requirements, and average customer bills by roughly $135 million in cumulative present value dollars. (Plan at p. 2). According to the results of the 2014 IRP, the Company could further reduce costs and bills by $215-$271 million in cumulative present value dollars with greater energy savings. (IRP, Chapter 10 at p. 8). As I demonstrate below, higher levels of efficiency savings are achievable and would lower electricity costs even further.

In terms of capacity, the programs in the proposed 2016-2018 Plan are expected to reduce electricity demand by roughly 114 MW, for the measures installed in 2016-2018. (Plan at 15). According to the results of the Potential Study, the Company could save a total of 156 MW of peak demand with additional efficiency savings. If Ameren were to achieve the savings provided in the MEEIA guidelines,[5] then it could save roughly 240 MW of peak demand through 2018 and roughly 812 MW through 2025. This cumulative amount is roughly equivalent to one boiler at Ameren's Sioux coal-fired power plant and a small gas plant.

Q. Please summarize your primary recommendations.

A. First, I recommend that the Commission approve the Efficiency Plan only on the condition that Ameren modifies the Plan to achieve greater efficiency savings during the 2016-2018 period. Specifically, Ameren should increase the efficiency savings in its Plan to reach the MEEIA energy savings guidelines for 2016-2018. I make this recommendation because I am confident that the MEEIA savings levels can be achieved with cost-effective efficiency, based upon my review of the Company's Plan and the opportunities described herein for expanded efficiency savings.

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[5] *See* 4 CSR 240-20.094 (providing that the commission shall use the greater of realistic achievable savings as determined through the utility's market potential study or savings goals provided in the regulation itself as a guideline to review progress toward an expectation that the electric utility's demand-side programs can achieve a goal of all cost-effective demand-side savings). My references to the MEEIA savings guidelines refer to the savings goals provided in this regulation.

Second, I recommend that the Commission direct Ameren to explore the use of all cost-effective energy efficiency resources as a means of mitigating the costs of complying with future federal greenhouse gas regulations.

Third, I recommend that the Commission direct Ameren to present and consider the results of the utility cost test in all future energy efficiency analyses, including potential studies, IRPs, and energy efficiency plans. These results should at least be considered when determining which efficiency programs are cost-effective.

Finally, I recommend against Ameren's request for a variance from the annual demand and energy savings target requirements in 4 CSR 240-20.094(1)(A), 20.094(3)(A) and 20.094(4)(A).

3. OVERVIEW OF AMEREN'S 2016-2018 ENERGY EFFICIENCY PLAN.

Q. Please summarize the process used by Ameren in preparing its 2016-2018 Plan.

A. The proposed Plan is the end product of many studies Ameren conducted, particularly the Potential Study and the 2014 IRP.

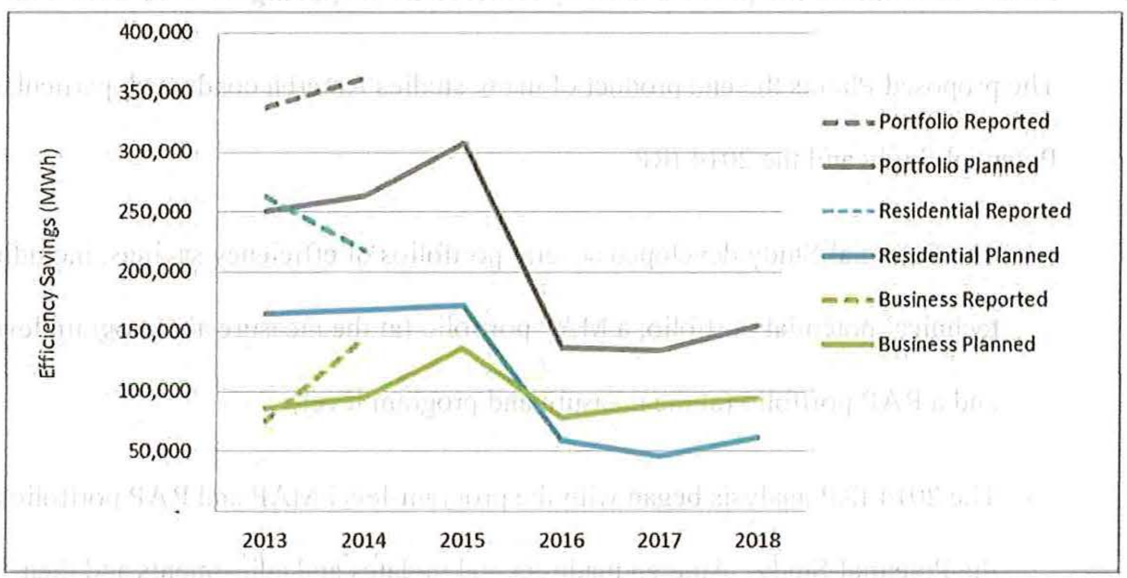
- The Potential Study developed several portfolios of efficiency savings, including a technical potential portfolio; a MAP portfolio (at the measure and program level); and a RAP portfolio (at the measure and program level).
- The 2014 IRP analysis began with the program-level MAP and RAP portfolios from the Potential Study. Ameren made several updates and adjustments and then modeled the modified MAP and RAP portfolios alongside supply-side options to determine a Preferred Resource Plan.

- The 2016-2018 Plan derives from the IRP RAP portfolio, which served as the foundation for the proposed energy efficiency programs, budgets, and savings estimates in the Plan.

Q. How much energy is the Company's proposed Plan expected to save?

A. Figure 3.1 below presents the 2016-2018 planned energy savings for the residential sector, business sector, and total portfolio. For comparison purposes, the figure also shows the same information presented in the Company's 2013-2015 Energy Efficiency Plan and the actual savings that Ameren reported for 2013 and 2014. As indicated, the anticipated savings from the 2016-2018 Efficiency Plan are significantly lower than those from the previous plan, and residential savings make up a smaller portion of the total relative to the business savings.

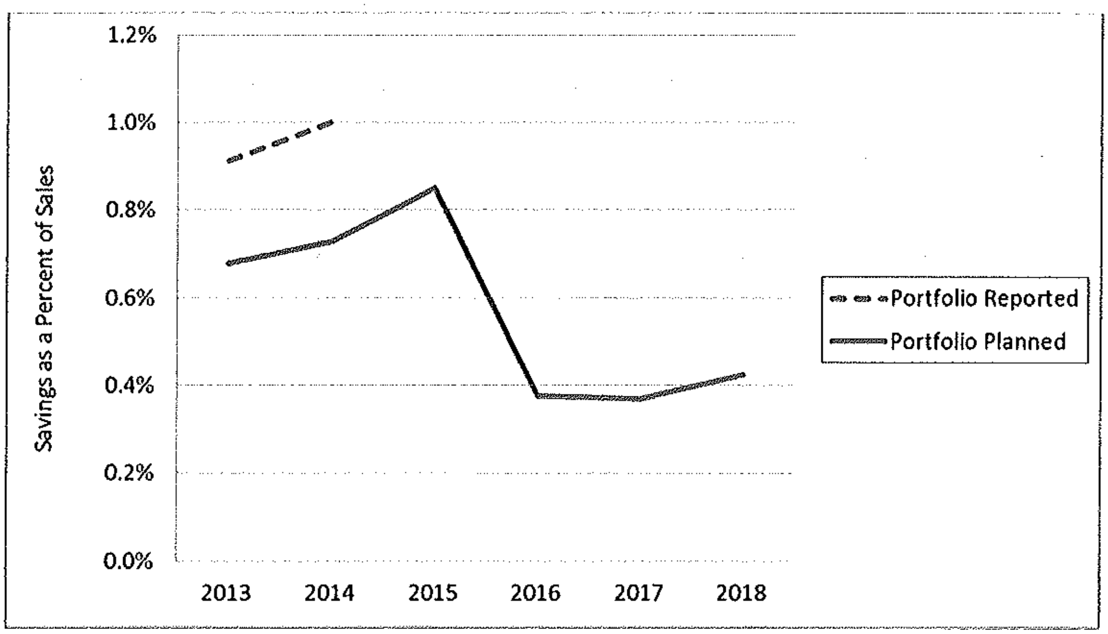
Figure 3.1 Energy Savings in Proposed Plan, 2013-2015 Plan, and Reported Savings



(Source: 2016-2018 Plan, Table 2.3 at p. 16; 2014 Annual Report).

Figure 3.2 presents the energy savings for the total portfolio, as a percent of total retail sales. In 2013 and 2014, Ameren achieved efficiency savings equal to roughly 1.0% of sales, but for 2016-2018, the Company plans to save roughly half of that amount.

Figure 3.2 Energy Savings, Planned and Reported, as a Percent of Retail Sales



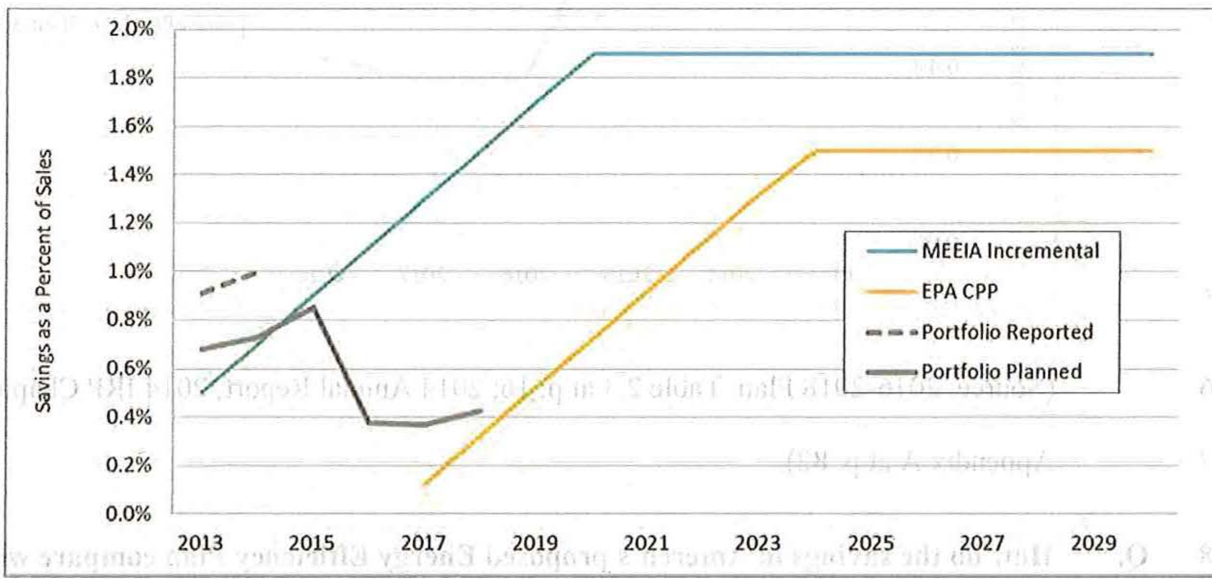
(Source: 2016-2018 Plan, Table 2.3 at p. 16; 2014 Annual Report; 2014 IRP Chapter 3 Appendix A at p. 82).

Q. How do the savings in Ameren's proposed Energy Efficiency Plan compare with the MEEIA guidelines?

A. Figure 3.3 presents the energy savings from the 2016-2018 Plan and the MEEIA savings guidelines. Whereas Ameren's planned savings in its 2013-2015 Plan and its 2013 and 2014 reported results met or exceeded the MEEIA guidelines, the 2016-2018 proposed savings levels are well below the MEEIA guidelines.

Figure 3.3 also presents the energy efficiency savings levels assumed in EPA's Clean Power Plan (CPP).[6] The Clean Power Plan anticipates that energy efficiency is one of the key building blocks that states can use to comply with greenhouse gas emission reduction requirements. The EPA estimated the amount of cost-effective efficiency savings that each state should be capable of achieving, based upon national experience and the historical experience of each state. The savings presented in Figure 3.3 are EPA's estimates for Missouri.

Figure 3.3 Energy Savings, Planned and Reported v. MEEIA Guidelines and CPP Targets, as a Percent of Retail Sales



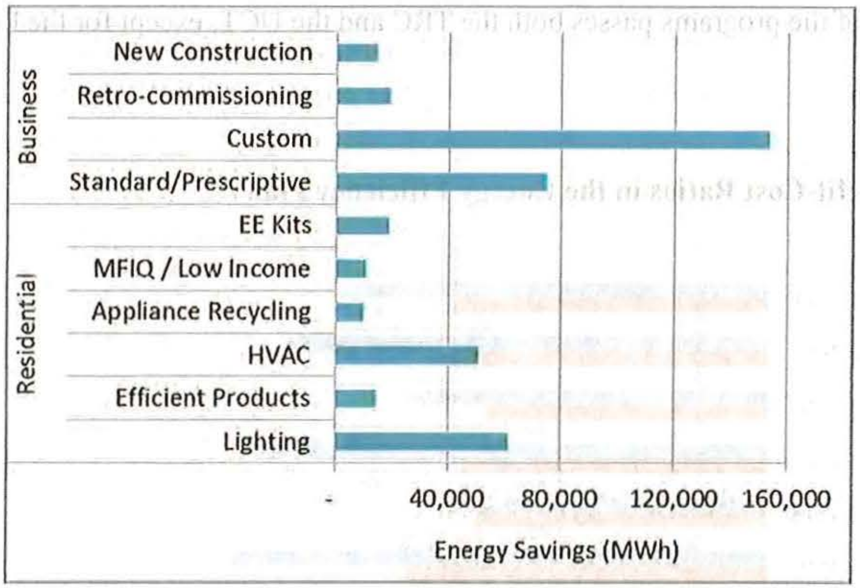
(Source: 2016-2018 Plan, Table 2.3 at p. 16; 2014 Annual Report; IRP Chapter 3, Appendix A at p. 82; 4 CSR 240-20.094; EPA 2014, CPP Data File: GHG Abatement Measures Appendix 5-4).

[6] Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 79 Fed. Reg. 34,830 (June 18, 2014).

Q. Please provide a summary of the energy savings and budgets for each program.

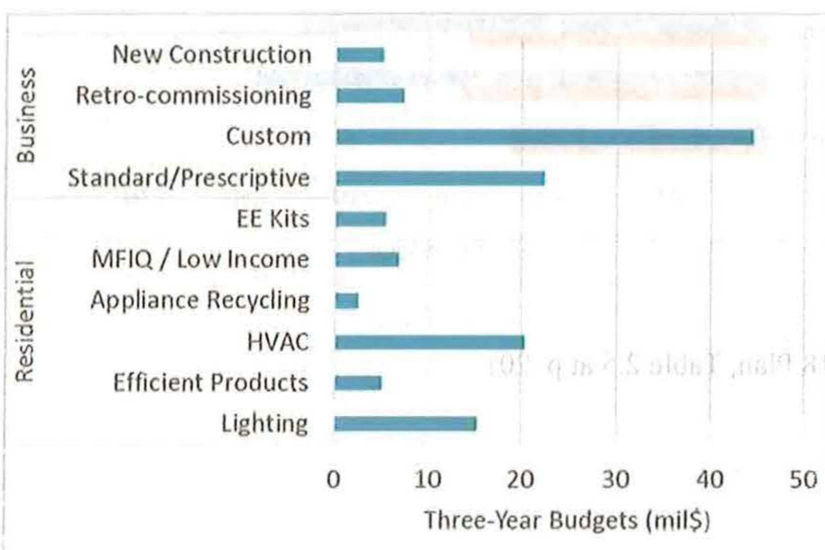
A. Figures 3.4 and 3.5 present a summary of projected energy savings and budgets, respectively, for each program, cumulative for 2016-2018.

Figure 3.4 Projected Energy Savings by Program, Cumulative for 2016-2018



(Source: 2016-2018 Plan at p. 22-23).

Figure 3.5 Projected Budgets by Program, Cumulative for 2016-2018

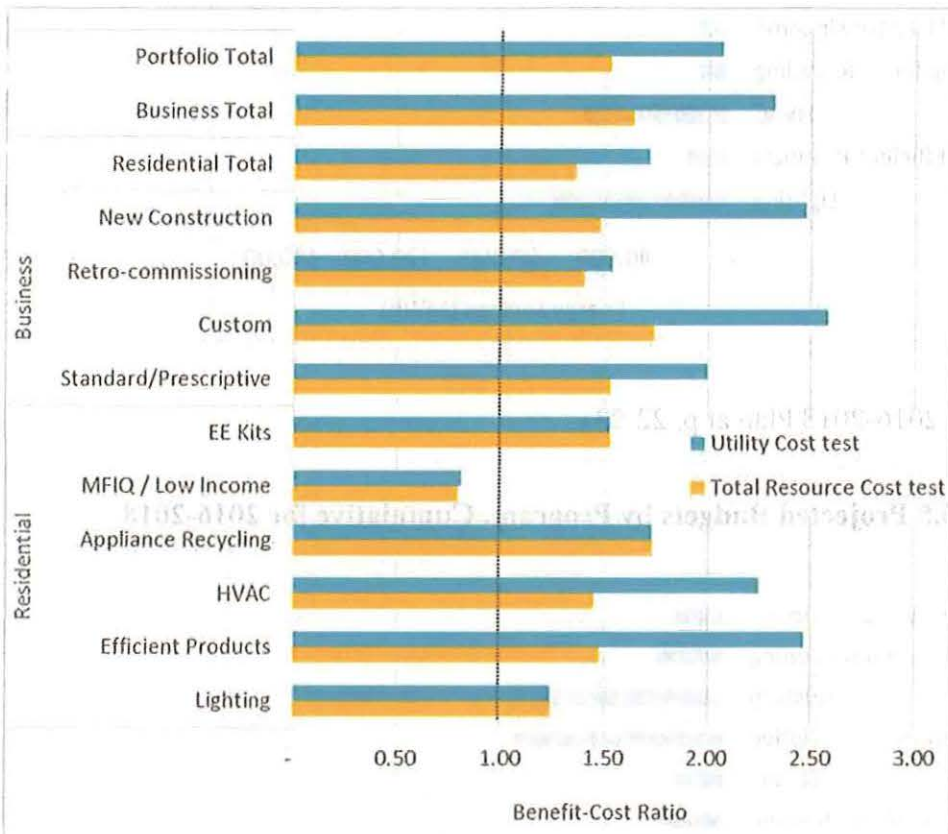


(Source: 2016-2018 Plan at p. 16).

Q. Are Ameren's proposed programs cost-effective?

A. Yes. Figure 3.6 presents the benefit-cost ratios for the total resource cost (TRC) test and the utility cost test (UCT) for each program, each sector, and the total portfolio. As indicated, each of the programs passes both the TRC and the UCT, except for the Low-Income program.

Figure 3.6 Benefit-Cost Ratios in the Energy Efficiency Plan



(Source: 2016-2018 Plan, Table 2.5 at p. 20).

4. AMEREN'S PLAN SIGNIFICANTLY UNDERSTATES COST-EFFECTIVE EFFICIENCY OPPORTUNITIES

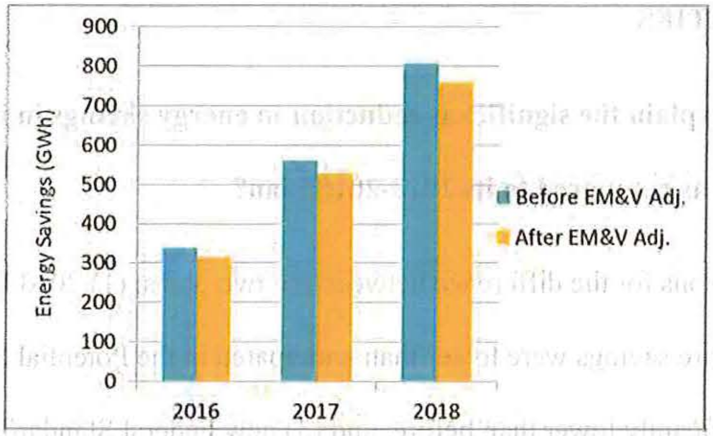
Q. How does the Company explain the significant reduction in energy savings in its proposed 2016-2018 Plan as compared to its 2013-2015 Plan?

A. Ameren provides three reasons for the difference between the two plans: (1) 2013 EM&V results indicated that measure savings were lower than anticipated in the Potential Study; (2) avoided costs are significantly lower than before; and (3) new Federal Standards reduce the potential for energy efficiency savings. (2016-2018 Plan at pp. 23-27).

Q. Do you agree that these reasons explain why Ameren's proposed savings for 2016-2018 are so much lower than the 2013-2015 savings?

A. No. I disagree with all three of the reasons Ameren provided. First, the 2013 EM&V results caused a very small adjustment to the savings estimated in the Potential Study. Figure 4.1 presents the estimated efficiency savings from the Potential Study (for RAP measure-level savings) and the estimated efficiency savings in the IRP after adjusting for the results of the 2013 EM&V studies. As indicated, the reduction in energy savings is relatively small and is not a major contributor to Ameren's dramatic reduction in planned efficiency savings.

Figure 4.1 Reduced Energy Savings in the IRP as a Result of 2013 EM&V Results



(Sources: 2014 IRP, Chapter 8, Tbls. 8.2 and 8.3 at pp. 9, 11).

Second, the efficiency measures and programs in the 2016-2018 Plan are all cost-effective, despite the reduction in avoided costs. While it may be true that the proposed efficiency programs are *less* cost-effective than those in the 2013-2015 Plan, this does not mean that they are *not* cost-effective. In addition, the Potential Study found that only six percent of the measures that were cost-effective in the 2013-2015 Plan were not cost-effective in the 2016-2018 Plan as a result of the reduced avoided costs. (NRDC's Comments on Ameren's 2014 IRP at p. 9). Therefore, reduced avoided costs are also not a large contributor to the disparity in efficiency savings between the two plans.

Third, recent Federal Standards do not explain the significant drop in proposed efficiency savings. Many cost-effective efficiency opportunities remain, even in the lighting sector, despite the Federal Standards.[7] In fact, Ameren achieved relatively high savings --

[7] *See generally, Northeast Regional Lighting Strategy: 2013-2014 Update*, Northeast Energy Efficiency Partnerships (October 2013). Attached as Schedule TW-2.

higher than the savings included in the 2013-2015 Plan – in 2014, when many of the new Federal Standards were in effect, as indicated in Figure 3.1. Additionally, the Potential Study accounts for Federal Standards in its estimates of the technical and economic potential levels.

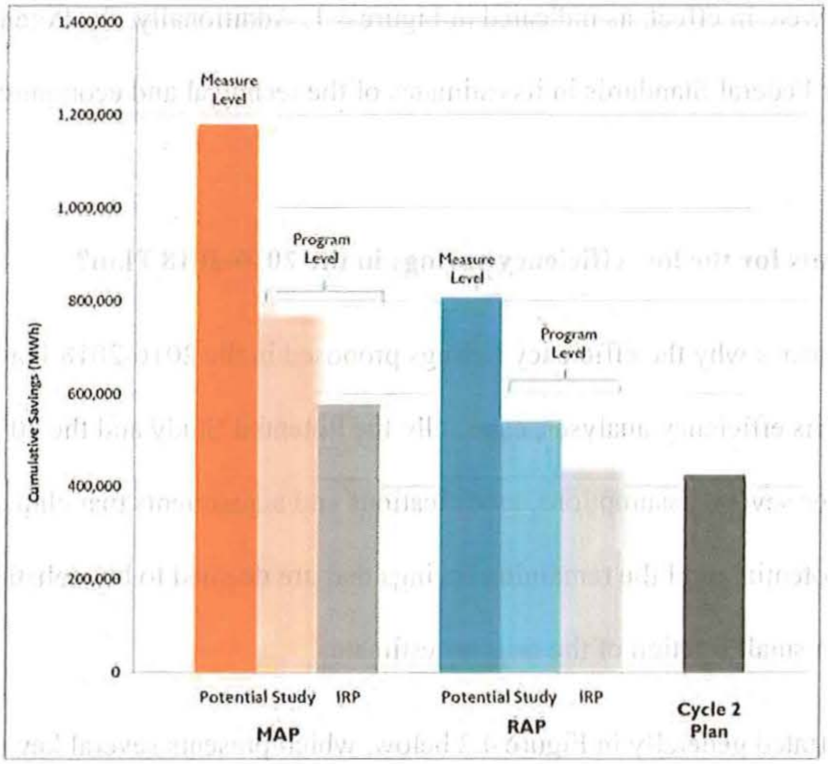
Q. What then accounts for the low efficiency savings in the 2016-2018 Plan?

A. There are many reasons why the efficiency savings proposed in the 2016-2018 Plan are so low. In each of its efficiency analyses, especially the Potential Study and the 2014 IRP, Ameren makes several assumptions, modifications and adjustments that chip away at the efficiency potential until the remaining savings that are deemed to be realistic and cost-effective are a small fraction of the original estimates.

This effect is illustrated generally in Figure 4.2 below, which presents several key efficiency savings estimates in the Potential Study, 2014 IRP, and 2016-2018 Plan. The figure indicates the following:

- There is a significant reduction in estimated efficiency savings between the measure-level estimates and the program-level estimates in the Potential Study. I address this issue further in Section 5 of my testimony.
- There is a significant reduction in efficiency savings between the MAP and RAP portfolios in both the Potential Study and the 2014 IRP. I address this issue in Sections 5 and 6 of my testimony.
- There is a significant reduction in estimated efficiency savings between the Potential Study and the Plan and the 2014 IRP. I address this issue in Section 6 of my testimony.

Figure 4.2 Program Level v. Measure Level Savings (2016-2018)



(Source: Potential Study, Vol. 3 at pp. 5-4, 5-8, 5-13, 6-9, 6-10; 2014 IRP, Chapter 8 at p. 22, [extracted from Figure 8-7]).

Q. Are there actions that Ameren can take to increase the efficiency savings in its Plan?

A. Yes. There are many things that Ameren can and should do to increase the amount of efficiency savings in its 2016-2018 Plan. For example, Ameren can:

- Maintain some programs that are proposed to be terminated; for example, the Residential New Construction and HEP programs.
- Add programs that have not been implemented and are not yet a part of the proposed Efficiency Plan; for example, a Small Business Direct Install, and a Street Lighting program.

- Modify existing program designs to increase customer adoption; for example, through increased use of upstream buydown practices for lighting products, HVAC measures, and certain efficient appliances.
- Expand program budgets to increase participation rates for programs serving key customer segments.

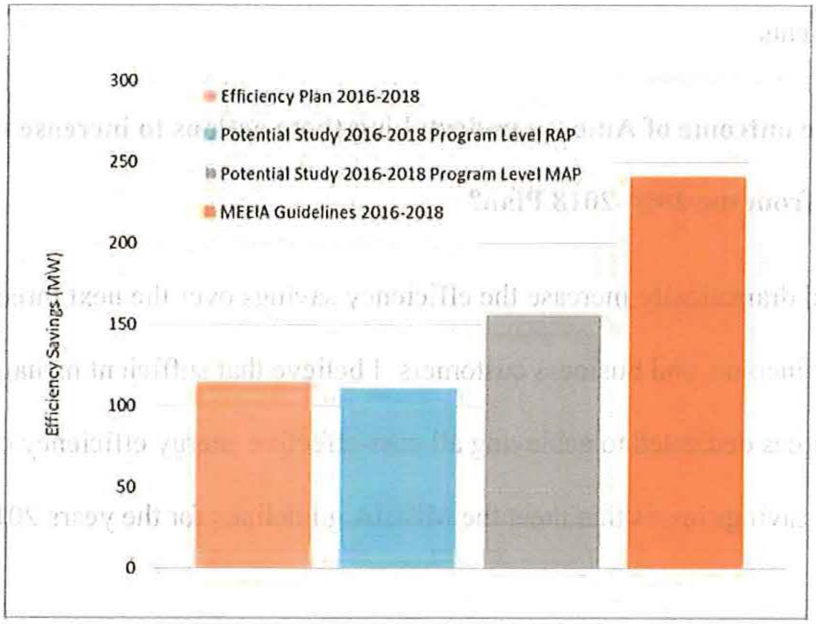
Q. What would be the outcome of Ameren undertaking these actions to increase the efficiency savings from the 2016-2018 Plan?

A. These actions could dramatically increase the efficiency savings over the next three years for residential, low-income, and business customers. I believe that sufficient management attention and resources dedicated to achieving all cost-effective energy efficiency could result in efficiency savings levels that meet the MEEIA guidelines for the years 2016-2018.

Q. How much of an impact will the efficiency programs have on the need for new power plants?

A. Figure 4.3 presents the amount of peak demand that could be avoided under different efficiency scenarios. The programs in Ameren's Energy Efficiency Plan are expected to save 114 MW of customer peak demand over the three-year period 2016-2018. If the Company were to implement efficiency programs consistent with the MAP portfolio in the Potential Study it could save roughly 156 MW of peak demand, and if it were to achieve the capacity savings in the MEEIA regulation guidelines then it could save roughly 240 MW of peak demand during this period and roughly 812 MW by 2025. This is very roughly equivalent to one boiler at Ameren's Sioux coal-fired power plant and a small gas plant.[8]

Figure 4.3 Demand Savings from the Potential Study, the Efficiency Plan and MEEIA Guidelines



(Source: Potential Study, Vol. 3, p. 6-10; 2016-2018 Plan, p. 6; 4 CSR 240-20.094(2)(A); 2014 IRP, Chapter 3, Appendix A at p. 83).

5. AMEREN'S 2013 DSM MARKET POTENTIAL STUDY

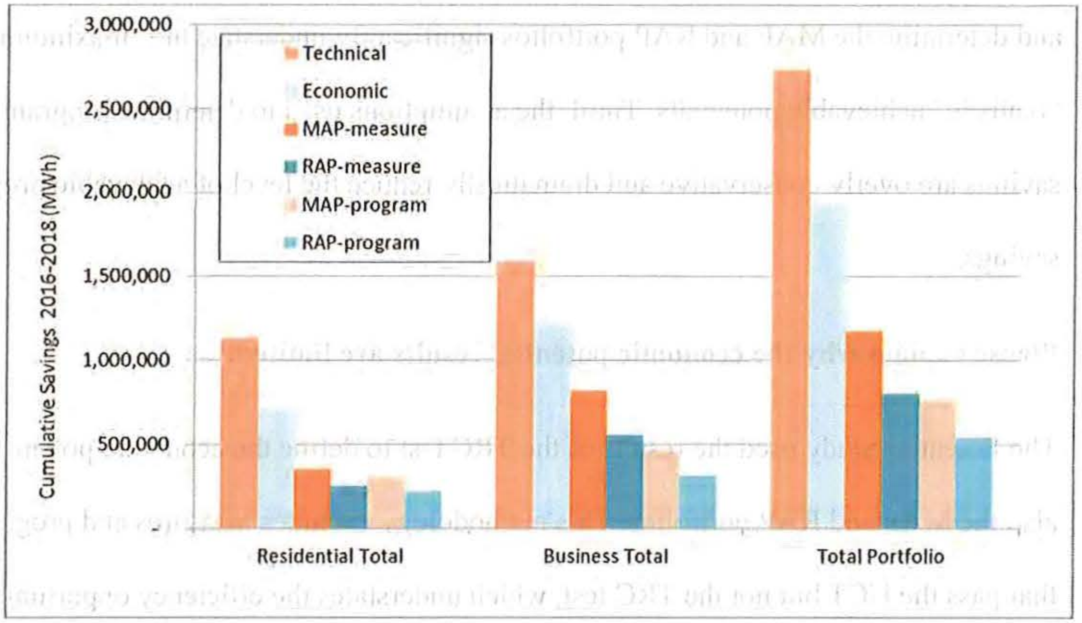
Q. Please provide a summary of the findings of the Potential Study

A. Figure 5.1 provides a summary of some of the key findings of the Potential Study. It shows the study's estimate of potential energy savings (by sector and by portfolio. The

[8] Note that the amount of generation capacity that can be avoided by energy efficiency is higher than the amount of reduced peak demand (by roughly 15 to 20 percent), because of the reserve margin used for generation planning. Consequently, to indicate the amount of generation capacity avoided by the 2016-2018 Plan, all of the numbers presented here should be increased by Ameren's planning reserve margin.

potential energy savings are presented in terms of technical, economic, RAP, and MAP portfolio levels.

Figure 5.1 Potential Study: Savings Under Different Portfolios, Cumulative (2016-2018)



(Source: Potential Study, Vol. 3 at pp. 5-4, 5-8, 5-13, 6-9 and 6-10).

As indicated, and as is typically the case with potential studies, there is a significant difference between the technical potential and the economic potential. Note that the economic potential for all of the scenarios is based on results of the TRC test. Also, there is a dramatic reduction in savings from the economic potential to the MAP and RAP portfolios.

Q. Please summarize your view of the Potential Study, particularly as the study affects the 2016-2018 Plan.

A. I have three main concerns with the study's assumptions and methodologies. First, the economic potential results are somewhat limited. Second, the methodology used to define and determine the MAP and RAP portfolios significantly understate the "maximum" and "realistic" achievable potentials. Third, the assumptions used to determine program-level savings are overly conservative and dramatically reduce the level of achievable program savings.

Q. Please explain why the economic potential results are limited.

A. The Potential Study used the results of the TRC test to define the economic potential and also the MAP and RAP portfolios. This methodology excludes measures and programs that pass the UCT but not the TRC test, which understates the efficiency opportunities from the economic portfolio and from all the MAP and RAP portfolios. (I discuss the cost effectiveness tests in more detail in Section 7).

In addition, in calculating the TRC benefits, the study authors do not include the benefits associated with fossil fuel savings or other resource savings such as water. These benefits can be significant and can make a material difference in the results of the TRC test. The costs required to achieve the fossil fuel and other resource savings are included in the TRC costs, so excluding the benefits of these savings results in a test that is skewed against energy efficiency by design. Consequently, defining the economic potential using these assumptions reduces the estimates of the economic potential. This is particularly true for certain programs that result in fossil fuel or other resource savings, such as a

Residential New Construction program or a Residential Home Energy Performance program. In these cases, the Company and the Commission should give considerable weight to the results of the UCT, for the reasons stated above and because it is not inherently skewed.

Q. Generally, how should estimates of achievable potential be viewed?

A. Estimating the amount of efficiency savings that is "achievable" is one of the more challenging aspects of any efficiency potential study. This is partly because the amount of efficiency savings that is achievable depends upon many factors (for example, customer incentives, customer education, technical assistance provided, program designs, marketing and delivery) that are difficult to model systematically. Many of these factors are not even developed yet at the time of the potential study, and therefore cannot be factored in to the achievable potential results. In addition, many of those factors are within the control of the utility implementing the efficiency programs.

Thus, the amount of achievable potential is actually a very dynamic value, which can be modified considerably depending upon a utility's energy efficiency initiatives. The ability of a utility to influence the amount of achievable potential is rarely (if ever) captured in efficiency potential studies.

As a result, estimates of achievable efficiency potential should be viewed as rough guidelines as to what might be achievable. Unfortunately, the results of efficiency potential studies are often construed as fixed upper limits of what is achievable, which typically understates what is really achievable.

Q. How do Ameren's MAP and RAP portfolios understate achievable efficiency savings?

A. The Potential Study's assumptions about participation rates are the primary reason why the MAP and RAP portfolios understate achievable efficiency savings. That study uses market adoption rates for each measure to estimate the extent to which customers are likely to adopt each measure. The adoption rates are based on Ameren customer surveys that were conducted by the study authors. For the RAP portfolio, the study authors assumed that customers would be offered financial incentives that reduced the payback of the efficiency measure to three years. For the MAP portfolio, the authors assumed that customers would be offered incentives resulting in one-year payback periods. (Potential Study, Vol. 3 at p. 2-12).

There are several limitations to this methodology. First, this approach does not account for the many factors beyond customer incentives that might cause customers to participate, including customer education, technical assistance, program design, marketing and delivery features.

- For example, many utilities deliver efficiency measures through upstream buydown programs, where a financial incentive is offered to manufacturers and distributors of efficiency products before they arrive at retail stores. These types of programs have proven to dramatically increase customer participation, yet they are not accounted for when estimating measure adoption rates, significantly understating the RAP and the MAP potential.

- Another example is customer behavioral programs, in which customers are not offered any incentive but are provided with information about consumption patterns and opportunities to reduce consumption. These behavior programs can result in a significant program participation, sometimes greater participation than all other programs, without offering any financial incentive at all. Again, this type of program design is not considered in developing market adoption rates.
- Yet another example is statewide marketing and outreach programs that can significantly increase customer awareness and adoption of efficiency measures, or statewide programs to train contractors, technicians and other trade allies to promote, deliver, install and maintain efficiency equipment.

The second limitation to this methodology is that Ameren could, and in some cases should, offer financial incentives equal to payback periods shorter than three years, but these are not included in the "realistic" portfolio. Ameren's three-year assumption could potentially eliminate a large portion of efficiency measures and savings from the RAP portfolio, even though incentives leading to payback periods of less than three years are realistic, reasonable and appropriate in many instances.

Finally, there are many ways that customers might adopt additional measures beyond those identified in the RAP and MAP portfolios, once the measures are offered as bundled programs. It is common for customers participating in a program to adopt several measures once they learn of all the opportunities available, and it is also common for customers to participate in additional efficiency programs as a result of being referred to them by other programs. This type of interactive effect between measures is not captured in the market adoption rates, again understating the amount of achievable potential.

Q. Do you have other concerns about customer participation assumptions in the Potential Study's MAP and RAP portfolios?

A. Yes. Ameren applied two downward adjustments on the market adoption rates for each measure in the Potential Study. First, it applied "take rate" downward adjustment factors to the potential efficiency savings, ranging from 56 to 62 percent for residential customers, and 72 to 83 percent for business customers. (Potential Study, Vol. 2, pp. 3-2 to 3-3 and tbls. 3-1, 3-2, 7-1 and 7-2). This eliminates a significant portion of savings from what is considered realistic.

Second, Ameren applied an additional downward adjustment based on responses to psychographic segmentation questions. Under these adjustments, a survey respondent would have to indicate that he or she is very satisfied with service from Ameren (with a score of "10" on a scale of 1-10), and that he or she believes that the threat from climate change is real and significant (agree or disagree). (Potential Study, Vol. 2, pp. 3-4 to 3-5).

These downward adjustments are completely unreasonable and are not an indication of whether a customer is likely to adopt any particular efficiency measure. Many customers adopt efficiency measures even if they do not have an excellent (10 out of 10) opinion of their electric utility, and many customers adopt efficiency measures for reasons other than environmental and climate change benefits. For example, many customers adopt efficiency measures because they will save money on their electric bills. These adjustments, in and of themselves, indicate that the Company's MAP and RAP portfolios are inconsistent with what customers actually do in practice, and do not indicate the full amount of achievable efficiency savings.

Q. How does Ameren use and describe the results of its RAP portfolio?

A. Ameren misstates what its RAP portfolio actually represents. A RAP portfolio should represent what can be achieved from "expected program participation and realistic implementation conditions." (4 CSR 240-22.020(49)). Ameren describes its RAP portfolio as representing "all cost-effective energy efficiency" (Plan at p. 17). However, Ameren's RAP portfolio represents neither.

Ameren's RAP portfolio dramatically understates the amount of efficiency savings available, primarily as a result of its methodology and assumptions regarding customer adoption rates, and does not represent what is realistically achievable.

With respect to Ameren's claim that its RAP portfolio represents all cost-effective efficiency, the Potential Study states that RAP reflects "expected program participation given barriers to customer acceptance, non-ideal implementation conditions, and limited program budgets. This represents a lower bound on achievable potential." (Potential Study at p. 1-4). This suggests that the RAP portfolio from the Potential Study does not represent all cost-effective demand-side savings, as the Company asserts.

In addition, a RAP portfolio, even one that presumably meets the theoretical definition of realistically achievable, is not necessarily equivalent to all cost-effective demand-side savings. The MEEIA regulations state that:

> The commission shall use *the greater of* the annual realistic achievable energy savings and demand savings as determined through the utility's market potential study or the following incremental annual demand-side savings goals as a guideline to review progress toward an expectation that the electric utility's demand-side programs can achieve a goal of all cost-effective demand-side savings...

(4 CSR 240-20.094(2)(A)) (emphasis added).

In my view, the fact that the regulations require the Commission to use *the greater of* realistic achievable energy savings and the annual savings goals suggests that a RAP portfolio is not necessarily equal to all cost-effective efficiency savings, and that higher levels of savings might be deemed to be cost-effective.

Q. How does Ameren use and describe the results of its MAP portfolio?

A. Similarly, Ameren describes its MAP portfolio as "the upper limit" of energy efficiency potential. (2014 IRP, Chapter 8 at p. 54). However, this is a misleading representation of its MAP portfolio. A MAP portfolio should represent an upper limit on the amount of energy efficiency that can be achieved based on "expected program participation and ideal implementation conditions" (4 CSR 240-22.020(40)). Ameren's "MAP" portfolio does not represent the maximum amount that is achievable, again because it understates what program participation rates could be and it does not apply idealistic implementation conditions.

Q. Turning to your third concern with the Potential Study, please explain why the assumptions Ameren used to determine program-level savings are overly conservative and dramatically reduce the level of achievable program savings.

A. The Potential Study eliminates a large amount of cost-effective efficiency savings as a result of its assumptions regarding program-level savings. This is illustrated in Figure 4.2 above, which shows the difference in efficiency potential between the measure-level savings and the program-level savings.

The Potential Study notes that "the most significant difference between the measure-level potential and the program potential is the assignment of program costs." The study adds base program costs and portfolio administration costs to the measure costs. (Potential Study at p. 6-2). The Potential Study also notes that these additional costs caused several measures to be uneconomic, and they were therefore removed from the programs.

Q. Do you agree with these assumptions and methodologies used to create program-level savings estimates?

A. No. I have not been able to assess the magnitude of the base program costs and the portfolio administration costs, as these were not presented in the Potential Study. However, it appears that these costs are very large, given the impact that their addition had on the efficiency savings estimates. I question whether those assumptions are reasonable, especially given that a lot of program costs and portfolio administration costs are fixed, and will not vary significantly by the addition of certain efficiency measures.

In addition, the methodology used to screen efficiency measures, by adding indirect costs and screening measure-by-measure, is not best practice. This measure-level screening approach has been rejected by many states. Most of the costs of efficiency programs are a result of getting customers to participate in a program, and providing them with an audit of their home or business. Once a customer has gotten to this point, the program and portfolio costs have already been incurred. They are not only fixed costs, they are also sunk costs. Thus, once a customer participates, the most economic and appropriate action is to install all of the measures that are cost-effective based on the measure costs alone. Otherwise, there will be a significant amount of lost opportunities, where cost-effective measures are not adopted and are very unlikely to be adopted at a later time. Many states do not screen efficiency programs on a measure basis at all, and just screen on a program basis, with reasonable estimates of program costs included, to avoid this effect.

6. AMEREN'S 2014 INTEGRATED RESOURCE PLAN

Overview of the IRP

Q. Turning to Ameren's 2014 IRP, please summarize how Ameren modeled efficiency programs in the IRP.

A. Ameren used the measure-level MAP and RAP portfolios from its Potential Study to develop similar MAP and RAP portfolios in its 2014 IRP. Ameren made several adjustments to the Potential Study results in developing inputs for the 2014 IRP. One of the key adjustments was to update the measure savings to reflect the data from the 2013 EM&V studies. (2014 IRP, Chapter 8 at pp. 9, 11). Another adjustment was to consider and remove, if not cost-effective, programs that were proposed in the 2014 IRP (2014 IRP, Chapter 8 at p. 12).

These inputs and assumptions resulted in two energy efficiency scenarios: a MAP portfolio and a RAP portfolio.[9] Ameren developed a set of alternative resource plans that included variations of either the MAP or RAP portfolios (2014 IRP, Chapter 10, pp. 6-7).

Finally, Ameren selected the RAP portfolio for its Preferred Resource Plan. The 2014 IRP notes that both the MAP and RAP portfolios result in reduced total cost to customers. In fact, the MAP portfolio resulted in the lowest PVRR, but the Company decided to include the RAP portfolio in its Preferred Resource Plan. (2014 IRP, Chapter 10 at p. 8, tbl. 10.3) The Company justifies choosing the RAP portfolio on the basis of risk and

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[9] The 2014 IRP also included a third efficiency scenario (MID) that assumed costs and savings half-way between these two cases.

reward considerations from the perspective of both customers and Ameren (2014 IRP, Chapter 10 at pp. 11-12).

Q. Please provide a summary of the results of the 2014 IRP as they apply to the development of the 2016-2018 Efficiency Plan.

A. Figure 4.2 above presents a summary of some of the key results of the efficiency portfolios in the 2014 IRP. It shows that the IRP MAP and RAP portfolio savings are less than the savings from comparable portfolios from the Potential Study, and the IRP RAP portfolio savings are close to the savings in the 2016-2018 Plan.

Table 6.1 presents a summary of the cost-effectiveness analysis of both the MAP and the RAP portfolios, for both the UCT and the TRC tests. (The table includes the RAP results for programs implemented over 2016-2018 only, and for programs implemented over 2016-2034, the entire study period.). As indicated, all of the programs are cost-effective under both tests, except for the Residential Low-Income program.

Table 6.1 Benefit-Cost Ratios for the MAP and RAP Portfolios in the 2014 IRP

		IRP 2016-2018 RAP		IRP 2016-2034 RAP		IRP 2016-2034 MAP	
		TRC	UCT	TRC	UCT	TRC	UCT
Residential	Lighting	1.05	1.06	0.96	0.96	0.96	0.96
	Efficient Products	1.29	1.98	1.71	3.17	1.44	2.07
	HVAC	1.34	1.99	1.72	2.70	1.29	1.73
	Appliance Recycling	1.08	1.08	1.27	1.27	1.02	1.02
	MFIQ / Low Income	0.79	0.81	1.00	1.01	0.93	0.95
	EE Kits	1.53	1.53	1.57	1.57	1.10	1.11
Business	Standard/Prescriptive	1.49	1.93	2.75	3.32	2.32	2.20
	Custom	1.67	2.43	2.13	2.84	1.83	1.90
	Retro-commissioning	1.59	1.59	2.36	3.21	1.97	2.02
	New Construction	1.46	2.40	2.42	3.82	2.10	2.47
	Residential Total	1.22	1.50	1.54	2.19	1.27	1.63
	Business Total	1.61	2.22	2.37	3.11	2.02	2.05
	Portfolio Total	**1.45**	**1.91**	**2.01**	**2.72**	**1.69**	**1.89**

(Source: 2014 IRP, Chapter 8 at tbls. 8-7, 8-9, and 8-10).

Q. Please summarize your findings on the 2014 IRP, particularly as it applies to the development of the 2016-2018 Plan.

A. The 2014 IRP significantly understates the amount of cost-effective efficiency savings that are achievable on the Ameren system. In sum, the IRP:

- focuses on the MAP and RAP scenarios from the Potential Study, which understate cost-effective efficiency potential;
- chooses the RAP portfolio for its Preferred Resource Plan, despite the fact that the MAP portfolio is expected to reduce costs by more than the RAP portfolio;
- improperly accounts for probable environmental costs, particularly the cost of complying with the EPA's Clean Power Plan; and

- reduces the amount of savings indicated by the MAP and RAP portfolios by excluding several key efficiency programs.

I address each of these points below.

<u>Analysis of MAP and RAP Portfolios</u>

Q. Why does focusing on the MAP and RAP scenarios understate the amount of cost-effective efficiency savings?

A. As discussed in Section 5, the MAP and RAP scenarios in the Potential Study do not account for all of the potentially achievable cost-effective efficiency savings. The MAP and RAP portfolios in the IRP are based directly on those from the Potential Study, with the exception of the few updates and modification listed above. Therefore, all of the limitations of the RAP and MAP studies described in Section 5 apply to the 2014 IRP as well.

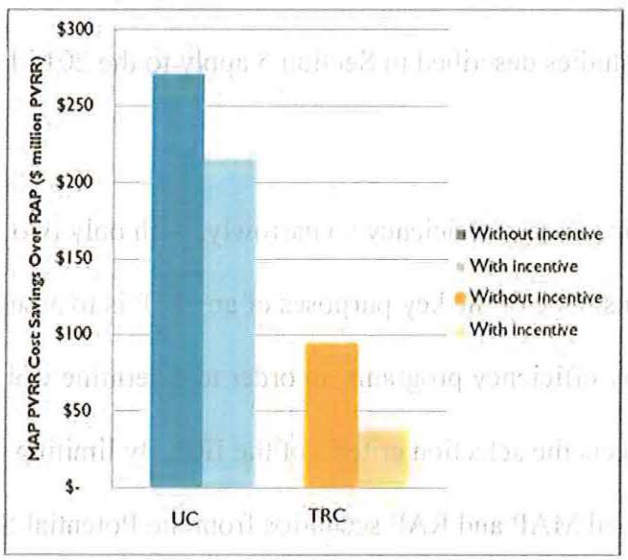
Furthermore, IRPs should not define energy efficiency so narrowly, with only two possible future efficiency portfolios. One of the key purposes of any IRP is to assess a variety of different levels of energy efficiency programs, in order to determine which level is most cost-effective and meets the selection criteria of the IRP. By limiting the IRP analysis to the narrowly-defined MAP and RAP scenarios from the Potential Study, the Company has not fully identified or investigated the amount of cost-effective energy efficiency savings that are available on its system.

In particular, the Company should at least investigate a portfolio of efficiency programs that is consistent with the energy efficiency building block assumptions used by the EPA in the proposed CPP and a portfolio of efficiency programs that is consistent with the energy savings guidelines in the MEEIA regulations. Even if the Company does not eventually include such portfolios in its Preferred Resource Plan, it would be very informative to at least study the potential costs and benefits of them.

Q. Do you have any concerns about how the Company chose the RAP portfolio for its Preferred Resource Plan?

A. Yes. The MAP portfolio would reduce electricity costs and average bills by significantly more than the RAP portfolio. Figure 6.1 presents a summary of the estimated reductions in PVRR from the RAP portfolio relative the MAP portfolio.

Figure 6.1 Reductions in PVRR from MAP v. RAP Portfolios in the 2014 IRP



(Source: 2014 IRP, Chapter 10 at p. 8).

The Company justifies its choice of the RAP portfolio by referring to its analysis of the year-by-year cost differences between the two portfolios, and its understanding of the increased level of risk in achieving MAP relative to RAP (2014 IRP, Chapter 10 at pp. 11-12).

Q. Do you agree with the Company's rationale for choosing the RAP portfolio for its Preferred Resource Plan?

A. No. First, I do not agree with the Company's conclusion regarding the year-by-year cost differences between the two portfolios. Ameren assumes a significant increase in the cost of saved energy for the MAP portfolio relative to the RAP portfolio, where the MAP portfolio budget is roughly twice that of the RAP portfolio budget but the MAP savings are only 35 percent greater than the RAP savings. (IRP, Chapter 10 at p. 9). This increase in the cost of saved energy is in direct contrast to the experience of many energy efficiency program administrators, who find that increased efficiency savings levels can be achieved for similar, or even reduced, cost of saved energy. This unreasonable assumption puts the MAP portfolio at a significant undue economic disadvantage relative to the RAP portfolio, and undercuts the Company's year-by-year cost analysis.

Second, I do not agree with the Company's conclusion regarding the risk associated with achieving MAP relative to RAP. Ameren disadvantages the MAP portfolio by applying a negative risk scalar of 18 percent, whereas the RAP portfolio has a symmetrical risk scalar of plus or minus only 8 percent. (2014 IRP, Chapter 8 at pp. 86-87). This scalar is too high for the MAP scenario, and should be symmetrical. In addition, the IRP does not take into account the ways that increased energy efficiency savings can help reduce risk. Nonetheless, despite this unreasonable scalar for higher risk, the MAP portfolio resulted in lower PVRR relative to the RAP portfolio. Apparently, the Company applied some *additional* quantitative risk considerations for rejecting the MAP portfolio. In my view, the Company's arguments do not justify its decision to reject an energy efficiency portfolio that will clearly lead to reduced costs and reduced average customer bills as compared to the RAP portfolio.

Accounting for Environmental Compliance Costs

Q. Please describe how Ameren accounted for the cost of complying with federal CO2 regulations in the 2014 IRP.

A. Ameren applied a forecast of CO2 allowance costs to represent the costs of complying with the CPP. It developed a forecast based upon a study prepared by my colleagues at Synapse Energy Economics.[10] Ameren used this report to make its own forecast, where the CO2 allowance prices are assumed to be zero through 2024, and are then equal to the Synapse forecast thereafter.

Moreover, Ameren did not assume that these prices will exist in all of its planning scenarios. It assumed that only five out of fifteen future scenarios will include any future cost of complying with federal CO2 regulations through 2035. Ameren then assigned probability weightings to each of its future scenarios, which result in a probability of only 15 percent that any one of the scenarios with CO2 costs will occur.

[10] Patrick Luckow et al., 2013 Carbon Dioxide Price Forecast, Synapse Energy Economics, (November 1, 2013, minor corrections made on February 2014), available at http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-11.0.2013-Carbon-Forecast.13-098.pdf.

Q. Do you agree with Ameren's methodology for modeling the cost of compliance with the CPP?

A. No. Ameren's assumptions about the timing and magnitude of costs of complying with the CPP (or any federal CO2 requirements) are unreasonable, untenable, and inconsistent with other statements and assumptions in the 2014 IRP. While there is some uncertainty regarding the implementation if the CPP, Ameren's assumptions about the probability of CPP are clearly too low.

A recent update to the Synapse CO2 price forecast, which accounts for the implications of EPA's proposed CPP regulations, provides a much more reasonable range of future CO2 prices. The study concludes that federal action to address climate change is "extremely likely," and that costs to comply with federal action will be required by 2020.[11]

Q. Is Ameren's modeling approach consistent with related statements in the 2014 IRP?

No. Immediately after describing the CO2 price forecast used in the 2014 IRP, the Company stated that "the actual cost of complying with greenhouse gas regulations can be higher depending upon the specifics of the regulation. As discussed later, we do in fact expect [*sic*] costs to comply with EPA's proposed Clean Power Plan to be higher than $53/ton." (2014 IRP, Chapter 1 at p. 11).

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[11] Patrick Luckow et al., 2015 Carbon Dioxide Price Forecast, Synapse Energy Economics (March 3, 2015), available at http://www.synapse-energy.com/sites/default/files/2015%20Carbon%20Dioxide%20Price%20Report.pdf.

The Company does not explain why its modeling assumptions differ so dramatically from its position that compliance costs are likely to be higher than the costs assumed in the High CO2 case, or why even this high case is assumed to have a probability of occurrence of only three percent.

Q. What are the implications of Ameren's decision to model the cost of complying with federal greenhouse gas regulations this way?

A. The implications are dramatic. A large portion of the Company's generation fleet is made up of older coal plants, which tend to have high GHG emission rates. Costs of complying with federal greenhouse gas regulations, combined with the costs of complying with other EPA emission regulations, will increase the costs of those plants, improve the economics of retiring those plants, and improve the economics of all the electricity resources that emit little, or no, CO2.

Q. More specifically, what are the implications of this decision with regard to the evaluation of energy efficiency resources in the 2014 IRP and the proposed Efficiency Plan?

A. Energy efficiency resources are widely regarded as the lowest-cost means of complying with the proposed CPP. Yet, the 2014 IRP does not even analyze or investigate the potential to mitigate the costs of complying with federal greenhouse gas regulations using increased energy efficiency savings.

First, by assuming very low probabilities that there will be any federal greenhouse gas emission requirements, and by assuming relatively low estimates for CO2 allowance prices, the Company significantly understates the additional costs that could be avoided by efficiency programs. Second, and very importantly, by modeling only two future efficiency scenarios (the MAP and RAP portfolios), the Company does not investigate the opportunity for *increased* levels of efficiency to be used to mitigate greenhouse gas compliance costs.

Q. Does the Company seriously consider energy efficiency as an option for complying with the CPP?

A. Apparently not. In the 2014 IRP, Ameren makes it clear that it does not intend to use energy efficiency resources to mitigate the cost of complying with the CPP. The Company presents a description of how it might modify its Preferred Resource Plan if the EPA CPP regulations were to be implemented. It lists four changes that it would make: (1) advancing the retirement of Meramec by three years; (2) constructing a 1,200MW combined cycle power plant by 2020; (3) altering the dispatch of new and existing coal and gas resources so that gas would run more frequently; and (4) constructing additional wind (or possibly nuclear) resources in the 2022-2030 timeframe (2014 IRP, Chapter 1 at p. 17). There is no mention of using efficiency to respond to the CPP regulations.

This is a remarkable omission. It is especially remarkable given that the Company is concerned about the high cost of complying with the CPP regulations, with an estimate of compliance costs as high as $4 billion over fifteen years starting in 2020 (2014 IRP, Chapter 1 at p. 17).

It is also remarkable given that the EPA has estimated that energy efficiency offers the greatest opportunity for Missouri to comply with the proposed CPP regulations. Specifically, EPA estimates that energy efficiency could account for 38 percent of needed emission reductions, while 27 percent could come from lower average coal emission rates, 25 percent could come from redispatch of natural gas units, 7 percent from incremental renewable resources, and 3 percent from at-risk nuclear plants (Synapse estimates based on Clean Power Plan Proposed Rule Data File: GHG Abatement Measures Appendix 5-4).[12]

Exclusion of Efficiency Programs

Q. Did the 2014 IRP include all of the efficiency programs that were included in the Potential Study?

A. No. Ameren excluded several programs from the IRP MAP and RAP scenarios that were included in the Potential Study, including: Residential New Construction, Residential Home Energy Performance, Residential Electronics, Residential Multi-Family, Small Business Direct Install, and Multi-family Common Area.

The Potential Study made the following findings with regard to these programs:[13]

- The Residential New Construction program could be cost-effective, and could save as much as 9,421 MWh.
- The Home Energy Performance (HEP) program could be cost-effective, and could save as much as 27,473 MWh. (Note that Ameren has replaced the HEP program with the Energy Efficiency Kits program, which is expected to save 18,636 MWh.

[12] The workbook used to make this calculation is available at http://www.synapse-energy.com/tools/111d-cost-estimate-tool-states. (Refer to "State Data" tab).

[13] The energy savings presented below are all cumulative for three years 2016-2018, from the RAP portfolio. The energy savings are provided in Table 6-3, and the benefit-cost results are provided in Table 6-5 of Volume 3 of the Potential Study.

Therefore the net effect of switching from the HEP program to the Energy Efficiency Kits program is a reduction in savings of 8,837 MWh.)

- The Residential Electronics program could be marginally cost-effective, and could save as much as 16,777 MWh.
- The Small Business Direct Install could be cost-effective, and could save as much as 30,536 MWh.
- The Multi-Family Direct Install and the Multi-Family Common Area programs could be cost-effective, and could save as much as 9,384 MWh combined.

The potential savings from these programs combined could be as high as 74,995 MWh, which would represent a roughly 18-percent increase in the total energy savings of the RAP portfolio of the 2014 IRP and the Efficiency Plan. Note that the savings presented above are from the RAP portfolio of the Potential Study. The combined potential savings from these programs under the MAP portfolio of the Potential Study would be approximately 111,108 MWh, which is 26 percent of the RAP savings assumed in the 2014 IRP and the Efficiency Plan.

Q. Why were these programs not included in the 2014 IRP?

A. Ameren provides several reasons why these programs were not included in the 2014 IRP. In particular:

- The Residential New Construction and Home Energy Performance programs were deemed to be not cost-effective by the Company. This finding was based upon

EM&V results, which show very low participation and savings levels. (2016-2018 Plan at p. 7).

- The Residential Electronics program has not been offered by Ameren to date. The Company notes that this program was not included in the 2014 IRP because the Potential Study relied upon secondary data sources. (2014 IRP, Chapter 8 at p. 12).
- The Small Business Direct Install program has not been offered by Ameren to date. The Company notes that this program can be challenging with regard to cost-effectiveness; specifically that direct install programs are more costly to administer, and opportunities are limited by more efficiency lighting baselines. Ameren also notes that it "will continue to gather data and analyze alternative program designs." (2014 IRP, Chapter 8 at pp. 98-99).
- The Multi-Family Direct Install and Common Area programs are covered as part of the Energy Efficiency Kits and Low-Income Program as well as the Business Standard program in the 2014 IRP. (Ameren's Response to Sierra Club Data Request No. SC 1-14).

Q. Do you agree with the Company's decision to exclude all of these programs from the 2014 IRP?

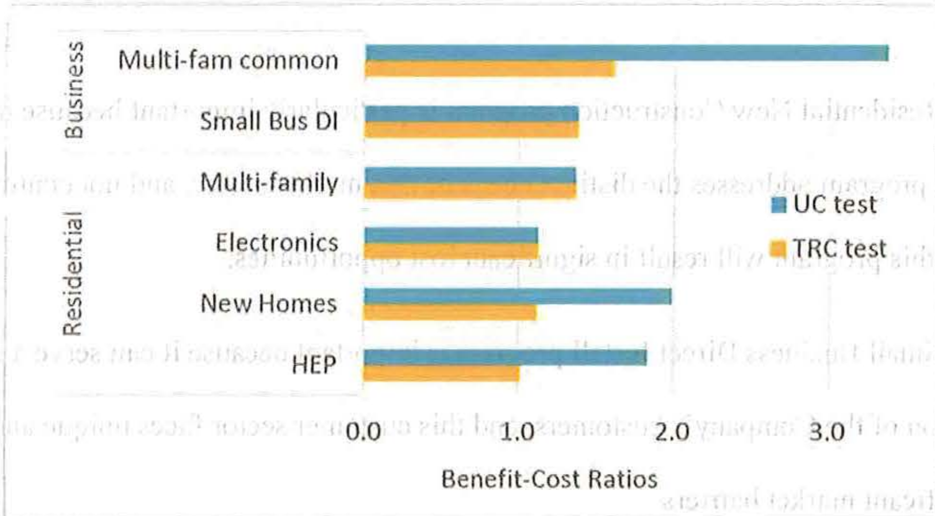
A. No, for several reasons. First, most of these programs are standard programs that are offered by many utilities and serve important customer sectors. The authors of the Potential Study specifically chose a set of programs that would offer "an effective and balanced portfolio of energy savings opportunities across all customer segments" (Potential Study at p. 6-1). Some of the programs that were not included in the 2014 IRP address important customer sectors that will not be adequately addressed by other programs.

- The Residential New Construction program is particularly important because no other program addresses the distinct needs of that market sector, and not continuing with this program will result in significant lost opportunities.
- The Small Business Direct Install program is important because it can serve a large portion of the Company's customers, and this customer sector faces unique and significant market barriers.
- The Company asserts that the Multi-Family Direct Install and Common Area programs will be covered as part of the Energy Efficiency Kits and Low-Income program as well as the Business Standard program. While multi-family buildings may be eligible for these programs, the owners and dwellers in the buildings are not as likely to participate in those programs, due to the unique market barriers associated with multi-family housing.

Second, these programs were found to be cost-effective in the Potential Study. Figure 6.2 presents the cost-effectiveness results from the Potential Study, for both the UCT and TRC test. As indicated, the programs are cost-effective, but the Residential New Construction and HEP programs are only marginally cost-effective under the TRC test, based on the assumptions used in the Potential Study.[14]

[14] Note that the Potential Study does not include the benefits of avoided fossil fuels or water consumption in the TRC test, and therefore underestimates the benefits in the TRC test, as described in Section 5.

Figure 6.2 Cost-Effectiveness Results for Programs Excluded from IRP



(Source: Potential Study, Vol. 3 at p. 6-11).

While it is true that Ameren's EM&V reports have found the Residential New Construction and HEP programs to be uneconomic, this finding requires further investigation before such important programs are eliminated. Why are these programs so uneconomic when other utilities are able to implement them cost-effectively? Has the Company properly accounted for the benefits of the programs, including fossil fuel benefits? Are there marketing and delivery techniques that can be used to increase participation and reduce costs? These questions should be addressed.

Third, the purpose of the IRP is to identify the universe of programs that might be cost-effective under a variety of scenarios. To exclude several important programs at the outset of the IRP process prevents this key inquiry.

Fourth, many utilities consider some of these programs (residential new construction, residential retrofit, small business) to be core programs that must be included in an efficiency portfolio to ensure that all customer sectors are being adequately served. These utilities continue to offer these programs, despite facing some of the same conditions as Ameren with regard to Federal Standards and reduced avoided costs. A recent study from the American Council for an Energy-Efficient Economy provides several examples of utility best practice programs that could serve as models for the programs that Ameren did not include in the 2014 IRP.[15]

Finally, these programs are important for many reasons that are not captured in the screening tests. They help to avoid lost opportunities by capturing efficiency savings when it is least cost to do so. They help to promote customer equity by serving customer sectors and types that would otherwise be under-served. Continuing certain key programs over time, such as the Residential New Construction and HEP programs, is necessary to maintain continuity, which is important for promoting market transformation, maintaining customer satisfaction, and supporting the state and regional energy efficiency infrastructure and trade allies. For these important policy reasons, Ameren should seek opportunities to make these programs cost-effective.

Q. Are you suggesting that Ameren should implement all of these programs that were in the Potential Study but not in the 2014 IRP?

A. Not necessarily. I do think that all ratepayer-funded energy efficiency portfolios should include a set of core programs that help to overcome key market barriers to all customer types and all market segments, and that in general new construction, home energy retrofit and small business direct install programs should be included among this set of core

[15] Seth Nowak et al., *Leaders of the Pack: ACEEE's Third National Review of Exemplary Energy Efficiency Programs*, American Council for an Energy-Efficient Economy (June 2013). Attached as Schedule TW-3.

programs. However, if there is clear evidence of distinct reasons why some of these core programs should not be implemented, then maybe alternative program approaches should be used to help address those customer types and market segments.

My main point is this: By excluding these programs from the 2014 IRP analysis, Ameren does not investigate certain key opportunities for achieving cost-effective savings. Consequently, the Ameren's MAP portfolio in the IRP and 2016-2018 Plan should not be viewed as the maximum amount of cost-effective energy efficiency achievable, and the RAP portfolio should not be seen as an upper limit on the amount of cost-effective energy efficiency that is realistically achievable.

7. MEEIA AND COST-EFFECTIVENESS

Q. Please summarize your concerns about how Ameren assesses the cost-effectiveness of energy efficiency programs.

A. At the outset, it is important to remember that MEEIA aims to encourage utilities to implement demand side programs proposed "with a goal of achieving all cost-effective demand-side savings." Mo. Ann. Stat. § 393.1075.4. Thus, defining cost-effectiveness properly is critical to achieving the key goal of MEEIA.

I believe that the Company takes an overly narrow view of what is cost-effective and, as a result, dramatically reduces the amount of energy efficiency measures and programs that it proposes to pursue. Ameren relies too heavily on the results of the TRC test to justify the cost-effectiveness of its portfolio of programs, without considering the results of the UCT.

Q. Why do you assert that Ameren should consider the results of the UCT when analyzing the cost-effectiveness of energy efficiency measures and programs?

A. Let me begin by noting that I'm not suggesting that the TRC test result should be ignored. I understand that MEEIA and its implementing regulations state that the TRC is the primary test. However, this does not mean that UCT should be disregarded. In fact, I think MEEIA provides for the opposite. Specifically, the statute states that:

> The commission shall permit electric corporations to implement commission-approved demand-side programs proposed pursuant to this section with a goal of achieving all cost-effective demand-side savings... The commission shall consider the total resource cost test as a preferred cost-effectiveness test. Programs targeted to low-income customers or general education campaigns do not need to meet a cost-effectiveness test, so long as the commission determines that the program or campaign is in the public interest. *Nothing herein shall preclude the approval of demand-side programs that do not meet the test if the costs of the program above the level determined to be cost-effective are funded by the customers participating in the program* or through tax or other governmental credits or incentives specifically designed for that purpose.

Mo. Rev. Stat. § 393.1075.4 (emphasis added).

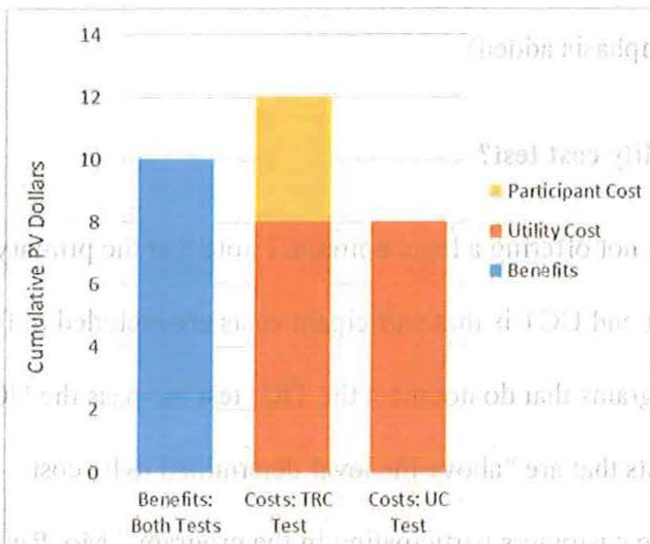
Q. How does this relate to the utility cost test?

A. While I am not a lawyer and am not offering a legal opinion, I note that the primary difference between the TRC test and UCT is that participant costs are included in former test but not the latter. Thus, programs that do not meet the TRC test but pass the UCT generally are programs with costs that are "above the level determined to be cost-effective [that] are funded by the customers participating in the program." Mo. Rev. Stat. § 393.1075.4.

Q. How do the TRC test and UCT differ?

A. Figure 7.1 provides an example to demonstrate the difference between the tests. While the benefits of the two tests are the same for the purpose of this example,[16] the costs differ in that the TRC test considers participant costs and the UCT does not. Given the program benefits of $10 million, the program would be considered cost-effective if the costs are less than that amount. In the absence of the participant cost (in other words, under the UCT), the program is cost-effective. Under the TRC test, however, the program is not cost effective because the total costs exceed $10 million. Thus, this hypothetical efficiency program would not pass the TRC test but would pass the UCT because "the costs of the program above the level determined to be cost-effective are funded by the customers participating in the program."

Figure 7.1 UCT and TRC Costs and Benefits



[16] In practice, the TRC test should also include the benefits associated with fossil fuel savings, as well as the participant non-energy benefits. However, those benefits are not used by Ameren and are not relevant to this example.

This is an important distinction between the two tests and an important clarification of the definition of cost-effectiveness because the benefit-cost ratios of the TRC test are often significantly lower than those of the UCT. This is true for most of the programs in Ameren's 2016-2018 Plan, as indicated in Figure 3.6 above.

Q. How do the MEEIA regulations address the UCT in terms of analyzing the cost-effectiveness of energy efficiency measures and programs?

A. The MEEIA regulations essentially mirror the requirements of the MEEIA statute on this point (4 CSR 240-20.094(3)(C)). In addition, the MEEIA regulations also require electric utilities to report the results of the "utility cost test, the participant test, the non-participant test, and the societal cost test," in addition to the results of the TRC test. (4 CSR 240-3.164(2)(B).2).

Q. Why it is important to account for the results of the UCT when analyzing the cost-effectiveness of energy efficiency measures and programs?

A. The UCT provides very valuable information to determine the cost implications of energy efficiency measures and programs. The UCT includes only those costs and benefits that affect a utility's revenue requirement. Customers pay for this revenue requirement through their electricity bills. This is why the UCT provides the best indication of the extent to which energy efficiency programs and measures can reduce electricity costs and therefore reduce customer bills on average.

Q. What do the results of the UCT indicate for the efficiency programs in the Plan?

A. Figure 3.6 above presents the benefit-cost ratios for each program in the Company's Plan, for both the UCT and the TRC. As indicated, in most cases the programs are significantly more cost-effective according to the UCT relative to the TRC test. (For several programs the results of the two tests are essentially the same because there is no participant cost.)

Under the TRC test, the portfolio of programs is expected to result in roughly $91 million in cumulative present value benefits, while under the UCT the portfolio is expected to result in roughly $135 million in cumulative present value benefits (2016-2018 Plan, Table 2.6 at p. 20). In other words, the Plan is expected to reduce electricity system costs, revenue requirements, and average customer bills by $135 million, 48 percent higher than the $91 million indicated by the TRC test.

Similarly, under the TRC test, the portfolio of programs is expected to have a benefit-cost ratio of 1.5, while the under the UCT the programs will have a benefit-cost ratio of 2.1 (2016-2018 Plan, Table 2.5 at p. 20). This means that for every ratepayer dollar spent by the Company on energy efficiency, it will be able to reduce ratepayer costs by 2.1 dollars. It also means that for every ratepayer dollar that the Company chooses *not* to spend on energy efficiency, it will forego the opportunity to reduce ratepayer costs by 2.1 dollars.

Q. Does this issue have a more significant effect than just making the proposed programs look more cost-effective?

A. Yes. The most significant problem with using the results of the TRC test to screen resources, without considering the results of the UCT, arises in a way that is much less apparent than what is indicated in Figure 3.6 and the results discussed immediately above. There are many places in the Potential Study, the IRP and the Plan in which Ameren claims that its measures, programs or savings are limited by cost-effectiveness. (*See, e.g.*, 2016-2018 Plan at pp. 7, 26-27; 2014 IRP, Chapter 8 at p. 98; Potential Study at p. 6-2). In many of these cases, the cost-effectiveness screen is based on the results of the TRC test, and the Company does not even report the results of the UCT. One of the clearest cases where this arises is in the Potential Study. As described above in Section 5, the Potential Study notes that the most significant difference between the measure-level savings and the programs level savings is the assignment of program and portfolio costs which makes certain measures uneconomic. As indicated in Figure 4.2, this dramatically reduces the estimates of program level savings. In cases such as this, the Company may be eliminating large amounts of measures and programs that could be considered cost-effective under the UCT, without even considering or reporting those results.

Q. Does Ameren consider the results of the UCT in other contexts?

A. Yes. Ameren uses minimization of the PVRR as its primary selection criterion in its IRP process (2014 IRP at p. 10-3). This is consistent with Missouri rules on electric utility resource planning (4 CSR 240-22.010(2)(B)), as well as standard industry practice.

As I mentioned above, the benefits and costs included in the UCT include only those impacts related to revenue requirements. Therefore, the goal of minimizing PVRR is essentially the same as the goal of implementing all cost-effective efficiency programs as defined by the UCT.

Thus, considering the results of the UCT in defining cost-effectiveness is consistent with the IRP portfolio selection process. However, there are two problems with the Company's methodology in this regard. First, the Potential Study uses a much narrower screen of the TRC test, thereby preventing many efficiency measures and programs from even reaching the IRP. Second, the Company did not even adhere to the practice of selecting the efficiency portfolio on the basis of the UCT when it chose the RAP portfolio over the MAP portfolio for the Preferred Resource Plan.

8. RECOMMENDATIONS

Q. Given your extensive review of the Ameren's 2016-2018 Plan and Ameren's underlying analyses, what do you recommend with regard to proposed Plan?

A. I recommend that the Commission approve the Efficiency Plan on the condition that Ameren commit to modify its Plan to achieve greater efficiency savings during the 2016-2018 period. These increased savings can be achieved through a combination of the following:

- Maintaining some programs that are proposed to be terminated; for example, the Residential New Construction and HEP programs;
- Adding programs that have not been implemented and are not yet a part of the proposed Efficiency Plan; for example, a Small Business Direct Install, and a Street Lighting program;
- Modifying existing program designs to increase customer adoption; for example, through increased use of upstream buydown practices for lighting products, HVAC measures, and certain efficient appliances; and
- Expanding program budgets to increase participation rates for programs serving key customer segments.

In particular, Ameren should increase the efficiency savings in its Plan to reach the MEEIA energy savings guidelines for 2016 (1.1 percent), 2017 (1.3 percent) and 2018 (1.5 percent).

There are several reasons that I recommend these savings as a reasonable and realistic target for Ameren: (a) the Company has already achieved efficiency savings roughly equal to one percent in 2014; (b) the efficiency savings in the 2013-2015 Efficiency Plan are slightly above the MEEIA energy savings guidelines, and the reported savings for 2013 and 2014 are higher than what was planned; (c) Ameren should be considering at least these levels of efficiency savings for the purpose of complying with federal greenhouse gas requirements in the lowest-cost way; and (d) many states have already achieved these levels of efficiency savings, even in recent years with federal appliance standards in place and lower avoided costs. I am confident that the MEEIA savings guidelines can be achieved with cost-effective efficiency savings, based upon my review of the Company's Plan and the opportunities described above for expanded efficiency savings.

In addition, I recommend that the Commission direct Ameren to explore the use of all cost-effective energy efficiency resources as a means of mitigating the costs of complying with future federal greenhouse gas regulations. Specifically, in future IRPs and Energy Efficiency Plans, the Company should (a) make more realistic assumptions about the likelihood of such regulations over the long-term, and (b) investigate a wide range of increased energy efficiency programs as alternatives to other options to comply with those regulations.

Q. What do you recommend with regard to the efficiency tests used to determine energy efficiency cost-effectiveness?

A. I recommend that the Commission direct Ameren to present and consider the results of the utility cost test in all future energy efficiency analyses, including potential studies, IRPs, and energy efficiency plans. These results should at least be considered as part of the decision as to which efficiency programs are cost-effective.

Q. Do you have any recommendations regarding Ameren's request for variances from the MEEIA regulations?

A. I have a recommendation regarding one of Ameren's requests for a variance.[17] The Company has asked for a variance from 4 CSR 240-20.094(1)(A), 4 CSR 240-20.094(3)(A) and 20.094(4)(A), which refer to annual demand and energy savings targets. Ameren seeks the flexibility to modify the demand and energy savings targets during the course of the 2016-2018 Plan. Specifically, Ameren seeks the flexibility to modify the energy savings targets used to determine the performance incentive included in the DSIM as efficiency programs are added or removed, and to adjust the targets based on updated values in the TRM.

I do not support this variance from the MEEIA regulations. This variance would provide Ameren with too much flexibility to modify energy savings targets without sufficient oversight by the Commission or input from stakeholders. It also creates too much

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[17] My silence on the other requests for variances should not be interpreted as support for, or opposition to, them.

uncertainty with regard to the level of efficiency savings to be achieved over time and the magnitude of the performance incentive.

Q. Does this conclude your direct testimony?

A. Yes, it does.

Ameren Transmission Company of Illinois's
Response to MPSC Data Request

In the Matter of the Application of Ameren Transmission Company of Illinois for Other Relief or, in the Alternative, a Certificate of Public Convenience and Necessity Authorizing it to Construct, Install, Own, Operate, Maintain and Otherwise Control and Manage a 345,000-volt Electric Transmission Line from Palmyra, Missouri, to the Iowa Border and an Associated Substation Near Kirksville, Missouri.
Data Request

Data Request No.: MPSC 0025 - Shawn Lange

If the Mark Twain Project is completed and operational: 1. How will Ameren Missouri's import capability change? 2. How will Ameren Missouri's export capability change? 3. How will ATXI's import capability change? 4. How will ATXI's export capability change? DR Shawn Lange (Shawn.Lange@psc.mo.gov).

RESPONSE

Prepared By: Dennis D. Kramer
Title: Sr. Director, Transmission Policy, Planning and Stakeholder Relations
Date: July 22, 2015

1. Assuming the rest of the MISO MVP portfolio is in service, implementing the Mark Twain Project will increase Ameren Missouri's import capability by approximately 24 MW from the MISO region and by approximately 131 MW from energy sources to the west of Ameren Missouri. This increase is compared to the conditions expected with the rest of the MISO MVP portfolio being in service but Mark Twain Project not in service.

2. Assuming the rest of the MISO MVP portfolio is in service, implementing the Mark Twain project will increase Ameren Missouri's export capability by approximately 24 MW to MISO. This increase is compared to the conditions expected with the rest of the MISO MVP portfolio being in service but Mark Twain Project not in service.

3. ATXI is only a transmission owner and does not own generation nor serve load. Therefore ATXI does not have an import or export capability calculation.

4. See response to 3.

Ameren Transmission Company of Illinois's
Response to Neighbors United Data Request

In the Matter of the Application of Ameren Transmission Company of Illinois for Other Relief or, in the Alternative, a Certificate of Public Convenience and Necessity Authorizing it to Construct, Install, Own, Operate, Maintain and Otherwise Control and Manage a 345,000-volt Electric Transmission Line from Palmyra, Missouri, to the Iowa Border and an Associated Substation Near Kirksville, Missouri.
Data Request

Data Request No.: NU-A9 - Jennifer Hernandez

For the three 161 kV line segments with projected voltage violations under NERC Category C contingency conditions, answer the following questions:

Describe the nature (transmission and substation elements affected) and magnitude (in MVA) of the NERC violations under the Category C contingencies on each of the three 161 kV line segments.

RESPONSE

Prepared By: Dennis Kramer
Title: Sr. Director – Transmission Policy, Planning and Stakeholder Relations
Date: October 10, 2015

The low voltage conditions that could result in the loss of both Ameren Missouri and Cooperative customer load in the northeastern Missouri area occur when two of the three existing 161 kV lines that supply that area are out of service during peak load conditions. This event could result in loss of customer load and would be a NERC Category C contingency condition.

During the development of the MVP portfolio, MISO (at that time named the Midwest ISO) performed a system analysis to identify facility overloads and resultant NERC contingency conditions that would be created by connecting additional wind generation resources to the existing 161 kV system in northeastern Missouri. MISO's analysis indicated that the Mark Twain Project was the best solution to address the overload conditions.

Describe the nature (transmission and substation elements affected) and magnitude (in MVA) of the NERC violations under the Category C contingencies on each of the three 161 kV line segments.

A NERC Category C contingency condition occurs when two of the existing 161 kV lines that supply the northeastern Missouri area are out of service during peak load conditions. This causes low voltage conditions that could result in the loss of up to approximately 300 MVA of customer load. The low voltage conditions are not caused by overloads on the 161 kV line segments and are not expressed as MVA.

The MISO analysis of the impact of connecting additional wind generation resources to the existing 161 kV system in northeastern Missouri identified facility overloads and the results of this analysis are contained in publically available MISO materials.

GRAY AND INDIANA BAT POPULATION TRENDS IN MISSOURI

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Abstract

Since 1975 the Missouri Department of Conservation (MDC) has systematically censused the endangered bats, *Myotis sodalis* (Indiana bat) and *M. grisescens* (Gray bat). A recent statewide reestimate of about 15,812 indicates that Indiana bats declined by 95% since 1979. Pilot Knob Mine, a National Wildlife Refuge, had 80,000-100,000 Indiana bats in 1958, but only 1,678 were found there in February 2008, a 98% decline. At other sites they declined or abandoned one cave for another, seeking protection and more optimal temperatures. Their decline probably was caused by multiple factors, including human disturbance, the partial collapse of Pilot Knob Mine in 1979, warming of hibernacula, and possibly by pesticides and loss of summer habitat in northern Missouri. White Nose Syndrome has not been found in Missouri.

Missouri's Gray bat population declined, but it is now stable or increasing in some protected caves. Many other caves remain abandoned for various reasons. At bottom, Gray bats lost at least 67% of their maximum past population, as measured in 56 important caves, and 53% of the caves were abandoned. The maternity population of Gray bats is currently estimated at approximately 635,000, but it may have been >1,700,000 in the past. The three largest Gray bat hibernacula were censused in 2006 and totalled 773,850. The Gray bat is a key species in Missouri ecosystems, providing nutrient input to cave animal communities and significant control of night-flying insects, some of which are agricultural or health pests. Although there has been a general increase, many maternity colonies are still threatened by intruders and vandals, so further conservation work is needed.

Key words: *Myotis sodalis*, Indiana bat, *Myotis grisescens*, Gray bat, population trends, disturbance of bats, cave temperatures, mine collapse, pesticides, cave gates, White Nose Syndrome, Missouri, Onyx Cave/Crawford County, Bear Cave/Franklin, Copper Hollow Sinkhole, Brooks Cave, Great Spirit Cave, Ryden Cave, Bat Cave/Shannon, Martin Cave, Great Scott Cave, Scotia Hollow Cave, Pilot Knob Mine, Devils Icebox Cave/Boone, Rocheport Cave, Coffin Cave, Mary Lawson Cave, Slaven Cave, Cookstove Cave, Hamilton Cave, Powder Mill Creek Cave, McDowell Cave, Mary Lawson Cave, Toby Cave, Moles Cave, Smittle Cave, Marvel Cave, Mose Prater Cave, Coffin Cave, Bat Cave #1/Franklin, Blackwell Cave, Grandpa Chippley Cave, Lower Burnt Mill Cave, Tumbling Creek Cave

Introduction and Literature Review

In this paper I focus on the status of the endangered bats, *Myotis sodalis* (Indiana bat) and *M. grisescens* (Gray bat) in "Missouri," by which I mean the Missouri region, insofar as we must be censusing some bats migrating to and from neighboring states. We know from previous work that these species migrate fairly long distances seasonally, and among different hibernacula, transient, bachelor, and maternity sites.

Caves provide important habitat to ten Missouri bat species and three other species have been found in caves. Colonies of Grays and Indianas hibernate in "cold air trap" caves, which have descending floors, deep pits, or large entrances that accept large amounts of winter air. Maternity colonies of Grays prefer warm caves with high ceilings to raise their young in spring/summer. Gray bats roost exclusively in various caves in different seasons for maternity, hibernation, bachelor, and transient colonies. Indiana bats primarily hibernate in caves and mines, are transient via other caves, then females leave caves for riparian forests, particularly snags, to raise their young during the summer.

To census these interesting animals is to track a moving target, literally and figuratively. The colonies are dynamic, even fluctuating significantly night to night at some Gray bat caves in late summer.

Richard F. Myers (1964) pioneered the study of myotine bats in Missouri. On February 22, 1958, Myers visited Pilot Knob Mine, Iron County, with three local men to photograph the hibernating Indianas (Figure 1). He visited the abandoned iron mine again on April 11 and December 27, 1958. In December the "Devils Icebox," as the lower mine was called, contained about 80,000 *M. sodalis* by Myers' conservative estimate, based on a density of 2,367 bats/m^2 (220 bats/ft.^{2}). Another photograph appeared to have about 3,229 bats/m^2 (300 bats/ft.^{2}), estimated from the size of a man's hand near the bats and by counting bats inside a frame drawn by Elliott and Kennedy (2008). Myers also estimated at least 35,000 *M. lucifugus* in the mine. Elliott and Kennedy (2008) concurred with the U.S. Fish and Wildlife Service (USFWS) that 100,000 may be a reasonable reestimate for 1958, especially since the upper mine was not visited during Myers' trips, but it is now known to harbor bats. In February, 1958, the interior of the mine appeared to be stable, with old wooden roof supports mostly in place. By December Myers noticed that boulders had shifted, and there had been some rock falls in the entrance area and on the route to the hibernaculum. Myers last visited the mine in March 1960.

In 1975 Richard and Margaret LaVal from the Missouri Department of Conservation (MDC) began harp-trapping estimates of *M. sodalis, M. lucifugus* and *M. septentrionalis* at the lower mine entrance, but they did not enter the mine, owing to its "dangerous" reputation. Richard Clawson

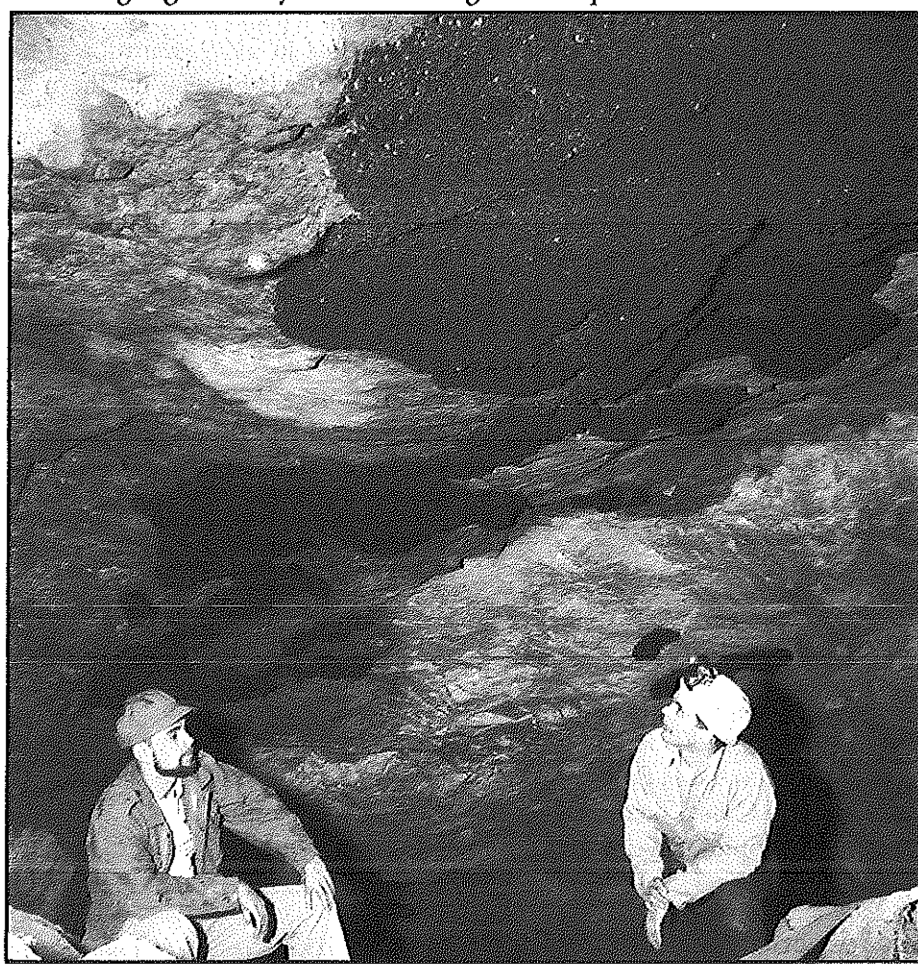

Figure 1 *Hibernating Indiana bats in the lower part of Pilot Knob Mine, February 22, 1958. Photo by Richard F. Meyers.*

soon joined their project, and they continued the effort until 1978 (Clawson and Titus 1988). Trapping usually was done in late September or early October during the fall mating swarm. The great majority of bats captured and released, usually over a two-hour period in two rounds or "bags," were *M. sodalis*, with some *M. lucifugus* (Little brown bat) and *M. septentrionalis* (Northern bat). They were identified to species, most were sexed, and some were weighed and examined in detail.

MDC continued to census cave bats after 1975 (Clawson and Titus 1988, Clawson et al. 1992, McGimsey and Johnson 1994, Clawson 2002, Clawson, Elliott and Burns 2006, Elliott 2005, Elliott 2007, Sasse et al. 2007). LaVal et al. (1977) completed an evaluation of bat caves in the proposed Meramec Park Lake and Union Lake project areas. Many important caves would have been inundated by the Meramec Lake, but it was not built (Elliott 2007).

On May 25, 1979, at Pilot Knob Mine, LaVal reported that "a colossal collapse has occurred, blocking the two entrances used by bats. Cold air is blowing out of the rocks above the old main exit site, it appears a person could still get in by climbing among newly fallen giant boulders. The higher main entrance that was being used by nearly half the bats earlier this spring appears to be completely blocked. The entire south wall of the 'Devils Icebox' has collapsed, partially filling the icebox ... We suspect foul play, but saw no evidence of same." A federal agent was sent to investigate, but he reported no evidence of violations. After the collapse there were no harp-trapping trips until 1992. Intruders may have affected the bats, but much of the subsequent decline probably was the result of this partial collapse of the lower mine, which may have killed many bats. Furthermore, it probably caused changes in airflow and the availability of habitat (Elliott and Kennedy 2008).

In 1986, a local boy was trapped and injured in the lower mine while exploring with a friend. He was rescued after a two-day ordeal, in which he barely survived and nearly lost his legs. Some called for permanent closure of the mine, but its value as a bat refuge also was publicized. Within a year the U.S. Fish and Wildlife Service received a donation of the mine and 90 acres from the Pilot Knob Ore Co., and the area was fenced (Elliott and Kennedy 2008). In 1992, Clawson and others resumed harp-trapping studies at Pilot Knob Mine, but they did not enter the mine. These studies continued through September 2007.

From 1978 to 1984, Gardner (1986) collected numerous invertebrate specimens from 436 caves and 10 springs, providing important baseline information on subterranean biodiversity. No comprehensive list of Missouri's cave vertebrates has been published, but a 1984 computer printout with a large number of bat observations was contributed by Gardner to the author's Cave Life Database (CLD). The author joined MDC as cave biologist in 1998, and he worked with other researchers to study Missouri's cave life. Bat census and cave protection were important duties of the cave biologist, shared with Clawson. Since 1978 Clawson contributed voluminous census data on bats from 103 caves and three mines in 38 counties, primarily of Grays and Indianas (Elliott 2007). A year-long study of 40 caves was led by MDC and the Missouri Caves and Karst Conservancy, in which common species were recensused 20 years after Gardner recorded them. A possible decline in *Eptesicus fuscus*, Big brown bat, was noted at some caves (Elliott and Ireland 2002).

For spot temperature readings and data logger checks, Clawson and Elliott used digital thermometers, with accuracy ±0.1C°, calibrated in freezing water to measure air and rock temperatures during hibernaculum surveys. In 1998, the author and others installed Hobo® H8 Pro temperature data loggers in seven caves and Pilot Knob Mine for a joint study by Bat Conservation International (BCI) and MDC. The study sites were Great Scott Cave and Scotia Hollow Cave, Washington County, Bat Cave, Shannon County, Pilot Knob Mine, Iron County, Onyx Cave, Crawford County, and Brooks Cave, Great Spirit Cave, and Ryden Cave, Pulaski County (Elliott and Clawson 2001). They obtained weather data from 1975 through 1998 for several Missouri cities from the Department of Soil and Atmospheric Sciences, University of Missouri–Columbia. The data set from Waynesville, Pulaski County, is geographically close to most of the study sites. They examined the secular trend of annual means, extreme lows, and extreme highs.

On February 7, 1999, Jim Kennedy and Sheryl Ducummon of Bat Conservation International (BCI) visited the lower part of Pilot Knob Mine, but found only 303 *M. sodalis*. MDC's harp-trapping results were used to estimate as many as 50,545 Indiana bats in the mine until 2007. This method was not calibrated against a count in the mine, but against catch rates at Great Scott Cave in the 1970s. Concern about the true number of bats in the mine continued, especially as the harp-trapping results decreased. Elliott and Kennedy (2008) found only 1,678 *M. sodalis* there in February 2008.

Missourians have built at least 67 cave gates, 55 of which were for Grays, Indianas or both. MDC built 22 cave gates on Conservation lands, and they assisted ten other landowners with cave gates. Forty-six caves were gated for Grays, 38 for hibernating Indiana bats, significantly helping endangered and other bats. Two gates were destroyed by flash floods and two were removed because they were not helping bats. In the last 30 years the downward trend in Gray bats was reversed at many caves where the landowner was involved or where MDC helped with signs and appropriate cave gates. However, Indiana bats continue to decrease at most sites, despite good protection of the larger colonies since the 1970s and 1980s.

Materials and Methods

General bat activity can be gauged with mist netting and Anabat detectors, but those methods are not used for censusing. In Missouri various methods have been used to census bats, listed below in generally increasing order of accuracy:

- Harp trap with catch rate calibrated against in-cave count,
- Measurements of guano or ceiling stains, with area times density (Figure 2),
- Roost counts: direct counts, measured area times density, counting virtual rows and columns, or counting from photographs (Figure 3),
- Stopwatch visual exit counts with spreadsheet estimate (Elliott et al. 2006),
- Near-infrared (NIR) videography with statistical counts or thermal infrared (TIR) videography with computer count (Sabol and Hudson 1995, Melton et al. 2005, Elliott et al. 2006).

MDC has used most of the above methods, but most of the data on Gray maternity colonies have been from guano estimates until we began using NIR in 2004. Both methods were used until we were satisfied that they were comparable.

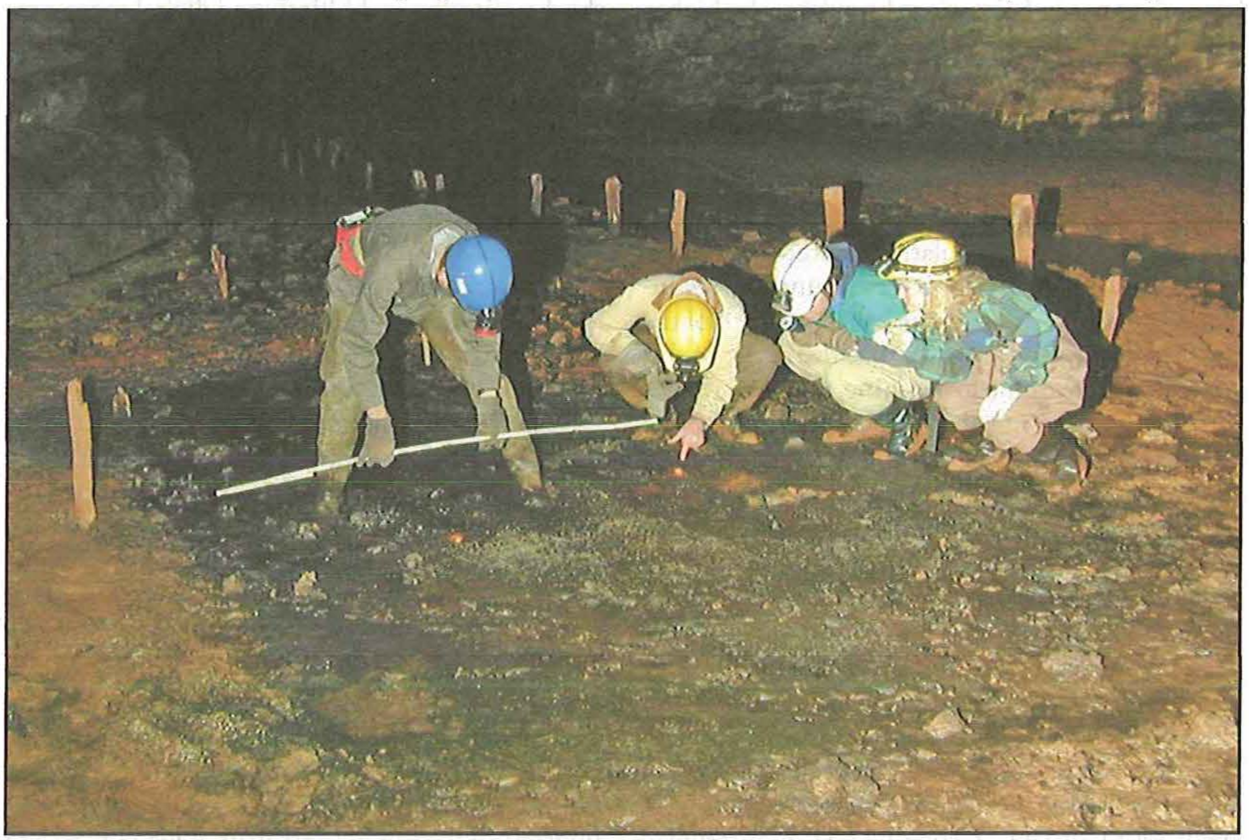

Figure 2 MDC biologists measure Gray bat guano in Smittle Cave, Wright County, Missouri.

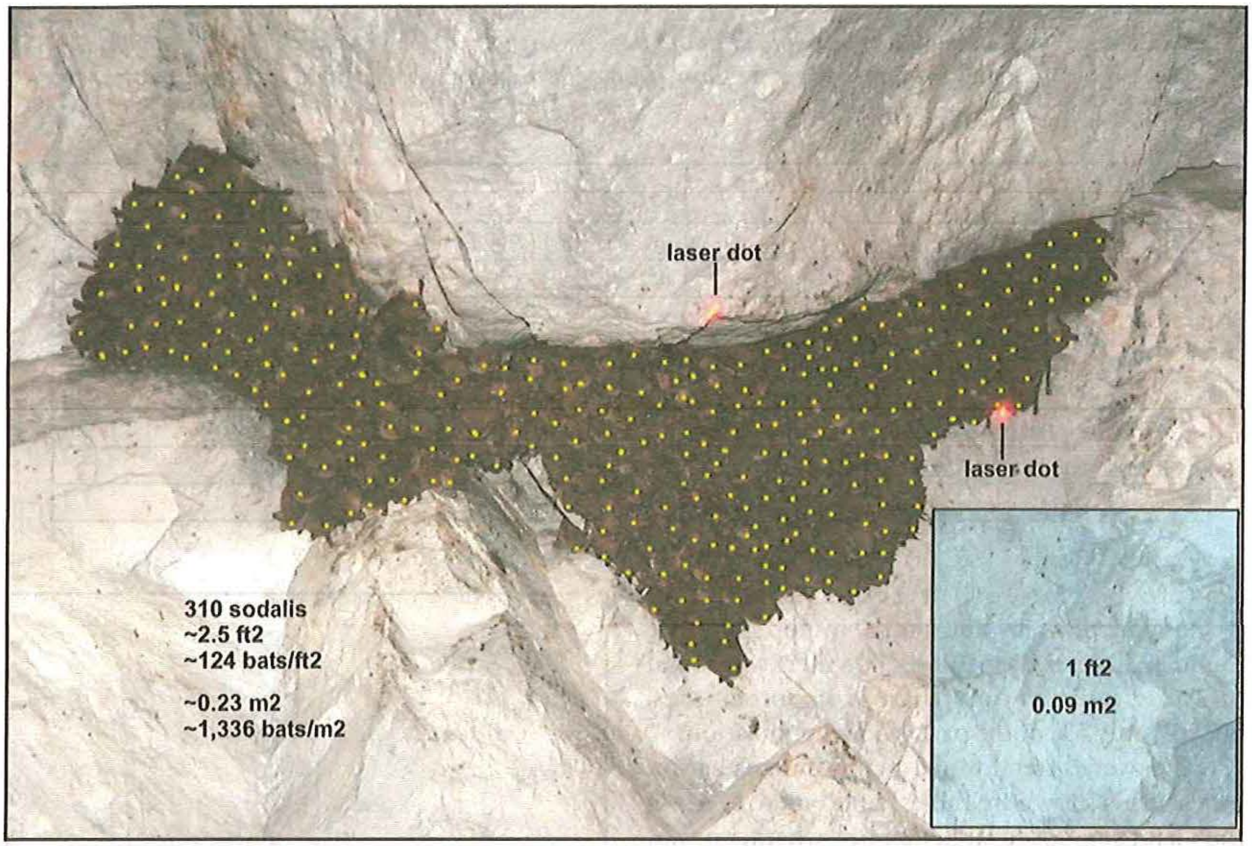

Figure 3 — *Pilot Knob Mine, February 25, 2008, view of about 310 Indiana bats. Visual counts were later corrected by adding digital dots on the photos. The two laser dots from a laser caliper are 30.48 cm (1 ft.) apart, yielding about 1,336 bats/m² (124 bats/ft.²).*

TIR became available experimentally in 2006, and we used it extensively in the summer of 2008. We may discontinue guano measurements after 2008. Winter visits used roost counts, to which we added high-resolution digital photographs in 2007.

Census data from many sources were entered into the Missouri Natural Heritage Database and the CLD, a Microsoft Access® database. Special queries were made to view and edit the data, export it to Excel® and graph it.

From 1975 to 1977 Indiana bat surveys were done yearly at some sites, but starting in 1979 most were biennial. To examine long-term trends, data from a few dates were moved to the nearest year in the same winter to put all on the same basis, and the 1978 Pilot Knob Mine harp-trap estimate was placed in 1979 for graphing. Five data for Great Spirit in 1981, Scotia Hollow in 1983, Brooks and Ryden in 1989, and Onyx Cave in 2003 were absent, so they were calculated as a mean of the previous two years to fill the cells for graphing. Most of the data for Pilot Knob mine are based on one harp-trap estimate from 1978 and two in-mine counts in 1999 and 2008, the rest were interpolated linearly between these anchor points. However, these estimates do not affect the overall estimate of decline since "1979." Although some hibernaculum surveys began in 1975, I focused on trends since 1979, when more data were available for the 11 major and 8 minor hibernacula. This did not ignore any significant 1975–1979 trends that I could see. I examined the trends for the major and minor sites separately.

Results

Overall results are provided in Table 1, and details are provided in Tables 2-6 and Figures 1-16.

Indiana bats. *M. sodalis* is known from 75 caves and 2 mines, about 1% of the 6,200 known caves in Missouri. Of these, 53 sites are hibernacula and 24 others are used by transients in spring or fall on their way to or from forest habitat, mostly in northern Missouri. The 1979 population was 315,045 as measured at 11 major sites, but it declined to 8,632 at the same 11 sites in 2007, a

Table 1 *Status of Gray bats and Indiana bats in Missouri. MPP is "maximum past population." The recent data are from 2006–2008. The recent hibernating populations were an aggregate of 31 caves.*

	Grays	Indianas
Past population	1,700,000 (MPP)	315,045 (1979)
Maternity caves	49	0
Hibernacula	13	53
Other sites	157	24
Total sites	219	77
Recent maternity colonies	635,000	---
Recent hibernating colonies	784,000	15,812
Percent of past population	37-46%	5%

drop of 97%. Two (18%) of the sites were essentially abandoned. Many additional, minor sites were found in 30 years, so in 2006-2008 there was a total of 15,812 Indianas counted in 31 important sites, but still only 5% of the past, known population.

The overall trend for 11 major Indiana bat hibernacula is shown in Table 2 and Figure 4. All of the major sites lost a large number, whether or not they also had large numbers of Gray bats hibernating nearby. The decline in Pilot Knob Mine, which contained 36-44% of the state population in 1979, was 98% depending on which estimate used.

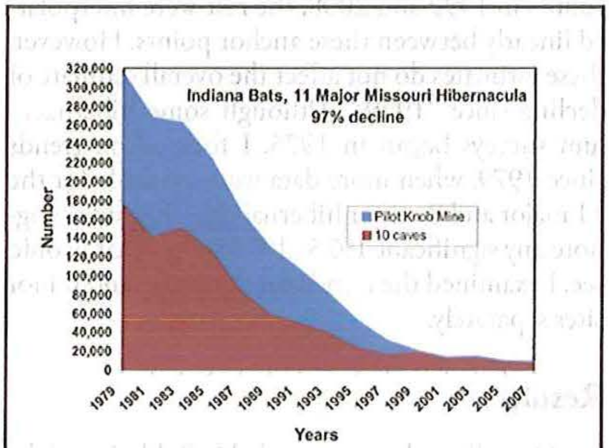

Figure 4 *Population trends at 11 major Indiana bat hibernacula, 1979-2007. The Pilot Knob data are stacked on the data for 10 caves.*

The trends for eight minor *M. sodalis* hibernacula are more difficult to assess numerically because all have not been followed completely for many years. Table 3 shows that four have been

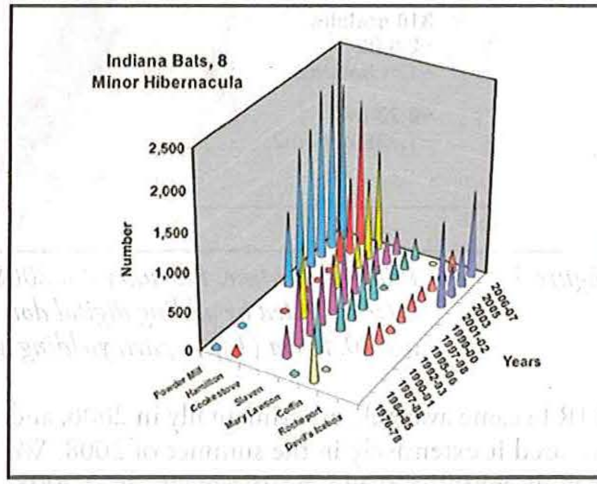

Figure 5 *Population trends at eight minor Indiana bat hibernacula, 1976–2007.*

censused since the 1970s, and most of the others since 1990-1991. Four of the colonies were up by 2006-2007, two were stable, and two were down (Figure 5). The largest increase was at Powder Mill Creek Cave, which was gated in 1995, after which the colony increased to >2,000 despite temperatures >10°C in the late 1990s. These bats may have moved from Bat Cave, Shannon County, about 28 km away, which essentially was abandoned, perhaps because of extremely variable temperatures, often below freezing (Elliott and Clawson 2001), and an increase in Gray bats there, but the true cause is uncertain (Figure 6). At Bat Cave the Grays usually moved up to the 10-meter-high ceiling where it is warmer, but the Indianas stayed under ledges and domes close to the floor where it was colder.

Gray bats are present at some of the sites that

Table 2 *Indiana bats in 11 major Missouri hibernacula, 1975–2007. Trends were examined and graphed from 1979-2007. Missing data (bold) were inserted from means of the previous two years (caves), or from a linear function between anchor points at Pilot Knob Mine. The 1979 estimate for Pilot Knob Mine was actually from October 1978, and the 2007 count was from February 2008. Since 1979 there was a 97% decline in the bats at the major hibernacula, and all lost a large number, whether they also had large numbers of Gray bats hibernating nearby or not.*

Year	Onyx Cave, Crawford	Bear Cave, Franklin	Copper Holow Sinkhole	Brooks Cave	Great Spirit Cave	Ryden Cave	Bat Cave, Shannon	Martin Cave	Great Scott Cave	Scotia Hollow Cave	10 caves	Pilot Knob Mine	Totals
1975	10,800	3,000	15,550						38,860	5,480	73,690	59,695	
1976	21,625	2,100	12,600				46,000		46,600	93	129,018	100,357	
1977	12,700	1,800	9,050				20,670		59,500	3,450	107,170	85,361	
1979	11,100	3,250	8,850	19,375	549	10,550	42,821	8,100	68,700	2,750	176,045	139,000	315,045
1981	5,325	1,750	5,200	11,850	1,792	5,800	32,800	2,425	72,350	3,100	142,392	125,130	267,522
1983	3,267	1,100	3,150	11,150	1,171	4,950	30,750	5,350	85,700	4,550	151,138	111,261	262,398
1985	2,250	650	1,050	5,500	500	2,000	30,450	3,550	77,950	3,400	127,300	97,391	224,691
1987	2,050	525	600	4,900	40	700	4,150	4,900	60,650	5,300	83,815	83,521	167,336
1989	1,575	400	250	5,200	35	1,350	4,275	2,600	38,875	5,150	59,710	69,652	129,362
1991	1,275	300	160	2,700	8	160	4,275	2,975	32,125	6,225	50,203	55,782	105,985
1993	700	225	125	1,550	625	80	6,175	2,250	22,750	4,550	39,030	41,912	80,942
1995	325	190	140	750	450	40	941	2,125	14,850	3,600	23,411	28,042	51,453
1997	260	95	175	600	195	14	450	1,500	11,875	1,615	16,779	14,173	30,952
1999	155	80	155	400	175	14	6,175	1,000	9,100	2,375	19,629	303	19,932
2001	265	105	185	235	285	10	89	2,460	8,250	450	12,334	647	12,981
2003	210	90	250	130	160	13	1,020	2,100	8,875	290	13,138	991	14,129
2005	180	100	250	70	40	10	0	1,300	6,450	150	8,550	1,334	9,884
2007	180	110	380	65	60	3	16	950	5,100	90	6,954	1,678	8,632

Table 3 *Indiana bats in eight minor Missouri hibernacula, 1975–2007.*

Year	Devils Icebox Cave	Rocheport Cave	Coffin Cave	Mary Lawson Cave	Slaven Cave	Cookstove Cave	Hamilton Cave	Powder Mill Creek Cave	Totals
1976–78			714	60			119	60	893
1984–85			0		405				405
1987–88				700	975			50	1,675
1990–91		350			900				1,250
1992–93		250		625	750	1,000	6		2,631
1995–96		80		400	775				1,255
1997–98		220		570	950		44	975	1,784
1999–00		215		500	450	500	1	1,660	3,326
2001–02	1,100	170		5	425			1,800	1,700
2003–04	420	180		280	440	430	530	2,175	2,280
2005–06	520	180		240	400	1,062	1,000	2,150	3,402
2007	1,140	259	17	275	290	1,300	1,900	2,050	5,181

had declines, but not all. Grays are absent at Pilot Knob Mine, which had the worst decline, so if crowding from Gray bats is a factor in the decline of Indianas, it is not the most important factor. New, minor hibernacula of Indiana bats have been found, most notably at Devils Icebox Cave, Boone County, in 2002, but they do not make up the large decline in the major hibernacula. Small colonies of transients are found in additional caves from time to time, they are not represented here, but their conservation also is important.

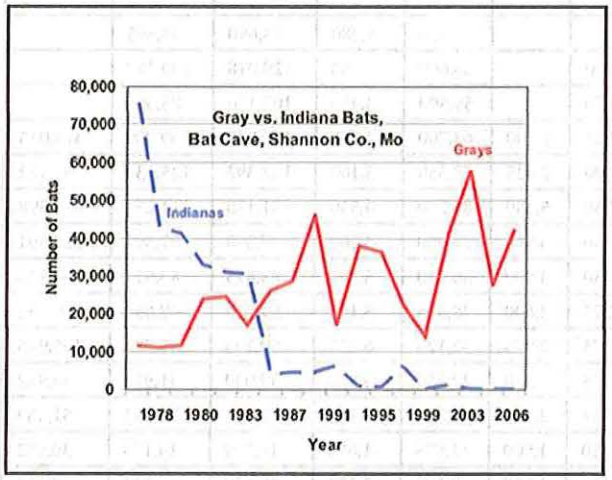

Figure 6 *Gray bats increased in Bat Cave, Shannon County, while Indiana bats declined since 1978. The trends are inversely correlated, but the true cause is uncertain.*

Gray bats. *M. grisescens* has been recorded from at least 219 caves, about 3.5% of Missouri caves (Table 1). Of these 49 are maternity caves, 13 are hibernacula (three with >30,000), 125 are transient and/or bachelor sites and 32 (15%) are abandoned. Additional sites likely exist, especially transient and minor maternity caves.

Table 4 and Figure 7 depict the trends at nine, priority 1, Gray bat maternity caves with a long census record: Devils Icebox, Great Spirit, McDowell, Mary Lawson, Toby (formerly confused with Mauss Cave), Moles, Rocheport, and Smittle caves. Data were placed in five-year bins for analysis. Overall, these colonies increased by 21% from about 1980 to 2005, and were at roughly 37% of their MPP (maximum past populations). Gray bats bottomed out between 1970 and 1985, but increased at many protected caves since then.

Table 5 and Figure 8 illustrate the trends at four, major, Gray bat hibernacula: Marvel, Mose Prater, Coffin, and Bat/Shannon caves. Marvel Cave, a show cave, lost most of its hibernating Grays because of warming trends in the cave caused by man-made alterations at the entrance, which decreased the influx of winter air. The other three hibernacula, which are protected without artificial alterations of airflow, have had increases in Gray bats.

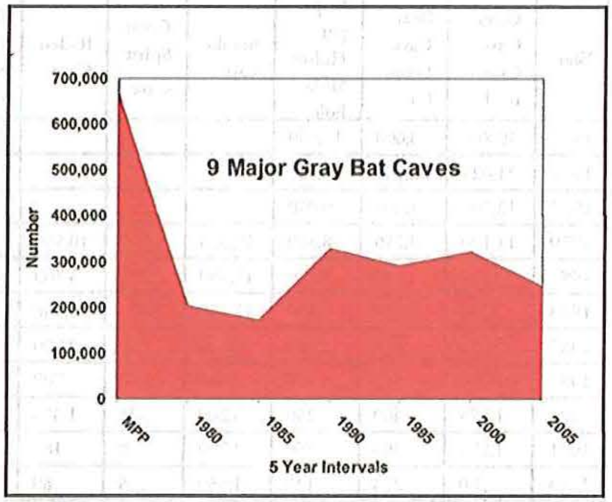

Figure 7 *Trends at nine, priority 1, Gray bat maternity caves with a long census record. See Table 4. Overall, these colonies increased by 21% about 1980 to 2005, and were at roughly 37% of their MPP (maximum past populations).*

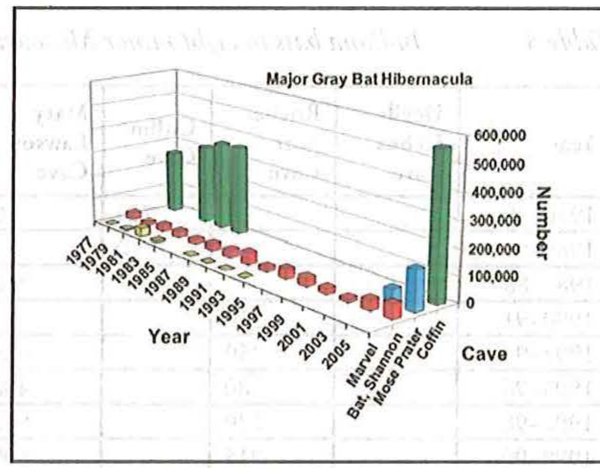

Figure 8 *Trends at four major, Gray bat hibernacula, 1977-2006. Some data have been shifted a year for graphing.*

Table 4 *Trends at nine, priority 1, Gray bat maternity caves with a long census record. Data were placed in five-year bins, bold numbers had no data so numbers were inserted from adjacent cells from the same cave. Overall, these colonies increased by 21% about 1980 to 2005, and were at roughly 37% of their MPP (maximum past populations). Toby was up to 97,000 and Smittle was currently down to 12,800 in the 2008 TIR census.*

	Devils Icebox, Boone	Great Spirit, Pulaski	Mc-Dowell, Miller	Mary Lawson, Laclede	Toby, Camden	Moles, Camden	Roche-port, Boone	Smittle, Wright	Totals
MPP	5,000	250,000	11,000	97,000	54,000	100,000	100,000	50,000	667,000
1980	5,000	10,000	12,000	21,500	42,800	40,000	25,000	46,000	202,300
1985	2,300	11,600	12,000	19,000	54,500	49,000	385	22,200	170,985
1990	9,350	10,200	10,200	36,700	71,400	67,320	16,320	105,500	326,990
1995	9,200	24,000	10,200	36,550	73,450	73,450	26,000	33,650	290,188
2000	13,050	22,000	7,800	34,300	76,700	93,840	41,000	33,650	320,815
2005	12,150	10,900	13,898	71,000	17,000	43,500	50,000	24,500	243,848

Table 5 *Trends at four major Gray bat hibernacula, 1977–2006. Some data have been shifted by one year for graphing. See Figure 8.*

	Marvel	Bat, Shannon	Mose Prater	Coffin
1977	86	27,299		250,000
1979	3,380	11,000		
1981	34,200	23,850		316,300
1983	8,850	24,400		349,500
1985		17,150		355,450
1987	2,425	26,050		
1989	1,286	28,725		
1991	1,300	46,300		
1993	900	17,030		
1995		37,945		
1997		36,400		
1999		22,400		
2001		14,100		
2003		41,100	52,000	
2005		57,850	155,000	561,000

Discussion and Conclusions

Indiana bats. Indiana bats have declined drastically in the Missouri region. The recent, statewide reestimate of about 15,812 indicates that Indiana bats declined by 95% since 1979. Some probably abandoned one cave for another, such as Powder Mill Creek Cave, seeking protection and more optimal temperatures. Pilot Knob Mine, a National Wildlife Refuge since 1987, had 80,000-100,000 Indiana bats in 1958, but only 1,678 were found there in February 2008, a 98% decline.

Tuttle and Kennedy (1999) analyzed 15 cave systems and found a strong correlation between increasing cave temperatures and declining populations of *M. sodalis.* Elliott and Clawson (2001) analyzed temperature data from Missouri caves and surface weather. From 1975 to 1999 the mean annual temperature (calculated from daily highs and lows) at Waynesville, Missouri, was 12.9°C (55.3°F). The standard deviation was 1.4°C and the range was 11.7 to 14.4°C (53 to 58°F). There appeared to be no significant change in mean annual temperature between 1975 and 1999. However, in examining extreme lows in January, they found a possible warming trend since 1975 from about -21 to -18°C (-7 to 0°F). The author believes that extremely low temperatures from severe cold fronts could influence hibernaculum temperatures all year, probably more than mean annual temperatures. Severe cold fronts are usually associated with strong winds and barometric pressure drops, which cause more cold air invasion into caves than weaker fronts. It is possible that the loss of extreme winter lows magnifies the warming at some cold-air traps in Missouri.

We have no continuous temperature records in the hibernacula for 30 years, but we do have spot readings taken with a digital thermometer on every winter trip. Figures 9–13 are selected graphs depicting trends in Indiana bat populations with the simultaneous air and rock spot temperatures. The data were not controlled for exact date, so there may be some hidden variance related to January vs. February visits, generally, and a few December and March dates. However, the rock temperature changes slowly. These graphs illustrate that temperatures were generally above the optimal 5°C for hibernation of *M. sodalis,* found by Dzurick (2007). However, the populations began plummeting generally without much change in hibernaculum temperature. Brooks Cave (Figure 9) is interesting in that it is located on Fort Leonard Wood with only a little disturbance, lacks Gray bats, was never gated, had little temperature change, and yet the bats declined. Ryden Cave (Figure 10) was gated, lacks Gray bats, had little warming and a recent cooling, and the Indianas declined. Great Scott Cave (Figure 11) warmed up mostly because its second entrance was blocked off, but it cooled again after a second cave gate was installed in 1999. Indianas increased there until 1983, then they declined despite the later cooling. Bat Cave, Shannon County (Figure 12), is extremely variable in temperature, and it has had a cooling trend since 1995. Yet Grays increased there while Indianas essentially abandoned the cave (Figure 6). Indianas may have moved from the latter cave to Powder Mill Creek Cave (Figure 13). In the author's opinion, these five examples indicate that the decline in Missouri's Indiana bats has not been caused by temperature changes alone.

Disturbance during hibernation was one of the important, early factors in the decline of Indiana bats, and it still is a threat at unprotected sites. Improperly designed cave gates have been implicated in some population declines, but all such gates have been removed or replaced at Missouri Indiana bat caves. Loss or reduction of roosting or foraging habitat during the warm season also has been suspected.

Pesticide residues were detected in Indianas, Grays, and other bats in Missouri (Clark et al. 1978, 1980, 1983, Clawson et al. 1983, 1989, 1991, McFarland 1998, O'Shea and Clark 2002, Schmidt and Glueck 2002). O'Shea and Clark (2002) pro-

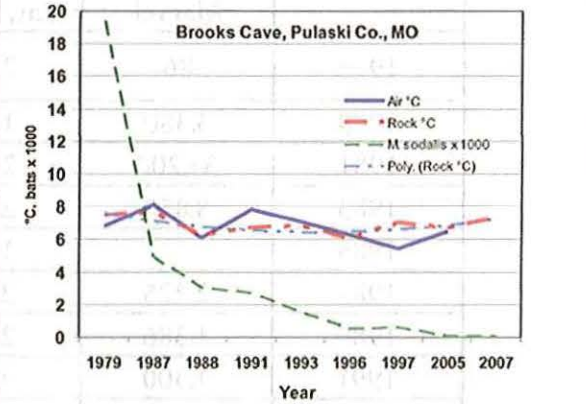

Figure 9 *Indiana bat population trend in Brooks Cave, Pulaski County, combined with concomitant air and rock temperature readings. A polynomial trend line (dot-dash line) has been fitted to the rock temperatures in this and Figures 10–13.*

vided a review and examined temporal and spatial patterns of agricultural pesticide use in Missouri and Indiana. Some Grays and Indianas died from organochlorine (OC) insecticides prior to their discontinuance in the 1980s. Dieldrin in carcasses of Indiana bats from Missouri in the 1970s was one to two orders of magnitude higher than the norm and reached lethal concentrations in brains of

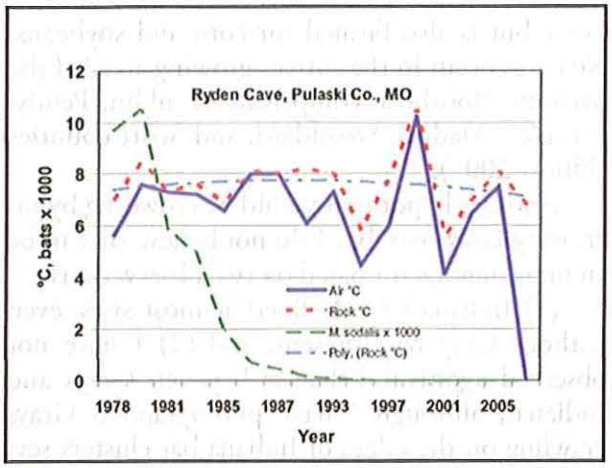

Figure 10 *Indiana bat population trend in Ryden Cave, Pulaski County, combined with concomitant air and rock temperature readings.*

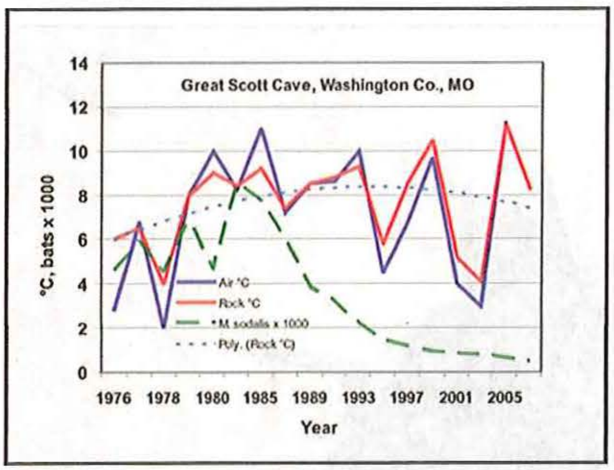

Figure 11 *Indiana bat population trend in Great Scott Cave, Washington County, combined with concomitant air and rock temperature readings. A blocked, secondary cave entrance was regated in 1999, which cooled the cave to somewhat normal temperatures.*

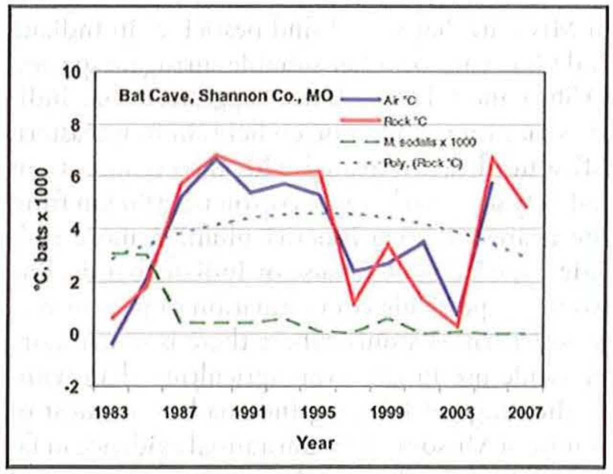

Figure 12 *Indiana bat population trend in Bat Cave, Shannon County, combined with concomitant air and rock temperature readings. This cave has extremely variable winter temperatures.*

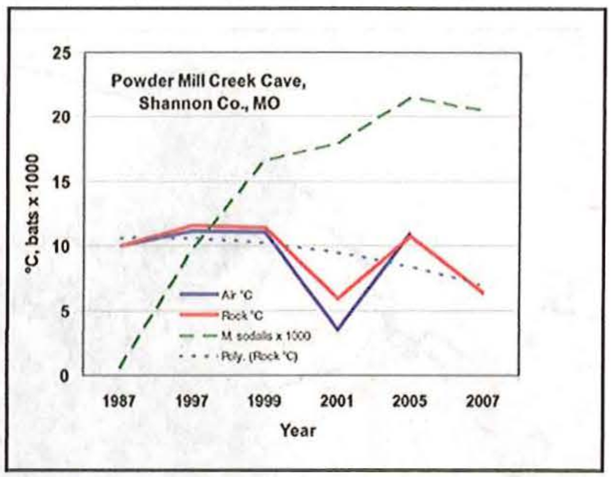

Figure 13 *Indiana bat population trend in Powder Mill Creek Cave, Shannon County, combined with concomitant air and rock temperature readings. Although temperatures were >10°C in the late 1990s, the population increased, possibly because they abandoned Bat Cave, Shannon.*

some individuals. Chronic mortality was suggested in these two endangered species even in the 1980s. McFarland (1998) found persistent OC residues in Little brown bats and Northern bats, long after OCs were discontinued.

Some studies found organophosphates (OP) and carbamates in Missouri bats. These insecticides are not as persistent as OCs, but they may cause acute toxicity, death, or sublethal intoxication leading to inability to fly, which is certain death in flying mammals. Other sublethal effects on thermoregulation, food consumption, and reproduction could lead to population declines. Pyrethroid use increased later in Missouri, and would also be toxic to bats.

No systematic surveys are currently being done in Missouri that would find pesticides in Indiana and Gray bats, or other suitable surrogate species. O'Shea and Clark's (2002) suggestion that Indianas may forage over cotton fields in southeastern Missouri, heavily treated with insecticides, is an unlikely scenario because cotton is > 100 km from the nearest, known hibernaculum. A more realistic hypothesis of a cause of Indiana bat decline would be pesticide contamination of prey insects in northern Missouri, where there is much more pesticide use in row-crop agriculture than within the range of foraging Indiana bats in most of southern Missouri. Circumstantial evidence in favor of this hypothesis is the continued increase of Gray bats, which range more in the southern part of the state, in forest, pasture, and hay areas with little pesticide use. The Missouri Natural Heritage Database has no current records of Indiana or Gray bats in the row-crop areas of southeastern Missouri, such as Perry County, which has many caves, but is also farmed for corn and soybeans. No caves occur in the cotton-growing areas of the Missouri Bootheel, comprising Dunklin, Pemiscot, New Madrid, Stoaddard, and Scott counties (Elliott 2007).

Another hypothesis would be crowding by increasing Gray bats, but I do not believe that to be an important factor based on two observations

(1) Indiana bats declined at most sites, even without Gray bats present, and (2) I have not observed agonistic behavior between Grays and Indianas, although I have photographed Grays crawling on the edges of Indiana bat clusters several times, and even on top of Indiana bats (Figure 14). Grays do this in their own clusters, but I have not observed Indiana bats leaving as a result of such behavior, although our visits are brief.

Disease is another hypothesis of decline that has not been eliminated. White Nose Syndrome, which had a recent outbreak in bats in the north-

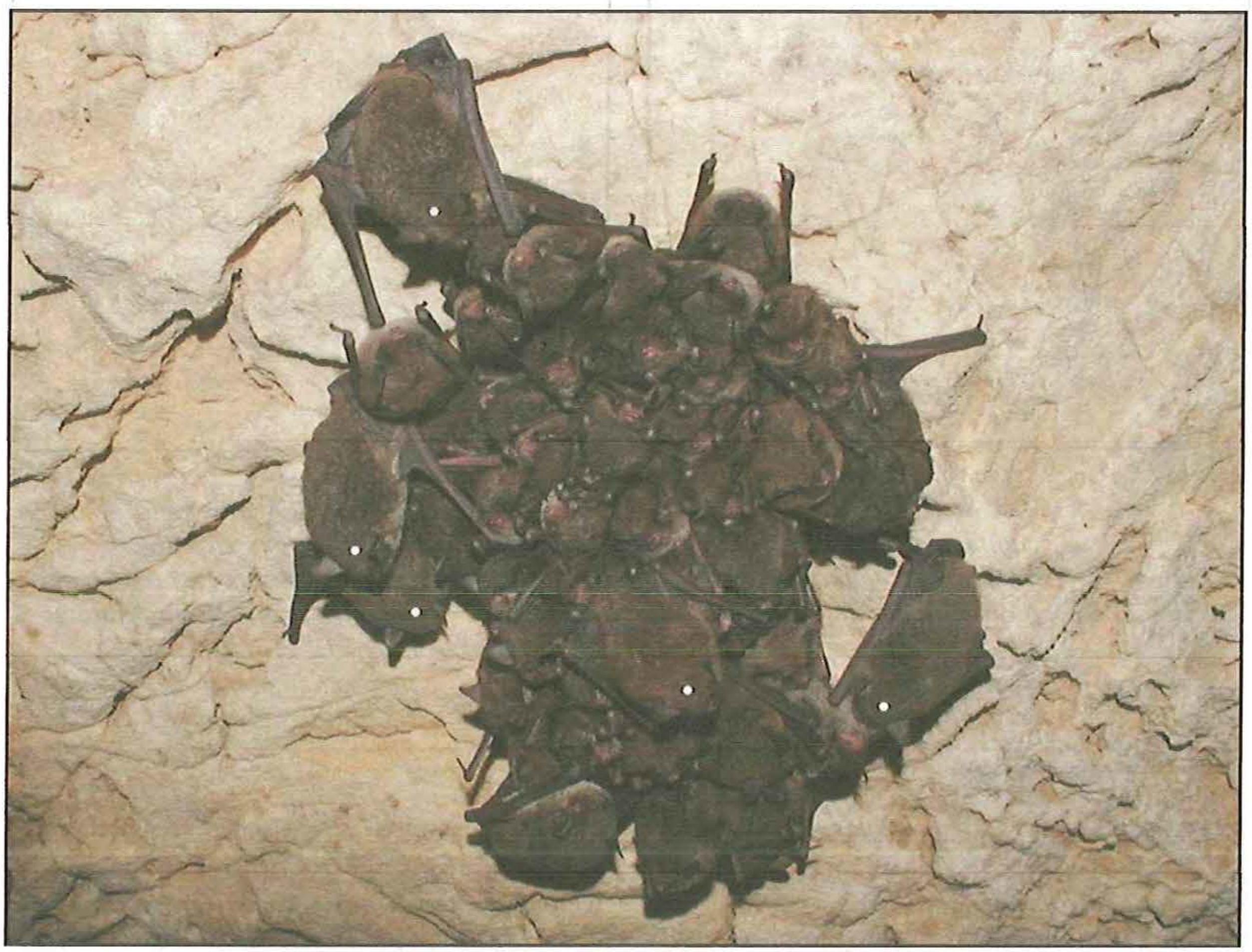

Figure 14 *A cluster of 43* Myotis sodalis *with five* M. grisescens *on the edge, indicated by white dots. Onyx Cave, Crawford County, Missouri, January 19, 2007.*

eastern U.S., has not been found in Missouri to date, and it probably was not involved in declines 30 years ago. Several Missouri bat caves were checked in the winter of 2007–2008 and, although some bats were seen with mold on their skin, they did not fly outside during the day or appear to be starving, which are characteristic of this syndrome.

I suggest that Indiana bats in Missouri have been adversely affected by several factors: disturbance by humans (especially 30 years ago, but at some sites even today), the partial collapse of Pilot Knob Mine in 1979, some effect from global warming at some hibernacula, (especially from the loss of extreme winter lows), and possibly pesticides and loss of summer habitat in northern Missouri.

Gray bats. Missouri's Gray bat population declined, but is now stable or increasing in some protected caves. Many other caves remain abandoned for various reasons. At bottom, Gray bats had lost at least 67% of their maximum past population, as measured in 56 important caves, and 53% of the caves were abandoned. The maternity population of Gray bats in Missouri is currently estimated at approximately 635,000. This is compared to evidence (guano and ceiling stains) suggesting that historic populations in the same set of caves once numbered over 1,700,000 (Table 1).

Thirty-one Gray bat hibernacula totaled 784,000 in recent years. The three major hibernacula were censused in 2006 and totaled 773,850. While Marvel Cave declined, Bat Cave, Shannon, was at 337% in 20 years, and Coffin Cave was at 157% (Tables 1 and 5).

Although there has been a general increase in Gray bats, many maternity colonies are still threatened by intruders and vandals. Table 6 summarizes events and population trends at 13 selected caves. These examples illustrate the typical problems that MDC has seen in managing these caves, and there are a few extreme examples as well. Figures 15 and 16 illustrate the vagaries of management at Blackwell and McDowell caves, whose bat populations have fluctuated with archaeological looting and breaches of the otherwise effective gates built in 2001.

The conclusion that I draw from ten years of bat cave management in Missouri, is that it requires a major effort by many people to keep Gray bat colonies stable or increasing, and to keep the few remaining Indiana bat colonies from being disturbed by intruders. One cannot gate a cave and consider it safe for long. Each cave gate must be checked and maintained periodically. It is common to find a breach in even the strongest cave gate within a few years. The more cave gates that are built, whether on state or private land, the more long-term commitment we have to maintain the gates. The gates may have an expected lifetime of 30 to 50 years in a relatively dry entrance, but at caves that are prone to flash flooding the gate may only last two to four years. Many lessons have been learned by wildlife agencies who build cave gates. Having lost three cave gates to floods in the last 11 years persuades the author to be cautious about building any more, unless they are built to higher engineering standards at greater cost.

Obtaining accurate census data also is a large task, now involving several experienced biologists, weeks of field time every year, high-quality digital cameras, flash units, infrared video gear, specialized software, and many hours for analysis. As pointed out by Martin (2007) and Sasse et al. (2007), more accurate and standardized census data are needed across the range of Gray bats before one could downlist or delist them from the U.S. Endangered Species List.

The Gray bat is a key species in Missouri cave ecosystems, providing nutrient input to animal communities. Conservation work has returned Gray bats in Missouri to about 46% (784,000) of the state population decades ago. I have calculated that the average colony of 10,000 Gray bats consumes about 45 kg (100 pounds) of insects each night between March and October, based on eating half their weight each night, or up to their weight each night for pregnant or nursing mothers. That translates to about 10 metric tons per year, about 4.3 billion insects. They eat a variety of species, such as aquatic insects—especially mayflies, caddisflies, and stoneflies—but also beetles and moths, some of which are agricultural pests. Statewide, Gray bats are eating 490 metric tons (223 billion) of insects per year. This is a major economic and environmental benefit to humans. We should also consider how much insect control we have lost by losing 300,000 Indiana bats in 30 years.

We have found that Grays and Indianas are unlikely to return to long-abandoned roosts, but this does not mean that restoration of caves and cave gating should not be tried where the potential payoff may be great. For Grays and Indianas, cave gates

Table 6 Examples of management problems and population trends at selected Gray bat maternity caves.

Cave, County	History	Population Trend
Bat Cave #1, Franklin	Upper entrance bulldozed 1970s, lower entrance full gate1989, air-flow reduced, cave cooled, pigeons infested lower entrance. MDC opened upper entrance and gated 2005, temperatures more natural. Upper gate breached and repaired 2007.	MPP 91,800 in 1976. Abandoned before 1990. Colony in nearby suboptimal cave might recolonize. MDC monitors for bats yearly.
Blackwell, Hickory	Difficult to monitor. Full rebar gate in 1979 hindered bats, modified to flyover in 1980. Break-ins by looters and abandonment 2000. New flyover gate 2001. Intrusions and break-in in 2004–2005, bats dropped to 700 in 2005.	Varies with intrusions.
Devils Icebox, Boone	No gate, intruders are infrequent because of strict park management, scheduled caving trips and long, cold water passage.	Stable since 1995.
Grandpa Chippley, Camden	MDC aquired 1997. Some intrusions, flyover gate 2004. Gate fell down April 2008 because of flooding and too few pins to walls.	Probably stable. Guano washes out, difficult to census until NIR and TIR.
Great Spirit, Pulaski	Show cave 1950s, MDC acquired 1981 and installed inadequate chain-link fence. Intense looting and bat disturbance. Large flyover gate 2002 for multiple resources.	Nearly abandoned. Struggling maternity colony.
Lower Burnt Mill, Camden	Frequent intruders from river recreators until April 2008 when MDC built chute gate and acquired land. Bats absent summer 2008, may be at Toby 5 km away.	Struggling maternity colony varied 0–30,600 since 1978 with intrusions.
Mary Lawson, Laclede	Good private protection for many years, MDC acquired and gated with flyover, 2004.	Up since gating
McDowell, Miller	Isolated area of park, frequent looting and visitors disturbed bats despite signs, chute gate 2001, breached 2003 or 2004, breached 2006 or 2007. More maintenance needed.	Varies with intrusions. Censused most summers since 2001.
Moles, Camden	In remote area, full constricted gate 1978, removed 1979 when it hindered bats.	Stable for long time, down in 2005, colony exchanges with Toby Cave.
Rocheport, Boone	Show cave 1965, owner tried to smoke out bats. MDC acquired 1995, flyover gate 1996, washed out 1997. New, very large flyover gate 2002, washed out 2004-2007. Second gate too heavy for structure, inadequately anchored, flood debris clean out a problem. Perimeter fence installed 2008.	Varies with flash floods, intrusions.
Smittle, Wright	Show cave 1950s. Acquired by MDC and fenced 1988. Flyover gate 1997. Some intrusions and two breaches. Open to permit caving in May and September. Key may have been copied by some permittees. Guano difficult to measure in cave stream.	Peaked at 105,500 in 1985 (guano). Down to 12,800 in 2008 (TIR).
Toby (Mauss), Camden	Large cave in remote area, protected well by private owner. Some caving allowed during appropriate times.	17,000–81,600 in 1977–2003, 97,000 in 2008.
Tumbling Creek, Taney	Intrusions led to constricted internal barrel gates 1966. Gates removed and large chute gate built 2004.	Declined 36,450–12,400 from 1976–2004. Up to 36,000 since regating.

are still important, and they must be checked and maintained periodically (Elliott 2006).

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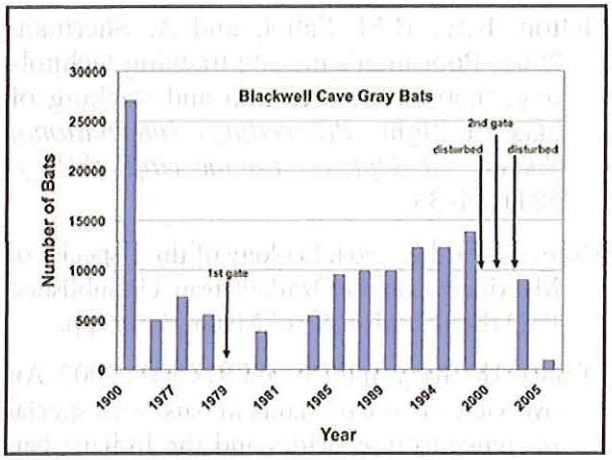

Figure 15 *Blackwell Cave's Gray bats have been repeatedly disturbed by archaeological looters and vandals. The flyover gate, built in 2001, was breached and a ladder was used to gain entry. Only 98 bats were seen in July 2008.*

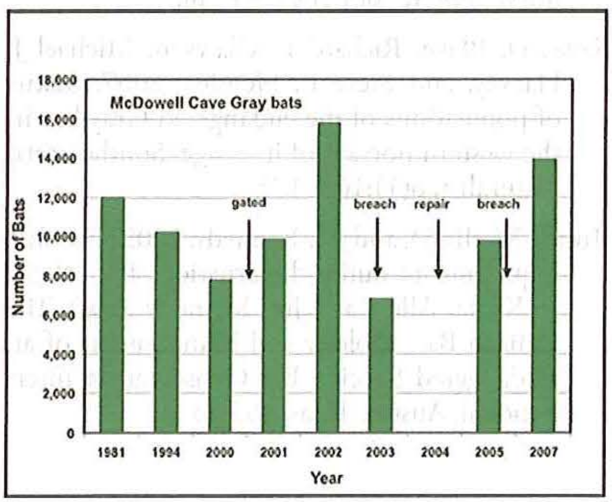

Figure 16 *A chute gate was built on McDowell Cave in 2001. No census was done in 2004. Small breaches of the chute were repaired, but the Gray bat colony was affected sometimes.*

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Effect of Forest Structure and Fragmentation on Site Occupancy of Bat Species in Missouri Ozark Forests

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Research Article

Effect of Forest Structure and Fragmentation on Site Occupancy of Bat Species in Missouri Ozark Forests

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Abstract

*Changes in structure and arrangement of forests may influence the distribution of bat communities by affecting roosting and foraging habitat. Using Anabat bat detectors, we determined presence of bat species at 316 sample plots in southeastern Missouri, USA, through qualitative identification of echolocation calls collected. We used maximum-likelihood estimation techniques incorporating detection probabilities into estimation of site occupancy by species of bats. We compared a priori models at 2 geographic scales using information theoretic methods. At the local-site scale, eastern pipistrelle (*Pipistrellus subflavus*) and red bat (*Lasiurus borealis*) occupancy was most influenced by structural characteristics of forested areas, whereas Indiana bats (*Myotis sodalis*) were influenced most by density of large-diameter snags that could provide roosting habitat. At the landscape scale, occupancy of Indiana bats was directly related to amount of nonforested land cover. Northern long-eared bat (*M. septentrionalis*) occupancy was inversely related to edge. These data describe implications of forest fragmentation and provide information that can be used when integrating forest-management practices into bat conservation.* (JOURNAL OF WILDLIFE MANAGEMENT 70(5):1238–1248; 2006)

Key words

acoustic detection, forest fragmentation, Lasiurus borealis, *Missouri Ozarks,* Myotis septentrionalis, Myotis sodalis, *occupancy,* Pipistrellus subflavus.

The continued decline of several bat species associated with forests underscores the need for increased understanding of habitat relationships for North American bats (Fenton 1997, O'Shea et al. 2003, Menzel et al. 2005*a*). Miller et al. (2003) noted the paucity of research on forest-dwelling bats, with particular gaps in studies conducted in the midwestern United States. As with many other species, habitat suitability for bats may be influenced by various factors at multiple spatial scales (Balcom and Yahner 1996, Grindal and Brigham 1999, Hagan and Meehan 2002). These factors and scales may be particularly important for bats because of differences between roosting and foraging requirements (Mager and Nelson 2001, Menzel et al. 2005*a*). At smaller stand scales, basal area and size distribution of trees and snags (Crampton and Barclay 1998, Waldien et al. 2000, Aguirre et al. 2003), solar exposure (Callahan et al. 1997, Lacki and Schwierjohann 2001), and stand openness (Thomas 1988, Ford et al. 2005) have been found to influence bat presence. Supporting this, Aldridge and Rautenbauch (1987) and Norberg and Rayner (1987) described morphological differences in echolocation call structure and wing form that may influence species response to forest structure characteristics. In addition, the presence of water has been cited as being of great importance as a habitat resource for bat species, particularly for gray (*Myotis grisescens*) and Indiana bats (*M. sodalis*; Menzel et al. 2001, Johnson 2002, Ford et al. 2005, Menzel et al. 2005*b*).

Fewer studies have investigated habitat characteristics of bats at larger landscape scales. Krusic et al. (1996) discussed the importance of a matrix of different land cover types to fulfill all of the habitat requirements of bats. Gorresen and Willig (2004) found that bat diversity in a tropical forest was greatest in a landscape of diverse cover types. Example landscape characteristics that influence bat species distribution include extent of fragmentation, patch size, and presence of edge habitat (Grindal and Brigham 1999, Law et al. 1999, Estrada and Coates-Estrada 2002).

Current shifts in land use and land ownership patterns influence forest structure and composition characteristics at both the local site and landscape scale (Sampson and DeCoster 2000). Shifts in ownership patterns of the Midwest may indicate increased fragmentation due to development and greater number of forest-management units (Gobster et al. 2000), and parcelization affects age structure and arrangement of forest landscapes (Ko 2005). In Southeastern Missouri 82% of the forested area is held by nonindustrial private landowners (Moser et al. 2003). With increased pressure on forest ecosystems for a variety of resources, a critical component of forest-management planning should include an understanding of how changes across a forested landscape affect bat distribution. Accordingly, our goal was to determine the influence of forest composition, structure, and arrangement at multiple scales on the occupancy of bat species across 2 forested watersheds in the Ozark Highlands of Missouri, USA.

Study Area

We conducted our study within the upper portions of the St. Francis and Black River watersheds of southeastern Missouri (Fig. 1) during summers of 2002, 2003, and 2004. These 2 adjacent watersheds encompassed 708,000 ha (1.75 million acres) of the central hardwood forest region (Braun 1950) within the Ozark Highlands section, which

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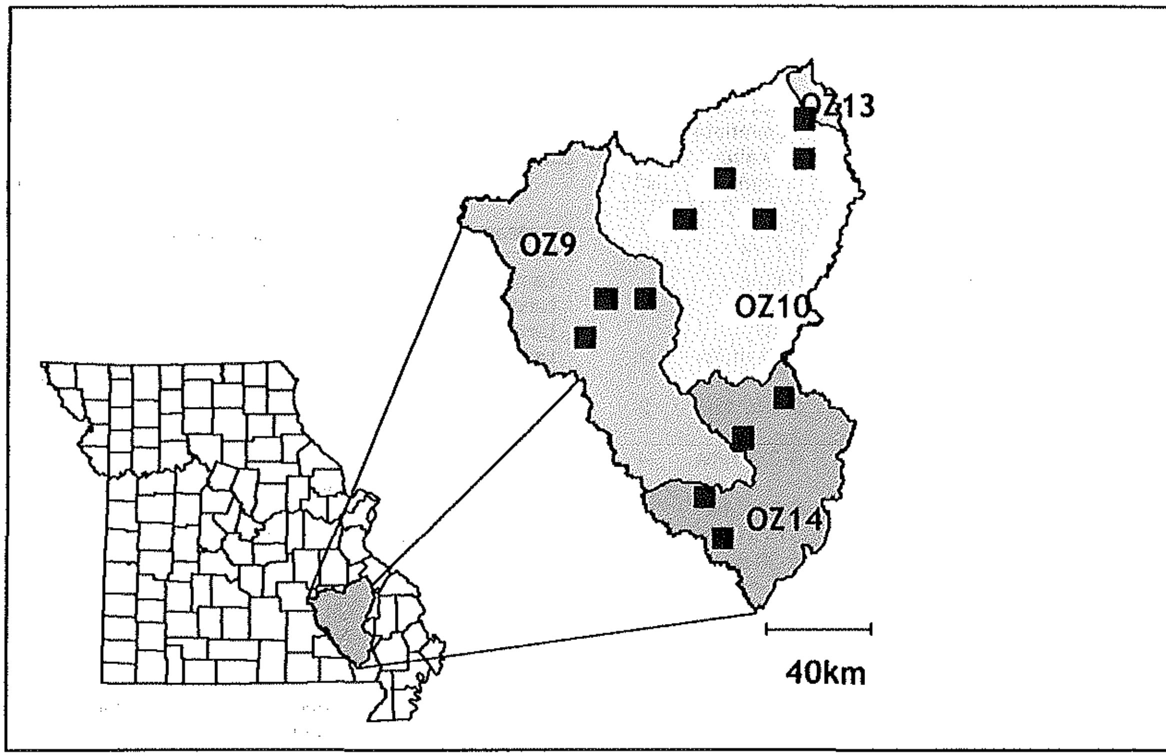

Figure 1. Study area (inset) in southeastern Missouri, USA, encompassing the watersheds of the St. Francis and Black Rivers. Ecological subsections of the study area are identified by shading and designated as OZ9, Current River Hills; OZ 10, St. Francis Knobs and Basins; OZ 13, Inner Ozark Border; and OZ 14, Black River Ozark Border. Squares represent locations of individual 23.3-km^2 study cells used for bat and habitat sampling in 2002–2004.

contained 4 different ecological subsections as described by Nigh and Schroeder (2002): 1) Current River Hills (OZ 9), 2) St. Francis Knobs and Basins (OZ 10), 3) Inner Ozark Border (OZ 13), and 4) Black River Ozark Border (OZ 14). This area was highly topographically dissected and geologically heterogeneous with a considerable number of karst features. Land cover classification derived from 30-m × 30-m-resolution Landsat imagery (1992) as determined by Missouri Resource Assessment Partnership (MoRAP) revealed a dominance of forested cover (90%), mostly in upland deciduous oak (*Quercus* spp.) forests with a lesser proportion in shortleaf pine (*Pinus echinata*)–mixed-hardwood forests.

Methods

Acoustic Detection

We collected bat echolocation calls using Anabat II bat detectors coupled with Zero-Crossing Analysis Interface Modules with CF memory card storage (CF ZCAIM; Titley Electronics, Ballina, New South Wales, Australia), passively sampling each location. To protect detectors from inclement weather, we housed the equipment in plastic containers with the microphone aligned with an opening leading to a 45° polyvinyl chloride (PVC) elbow directed upwards. We placed 2 detector units at each location for one evening during the 2002 and 2003 field season and 2 consecutive evenings during the 2004 field season. During the 2002 field season, we conducted acoustic sampling from July to the first week of September. During the 2003 and 2004 field seasons, we conducted acoustic sampling from mid-May to the first week of September. We suspended detectors 1 m above the ground and oriented detectors at a sample point to maximize the probability of recording bat calls and minimize overlap of detection zones between detectors (Larson and Hayes 2000, Weller and Zabel 2002, Duchamp et al. 2006). We calibrated detectors to minimize variation in zone of reception among detectors as described by Livengood (2003), as this variation can result in unequal sampling areas among detector sites and lead to biased occupancy rates associated with certain detectors (Hayes 2000, Larson and Hayes 2000). We recalibrated detectors from one field season to the next to minimize detector biases.

We downloaded the bat echolocation calls that were collected, and we analyzed them using Analook software (http://users.lmi.net/corben/anabat.htm). We identified species based on qualitative and quantitative parameters from known call libraries (C. Corben and M. O'Farrell, O'Farrell Biological Consulting, unpublished data) and published accounts (Fenton and Bell 1981, O'Farrell et al. 1999, Livengood 2003, Menzel et al. 2003). We made species determination by using call characteristics such as slope, and minimum frequency as calculated by Analook, as well as general shape and consistency of minimum frequency throughout the call sequence. To minimize error rates, we used a strict filter (Britzke 2003) to eliminate call sequences

Table 1. Model name, habitat covariates, and range of data values of each covariate included in a priori models used to explain bat occupancy at the local site scale during 2002–2004 in the St. Francis and Black River watersheds, Missouri, USA.

Model name	Covariates	Covariate value range	*k*[a]
Topography model 1	Aspect	0–360°	2
Topography model 2	Aspect,	0–360°	3
	% slope	0–60%	
Topography model 3	Aspect,	0–360°	3
	Relative slope position	1–10[b]	
Roosting model 1	BA of live trees >30 cm dbh	0–23 m^2/ha	2
Roosting model 2	BA of snags >30 cm dbh	0–3 m^2/ha	2
Roosting model 3	BA of live trees >30 cm dbh,	0–23 m^2/ha	4
	BA of snags >30 cm dbh,	0–3 m^2/ha	
	Overstory height	6–30 m	
Roosting model 4	BA of all snags	0–7 m^2/ha	2
Roosting model 5	BA of shortleaf pine >30 cm dbh	0–14 m^2/ha	2
Clutter model 1	BA of all live trees,	8–45 m^2/ha	3
	Canopy closure	1–10[c]	
Clutter model 2	BA of all live trees,	8–45 m^2/ha	3
	Understory density from 1–2 m,	0–28[d]	
	Understory density from 2–3 m	0–30[d]	
Clutter model 3	Understory density from 1–2 m,	0–28[d]	3
	Understory density from 2–3 m,	0–30[d]	
	Overstory height	6–30 m	
Water Model 1	Distance to nearest water	0.008–5.7 km	2

[a] *k* represents the number of variables incorporated in the model with the addition of 1 for the intercept.
[b] Relative slope measured as a categorical variable where 1 represents bottom of the slope and 10 the top of the slope.
[c] Canopy closure measured as categorical variable where 1 = ≤5% canopy closure, 2 = 5–25% canopy closure, 3 = 25–50% canopy closure, 4 = 50–75% canopy closure, and 5 = 75–100% canopy closure.
[d] Understory density consists of 2 measurements each representing the number of 10-cm squares obscured more than 50% from a total of 30 squares.

with <5 call pulses as well as call sequences of poor quality, and we identified each call sequence twice. If the 2 identifications of the call sequence differed, we accessed it a third time.

Bats are known to switch frequently among roost trees within a defined area (Lewis 1995, Vonhof and Barclay 1996, Brigham et al. 1997*b*, Hutchinson and Lacki 2000, Menzel et al. 2000, Mager and Nelson 2001). Therefore, to meet the requirement of a closed population, we divided a single evening into 4 equal time periods (2000–2230, 2230–0100, 0100–0330, and 0330–0600 hours) with each time period treated as a sampling visit. If a call was recorded during that time period, we considered that species present and occupying the site. We defined occupancy as having a species present during the time sampled. If no identifiable

Table 2. Model name, landscape covariates, and range of data values of each covariate included in a priori models used to explain bat occupancy at the landscape scale during 2002–2004 in the St. Francis and Black River watersheds, Missouri, USA. Landscape metrics were derived using Fragstats and all values other than proportional land cover are unitless.

Model name	Covariates	Covariate value range	*k*[a]
Landtype model 1	Ecological subsection		4
Land index model 1	Patch richness density	827–1861	2
Land index model 2	Area-weighted shape index	1.18–1.47	2
Land index model 3	Contagion	70–89	2
Land index model 4	Area-weighted shape index,	1.18–1.47	3
	Contagion	70–89	
Land cover model 1	Upland deciduous forest cover,	31–90%	3
	Area-weighted mean patch area	3.4–7.8	
Land cover model 2	Non-forested cover,	6–64%	3
	Area-weighted mean patch area	3.4–7.8	
Land cover model 3	Urban cover,	0–1%	3
	Area-weighted mean patch area	3.4–7.8	

[a] *k* represents the number of variables incorporated in the model with addition of 1 for the intercept.

call was recorded during a time period, we considered that species as not detected. We analyzed the resulting detection history with methods discussed in MacKenzie et al. (2002) using the software package PRESENCE to estimate proportion of sites occupied (http://www.mbr-pwrc.usgs.gov/software.html#surviv).

Study Area and Sample Point Selection

Using Global Information System, we superimposed the 2 watersheds with a grid of cells each 23.3 km^2 (9 $mile^2$) in size. We randomly selected 12 cells distributed across the 2 watersheds as study cells in which to focus our acoustic sampling effort. Our study was a portion of a larger project accessing the sustainability of central hardwood forests incorporating social, economic, and biological dimensions of natural resource management (Swihart and Slade 2004). We selected these 2 watersheds as representative in both landownership patterns and land cover found in the Ozark Highlands of Missouri. Therefore, we delineated size of the study cell to encompass the needs of multiple research projects. To determine placement of sample points within each study cell, we used a random point generator in ArcView 3.2 under the constraint of being within either upland deciduous forest or shortleaf pine–mixed-hardwood forest. We categorized forest patches in either of these cover types into 1 of 3 size classes: small (0.5–25 ha), medium (25–100 ha), and large (>100 ha), for a total of 6 sample-unit categories. We apportioned sample effort according to relative area in each size class–forest cover type combination.

Model Selection

We developed a priori models to examine the relationship between bat species occupancy and site (Table 1) and landscape (Table 2) characteristics based on the literature and field observations. We used information theoretic methods to determine which of the models within the selected set provided the best fit with the fewest parameters (i.e., most parsimonious model [Anderson et al. 2000]). Due to the relatively low number of sample points in relation to the number of covariates used in the models, we used Akaike's Information Criteria adjusted for small sample size (AIC_c) in the model selection process. We considered the model with the smallest AIC_c value to best fit the data in relation to others in the given model set. We tested data for each species at each spatial scale to determine if the sampling variance exceeded theoretical sampling variance using methods described by MacKenzie and Bailey (2004). We developed these models for both local site and landscape scale from our field observations and from results in related literature (Decher and Choate 1995, Vonhof and Barclay 1996, Carter et al. 1999, Foster and Kurta 1999, Mager and Nelson 2001).

To incorporate detection probability properly into estimation of occupancy, we compared models influencing ability to detect a bat species using AIC_c (Hayes 2000, Sherwin et al. 2000, Weller and Zabel 2002, Patriquin et al. 2003, Broders et al. 2004). Covariates for detectability included year, time of season a site was sampled as divided into 7 2-week time periods (25 May–31 Aug), Julian date, understory density, minimum temperature (range 6–25°C), maximum temperature (range 17–38°C), and total precipitation during the day sampling took place (range 0–3.8 cm). We obtained weather data from 4 weather stations within the bounds of the 2 watersheds from National Climate Data Center on the National Oceanic and Atmospheric Administration website. We used existing literature to develop a list of covariates that could be used to explain detectability of bat echolocation calls. We did not, however, conclude that existing knowledge on the topic was sufficiently comprehensive to allow for the creation of a priori models. Using the program PRESENCE, we compared the AIC_c values of each of the detection covariates alone, and we then combined the 2 covariates with the highest values to see if the combination yielded a model that better fit the data than the highest single covariate alone. Once we determined the most parsimonious combination of covariates for each species, we included this detection probability model as part of all occupancy model comparisons for both the local site and landscape scales of that species.

We used AIC_c weights (w_i) for model selection among a priori habitat occupancy models at both spatial scales. We used the global model containing all habitat covariates for a given scale to test whether a significant difference existed between the covariates of the detectability model alone and occupancy model with the lowest w_i, using likelihood ratio test ($P < 0.1$; Anderson et al. 2000). Due to high levels of model uncertainty, we used model averaging as described by Anderson et al. (2000) to increase precision and minimize bias of parameter estimates. For model averaging we included the model with the highest w_i, adding additional models of the next-highest w_i until their sum was ≥ 0.95. We considered covariates included in models within 2 AIC_c units of the best model important in describing probability of occupancy of a bat species at that spatial scale.

Forest Structure and Composition

We determined basal area (BA) of each sample site using a 10-factor prism and 5 variable-radius plots arrayed around the sample site (Avery and Burkhart 2002). At point center, we took a single variable-radius plot measurement and at 60 m in each cardinal direction from the center. We used these measures to estimate size and species composition of tree species at forest plots. We estimated overstory and understory density at each sample point by taking measurements 5 m from center in each cardinal direction. By observing the number of 10×10-cm squares obscured on a 3-m $\times$ 0.3-m-tall density cover board from plot center in each cardinal direction, we estimated the density of the understory (Nudds 1977) from 1–2 m and from 2–3 m. We measured overstory canopy closure using a 12.5-cm section of 5-cm-diameter PVC pipe and estimating amount of canopy closure as viewed through the tube and assigned measurement values into one of 5 categorical classifications. We measured distance to water in km from a particular sample plot center to the nearest water source designated in land cover image.

Landscape Metrics

To assess landscape-level habitat metrics, and to avoid the abrupt delineation associated with the cell, we digitally circumscribed each 23.3-km^2 study cell with a 1.6-km (1-mile) buffer. The buffer incorporated additional area surrounding each study cell to ensure that landscape characteristics influencing sample locations near the edge of the 23.3-km^2 cell would be included in the calculation of metrics at this scale. We calculated landscape metrics from the resulting 64.8-km^2 (25-$mile^2$) area of each study cell, using FRAGSTATS 3.3 (MacGarigal et al. 2002). We used area-weighted mean shape index as a measure of the patch shape complexity, with increasing values indicating greater complexity and amount of edge present in the landscape. We used contagion as index of land cover interspersion, where a low value indicated high levels of interspersion and, thus, indicated higher levels of fragmentation. Patch richness density reflected the diversity of patch types within a study cell. Area-weighted mean patch size represented a measure of the average patch size within a study cell. We calculated the proportion of the landscape found in upland deciduous forest, nonforested and urban cover types within the GIS of each of the study cells. The nonforested coverage class incorporated agricultural lands, glades, and grasslands, whereas urban and upland-deciduous forest cover types remained as defined by MoRAP classification.

Results

We detected bat presence at 48% of 316 sites. From bat calls, we identified 9 species; 5 of these were present at $\geq$10% of the sample points, and we used them for further

Table 3. Covariates incorporated into models for detection probability of each bat species as determined by lowest value of Aikaike's Information Criterion adjusted for small sample size. The indicated covariates were used as the null model during model selection process for occupancy rates during 2002–2004 in the St. Francis and Black River watersheds, Missouri, USA.

Species	Covariates	k[a]
Eastern pipistrelle	Minimum temperature, within-season time period	8
Red bat	Precipitation	2
Northern long-eared bat	Year, precipitation	4
Indiana bat	Year	3
Gray bat	Year	3

[a] k represents the number of variables incorporated in the model with addition of 1 for the intercept.

analysis: 1) eastern pipistrelle (*Pipistrellus subflavus*; 25% of sites), 2) red bat (*Lasiurus borealis*; 20% of sites), 3) northern long-eared bat (*Myotis septentrionalis*; 19% of sites), 4) gray bat (10% of sites), and 5) Indiana bat (11% of sites).

Detection Probability

The most parsimonious model for detectability varied among species (Table 3). Year during which sampling occurred was the most-frequently included covariate in the detectability model with the lowest AIC_c weight. Year alone was the model with the most support for both the gray bat ($AIC_c = 399.2$) and the Indiana bat ($AIC_c = 469.6$). For both of these species, detectability was lowest during the 2002 field season and highest during the 2003 field season. Year and precipitation (range = 0–3.75 cm) were the covariates in the detectability model with the most support for northern long-eared bat ($AIC_c = 684.3$). Detectability for the northern long-eared bat was lowest during 2002 and highest in 2003, while an inverse relationship existed between detectability and precipitation during sampling. Precipitation alone was the detectability model with lowest AIC_c value for red bat ($AIC_c = 795.8$) with an inverse relationship between detectability and precipitation. The detectability model with the most support for eastern pipistrelle included minimum temperature (range = 6–25°C) and 2-week period of field season during which sampling occurred ($AIC_c = 894.3$). Minimum temperature was inversely related to detectability. Detectability varied across field season with the sixth 2-week time period having the highest and the seventh 2-week period having the lowest detectability.

Local-Site Scale

None of the a priori models were significantly better than the null model at explaining the occupancy of gray bat or northern long-eared bat across the 2 watersheds ($P > 0.1$). Among the remaining 3 species, the global model including all of the site covariates in addition to the most parsimonious sampling covariate model was significantly greater than the null model consisting of sampling covariates ($P < 0.1$).

At the local-site scale, the model with the highest AIC_c weight for eastern pipistrelle consisted of variables describing structural complexity of the forest (Table 4). Live BA was inversely related to occurrence (odds ratio = 0.95, SE = 0.05), whereas overstory canopy density was directly related to occurrence (odds ratio = 1.08, SE = 0.14) of eastern pipistrelle. The second-most-important model included live BA and understory density. Understory density from 1–2 m was directly related (odds ratio = 1.01, SE = 0.02), whereas understory density from 2–3 m was inversely related to probability of site occupancy (odds ratio = 0.99, SE = 0.01). The averaged model output for eastern pipistrelle estimated the proportion of sites occupied as 0.31 (SE = 0.032), an increase of 0.06 over observed occupancy.

Red bat occurrence at a site was best explained by the same covariate model as eastern pipistrelle (Table 4), with an inverse relationship with live BA (odds ratio = 0.97, SE = 0.03) and a direct relationship with overstory canopy density

Table 4. All a priori local-site habitat characteristic models for 3 species of forest-dwelling bats in the Ozark Highlands of Missouri, USA. Covariate components[a] of each model listed with the number of parameters (k), Aikaike's Information Criterion adjusted for small sample size (AIC_c), distance from the most parsimonious model (ΔAIC_c) and AIC_c weight (w_i). Lower AIC_c and ΔAIC_c and greater w_i represent models with more substantial support.

	Eastern pipistrelle				Red bat				Indiana bat			
Model	k	AIC_c	ΔAIC_c	w_i	k	AIC_c	ΔAIC_c	w_i	k	AIC_c	ΔAIC_c	w_i
Null	9	912.9	5.08	0.03	3	795.8	4.43	0.04	4	469.6	5.71	0.03
Topography model 1	10	911.8	3.95	0.06	4	796.2	4.80	0.03	5	471.7	7.77	0.01
Topography model 2	11	913.9	6.10	0.02	5	792.2	0.81	0.24	6	473.4	9.53	0.005
Topography model 3	11	913.8	6.02	0.02	5	798.2	6.86	0.01	6	471.6	7.68	0.01
Roosting model 1	10	914.7	6.93	0.01	4	796.0	4.64	0.04	5	470.0	6.05	0.03
Roosting model 2	10	910.5	2.68	0.11	4	795.0	3.65	0.06	5	463.9	0	0.54
Roosting model 3	12	914.4	6.58	0.02	6	797.0	5.60	0.02	7	466.1	2.14	0.18
Roosting model 4	10	913.1	5.35	0.03	4	797.9	6.45	0.01	5	468.7	4.80	0.05
Roosting model 5	10	910.1	2.28	0.13	4	797.0	5.63	0.02	5	471.8	7.76	0.01
Clutter model 1	11	907.8	0	0.41	5	791.4	0	0.35	6	469.4	5.50	0.03
Clutter model 2	12	909.7	1.88	0.16	6	796.6	5.26	0.03	7	468.9	4.99	0.04
Clutter model 3	12	917.6	9.75	0.003	6	797.2	5.81	0.02	7	469.7	5.79	0.03
Water Model	10	914.53	6.73	0.01	4	797.8	6.42	0.01	5	470.0	6.1	0.03
Global	21	920.3	12.45	0.001	15	793.6	2.20	0.12	16	475.6	11.66	0.002

[a] Specific covariates for each model are described in Table 1.

Table 5. All a priori landscape habitat characteristic models for 3 species of forest-dwelling bats in the Ozark Highlands of Missouri, USA. Covariate components[a] of each model listed with the number of parameters (k), Aikaike's Information Criterion adjusted for small sample size (AIC_c), distance from the most parsimonious model (ΔAIC_c) and AIC_c weight (w_i). Lower AIC_c and ΔAIC_c and greater w_i represent models with more substantial support.

	Red bat				Northern long-eared bat				Indiana bat			
Model	k	AIC_c	ΔAIC_c	w_i	k	AIC_c	ΔAIC_c	w_i	k	AIC_c	ΔAIC_c	w_i
Null	3	795.8	4.71	0.03	5	684.3	7.09	0.02	4	469.6	8.90	0.01
Land index model 1	4	793.7	2.64	0.10	6	683.4	6.23	0.03	5	470.6	9.84	0.01
Land index model 2	4	796.4	5.35	0.03	6	677.2	0	0.57	5	468.1	7.38	0.02
Land index model 3	4	797.7	6.57	0.01	6	682.8	5.62	0.03	5	468.4	7.65	0.02
Land index model 4	5	798.5	7.37	0.01	7	679.0	1.82	0.23	6	469.1	8.42	0.01
Land type model 1	6	791.9	0.83	0.24	8	682.1	4.89	0.05	7	468.4	7.64	0.02
Land cover model 1	5	792.4	1.31	0.19	7	687.6	10.38	0.003	6	469.1	8.37	0.01
Land cover model 2	5	798.5	7.42	0.01	7	683.3	6.13	0.03	6	460.7	0	0.82
Land cover model 3	5	797.2	6.08	0.02	7	686.8	9.65	0.004	6	470.2	9.46	0.01
Global	13	791.1	0	0.36	16	682.6	5.46	0.07	14	465.7	4.98	0.07

[a] Specific covariates for each model are described in Table 2.

(odds ratio = 1.32, SE = 0.32). The model with next-highest AIC_c weight included aspect (odds ratio = 0.91, SE = 0.16) and percent slope (odds ratio = 0.99, SE = 0.02). Probability of red bats occurring at a site decreased as the aspect deviated from south and decreased with steeper slopes. Estimated proportion of sites occupied from averaged model was 0.24 (SE = 0.028), an increase of 0.04 over observed occupancy.

The greatest weighted model for Indiana bat occurrence at the local-site scale involved BA of snags >30-cm diameter at breast height (dbh; Table 4). There was a direct relationship between the number of large-diameter snags (odds ratio = 2.06, SE = 0.51) and occurrence of Indiana bats. No other model was within 2 AIC_c units of this model. Using model averaging, the proportion of sites occupied was estimated to be 0.18 (SE = 0.032), an increase of 0.07 over observed occupancy.

Landscape Scale

None of the a priori models were significantly better than the null model at explaining the occupancy of gray bats and eastern pipistrelle across the 2 watersheds ($P > 0.1$). There was a significant difference between the global model and the null model for the red bat, northern long-eared bat, and Indiana bat ($P < 0.1$).

At the landscape scale the model with the greatest support for red bat was the global model containing all landscape covariates (Table 5). The model with the second-highest AIC_c weight incorporated ecological subsection. The red bat was most likely to be found in St. Francis Knobs and Basins ecological subsection (odds ratio = 6.8, SE = 2.52) and least likely to be found in the Black River Ozark Border subsection (odds ratio = 0.93, SE = 0.79). A model consisting of proportion of the landscape in upland-deciduous forest cover type (odds ratio = 2.85, SE = 4.20) and average patch size (odds ratio = 1.50, SE = 0.58) was also within 2 AIC_c units. Estimated proportion of sites occupied from model averaging was 0.24 (SE = 0.029), an increase of 0.04 over the observed occupancy.

Northern long-eared bat occupancy was best explained by area-weighted shape index (odds ratio = 0.91, SE = 0.07) where probability of northern long-eared bat occupancy decreased as average patch shape increased in complexity (Table 5). The second-most supported model included area-weighted shape index and contagion (odds ratio = 0.97, SE = 0.08). Although decreasing with shape complexity, northern long-eared bat occupancy increased with greater interspersion of patch types. Estimated proportion of sites occupied using model averaging was 0.31 (SE = 0.043), an increase of 0.12 over the observed occupancy rate.

The best model for the Indiana bat included area-weighted mean patch size and the proportion of landscape in nonforested cover types (Table 5). There was a direct relationship between both area-weighted mean patch size (odds ratio = 1.64, SE = 0.27) and proportion of landscape in nonforested cover type (odds ratio = 217.75, SE = 2.50) and the probability of Indiana bat occupancy at a sample point. There was no other model within 2 AIC_c units of this model. The average proportion of sites occupied by Indiana bat as estimated through model averaging was 0.16 (SE = 0.002), an increase of 0.05 over the observed occupancy rate.

Discussion

Species occupancy rates were influenced by characteristics at both the local site and landscape scales in the St. Francis and Black River watersheds during this study. Significant trends were found for red bats and Indiana bats at both the local site and landscape scales. Only models including variables measured at the local-site scale influenced the occupancy rates of eastern pipistrelle, while landscape metrics more appropriately explained the occupancy of northern long-eared bats. None of the variables measured at either scale adequately explained the occupancy of gray bats.

Detection Probability

While not directly influencing occupancy, the ability to detect species may drastically influence perceived occupancy as data from this study indicate. It is important, therefore, to highlight the environmental factors influencing the acoustic detection of species in forested areas. The probability of detecting a given species is generally <1 (MacKenzie et al. 2002, Gu and Swihart 2004), and this is particularly true of bats (Hayes 2000, Sherwin et al. 2000, Patriquin et al. 2003, Duchamp et al. 2006). We used methods described by MacKenzie et al. (2002) to incorporate estimates of detection probability into occupancy estimates. Gu and Swihart (2004) suggested that some variables are interpreted as affecting occupancy when they may actually be influencing detection, leading to inappropriate conclusions. With this in mind, we included year as a detectability covariate rather than a covariate estimating occupancy.

Detection probabilities for the gray bat, the Indiana bat, and the northern long-eared bat were lowest in 2002. While annual shifts in population size may alter site occupancy among species with high reproductive potential, bats are long-lived and have low reproductive rates with noncyclic population patterns (Kunz and Racey 1998, Kunz and Fenton 2003). Small changes in population density may affect detectability of a species in a landscape, while not influencing occupancy (Royle and Nichols 2003). Shifts in general weather conditions among years may also influence levels of bat activity. Erickson and West (2002) found that bat detections in the Pacific Northwest were highest in areas with low precipitation and high temperatures. Shifts in overall weather patterns among years may have had a similar impact on the activity levels of bats during our study. Additionally, experience in placement of detectors gained during the 2002 field season may have led to increased detectability during 2003 and 2004. Weller and Zabel (2002) highlighted the impact of positioning of detectors on detectability of bats during acoustic surveys. Our use of 2 detectors at each sample location on each evening may compensate in part for inadequate placement for presence data; however, having 2 detectors did not eliminate the problems with detection from inappropriate placement.

Precipitation influenced the probability of detection for both the northern long-eared bat and the red bat. Precipitation can influence both activity levels of bat species and the attenuation of echolocation calls (Hayes 2000, Erickson and West 2002). Increased humidity following rainfall may negatively affect echolocation call detection distance, resulting in a decrease in the probability that a bat would fly through the zone of reception (Griffin 1971, Livengood 2003).

Eastern pipistrelle detection was most influenced by minimum air temperature and 2-week time period during the field season. Changes in detectability across field season could represent shifts in foraging activity caused by changing energy requirements during birth and rearing of pups (Racey and Swift 1985, Barclay 1989). Increases in foraging activity and more frequent returns to roosting location increase the probability of detection for lactating bats (Clark et al. 2002). The lowest probability of detection occurred during the fourth 2-week time period (7–20 Jul) and coincided with the onset of juvenile volancy (Whitaker 1998). Immediately after 20 July, an increase in detection probability occurred for 4 weeks until a decrease in the final 2-week time period. Increases in activity likely correspond with increasing temperature, a trend noted by Erickson and West (2002).

There were no significant models at either scale describing gray bat occupancy, even though calls were identified at 10% of the study sites. While variables included in models at both scales are appropriate for describing habitat for forest-dwelling bats, the gray bat is a cave-obligate species, using caves as both winter and summer roost sites (Decher and Choate 1995). A dependence on cave habitat may supersede other forest habitat characteristics in determining its distribution across the landscape. Although including cave locations could provide improved modeling information these data were not available. Open water or large rivers represent dominant foraging areas for gray bats (LaVal et al. 1977, Johnson 2002); hence, the time this species spends in the forest would be minimized, thereby explaining the lack of correlation between species presence and measured habitat characteristics we observed.

Local-Site Scale

The most parsimonious occupancy models at this scale for eastern pipistrelle and red bat included total BA as a covariate. Increases in live BA corresponded with decreases in the occupancy rate of these 2 bat species. The red bat is a foliage-roosting species, preferring clumps of leaves at the end of branches of deciduous trees as day roosts (Shump and Shump 1982, Hutchinson and Lacki 2000, Schwartz and Schwartz 2001). Eastern pipistrelles are known to roost in anthropogenic structures (Fujita and Kunz 1984, Whitaker 1998, Schwartz and Schwartz 2001); however, Veilleux et al. (2003) found eastern pipistrelles roosting in foliage of deciduous trees in Indiana, and others have reported eastern pipistrelles roosting in cavities (Carter et al. 1999, Kurta et al. 1999). Carter and Menzel (2006) further discuss the importance of foliage roost sites for eastern pipistrelle bats. Upland deciduous tree species (e.g., oak and hickory [*Carya* spp.]) dominated the 2 watersheds in our study, providing abundant roost sites across the landscape for foliage-roosting species (Lewis 1995).

Elmore et al. (2004) found that stand-level characteristics were more important than individual tree characteristics in explaining roost location for the red bat. Contrary to our findings, Hutchinson and Lacki (2000) found significantly lower BA surrounding red bat roost sites. The covariate of live BA includes all size classes and therefore could represent an increase in structural complexity within the stand a potential impediment for navigation (Crome and Richards 1988, Erikson and West 1996, Brigham et al. 1997*a*).

Although red bats are known to forage along forest edges, above canopies, and in forest openings, Mager and Nelson (2001) found that selected roosts were larger in diameter than randomly selected trees and suggested that the thicker canopies of such trees provided greater concealment from predators or protection from wind (Menzel et al. 2003, Elmore et al. 2004). Similarly, Menzel et al. (2000) found red bats roosting in areas with relatively dense overstory canopies.

The model with the second-highest AIC_c weight for eastern pipistrelle included live BA and measures of understory density. Probability of occupancy for eastern pipistrelle was directly related to density at 1–2 m and inversely related to density at 2–3 m. Increased density of vegetation from 2–3 m represented a greater amount of shrubs and midstory vegetation in the forest, creating additional obstacles during commutes from roosting sites to foraging areas. Meanwhile, increases in vegetation density from 1–2 m represented greater density of lower shrubs, which may indicate a less dense midstory and greater light levels reaching the forest floor. This pattern represents additional evidence that changes in structural complexity beneath the forest canopy impact the occupancy of a site by eastern pipistrelle.

Aspect and slope were components of the model with the second-highest AIC_c weight for the red bat and the probability of occupancy decreased with deviance from south. This trend may be linked to thermoregulation needs during diurnal roosting periods since less solar exposure might compromise the increased energy requirements of lactating females and developing young (Crampton and Barclay 1998). Hutchinson and Lacki (2000) noted that red bats prefer upland habitats rather than bottomland habitats and attributed this habitat preference to increased solar radiation. Probability of red bat occupancy decreased as percent slope increased.

The most parsimonious model for the Indiana bat indicated a direct relation between the probability of occupancy and BA of large-diameter snags. Previous studies have indicated the use of large-diameter trees and snags by Indiana bats as roosting sites for maternity colonies (Callahan et al. 1997, Foster and Kurta 1999, Britzke et al. 2003, Carter and Feldhamer 2005). Larger snags can contain larger cavities and areas of loose bark, providing greater-capacity roosts for sheltering numerous bats. This increase in numbers of individuals in a roost provides greater thermoregulatory benefits for pup-rearing females in maternity colonies through concentrating of body heat. Other benefits may include possible information transfer among individuals within the same roost about quality foraging areas (Wilkinson 1992).

Surprisingly, the local-site model consisting of distance to water was ranked low for all species. Water is a dominant foraging habitat for several bat species (Krusic et al. 1996, Menzel et al. 2001, 2003, 2005*b*, Johnson 2002). This model was not included in any of the averaged models at the local-site scale, possibly attributed to the coarse scale at which we measured water. Owing to the ephemeral nature of many stream systems in the Ozark Highlands region (Nigh and Schroeder 2002), the land cover classification of water we used included only permanent water sources in the landscape easily visible from satellite imagery, and represents an under-representation of aquatic or riparian habitat.

Landscape Level

The global model including all covariates included in landscape models had the greatest amount of support for red bat, indicating that no one model was able to adequately predict occupancy of this species. Similarly, Elmore et al. (2004) failed to find distinguishing landscape characteristics influencing red bat roost selection, attributing this to the ubiquitous nature of foliage roost sites. Ecological subsection had the next-largest support for prediction of red bat occupancy. Additional investigation is necessary to further determine differences among these 4 subsections of the Ozark highlands. A third relevant model included a direct relationship with proportion of upland deciduous forest and an inverse relationship with mean patch size. Increase in upland deciduous forest type in the landscape would represent an increase in roosting habitat (Hutchinson and Lacki 2000).

The most parsimonious model for the northern long-eared bat indicated an inverse relation between occupancy and shape index. Higher values of shape index indicate a greater amount of edge in the landscape and can result in less core area of forest. Northern long-eared bats are associated with forested areas, roosting in snags and trees (Sasse and Pekins 1996, Waldien et al. 2000, Menzel et al. 2002), and foraging beneath the forest canopy (LaVal et al. 1977, Schwartz and Schwartz 2001, Owen et al. 2003, Ford et al. 2005). Our findings agree with studies that suggest this species requires contiguous tracts of forest cover (Lacki and Schwierjohann 2001, Owen et al. 2003). The model with the next-highest AIC_c weight for describing northern long-eared bat occupancy again inferred an inverse relationship with shape index, but it additionally suggests an inverse relationship with levels of contagion in the landscape. As cover type interspersion became greater, the probability of occupancy increased; therefore, it appears that fragmentation has no obvious negative influence on northern long-eared bats at levels found in these 2 watersheds. It should be noted that in the landscapes studied, the interspersion represents parcelization of different forest types rather than fragmentation by nonforested cover type.

Indiana bat occupancy at the landscape scale was directly related with the proportion of landscape in nonforested land cover type. Many studies have shown that Indiana bats roost and forage in forested and forest riparian areas (LaVal et al. 1977, Callahan et al. 1997, Ford et al. 2005, Menzel et al. 2005*a*), suggesting that increased proportion of nonforested area in the landscape should decrease the habitat occupancy of an area. Menzel et al. (2005*a*) tracked foraging Indiana bats and found that they avoided open areas, preferring bottomland forests and linear landscapes; however, the landscape in that study consisted of only 33% forested land cover, compared to 90% in our study. Miller (1996) found no significant difference in Indiana bat presence between forest- and nonforest-dominated landscapes in northern Missouri; however, Sparks et al. (2005) found that while Indiana bats foraged in forested areas more than expected by availability, they did spend nearly 50% of the time foraging over agricultural land cover types. Our results suggest that in a southern Missouri landscape dominated by forest cover, nonforest areas may provide landscape heterogeneity fulfilling some habitat requirement not provided in a fully forested landscape.

Caveats

Although acoustic data may provide insight into trends in bat activity, caution should be taken when using results to develop management plans. Inability to distinguish among individuals and sexes within species as well as variability in detectability can lead to limited interpretation of species data collected acoustically. Difficulty in separating certain groups, such as *Myotis,* must be acknowledged and efforts made to avoid errors in classification of recorded calls. One method of minimizing errors drawn from misidentified call sequences is to combine similar species into groups or clades. We chose not to combine since it may result in the homogenization of habitat characteristics among and between bat species. While acoustic detection methods indicate the presence of bats, these methods provide little insight into how bats are using the site, a primary concern when developing management plans. Using recent methods incorporating detection probability addresses some of the limitations associated with acoustic sampling. Results from this study demonstrate the need to further investigate habitat relationships for bats in the Missouri Ozark region.

Management Implications

Several species of bats are endangered or of special concern, making it important to include bat habitat considerations when developing management plans. The St. Francis and Black River watersheds are dominated by contiguous forest cover, yet even within a landscape with little fragmentation, our data indicate that bat occupancy rates can be influenced by forest-management practices. We found trends indicating that occupancy rates of red bat and eastern pipistrelle were higher in stands with a more open understory, particularly from 2–3 m in height. Our study also suggests that management practices promoting retention of large-diameter snags (>30-cm dbh) may provide valuable roosting habitat for the federally endangered Indiana bat. In addition, our results showed that in a heavily forested landscape some heterogeneity in land cover may fulfill some additional habitat requirements for both Indiana and northern long-eared bats.

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Review of the Forest Habitat Relationships of the Indiana Bat (*Myotis sodalis*)

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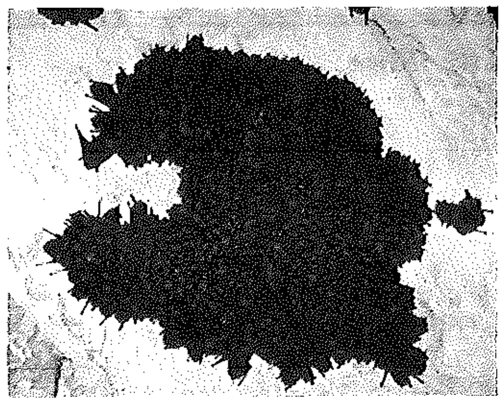

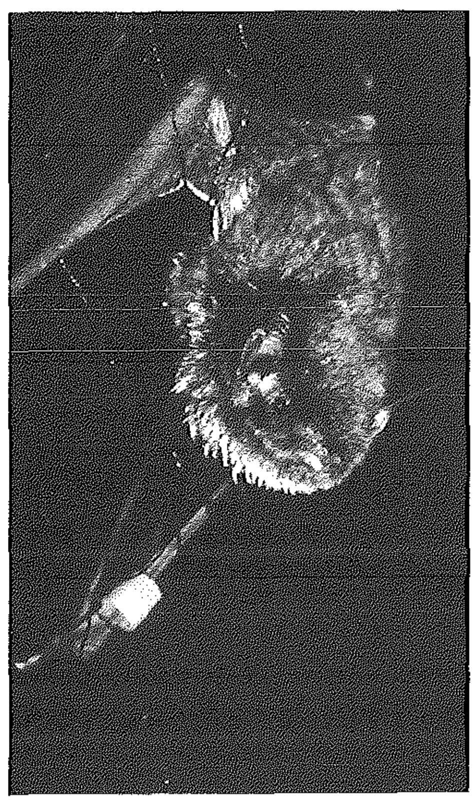

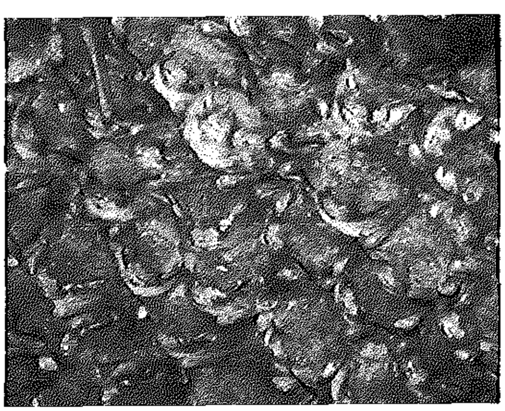

Abstract

Reviews the available literature on the ecology of the endangered Indiana bat (*Myotis sodalis*), including its selection of and use of hibernacula, roost trees, and foraging habitat. An extensive list of published references related to the Indiana bat is included.

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Contents

Introduction

The estimated population of the small, insectivorous Indiana bat (*Myotis sodalis*) totaled approximately 350,000 following a census conducted in 1995-97. This represents a decrease in population of nearly 400,000 since the 1960's (USDI Fish and Wildl. Serv. 1996). Officially listed as an endangered species in 1967, *M. sodalis* has seen its population continue to decline despite efforts to protect its winter habitat. As a result, scientists are studying how forest management techniques affect the summer habitat and foraging areas of the Indiana bat.

The Indiana bat closely resembles other *Myotis* species, all of which have brown pelage and a nondescript appearance. *M. sodalis* commonly are mistaken for the little brown myotis (*Myotis lucifugus*), but is differentiated from other myotid bats within its range by the presence of short toe hairs (not extending beyond knuckle), a small foot (9 mm), and a keeled calcar. The pelage is generally dull and pinkish-brown dorsally. Length measurements of the Indiana bat throughout its area of distribution produced the following ranges (in mm): total length, 70.8 to 90.6, tail, 27 to 43.8, hind foot, 7.2 to 8.6, forearm, 36 to 40.4. Measurements of weight ranged from 5 to 11 g (Whitaker and Hamilton 1998).

The distribution of this species is generally associated with limestone caves in the Eastern United States. The northern extent of the range extends southward from New England to the panhandle of Florida (excluding the Atlantic Coast). The western margins of the range include the Ozark Plateau of Missouri, Arkansas, and Oklahoma. *M. sodalis* roost in trees during the summer and hibernates in caves and mines during the winter. Most of the Indiana bat population occupies only nine winter hibernacula located in Indiana, Kentucky, and Missouri (USDI Fish and Wildl. Serv. 1996).

We conducted an extensive review of the literature on the natural history of the Indiana bat, particularly those aspects that might be influenced by forest management. We particularly sought information on hibernacula selection, tree roosts in spring, summer, and fall, and use of foraging habitat in summer and during fall swarm. Information on hibernacula, roosting, and foraging is summarized in Tables 1-3 in the Appendix.

Indiana Bat Hibernacula

Distribution of Caves

Since 1960, most (85+ percent) Indiana bats have used nine Priority I hibernacula caves/mines in Indiana (n=3), Kentucky (n=3), and Missouri (n=3) (Hall 1962; Humphrey 1978; Richter et al. 1978; USDI Fish and Wildl. Serv. 1996). Priority I hibernacula contain at least 30,000 bats (USDI Fish and Wildl. Serv. 1996). The remaining 15 percent of Indiana bats have been or currently are distributed among 50+ Priority II and III hibernacula in the aforementioned states and Alabama, Arkansas, Connecticut, Georgia, Illinois, Iowa, Massachusetts, Michigan, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin (Humphrey 1978; Dunn and Hall 1989; USDI Fish and Wildl. Serv. 1996). Priority II and III caves contain 500 to 30,000 and fewer than 500 hibernating bats, respectively. The small number of Priority I hibernacula means that fewer, peripheral hibernacula have significant importance in the protection of Indiana bats (Gates et al. 1984; Hobson and Holland 1995). Most hibernacula are found west of the Appalachian Mountains (though some are found in the Ridge and Valley and the southern Blue Ridge provinces) and are centered on the lower Ohio River Valley area of southern Indiana, eastern and central Kentucky, and the eastern Ozark Plateau region in Missouri. Hall (1962) hypothesized that this distribution is related to both cave suitability/availability and proximity to major river courses that are used for annual migration. Most Indiana bats return to the same cave or localized cave cluster each fall (Griffin 1940; Hall 1962; LaVal and LaVal 1980).

Cave Characteristics

Because the number of Indiana bat hibernacula is limited relative to other species (Raesly and Gates 1986), the physical and microclimatic characteristics of the known hibernacula are well documented (Hall 1962; Myers 1964; Henshaw 1965; Henshaw and Folk 1966; Barbour and Davis 1969; LaVal et al. 1976; LaVal and LaVal 1980; Clawson 1984; Harvey and McDaniel 1986; Brack et al. 1984; Raesly and Gates 1986; Saugey et al. 1990; USDI Fish and Wildl. Serv. 1999; Tuttle and Kennedy 1999). Variables that influence the suitability of caves for hibernacula include size of cave entrance, size and configuration of cavern room and passageway, ceiling structure, airflow, temperature, fluctuation in seasonal temperatures, humidity, previous occupancy by Indiana bats, and occupancy by other species (Hall 1962; Raesly and Gates 1986).

Occupied hibernacula have noticeable airflow (Henshaw 1965). Tuttle and Kennedy (1999) hypothesized that Indiana bats prefer hibernacula with the lowest nonfreezing temperatures possible. Core range (Indiana, Kentucky, and Missouri), midwinter cave temperatures of 2° to 5°C have been reported for Indiana bat cluster sites (Hall 1962; Henshaw 1965; Henshaw and Folk 1966; Thomson 1982). However, Barbour and Davis (1969) and Humphrey (1978) found hibernacula temperatures ranging from −1.6° to 17°C across the entire wintering season and hibernating range. Using continually recording data loggers, Tuttle and Kennedy (1999) recorded an overwinter range of −8.3° to 13.1°C from 15 important hibernacula in Kentucky (4), Illinois

(1), Indiana (5), Missouri (3), Tennessee (1), and Virginia (1). A retrospective analysis of temperature and population trend for some of these caves revealed population increases in four of six caves where overwinter temperatures ranged from 3° to 7.2°C and population declines in all four caves/mines where overwinter temperatures exceeded 8.1°C or were less than 0°C (Tuttle and Kennedy 1999). Hibernacula temperatures in Arkansas and Oklahoma and in Maryland, Virginia, and West Virginia typically are warmer (7° to 10°C) than caves in other portions of the range (Harvey and McDaniel 1986; Raesly and Gates 1987; Saugey et al. 1990). Warmer temperatures may increase metabolic rates in Indiana bats and cause premature fat depletion during the hibernation period (Richter et al. 1993). Stable midwinter temperatures of 1° to 10°C may represent a thermal threshold for hibernacula occupancy by *M. sodalis* (Clawson 1984).

Relative humidity ranged from 70 to nearly 100 percent in most hibernacula surveyed (Hall 1962; LaVal et al. 1976; Humphrey 1978; Tuttle and Kennedy 1999). Large caves, such as those in the Mammoth Cave and nearby systems in Kentucky, generally are too dry for the Indiana bat (Hall 1962). Raesly and Gates (1986) quantitatively compared hibernacula microhabitat and microclimate variables for Indiana bats, eastern pipistrelles (*Pipistrellus subflavus*), little brown myotis, northern long-eared myotis (*M. septentrionalis*), and big brown bats (*Eptesicus fuscus*). Relative to cave conditions chosen by other bat species, Indiana bats occupied open cave ceiling areas where the ambient air temperature and cave wall temperature were lowest, relative humidity was highest, and airflow was greatest. Because Indiana bats cluster in large groups in most hibernacula, intraspecific spacing was lowest among all species surveyed. *M. sodalis* clusters can reach densities of 3,000 per m^2 (Barbour and Davis 1969). Raesly and Gates (1986) also compared microhabitat and microclimate variables between occupied (n = 8) and unoccupied (n = 42) caves and mines. They found that Indiana bat hibernacula tended to have larger openings (9.7 vs. 2.8 m^2) and cave passages (858.8 vs. 131.6 m), and higher ceilings (13.2 vs. 6.3 m) than unoccupied sites.

Hibernation Chronology and Ecology

Indiana bats arrive at hibernacula or hibernacula areas (< 5 km radius of hibernacula) from mid-August to October (Kiser and Elliot 1996) and November (Hall 1962; Humphrey 1978). Copulation occurs during this time (LaVal and LaVal 1980), though ovulation, fertilization, and implantation do not occur until females have left hibernacula in the spring (Thomson 1982). Intense foraging and subsequent fat deposition critical for the wintering period occur after arrival at hibernacula and prior to cessation of aboveground activity in October for females and November for males (Humphrey 1978; Kiser and Elliot 1996).

In late summer and fall, Indiana bats swarm or gather in large numbers near cave entrances. The reason for this swarming behavior is not completely understood, but is possibly related to mating behavior. Early researchers mistakenly believed that sex ratios were skewed toward males because their netting efforts occurred in the late swarm after most females had entered hibernacula for the winter season (Hall 1962). Intercave movements may occur from the latter portion of the swarm to the early portion of the hibernation period. Consequently, population estimation using banding and mark-recapture techniques is unreliable if focused solely on single caves within this period (Clawson and Sheriff 1982).

Arrival weights of bats at the hibernacula range from 6 to 10 g (Hall 1962; Kiser and Elliot 1996). During the early swarm, *M. sodalis* roost in the warmer portions of the hibernacula and forage nightly to build fat reserves (Hassel 1967; Kiser and Elliot 1996). Prior to hibernation, females reach a maximum mass of 8.9 g vs. 8.0 g for males (LaVal and LaVal 1980). Fecal analysis of netted Indiana bats revealed that prehibernation diets were dominated by Lepidoptera (28.5 to 34 percent), Coleoptera (15.9 to 40.2 percent), Homoptera (4.5 to 15.3 percent), and Diptera (14.8 to 28.2 percent).

Exposure to and accumulation of environmental contaminants could occur during the prehibernation period of intense foraging and rapid fat deposition (Reidinger 1972). Contaminants were directly implicated in some local extirpations and are suspected as a factor in the decline of insectivorous bat species in North America (Clark 1981). Body burdens of organochlorine insecticides (now banned for agricultural use in the United States) in insectivorous bats were higher in modified agricultural landscapes than in wild or seminatural landscapes (Reidinger 1976). Clark and Prouty (1976) found lower pesticide burdens in eastern pipistrelles, northern long-eared myotis, and big brown bats near known *M. sodalis* hibernacula sites in forested areas of West Virginia where industrial facilities and agricultural land were largely absent. McFarland (1998) reported that Indiana bats in northern Missouri were routinely exposed to agricultural pesticides. Little brown myotis and northern long-eared myotis collected in northern Missouri in 1996 contained residues of eight historically applied organochlorine insecticides and two synthetic pyrethroids. Further, depressed brain acetylcholinesterase levels in these bats showed evidence of exposure to organophosphate and/or carbamate insecticides (McFarland 1998). Little is known about Indiana bat-pesticide relationships (USDI Fish and Wildl. Serv. 1996).

During the prehibernation swarming period in the mountainous and heavily forested Cumberland Escarpment and Cliff section of eastern Kentucky, Kiser and Elliot (1996) used radiotelemetry to determine that

Indiana bats foraged more on upper slopes and xeric ridgelines with second-growth chestnut oak (*Quercus prinus*)-pine (*Pinus* spp.) and oak-hickory (*Carya* spp.) forests than in riparian areas or moist slope-cove forests. LaVal et al. (1977) and Brack (1983) reported that chemiluminescent light-tagged Indiana bats foraged over oak-hickory forested hillsides and ridgetops in Missouri and upland habitats in Indiana, respectively, during the early swarm, prehibernation period. Kiser and Elliot (1996) hypothesized that cooler autumn temperatures (and subsequent cold-air drainage in locations with hilly or mountainous relief) limit insect abundance and activity in riparian areas and sheltered cove forests, whereas upper slopes and ridgelines have more favorable "warm" exposures. The maximum size of Indiana bat foraging areas during October, including the cave site, was 318 ha in 1994 and 194 ha in 1995; travel distances from the cave site were ≤ 2.5 km (Kiser and Elliot 1996).

Indiana bats periodically use tree roosts during the fall swarm. In eastern Kentucky, these roosts were located predominately in medium-size hardwood snags (mean diameter breast height [d.b.h] of 27.0 cm) within small forest openings or canopy gaps (Kiser and Elliot 1996). On the Fernow Experimental Forest in West Virginia, Indiana bats chose similar-size tree roosts (mean d.b.h. of 33.1 cm) in the early swarm period. However, 80 percent of the roosts were in live trees rather than snags (Thomas Schuler, Northeastern Research Station, unpubl. data). Neither study quantitatively measured use versus availability of tree roosts.

The relationship between hibernacula of *M. sodalis* and landscape features is poorly understood (USDI Fish and Wildl. Serv. 1996). Raesly and Gates (1986) found that hibernacula occupied by Indiana bats in Maryland, Virginia, and West Virginia ($n = 8$) tended to have more surrounding forest cover and less area in cultivated fields within a radius of 1 km than unoccupied caves and mines ($n = 42$). However, the authors cautioned that more meaningful habitat analyses during the swarm period must include measures of insect abundance and availability.

Kiser and Elliot (1996) suggested that all snags within 2.5 km of hibernacula be retained and encouraged snag creation through girdling and reforestation of abandoned pastures and reclaimed surface mines with native hardwood tree species. Clawson (1984) reported that deforestation around hibernacula has decreased available foraging habitat throughout the Indiana bat's range during prehibernation.

Wintering

The inactive hibernation period for Indiana bats is approximately 190 days (October to April for females, November to May for males) depending on the hibernacula (Hall 1962). Indiana bats form large clusters in cooler hibernacula or cooler portions within hibernacula and smaller, more transient clusters in warmer hibernacula (Hall 1962; Thomson 1982). Indiana bats are true hibernators (Guthrie 1933; Thomson 1982); though, they arouse every 8 to 10 days (Hardin and Hassell 1970). *M. sodalis* that use low roosts in Great Scott Cave in Missouri moved throughout winter to areas within the cave with more optimal temperatures (Tuttle and Kennedy 1999).

Arousal following disturbance (e.g., by spelunkers, scientists, predators) can be detrimental, and may be one of the greatest threats to *M. sodalis* (Hall 1962; Myers 1964; LaVal et al. 1976; Humphrey 1978; LaVal and LaVal 1980; Brack et al. 1984; Clawson 1984). Mild sound and light stimuli can initiate arousal (Humphrey 1978), as can a drop in cave humidity below 85 percent (Tuttle and Kennedy 1999). Sudden arousal is accompanied by excessive agitation, movement and in-cave flight that can expend 20 to 30 days of stored energy reserves (Daan 1973). Sudden arousal events can accelerated fat depletion, result in premature emergence from hibernacula, and lower body condition and survival in spring (Clawson 1984; Tuttle and Kennedy 1999). Even in the absence of disturbance, weight loss in early winter is rapid. Bats lose 0.016 g/day, slowing to 0.008 g/day by mid- to late winter (Hall 1962).

Indiana bats are particularly vulnerable to vandalism during hibernation (Dunn and Hall 1989) as many instances of wanton destruction of bat colonies have been documented (Hall 1962; Myers 1964; LaVal et al. 1976; Humphrey 1978; LaVal and LaVal 1980; Brack et al. 1984; Clawson 1984). Potential or historic hibernacula that regularly are disturbed will not support wintering *M. sodalis*. In most instances, recolonization following cave protection has not occurred (Harvey and McDaniel 1986). Entry by humans into Indiana bat hibernacula should be prohibited from September through May (Humphrey 1978; LaVal and LaVal 1980; Clawson 1984; USDI Fish and Wildl. Serv. 1996).

Improperly designed cave gates that alter cave airflow regimes (particularly trapping warm air) reduce and in some instances make hibernacula unsuitable (Tuttle 1977; Humphrey 1978; Richter et al. 1993; Tuttle and Kennedy 1999). Tuttle and Kennedy (1999) suggested restoring airflow or improving temperature regimes in 15 Indiana bat hibernacula by removing entrance obstructions, building cold-air dams, or installing ventilation shafts. Cave-specific recommendations are dependent on cave characteristics and the extent of anthropogenic alteration.

Numerous instances of intra- and inter-hibernacula movements by Indiana bats have been documented (Myers 1964; Hardin and Hassell 1970; Fenton and Morris 1976). Although most movement were attributed to cave disturbance by humans (Myers 1964; LaVal and LaVal 1980), *M. sodalis* will move within caves during hibernation to roost sites where microclimatic conditions are better (Tuttle and Kennedy 1999). Generally, midwinter movements are limited to intra-hibernacula sallies in colonies that are minimally disturbed; colonies subjected to frequent or intense human disturbance will shift hibernacula (Myers 1964). Hall (1962) believed that Indiana bats wintering in Coach Cave, Kentucky, engaged in midwinter feeding during warm weather based on the presence of fresh fecal discharge of chitin.

Indiana bats in hibernacula also are vulnerable to natural disturbances. Local catastrophes can have tremendous conservation implications because of the limited number of hibernacula (Hall 1962). Midwinter flooding of caves can cause significant mortality by drowning trapped bats or inducing energy-expensive arousal (Cope and Ward 1965). Hibernating *M. sodalis* can freeze to death in caves that trap and hold cold air during periods of unseasonably frigid temperatures (Humphrey 1978; Richter et al. 1993). Ceiling collapses, which have killed Indiana bats and blocked passageways in mine sites (Hall 1962; Humphrey 1978), can occur in caves and mines (USDI Fish and Wildl. Serv. 1996).

Emergence

Indiana bats emerge from hibernacula from mid-April through May (Hobson and Holland 1995). Females typically leave caves before males (Humphrey 1978; LaVal and LaVal 1980); they are not visibly pregnant at emergence (LaVal and LaVal 1980). The chronology and patterns of female movements to maternity areas are unknown. Smaller caves in the hibernacula area may serve as "spring movement" roosts for Indiana bats following initial emergence (Myers 1964). Hobson and Holland (1995) tracked a single radio-marked male Indiana bat for 2 weeks following mid-May hibernacula emergence in western Virginia. The bat traveled 16 km from the hibernaculum to forage over a 625-ha patch of mature, second-growth, oak-hickory forest with a hemlock (*Tsuga canadensis*) riparian component. Diurnal roosting during this period occurred in a mature shagbark hickory (*C. ovata*) with other male Indiana bats. Additional identification of postemergence foraging and roosting habitat may be required for meaningful efforts designed to protect Indiana bats (Hobson and Holland 1995).

Research Questions and Needs

There are several important research questions related to Indiana bat hibernacula that remain to be addressed:

1. What landscape-scale characteristics and biological factors are ecologically important to Indiana bats with respect to hibernacula? Since all Priority I and II, and most Priority III, hibernacula sites probably are known, an attempt should be made to distinguish landscape and land-use features for hibernacula where *M. sodalis* is increasing, stable, or declining. The effects of forest management directly around hibernacula on the microclimate and suitability of the mines/caves should be identified. Researchers should use remote-sensing and GIS technologies with data from Indiana, Kentucky, and Missouri to examine the relationship of forest cover, type, and structure/age to population trends of hibernacula. Because only three radiotelemetry studies have addressed pre- and posthibernation habitat and roost selection, a geographically expanded program using radiotelemetry should be undertaken for a more complete understanding of Indiana bat foraging and roost selection. If bats rely on this period to accumulate overwinter energy stores, this aspect of the biology of *M. sodalis* may prove the most crucial to conservation efforts. Concomitant efforts are needed to more clearly identify Indiana bat food habits during prehibernation and postemergence across its entire range. The relation between insect abundance and availability and *M. sodalis* population densities and trends among hibernacula also should be explored.

2. What is the continued vulnerability of Indiana bats to pesticide exposure during the prehibernation swarm and postemergence? Considering the proximity of large agricultural landscapes to most Priority I hibernacula, is there a continued and measurable bioaccumulation of organochlorines? What other unknown environmental contaminant burdens do Indiana bats currently face, e.g., organophosphate insecticides and heavy metals? Could environmental contaminants that singularly occur at harmless tissue concentrations act in synergistic fashion to cause Indiana bat mortality or to lower overall fitness and survival? What role does insecticide use play in decreasing insect abundance and *M. sodalis* foraging efficiency during the prehibernation swarm or postemergence?

3. Should wintering colonies of Indiana bats be considered in the context of genetically or evolutionarily significant management units because of the extreme philopatry they show toward an individual hibernaculum, and because breeding occurs upon hibernacula arrival during the swarm? Accordingly, natural recolonization and use of historical but abandoned hibernacula following restoration and protection may not occur or at a rate too slow to overcome population declines. How can recolonization of historical hibernacula by Indiana bats be encouraged or enhanced via active management?

Spring, Summer, and Fall Roosting Habitat

General Roosting Ecology

Female Indiana bats form small maternity colonies (usually <100) under exfoliating bark during the summer months (Whitaker and Hamilton 1998). A single young is born in early summer (Mumford and Calvert 1960). Maternity colonies usually are composed only of females and young (Humphrey et al 1977) with the males roosting separately (Hall 1962). Young usually are volant by early to mid-July (Humphrey et al. 1977). Maternity roosts most commonly are located in bottomland or riparian areas (Gardner et al. 1991b; Callahan et al. 1997). However, maternity roosts occasionally have been found in other areas, e.g., pastures and upland hardwoods (Kurta et al. 1993a; Whitaker and Hamilton 1998). Male summer roosts can be found in a variety of locations. In Illinois, bachelor colonies of 1,000 to 1,500 were located in an abandoned mine. Other roosts of males have been found under exfoliating bark (Gardner et al. 1991b).

Indiana bat roosts used during spring, summer, and autumn can be placed into one of two categories: primary or alternate (Callahan et al. 1997). Primary roosts are trees that are used by more than 30 bats on more than one occasion. Alternate roosts are used by fewer individuals. Both roost types are essential to meet the maternity requirements of *M. sodalis*. Although a 30-bat threshold may not be applicable to all colonies (especially to those with fewer than 30 bats), the concept of primary and alternate roosts is used throughout this section.

Tree Species Used/Preferred

One of the earliest reported maternity roosts of the Indiana bat was a primary roost in a bitternut hickory (*C. cordiformis*) snag and an alternate roost in a live shagbark hickory (*C. ovata*; Humphrey et al. 1977). Roosts in living trees are most commonly found in shagbark hickory (Gardner et al. 1991b; Callahan et al. 1997). Indiana bats roost in snags of many tree species, including red (*Acer rubrum*), silver (*A. saccharinum*), and sugar (*A. saccharum*) maple, bitternut, shagbark, and pignut (*C. glabra*) hickory, cottonwood (*Populus deltoides*), white (*Fraxinus americana*), black (*F. nigra*), and green (*F. pennsylvanica*) ash, American sycamore (*Platanus occidentalis*), white (*Q. alba*), scarlet (*Q. coccinea*), shingle (*Q. imbricaria*), northern red (*Q. rubra*), and post (*Q. stellata*) oak, eastern hemlock (*Tsuga* canadensis), sassafras (*Sassafras albidum*), and American (*U. americana*) and slippery (*Ulmus rubra*) elm (Brack 1983; Gardner et al. 1991b; King 1992; Kurta et al. 1993a; Caryl and Kurta 1996; Kurta et al. 1996; Salyers et al. 1996; Callahan et al. 1997). In Kentucky, Indiana bats may roost in Virginia pine (*P. virginiana*) and shortleaf pine (*P. echinata*) and females also may use sourwood (*Oxydendum arboreum*) in autumn and early spring (Kiser and Elliott 1996; MacGregor et al. 1999).

Some biologists consider the previously mentioned tree species as "acceptable" (Gardner et al. 1991b; Rommé et al. 1995). However, new tree species frequently are added to this list (MacGregor et al. 1999), so it may be premature to consider the list as definitive. Except for Kurta et al. (1996), all reports of roost-tree preference are observational. Statistical designs were not used to test preference, though Kurta et al. demonstrated that Indiana bats prefer green ash to silver maple. Silver maple also was documented as a roost tree in other studies (Gardner et al. 1991b; Callahan et al. 1997).

The use of snags by Indiana bats may be influenced by bark characteristics. Because virtually all maternity roosts are found under exfoliating bark, the characteristics of a species as a snag may be more important than the tree species on which the bark is present (Rommé et al. 1995).

Indiana bats also use artificial roost structures. In central Indiana, Salyers et al. (1996) found two male *M. sodalis* roosting in a bat box. Using radiotelemetry, they tracked one bat to other bat boxes and a cedar shake garland. Butchkoski and Hassinger (2001) found a maternity colony roosting in the attic of a church in Pennsylvania. Wilhide et al. (1999) found a male Indiana bat roosting under the metal brackets of a utility pole top in the Ozark National Forest in Arkansas, and Mumford and Cope (1958) made two references to *M. sodalis* males roosting under bridges in Indiana.

Tree Condition

Although, some alternate roosts occur in living trees (primarily shagbark hickory), most Indiana bats roost in dead or dying trees. One of the two roost trees reported by Humphrey et al. (1977) was a live shagbark hickory. About 10 percent of the roost trees from Illinois reported by Gardner et al. (1991b) and 28 percent of the trees reported by Callahan et al. (1997) were classified as live. Live and dead trees may differ in protection from rain and solar radiation provided by their canopy as rates of heat loss (Humphrey et al. 1977; Garner et al. 1991b; Callahan et al. 1997).

Structural Characteristics of Roost Trees

Few maternity colonies have been located in tree cavities. Most primary maternity roosts are situated under exfoliating bark. The ability of a tree species to produce exfoliating bark probably influences Indiana bat use (Callahan et al. 1997; Rommé et al. 1995). Both Kurta et al. (1996) and Callahan et al. (1997) found that the quantitative amount of loose, peeling bark did not differ between roost trees used and random snag samples not used. These studies did not address the qualitative features of exfoliating bark.

Most maternity roosts are found in large trees. The average diameter for all roosts described by Gardner et al. (1991b) was 36.7 (range: 8 to 83 cm); the four roosts with the largest numbers of bats averaged 40 cm d.b.h. Primary roost trees described by Callahan et al. (1997) averaged 58.4 ± 4.5 cm d.b.h. Alternate roosts averaged 53.0 ± 4.1 cm d.b.h. Kurta et al. (1996) found that the average diameter of Indiana bat tree roosts (0 = 40.9 ± 1.2 cm; range: 30 to 52 cm) were significantly less variable than the average diameter of random trees (0 = 33.4 ± 1.4 cm; range: 11 to 70 cm).

The results of studies examining roost tree size effect on selectivity are conflicting (Kurta et al. 1996; Callahan et al. 1997). Gardner et al. (1991b) arbitrarily concluded from 48 roost trees that dead trees at least 22 cm d.b.h provided essential *M. sodalis* roosting habitat, but their designation of appropriate species was limited to tree species that they documented. Additionally, Indiana bats sometimes roost in snags smaller than 22 cm d.b.h and in species not found in Gardner et al.'s (1991b) list. The spring and autumn roosts of male Indiana bats do not differ greatly in size from those used during summer. Autumn and spring roosts reported from western Virginia and Kentucky ranged from 8.4 to 86.6 cm d.b.h, with a mean of 31 cm (Hobson and Holland 1995; Kiser and Elliott 1996; MacGregor et al. 1999).

Solar Exposure and Spatial Relation to Neighboring Trees

Most primary roosts are well exposed to extensive solar radiation. However, some alternate roosts are completely shaded while others are totally exposed. Indiana bats may pick maternity roosts with high solar exposure to increase the roost temperature, which might decrease the time of fetal development and juvenile growth (Callahan et al. 1997). However, because males are not associated with maternity colonies and the need for high roosting temperatures (Callahan et al. 1997), they may seek cooler roosts to conserve energy.

Gardner et al. (1991b) reported that most Indiana bat roosts in Illinois were beneath the forest canopy. However, canopy closure was estimated using multiple readings with a spherical densiometer taken near tree bases. These readings would most accurately reflect canopy closure of the forest where the roost was located rather than solar exposure of the roost. Callahan et al. (1997) considered roosts as open (exposed to solar radiation) or interior (less than 50 percent canopy cover) and found all primary roosts in open snags. Live interior roost trees averaged 70 percent canopy closure and were more open on the western aspect than random live trees. Interior snags used as roosts averaged 60 percent canopy closure and were more open on all aspects than random interior snags. MacGregor et al. (1999) reported that canopy closure ranged from 20 to 93 percent for male Indiana bat roosts (0 = 80 percent). However, MacGregor et al. (1999) noted that there is no effective method for measuring the canopy closure (solar exposure) at the actual roost. And tools such as the spherical densiometer, fisheye photography, and competition indexes used to assess canopy closure can yield different results (Cook et al. 1995; Comeau et al. 1998).

Different methodologies might explain discrepancies among studies of primary roosts and solar exposure. Reports of solar exposure for alternate roosts range from complete shade to total exposure. Alternate roosts are used when conditions in the primary roost are suboptimal (Callahan et al. 1997). Because conditions that make roost sites temporarily uninhabitable can vary (e.g., extreme high or low temperatures, precipitation), the structural characteristics of alternate roosts also vary.

In addition to canopy cover, roost height also affects the degree of solar exposure. The average height of closed-canopy roost trees used as primary maternity roosts in Illinois was 7.8 m (Gardner et al. 1991b). The average height of alternate roosts used by females was 6.4 m in areas under a forest canopy, 5.2 m in areas with a "patchy" forest canopy, and 2.7 m in trees in the open. Although not compared statistically, this trend shows that females tended to roost higher in the canopy in closed-canopy forests.

Roost heights may vary with canopy cover so that bats can to maintain a relatively constant level of solar exposure. Callahan et al. (1997) reported that 45 percent of maternity roosts in Missouri were in open areas and that more Indiana bats used open-area than closed-canopy roosts. The maternity colony in Michigan roosted in snags in the middle of a flooded pasture turned wetland (Kurta et al. 1996). All snags were unshaded and the mean roost height was 9.9 m (± 0.9; range: 1.4 to 18 m).

Male Indiana bats exhibit different habits with regard to roosting height and solar exposure. Gardner et al. (1991b) found that the average roost height used by males was 4.2 m (4.9 m in closed canopy and 3 m in "patchy" canopy). They also reported only one male roost from an open canopy at a height of 4 m. A male Indiana bat tracked in western Virginia by Hobson and Holland (1995) roosted at a height exceeding 8 m each night for 19 consecutive nights.

Canopy Cover of Stands

The canopy cover in stands used by Indiana bats is described inadequately, though stand characteristics can be inferred from Gardner et al. (1991b), Kurta et al. (1996), and Callahan et al. (1997). Methods used by Gardner et al. to measure canopy closure best describe closure at the stand level. Of 48 roosts that they found in forested habitats, 32 were in closed-canopy forests, 12 were in intermediate forests, and 4 were in open-canopy forests. All roosts reported by Kurta et al. (1996) were from a 5-ha flooded wetland where all trees were dead or dying. This wetland had an open canopy. The American sycamore roost reported by Kurta et al. (1993a) was unshaded indicating reduced canopy closure. In Missouri, Callahan et al. (1997) calculated the canopy closure of random trees located within the stand as an indication of stand canopy closure. Forest canopy closure averaged nearly 70 percent for all non-used trees.

Spatial Relationship of Roost to Water Sources and Foraging Areas

The proximity of Indiana bat roosts to water sources and foraging areas has not been well studied. Two roost trees reported by Humphrey et al. (1997) in Indiana were located less than 200 m from the creek that *M. sodalis* used for foraging. A roost tree described by Brack (1983) was on the bank of the Blue River in Indiana. Also in Indiana, Kurta et al. (1993a) reported a hollow sycamore roost that was 28 m from a dry intermittent stream and 2 km from the nearest perennial stream. Roost trees described by Kurta et al. (1996) were located within a 5-ha Michigan wetland inundated with as much as 1 m of water. The bats left this area each night to feed in the surrounding landscape that was composed of agricultural lands (pasture and corn), woodlots, and an extensive riparian strip of woods. All colonies reported by Callahan et al. (1997) were located near a stream or river.

Gardner et al. (1991b) reported distances from roosts to foraging areas in Illinois as great as 3,200 m (post-lactating female), with approximately equal distances for pregnant and lactating bats (1,000 m). Juveniles and adult males traveled about half the distance of females as their roosts were closer to streams than any other habitat feature measured. The mean distance between all Indiana bat roost trees tracked to the nearest intermittent stream was 124 m. In western Virginia, a single adult male Indiana bat repeatedly traveled 1 km from its roost site to foraging areas that included a stream and a road (Hobson and Holland 1995).

Spatial Relationship to Other Roost Trees

There is considerable variation in the distances that Indiana bats travel between roost trees within a colony. In Indiana, Humphrey et al. (1977) reported that two roost trees they observed were approximately 30 m apart. In Illinois, Gardner et al. (1991b) collected one of the largest data sets to date of *M. sodalis* roost trees, but did not associate roosts with particular colonies or report distances among roost trees that were used by each Indiana bat. In Michigan, Kurta et al. (1996) found that the average distance between roosts used by a single Indiana bat colony was 38.7 ± 7.1 m (range 1 to 147 m). In Missouri, Callahan et al. (1997) did not report the distance between roosts but provided the diameter of a circle that would encompass all roosts used by a single maternity colony. The smallest and largest "colony areas" had diameters of 1.6 and 3 km, respectively. In Kentucky, MacGregor et al. (1999) reported that distances between autumn roosts of males ranged from 48 m to 2,688 m encompassing areas from 0.4 to 568 ha.

Density of Potential Roost Trees

There is little information on densities of potential tree roosts for Indiana bat maternity colonies primarily because there is no universally accepted definition of a potential roost. Gardner et al. (1991b) listed the optimal number of roost trees as 64 per ha for upland habitat and 41 per ha for floodplains. Rather than describing a quantitative method for obtaining these data, their numbers were derived from a snag density survey (d.b.h. > 22 cm) of acceptable species within the study area. Bark characteristics and decay classes were not reported. As part of a mitigation project, Salyers et al. (1996) reported a potential roost density of 15 trees/ha, which was raised to 30.4 roost sites/ha after instillation of artificial roost structures.

In Missouri, Callahan et al. (1997) reported the largest distances between roosts of a single maternity colony. Although all roosts were not discovered, the highest density was 0.25 roost tree/ha. In a 5-ha Michigan wetland, Kurta et al. (1996) found that Indiana bats roosted in 23 different trees at a density of 4.6 ha. They reported that there were 66 available roost trees in the wetland (13.2 potential roost trees/ha), an unusually high snag density.

Due to features such as species, size, and bark characteristics, not all snags make acceptable Indiana bat roosts (Gardner et al. 1991b; Kurta et al. 1996; Callahan et al. 1997). These features vary from area to area with no predictable pattern (Kurta et al. 1996; Callahan et al. 1997). As a result, a variety of snag types must be maintained to maximize the chance that snags with suitable structural characteristics for Indiana bats will be present. Additional information is needed to define what constitutes suitable Indiana bat roost.

The number of roost trees needed by an Indiana bat colony is unknown and probably varies by colony size and roost availability. Roost use also can change in response to unpredictable climatic conditions. Roost attrition precludes managers from being able to set aside a minimum number of potential roosts. Also, the unpredictable nature of natural roost destruction hinders managers in predicting the longevity of current roost trees, and the time needed for a tree to become "suitable" for Indiana bats is unknown and probably varies by tree species and location.

Stand Composition

There are no quantitative descriptions of stand composition for forests surrounding Indiana bat roosts. However, all studies provide descriptions of the study areas. Based on most descriptions, the stands surrounding roosts do not differ substantially in composition from the list of species used as roosts (see Tree Species Used/Preferred). Kurta et al. (1996) commented that, although there were 99 green ash, 34 silver maple, and 9 American elm trees in their study area, only green ash trees were used as roosts. However, Indiana bat roosts have been found in both silver maple and American elm in other studies (Gardner et al. 1991b). Tree species reported in study areas that have not been used as roosts by Indiana bats include box elder (*A. negundo*), black walnut (*Juglans nigra*), and willow (*Salix* sp.). Further study is needed to elucidate how tree species composition at the landscape scale affects roost site selection by Indiana bats.

Stand Structure

The stand structure surrounding Indiana bat maternity colonies have not been described quantitatively, though there have been comparisons with roost trees to randomly located potential roosts within a stand. In Michigan, Kurta et al. (1996) found that roost trees within in the stand were larger (d.b.h.) and less variable in diameter than randomly located potential roost snags. However, Callahan et al. (1997) found that roost-tree characteristics such as d.b.h. or bark cover did not differ statistically from potential roosts within a stand in Missouri.

Roost trees occur in many habitat types with different stand structures. Gardner et al. (1991b) found roosts in grazed uplands ($n = 26$), nongrazed uplands ($n = 9$), nongrazed floodplains ($n = 8$), a clearcut ($n = 1$), a hoglot ($n = 1$), and a pasture ($n = 1$). Kurta et al. (1993a) also reported a roost tree from the middle of a heavily grazed pasture. Recent research has documented maternity colony use in a green-tree reservoir and along swamp edges in southern Illinois where tree mortality was substantial due to from flooding of the Mississippi River during 1993 and 1995 (T. C. Carter, unpubl. data).

MacGregor et al. (1999) reported that two-age shelterwood harvests on the Daniel Boone National Forest in Kentucky can produce different amounts of autumn roosting habitat for Indiana bats depending on the harvests' snag retention. Their guidelines called for retention of all snags, hollow trees, live trees with large dead limbs, and shagbark hickories. These guidelines produced stands with 15 times the roost trees retained with conventionally managed two-age shelterwoods (5 snags/ha). Roost sites were also found in burned areas managed for the red-cockaded woodpecker (*Picoides borealis*).

Although this information is anecdotal, it suggests that Indiana bats may be more tolerant of limited disturbance of the roosting area. Practices such as even-age and uneven-age management can be used provided they include provisions for snag retention and favor oaks and shagbark hickories (Callahan et al. 1997). Still, there is little quantitative information on the effect of timber management practices on roost selection by Indiana bats.

Forest Type and Topography

Indiana bat roosts have been commonly found among mixed mesophytic hardwood and mixed hardwood-pine habitat types. Humphrey at al. (1977) and Brack (1983), located roosts in riparian habitats in Indiana. In Illinois, Gardner et al. (1991b) found 37 roost in uplands and 11 roosts in bottomlands. All roosts located by Kurta et al. (1996) were in a Michigan wetland habitat. In Missouri, Callahan et al. (1997) located roosts in riparian and upland habitats. In eastern Kentucky, MacGregor et al. (1999) reported that male Indiana bats roosted in pine-dominated forests during the autumn.

Size of Area Surrounding Roosts

The area used by Indiana bats surrounding their roosts varies among colonies. However, it is not always known where colony members forage and whether or not all colony roosts were discovered. Indiana bats tracked by Kurta et al. (1996) traveled outside their immediate roosting area to forage, but the exact location or extent was not known (Allen Kurta, Eastern Michigan University, pers. commun.). Humphrey et al. (1977) observed that bats traveled from their roosts to a nearby stream where they foraged along a 0.81-km section. Indiana bats have been observed foraging among and adjacent to roosts, and in areas disjunct from roosts.

Landscape Structure

Gardner et al. (1991b) made the only attempt to document composition of landscape habitat. Within the study area, 65 percent was cropland or old fields, 2 percent other agriculture, 33 percent forested (30 percent upland and 2.2 percent floodplain), and 0.1 percent impounded water habitat. At a larger scale, Illinois was 63 percent agricultural, 1.6 percent urban, 33 percent forested, 6.4 percent forested wetlands, and 1.3 percent impounded water. The impact of forest fragmentation on roost availability of Indiana bats at the landscape scale is unknown.

We are not aware of studies that have examined the effect of landscape-level disturbance regimes (e.g., fire, timber harvest) on availability of Indiana bat roosts. As suggested by the Indiana Bat Recovery Plan (USDI Fish and Wildl. Serv. 1996), the effect of availability of stands with "suitable" roosting habitat must be examined.

Rommé et al. (1995) used previously published data to develop a Habitat Suitability Index model for Indiana bats that asses habitat quality across the landscape. We are not aware of studies that have applied or validated the HSI model.

Research Questions and Needs

1. Further study of the Indiana bat's summer roosting habitat is needed as the mechanisms influencing roost selection remain unknown. We know that Indiana bat colonies use multiple trees to meet maternity requirements, but we do not know what resources each of these roosts provides or how resources change under different conditions. Also needed are studies of the factors that affect Indiana bat roosting behavior.

2. Research is needed on the effects of forest management on Indiana bat roosting ecology. It is not known how different management practices affect the quantity and quality of roosting structure and roosting habitat.

3. No studies have examined the reproductive output of an Indiana bat colony. This information is crucial to understand the species' capacity to recover from its current decline. Bats have relatively low reproductive outputs (Findley 1993). Without an understanding of Indiana bat reproduction, the period needed for this species to rebound from past disturbances cannot be assessed accurately. Claims of short-term declines or increases in populations (local or species wide) require an understanding of recruitment.

4. The relationships between stand structure and Indiana bat reproduction should be evaluated. Little or no work has investigated the impacts of timber harvests on maternity colonies. However, anecdotal evidence suggests that *M. sodalis* may benefit from limited disturbance around potential roosting areas. Limited disturbance can create potential roost trees and open the canopy around potential roost trees (Gardner et al. 1991b; Kurta et al. 1993a). It is important that such research evaluates how these practices affect both colony behavior and individual fitness. Disturbances from forest management that change behavior but do not adversely affect fitness may be benign.

Foraging Habitat

Species Composition/Vegetational Community Type

Indiana bats often forage in riparian areas (Humphrey et al. 1977; LaVal and LaVal 1980; Kessler et al. 1981; Brack 1983), woodlots (Mumford and Cope 1958), and upland forests (Easterla and Watkins 1969; LaVal et al. 1977; LaVal and LaVal 1980; Brack 1983). In summarizing past captures of Indiana bats, Mumford and Whitaker (1982) noted that some individuals had been collected (shot) when foraging around the crowns of oak and hickory trees. Brady (1983) observed in east-central Indiana that in riparian areas where four *M. sodalis* maternity colonies were located, 90 percent of the tree species were (in frequency of occurence) boxelder, silver maple, ash, sycamore, snags, sugarberry (*Celtis occidentalis*), American elm, willow, cottonwood, black walnut, honey locust (*Gleditsia triacanthos*), Ohio buckeye (*Aesculus glabra*), and slippery elm. Brack (1983) noted that at net sites where Indiana bats were captured, oaks or hickories (or both) dominated.

In Missouri, LaVal et al. (1977) observed 69 Indiana bats to which Cylalume Chemical Lightsticks (chemoluminescent tags) had been attached. The bats foraged under the forest canopy in dense wooded areas along ridges and hilltops. Their observations supported previous reports that Indiana bats primarily forage 2 to 30 m above the ground (Humphrey et al. 1977). Their results also indicated that Indiana bats forage in a greater diversity of habitat types, including uplands, than reported by Humphrey et al. (1977). LaVal et al. (1977) rarely observed Indiana bats foraging directly over water and suggested that low capture rates over streams experienced by Humphrey et al. supported these observations. However, the latter noted that low capture rates over water probably were related to the ability of Indiana bats to avoid nets rather than to the absence of bats along stream corridors. A study by Gardner et al. (1989) supported this hypothesis.

Brack (1983) observed chemoluminescent-tagged Indiana bats foraging in riparian areas, upland forests, and over a pond, a pasture, and an old field in Indiana. Most foraging occurred along habitat edges. Foraging occurred above, below, and around tree canopies in forested habitats, along the forest/stream edge in riparian areas, and along the edge of pastures and old fields.

Clark et al. (1987) captured Indiana bats in mist nets along narrow, disturbed riparian strips, wooded floodplains, and upland forests. Nearly 43 percent of Indiana bats ($n = 12$) were netted during nine nights of sampling at a highly disturbed, fragmented riparian strip. Cooling degree- days in May, heating degree-days in June, June maximum temperature, and June minimum temperature best predicted the presence of Indiana bats. These and other climatic factors may serve as environmental covariates when testing the significance of vegetation structure and vegetational community type on the presence of *M. sodalis*.

Bowles (1981) used mist-net surveys to document Indiana bat occurrence at four sites in Iowa. He captured reproductively active females at sites that varied greatly in structure and vegetational composition. These included highly disturbed, narrow (< 15 m) riparian habitats containing young trees (< 15 m tall and < 40 cm d.b.h.), mature riparian areas, and mature upland forests. Bowles suggested that Indiana bats are at least somewhat opportunistic in selecting summer foraging habitat.

Hobson and Holland (1995) used triangulation techniques, direct observation, and the receiver's attenuator to delineate foraging areas of radio-tagged bats. The 625-ha foraging area used by one male Indiana bat was an 80-year-old oak-hickory, mixed deciduous forest with a conifer component. The bat foraged in an elliptical pattern at canopy height. The authors did not indicate how many foraging locations were used to delineate the foraging area, how many points were obtained using triangulation or direct observation, or the degree of error associated with the radiotelemetry.

LaVal and LaVal (1980) captured Indiana bats along narrow riparian strips and in forest patches adjacent to streams in eastern Missouri. If riparian forests were the preferred foraging habitat for Indiana bats, then their summer foraging habitat was reduced greatly. However, if one uses the metric "one colony/km suitable riparian habitat and 12 colonies/county," the available habitat was not fully utilized.

Examination of fecal pellet also can provide insight into the foraging habitats of *M. sodalis*. Most myotids are opportunistic foragers and the differences observed between bat diets and available insects are a result of bats foraging in specific habitats and randomly feeding on insects rather than randomly foraging across habitats and selecting specific types of insects (Belwood and Fenton 1976; Fenton and Morris 1976; Whitaker 1995). If this is true for Indiana bats, foraging habitat can be assessed by examining the insects consumed.

Analyses of Indiana bat diets suggest that foraging habitats differ between their southern and northern distributions (Kurta and Whitaker 1998). Studies by Belwood (1979) and Brack (1983) in Missouri indicate that *M. sodalis* commonly forages in upland habitats in the southern portion of its range. Conversely, in Michigan, Kurta and Whitaker (1998) found that Indiana bats forage primarily in wetland habitats. Additional information is needed on the Indiana bat's diet and foraging habitat selection throughout its range.

Selection and Avoidance at Stand Scale

Humphrey et al. (1977) used Indiana bats tagged with fluorescent bands to determine relative levels of foraging activity among different vegetation communities. The bats foraged exclusively in riparian habitats despite the availability of upland forests, pastures, cornfields, upland hedge rows, and treeless creek banks. Although no statistical comparison of use versus available habitat was conducted to test for foraging habitat selection, the study indicated that *M. sodalis* forages primarily in wooded riparian areas and did not use other habitats. A criticism of fluorescent bands is that researchers must make visual contact with the marked bats. Another source of bias is the implicit assumption that foraging Indiana bats were equally visible among all habitat types examined. Humphrey et al. (1977) also assumed (albeit unstated) that if no marked Indiana bats were observed foraging in the individual forest stand, pasture, cornfield, upland hedge row, or treeless creek bank they surveyed, then these habitat types were not used elsewhere. It is unclear whether these assumptions were valid. Their results show that Indiana bats foraged in wooded riparian areas, but do not confirm that wooded riparian areas were preferred over the other habitat types they observed.

Following LaVal et al. (1977), Brack (1983) used chemoluminescent tags to compare the proportion of sightings in riparian habitat to that expected based on the availability of riparian habitats in the study area. Brack observed that foraging occurred mostly in upland woods, though his statistical analyses comparing habitat availability and use indicated that *M sodalis* did not preferentially forage in, or avoid, riparian habitats (Brack 1983, 1991). Brack (1983) also compared the proportion of foraging activity that occurred in forested habitats to that expected based on forested habitat abundance in the study area. Forested areas were selected over open areas (e.g., pastures, old fields) by foraging Indiana bats. These results provide one of the most quantitative examinations of foraging habitat selection by *M. sodalis*. However, the authors relied on the assumption that the probability of observing light tagged Indiana bats did not differ among riparian and nonriparian habitats, and among forested or nonforested habitats.

In Illinois, Gardner et al. (1989, 1991b) used radiotelemetry to analyze the foraging habits of the Indiana bat and to determine the size of the foraging ranges of 17 *M. sodalis* (2 pregnant, 6 lactating, 1 postlactating, 2 juvenile females, 3 juvenile males, 3 adult males). The study area in each foraging range was divided into 11 cover types: cropland, hayfield or pasture, old field, other agricultural land, upland forest with closed, intermediate, or open canopy, and floodplain forest with closed, intermediate, or open canopy, and pond. Foraging areas consisted primarily of cropland (49 percent), closed canopy floodplain forest (14.8 percent), and closed canopy upland forest (11.6 percent). Hayfield and pastures accounted for 7.1 percent, as did old fields.

Gardner et al. quantitatively tested for differences between proportions of habitat used and available using the program PREFER. Foraging Indiana bats selected closed-canopy (80 to 100 percent closure) floodplain forest. However, Gardner et al. used the minimum convex polygon method to define foraging ranges. Large areas unused by *M. sodalis* may have been included in the home range analysis (see White and Garrott 1990). For example, on average, 49 percent of minimum convex polygon foraging areas was composed of row crops. However, this does not necessarily mean that the bats spent 49 percent of their time foraging in row crops. Thus, the results presented by Gardner et al. (1991b) may not have reflected the amount of use for each habitat type. Determining the proportion of actual foraging locations in each habitat type would have been a more useful analysis of habitat use.

Another potential limitation of the analyses by Gardner et al. (1991b) is their definition of available habitat. Thomas and Taylor (1990) suggested that habitat use and availability be compared at multiple spatial scales. The size of the available foraging area (3,672 ha) defined by Gardner et al. (1991b) seems reasonable based on distances that Indiana bats traveled between roost and foraging areas. However, they reported use versus availability for only one spatial scale, and comparison among studies will be difficult unless the same spatial scale is used in future studies.

Gardner et al. (1991b) characterized habitats in 340-, 1,809-, and 5,278-ha concentric circles around sampling sites where Indiana bats had been captured. There was great variability in habitat use, e.g., deciduous forest (5 to 98 percent), evergreen forest (5 to 26.7 percent), total forest (5 to 98 percent), forested wetlands (0.07 to 59.6 percent), and cropland (zero to 95 percent). Although. these results support Bowles' (1981) observation that *M. sodalis* are somewhat opportunistic in selecting summer foraging habitats, they should be interpreted with caution. This type of analysis assumes that Indiana bats are captured near the center rather than at the edge of their home range, and gives equal importance to abundance of habitats 1 to 4 km from capture locations and habitats immediately surrounding the point of capture.

Foraging Height

Using ultrasonic detectors, Humphrey et al. (1977) found that Indiana bat foraging height was 2 to 30 m. Because of atmospheric sound attenuation, the ability to detect foraging bats with ultrasonic detectors decreases with increasing distance. Therefore, most myotid calls are difficult to detect with ultrasonic detectors at distances beyond 30 m. It is unclear how Humphrey et al. considered the relationship between distance and observability, both visually and with ultrasonic detectors. Thus, Indiana bat foraging activity at heights greater than 30 m may not have been observed due to limitations associated with methods used rather than a lack of foraging activity above this height.

On the basis of mist-netting captures, Brack (1983) found that Indiana bat capture rates were significantly greater at heights of 7.6 to 10.6 m than at 0.6 to 7.5 m. No bats were captured at heights less than 0.60 m. When interpreting data on capture per unit effort from mist nets, one must assume equal observability (in this case observability = capturability) among all treatments. If capture probability is unequal among treatments, differences in capture rates may result from differences in capture probability rather than from actual differences among treatments. Brack (1983) did not address potential differences in capture probability among vertical sampling strata, and it is unclear whether the assumption of equal capture probability was valid. Although Brack's results support Humphrey's observations, neither study provides conclusive evidence that Indiana bats selectively forage in specific strata within the forest canopy. Results of Brack's light-tagging experiment supported his mist-netting data with respect to preferred foraging heights used by *M sodalis* in the upper canopy.

Stand Structure/Canopy Cover

Brack (1983) noted that net sites where Indiana bats were captured had openings (gaps) in the forest canopy. Callahan (1993) located Indiana bat maternity roosts in northern Missouri in a stand that had been heavily logged within the past 20 years and in a hoglot where many overstory trees had been killed. He noted that these habitat modifications may have benefited *M. sodalis* by removing most of the canopy cover and leaving many standing dead trees. It is unclear how structural changes caused by logging or the girdling of overstory trees in the hoglot affected the use of these areas by foraging bats.

In Illinois, Indiana bats forage in areas that had been selectively harvested (Gardner et al. 1991b; J. MacGregor pers. observ.). These observations suggest that Indiana bats forage in areas where some timber harvesting has occurred, but they are not useful in determining preference or avoidence of harvested areas. Research is needed on the effect of timber harvest (e.g., shelterwood, deferment, and clearcuts) on the suitability of Indiana bat foraging habitat.

Relationship Between Habitat Selection and Stand Structure

Humphrey et al. (1977) suggested that Indiana bats forage only in riparian areas with some vertical structure, i.e., *M. sodalis* were not observed foraging along riparian areas denuded of woody vegetation. In addition, although there were other habitats with little or no vertical structure (e.g., pastures, cornfields) near the maternity roosts monitored, Humphrey et al. did not observe Indiana bats foraging in them.

Brack (1983) found that forest stand structural components that significantly influenced Indiana bat captures included (in order of importance): (1) whether the habitat was riparian or nonriparian, (2) amount of vegetation in the understory, (3) overstory species richness, and (4) understory species richness. The probability of capturing an Indiana bat in a mist net increased if habitat was riparian, understory density was low, overstory species richness was high, and understory species richness was low. However, these results depend on the assumption that the probability of bat capture did not differ among the 35 netting sites and that none of the factors listed affected capture probability. If Indiana bats are easier to net in riparian than in nonriparian areas, the observed differences in capture rates may be a reflection of differences in capture probability rather than actual differences in habitat use.

Assumptions associated with capture probability must be considered when indices are used. Brack (1983) recognized problems associated with using mist nets to determine bat spatial activity patterns. Many researchers have a feel for where a species can be captured, and when to try and capture it, but there is little quantitative evidence available for most species as to where, how high, and when they are active. There are problems associated with any capture method that is intended to show true abundance of an organism at a given place or time. The same is true for mist netting.

Forest Type and Topography

The relationship between stream corridors and Indiana bat foraging activity is unclear. Humphrey et al. (1977) suggested that Indiana bats forage preferentially in areas near streams (i.e., riparian corridors). However, most foraging activity observed by LaVal et al. (1977) occurred in upland forests. Sampling both riparian and nonriparian areas, Brack (1983) found that capture per unit effort of *M. sodalis* was higher in riparian areas, though the effect of stream proximity on Indiana bat foraging activity remains unknown.

Size of Home Range or Colony Foraging Area

Humphrey et al. (1977) found that foraging area used by one Indiana bat maternity colony in Indiana ranged from 1.5 to 4.5 ha. However, it is possible that maternity colony foraging areas were much larger than observed. As bats disperse from a central location such as roost trees, density decreases and observability declines. This also is true for radiotelemetry studies, and it becomes more severe as detection distance decreases. The extent to which decreased observability with distance from roost affected results of Humphrey et al. is unknown.

Humphrey et al. (1977) also suggested that foraging area is influenced by the time of summer and the level of development of young bats in the colony. Because they studied the foraging range of a single colony during two periods of a single summer, the significance of the observed change in size of foraging area is difficult to determine. All light-tagged Indiana bats observed by LaVal et al. (1977) were within 2 km of their release point, supporting the assertion by Humphrey et al. that Indiana bats use smaller foraging areas than other myotids (LaVal et al. 1977; Menzel et al. 2000).

Spatial Relations Between Roost and Foraging Areas

Foraging areas may be unimodal (one area with no patches of activity elsewhere) in and near summer roosts (usually ≤ 1,000 m; see Gardner et al. 1991b). LaVal and LaVal (1980) used a helicopter to observe two light-tagged male Indiana bats foraging (in July) 5 km from their roost in Great Scott Cave in Missouri. Using radiotelemetry, Hobson and Holland (1995) documented a male Indiana bat foraging within 1 km of the roost tree.

Foraging Site Philopatry

Indiana bats migrate yearly between hibernacula and summer maternity areas. Cope et al. (1973), Humphrey et al. (1977), and Gardner et al. (1991b, 1996) suggested that some individuals return to the same summer breeding areas each year. Data provided by Gardner et al. (1991b, 1996) are quantitative and therefore reliable. One individual tracked by radiotelemetry in 1986 and 1988 in the same summer breeding area exhibited a high degree of foraging area overlap. Gardner et al. (1991b) also found a high degree of overlap used by a Indiana bat colony in Illinois in 1987 and 1988.

Proportion of Landscape in Foraging Habitat

At the landscape scale, Miller et al. (1996) compared abundances of several habitat types, forest perimeter, tree species present, d.b.h., and percent canopy cover between sites in Missouri where Indiana bats had and had not been captured. They found no difference in percent coverage of forest, row crop, grassland, or water cover between capture and noncapture sites. However, sites where Indiana bats were present contained a significantly greater number of large-diameter trees than sites where *M. sodalis* were absent. Miller et al. used mist netting to verify the presence or absence of Indiana bat maternity colonies. It is relatively easy to verify Indiana bat presence via mist nets, but failure to capture an Indiana bat does not verify absence.

Callahan (1993) characterized roost types selected by *M. sodalis* maternity colonies. He also attempted to elucidate "habitat characteristics of areas used by maternal Indiana bat colonies." He defined the use areas in two ways: (1) the smallest circle that encompassed all maternal roost tees located in a colony (defined as the minimum roost range), and (2) a 3-km circle centered around the minimum roost range. Callahan classified the habitat types in these two areas surrounding four Indiana bat maternity colonies as forest, row crop, or field/pasture. The average minimum roost range and 3-km circle surrounding the four colonies was 39 percent forest, 12 percent row crop, and 49 percent field/pasture, and 24 percent forest, 8 percent row crop, and 65 percent field/pasture, respectively. No information about actual use of foraging habitats was provided.

Research Questions and Needs

1. Quantitative studies of Indiana bat foraging habitat selection are needed. Methods previously used to determine foraging areas used by *M. sodalis* include unaided visual observations, visual observations of light-tagged individuals and reflectively banded individuals, comparison of netting sites where Indiana bats have and have not been captured, examination of diet, and radiotelemetry. Indiana bat calls can be differentiated from the calls of other myotids. If technology continues to improve, future studies may rely more on the use of bat detectors. However, radiotelemetry currently is most reliable method for gathering data related to foraging habitat selection. Obviously, it will be important to sample throughout the night and to minimize error polygons.

2. Foraging point distribution (i.e., the vegetational community types and habitat structure where they fall) should be statistically compared to a random distribution of locations from the available foraging area (or the proportion of each vegetative community type in the study area). How available foraging areas are defined should be better described and should be spatially related to roosts. Error associated with radiotelemetry should be quantified and described. Differences between the distribution of foraging locations and randomly located points also should be examined in relation to abiotic factors (e.g., streams, roads, buildings). Efforts should be made to conduct these studies on colonies inhabiting areas near forests that have recently been subjected to disturbance, e.g., timber harvests and road construction.

3. Large portions of the Indiana bat's home range can occur over agricultural fields. Additional data on point foraging are needed to determine the extent to which *M. sodalis* forage over agricultural fields. If agricultural fields are used appreciably, the direct or indirect (by affecting preferred insects) effect of pesticides on Indiana bats should be quantified.

Conclusion

Indiana bat hibernacula and hibernacula characteristics have been well documented by numerous observational studies reported in the literature. However, reported research on foraging and roosting habitat use during the prehibernation swarm and posthibernation emergence is limited. We are aware of only three studies, one in eastern Kentucky and one each in north-central West Virginia and western Virginia, on the perhiphery of this species' range. Similarly, food habits during these critical periods are poorly documented. The implications of exposure to environmental contaminants such as agricultural pesticides during prehibernation and posthibernation emergence are not understood. Issues such as winter hibernacula protection to minimize or prevent Indiana bat disturbance and manage cave airflow are well understood and must be addressed on a cave-by-cave basis.

Outside the hibernation period, Indiana bats use both live trees and snags for roosts. Although roosts have been documented in a wide array of hardwood and pine species, trees and snags that have exfoliating bark, such as shagbark hickory, may be important. Indiana bat roost trees have been reported within forests above and below the canopy and among isolated trees or single trees in open areas such as wetlands, fields, and pastures with correspondingly wide ranges in solar exposure. Distances from known roosts to water, foraging areas, and alternative roost trees also are variable, ranging up to 3 km, depending on landscape and topography. Roost-tree density necessary to support Indiana bats is not understood and negative or positive biological thresholds linked to roost abundance are unknown. Similarly, there are no quantitative studies that adequately describe species composition of forest stands or stand structure surrounding occupied roosts. Forest cover around Indiana bat roosts ranges from less than 33 percent in the agricultural Midwest to virtually 100 percent in the Appalachians. In the Midwest, Indiana bats have been observed roosting in or near both bottomland/wetland forest habitats and upland forest habitats; in the eastern and southeastern peripheries of their distribution in the Appalachians, *M. sodalis* have been observed roosting in upland forests.

Indiana bats use many habitats for foraging, including riparian areas, upland forests, ponds, and fields. *M. sodalis* may forage in specific vertical strata in these habitats, though the preferred heights are unknown. The effects of timber harvesting on Indiana bat foraging patterns also is unknown. Research is needed to understand the effects forest management on the foraging habitats of *M. sodalis* during the spring and fall swarm and during summer. Size of foraging habitat seems to be dependent on the sex and age of the bat and location of the foraging area. Indiana bats have smaller foraging ranges than other myotids, and the foraging ranges of individual bats commonly overlap. There also is evidence that Indiana bats return to the same summer foraging areas each year.

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Appendix

Table 1.—Issues and techniques in studies of Indiana bat hibernacula

Study	Issue	Technique	Comment
Barbour and Davis (1969)	General biology	Review paper	
Brack (1983)	Swarm foraging	Light tags	Foraged over oak-hickory uplands
Brack et al. (1984)	Hibernacula characteristics	Observation	
Clark (1981)	Contaminants	Review paper	Includes many species of bats
Clark and Prouty (1976)	Contaminants	Bioassay	Examined other bats near Indiana bat hibernacula in mid-Atlantic
Clawson (1984)	General biology	Review paper	Identifies management issues
Clawson and Sheriff (1982)	Population estimation at hibernacula	Observation	
Cope and Ward (1965)	Natural mortality	Observation	Identifies cave flooding as mortality agent
Dunn and Hall (1989)	Population status	Observation	
Gates et al. (1984)	Cave habitat analysis	Observation	Only study that addresses landscape characteristics as environmental variables influencing cave use and Indiana bat populations
Griffin (1940)	General biology	Observation	
Kiser and Elliot (1996)	Swarm foraging	Radiotelemetry	Identified habitat use, roost tree use and food habits in prehibernation swarm
Hall (1962)	General biology	Observation	Comprehensive review of Indiana bat biology up to 1962
Hardin and Hassell (1970)	Hibernation activity	Observation	
Harvey and McDaniel (1986)	Population status	Observation	Population decline in Arkansas
Hassell (1967)	Hibernation activity	Observation	
Henshaw (1965)	Hibernation physiology	Observation	
Henshaw and Folk (1966)	Hibernation physiology	Observation	
Hobson and Holland (1995)	Posthibernation emergence	Radiotelemetry	Notes movement of single male in western Virginia
Humphrey (1978)	Hibernacula characteristics	Review paper	Comprehensive discussion of hibernacula conservation
LaVal et al. (1976)	Habitat analysis	Observation	
LaVal et al. (1977)	Foraging activity	Light tags	
LaVal and LaVal (1980)	Hibernacula characteristics	Observation	
McFarland (1998)	Contaminants	Bioassays and LD_{50} trials	Used surrogate myotids
Myers (1964)	Hibernacula characteristics	Observation	
Rasely and Gates (1986)	Hibernacula characteristics	Observation	
Reidinger (1976)	Contaminants	Bioassays	Does not include Indiana bats
Richter et al. (1993)	Cave airflow	Observation	Changed airflow from modified cave entrances is responsible for some declining Indiana bat populations
Richter et al. (1978)	Population status	Observation	Documents discovery of unknown hibernacula
Saugey et al. (1990)	Population status	Observation	
Thomson (1982)	General biology	Review paper	Mammalian species account
Tuttle (1977)	Cave gating	Review paper	
Tuttle and Kennedy (1999)	Hibernacula characteristics	Observation	Detailed microclimatic conditions in major Indiana bat hibernacula
U.S. Fish and Wildl. Serv. (1996)	General biology	Review paper	Recovery plan

Table 2.—Issues and techniques in studies of Indiana bat roosting habitat

Study	Issue	Technique	Comment
Brack (1983)	Maternity roost-tree selection	Observation	Single roost tree
Brady (1983)	Summer ecology	Review paper	Discusses cause of endangerment, summer habitat, and threats; makes recommendations
Callahan et al. (1997)	Maternity roost-tree selection	Telemetry	Data collected in early 1990s; four different colonies
Carly and Kurta (1996)	Maternity roost	Observation	Abstract only; preliminary work
Gardner et al. (1996)	Roost-tree selection (male and female)	Telemetry, observation	Same data set as in publications from 1990, 1991a
Harvey and McDaniel (1986)	Population decline	Review paper	
Hobson and Holland (1995)	Spring roost-tree selection	Telemetry, observation	Single roost tree
Humphrey et al. (1977)	Maternity roost-tree selection	Roost destruction, observation	First report of roost trees
King (1992)	Michigan	Telemetry, observation	Initial discovery of location for Kurta et al. 1993a, 1996
Kiser and Elliott (1996)	Autumn roost-tree selection	Telemetry, observation	Habitat and roost-tree use and food habits in prehibernation swarm
Kurta et al. (1993a)	Maternity roost-tree selection	Telemetry, observation	
Kurta et al. (1993b)	Maternity roost-tree selection	Telemetry, observation	Pilot study of Kurta et al. 1996
Kurta et al. (1996)	Maternity roost-tree selection	Telemetry	Northern edge of *M. sodalis* range; small flooded wetland
MacGregor et al. (1999)	Autumn roost-tree selection	Telemetry, observation	22 males tracked to 102 trees
Mumford and Cope (1958)	Indiana	Observation	One roost tree and one bridge
Salyer et al. (1996)	Artificial roosts	Observation	Two trees and first use of bat box
Tingle and Mitchell (1985)	Habitat delineation	HSI Model	No data based on Gardner et al. (1991)

Table 3.—Issues and techniques in studies of Indiana bat foraging habitat

Study	Issue	Technique	Comment
Belwood (1979)	Feeding ecology	Fecal analysis	Morphology, prey selection
Belwood and Fenton (1976)	Diet	Observation	Includes *Myotis lucifugus*
Bowles (1981)	Summer status	Observation	
Brack (1983)	Swarm foraging	Light tags	Foraged over oak-hickory uplands
Brady (1981)	Recovery plan	Review paper	Abstract
Callahan (1993)	Summer habitat	Radio-telemetry	Includes roost trees
Clark et al. (1987)	Summer distribution	Mistnetting	
Cope et al. (1973)	Maternity colony	Mistnetting	Elm tree maternity roost
Esterla and Watkins (1969)	Maternity colony	Observation	
Fenton and Morris (1976)	Foraging	Observation	Opportunistic feeders
Gardner et al. (1991b)	Foraging behavior	Radiotelemetry	Includes roosting sites
Gardner et al. (1996)	Summer distribution	Banding	Cave surveys in Illinois
Gardner et al. (1989)	Capture technique	Mistnetting	Emphasis on *M. sodalis*
Hobson and Holland (1995)	Posthibernation emergence	Radiotelemetry	Notes movement of single male in western Virginia
Humphrey (1977)	Summer habitat	Banding	Foraging habitat
Kessler et al. (1981)	Summer survey	Mistnetting	Maternity colony indentified
Kurta and Whitaker (1998)	Diet	Fecal pellets	Opportunistic feeders
LaVal and LaVal (1980)	Hibernacula characteristics	Observation	
Mumford and Cope (1958)	Summer records	Observation	
Miller et al. (1996)	Habitat use	Mistnetting	Summer habitat patterns
Romme et al. (1995)	Habitat suitability model	Review paper	Foraging habitat
Whitaker (1995)	Food habits	Fecal pellets	Includes *Eptesicus fuscus*

Menzel, Michael A.; Menzel, Jennifer M.; Carter, Timothy C.; Ford, W. Mark; Edwards, John W. 2001. **Review of the forest habitat relationships of the Indiana bat (*Myotis sodalis*).** Gen. Tech. Rep. NE-284. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 21 p.

Reviews the available literature on the ecology of the endangered Indiana bat (*Myotis sodalis*), including its selection and use of hibernacula, roost trees, and foraging habitat. An extensive list of published references related to the Indiana bat is included.

Keywords: foraging habitat, hibernacula, tree roosts, silviculture

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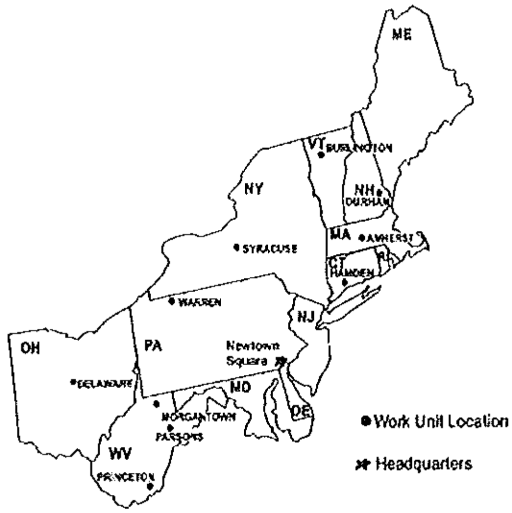

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"Caring for the Land and Serving People Through Research"

Review

Investigating and Managing the Rapid Emergence of White-Nose Syndrome, a Novel, Fatal, Infectious Disease of Hibernating Bats

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Abstract: *White-nose syndrome (WNS) is a fatal disease of bats that hibernate. The etiologic agent of WNS is the fungus* Geomyces destructans, *which infects the skin and wing membranes. Over 1 million bats in six species in eastern North America have died from WNS since 2006, and as a result several species of bats may become endangered or extinct. Information is lacking on the pathogenesis of* G. destructans *and WNS, WNS transmission and maintenance, individual and site factors that contribute to the probability of an outbreak of WNS, and spatial dynamics of WNS spread in North America. We considered how descriptive and analytical epidemiology could be used to fill these information gaps, including a four-step (modified) outbreak investigation, application of a set of criteria (Hill's) for assessing causation, compartment models of disease dynamics, and spatial modeling. We cataloged and critiqued adaptive-management options that have been either previously proposed for WNS or were helpful in addressing other emerging diseases of wild animals. These include an ongoing program of prospective surveillance of bats and hibernacula for WNS, treatment of individual bats, increasing population resistance to WNS (through vaccines, immunomodulators, or other methods), improving probability of survival from starvation and dehydration associated with WNS, modifying hibernacula environments to eliminate* G. destructans, *culling individuals or populations, controlling anthropogenic spread of WNS, conserving genetic diversity of bats, and educating the public about bats and bat conservation issues associated with WNS.*

Keywords: emerging infectious disease, extinction, fungal disease

Investigando y Manejando la Rápida Emergencia del Síndrome de Nariz Blanca, una Enfermedad Infecciosa, Nueva, Fatal, en Murciélagos Invernantes

Resumen: *El síndrome de nariz blanca (SNB) es una enfermedad fatal en murciélagos que invernan. El agente etiológico del SNB es el hongo* Geomyces destructans, *que infecta la piel y las membranas alares. Desde 2006 más de 1 millón de murciélagos de 6 especies han muerto de SNB, y como consecuencia varias especies de murciélagos pueden estar en peligro o extintas. Se carece de información de la patogénesis de* G. destructans *y SNB, la transmisión y mantenimiento de SNB, los factores individuales y de sitio que contribuyen a la probabilidad de una epidemia de SNB y de la dinámica espacial de la dispersión de SNB en Norte América.*

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Consideramos cómo la epidemiología descriptiva y analítica podrían contribuir a llenar esos vacíos de información, incluyendo una investigación de la epidemia, aplicación de un conjunto de criterios (de Hill) para evaluar las causas, modelos de compartimiento de la dinámica de la enfermedad y modelado espacial. Clasificamos y criticamos las opciones de manejo adaptativo que se han propuesto anteriormente para SNB o que fueron útiles para atender otras enfermedades emergentes en animales silvestres. Estas incluyen un programa de vigilancia prospectiva de murciélagos y sus sitios de hibernación para detectar SNB, tratamiento de murciélagos individuales, incremento de la resistencia a SNB (mediante vacunas, inmunomoduladores u otros métodos), incremento de la probabilidad de supervivencia a la inanición o la deshidratación asociadas con SNB, modificación de los ambientes de hibernación para eliminar G. destructans, *sacrificio de individuos o poblaciones, control de la dispersión antropogénica de SNB, conservación de la diversidad genética de murciélagos y campañas para educar al público sobre murciélagos y temas de conservación asociados con SNB.*

Palabras Clave: enfermedad fúngica, enfermedad infecciosa emergente, extinción

Introduction

White-nose syndrome (WNS) is a fatal disease of insectivorous bats that hibernate (hereafter hibernating bats), and it is presumed to be caused by a newly discovered psychrophilic (cold adapted) fungus, *Geomyces destructans* (Blehert et al. 2009). The genus *Geomyces* contains other psychrophilic saprophytic fungi that can colonize skin (Marshall 1998; Gianni et al. 2003), but *G. destructans* is the only species that invades and destroys the skin of hibernating bats (Cryan et al. 2010). WNS is the first epizootic documented in bats, and the disease has caused unprecedented reductions in the abundance of hibernating species in eastern North America, with up to 95% mortality in some hibernacula (Frick et al. 2010*a*). As a result, over 1 million bats are estimated to have died due to WNS (Frick et al. 2010*a*), and species may become endangered or extinct if the disease maintains its virulence and continues to spread across North America.

WNS was first documented in photographs taken in winter 2005–2006 in Howes Cave, and subsequently dead and dying bats were found with WNS in four nearby caves 30 km west of Albany, New York, in winter 2006–2007. By July 2010, DNA of *G. destructans* or WNS characteristic lesions were detected in hibernating bats in New York, Vermont, Massachusetts, New Jersey, Connecticut, Pennsylvania, New Hampshire, Delaware, Virginia, West Virginia, Tennessee, Missouri, and Oklahoma, and Ontario and Quebec (Fig. 1). Species in which WNS lesions or *G. destructans* DNA have been detected are: the endangered gray and Indiana bats (*Myotis grisescens* and *M. sodalis*), little brown bat (*Myotis lucifugus*), northern long-eared bat (*M. septentrionalis*), eastern small-footed bat (*M. leibii*), southeastern bat (*M. austroriparius*), cave bat (*M. velifer*), tricolored bat (*Perimyotis subflavus*), and big brown bat (*Eptesicus fuscus*). In Europe infection with *G. destructans* has been confirmed in at least five species: greater mouse-eared bat (*M. myotis*), Daubenton's bat (*M. daubentonii*), pond bat (*M. dasycneme*), Brandt's bat (*M. brandtii*), and Monticelli's myotis (*M. oxygnathus*) (Martínková et al. 2010; Puechmaille et al. 2010; Wibbelt et al. 2010). Nevertheless, monitoring has not documented major mortality events associated with *G. destructans* on bats in Europe.

G. destructans Biology and WNS Pathogenesis

G. destructans is detected consistently in skin of bats with characteristic lesions of WNS (Blehert et al. 2009; Meteyer et al. 2009; Lorch et al. 2010). This fungus grows at temperatures 3–15 °C and >90% relative humidity, conditions similar to bat hibernacula and bodies of hibernating bats (Cryan et al. 2010). Transmission occurs through direct bat-to-bat contact (D. Blehert et al., personal communication), but other routes (e.g., exposure to environments in which the fungus is present, human or animal vectors) are also possible (Lindner et al. 2010). Illness occurs mostly in winter, and WNS lesions and aberrant behaviors are most detectable after January. In autumn hibernating bats build up fat reserves and then at the onset of winter hibernate in sites that are cold and damp where food is scarce (Davis 1970; Ransome 1990). The metabolic rate of a hibernating bat is low and its body temperature is within a few degrees of the ambient temperature for extended periods (Geiser 2004; Speakman & Thomas 2003). Every few weeks bats must arouse from hibernation to restore homeostatic balance (e.g., drink, urinate, relocate, and probably induce immune functioning) (Thomas & Geiser 1997; Speakman & Thomas 2003). Over the winter this periodic arousal consumes most of the stored body fat (Thomas et al. 1990). Bats with WNS may arouse from hibernation more frequently or for longer periods than average and thereby prematurely expend fat reserves (Boyles & Willis 2010). Direct mortality from infection of the wings with *G. destructans* may also occur (Cryan et al. 2010). Aberrant behaviors associated with WNS observed in large numbers of bats include movement to roosting areas near cave entrances or other exposed sites and flying during the day from hibernacula in mid winter; fatalities often occur inside the hibernacula and/or near the entrance. In spring, a few affected

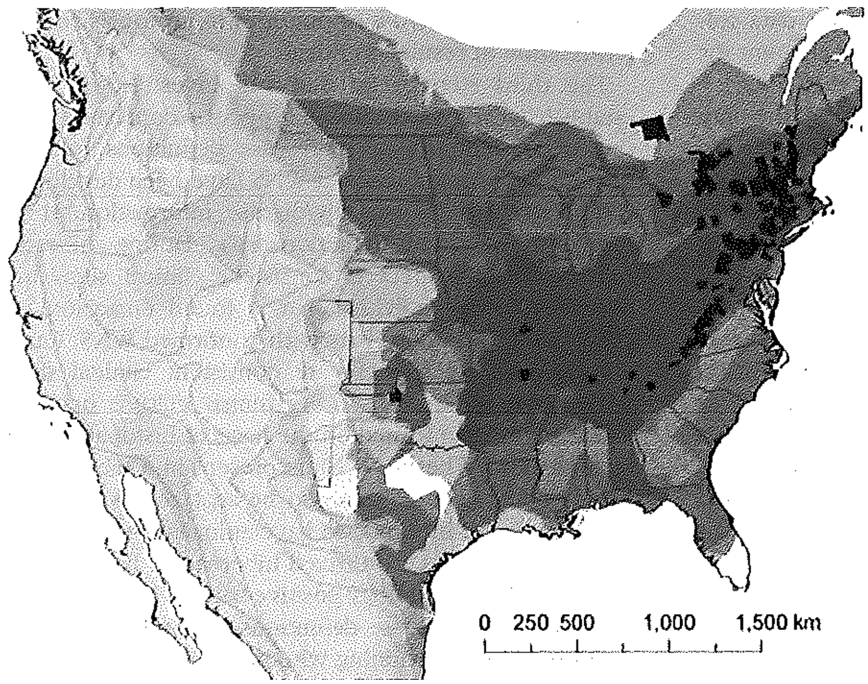

Figure 1. Areas in North America where white-nose syndrome or Geomyces destructans *has been detected in bats (black) superimposed on the overlapping distributions of bat species known to be infected with* G. destructans *(darker grays; n = 9 species) and of hibernating species of bats that are not yet known to be affected by the* G. destructans *(lighter grays; n = 13 species). Fungus distribution is based on maps created by C. Butchkowski, Pennsylvania Game Commission (http://www.fws.gov/whitenosesyndrome/). Bat distributions are based on data from U.S. Geological Survey and Bat Conservation International and available through a national atlas (http://www.nationalatlas.gov/mld/bat000m.html).*

animals may recover but with wing damage (Reichard & Kunz 2009).

More than half of the 45 species of bats that occur in the continental United States hibernate in caves, mines, and/or deep rock crevices, including four species and subspecies listed as endangered under the U.S. Endangered Species Act (Indiana, gray, Virginia big-eared [*Corynorhinus townsendii virginianus*], and Ozark big-eared bats [*C. t. ingens*]). In North America all species of bats that hibernate could be susceptible to WNS, and it is unknown whether WNS will be a major source of mortality in bats that rarely occur in caves, such as migratory tree-dwelling species (e.g., silver-haired bats [*Lasionycteris noctivagans*], hoary bats [*Lasiurus cinereus*], and eastern and western red bats [*Lasiurus borealis* and *L. blossevillii*]).

Certain characteristics of hibernating bats may affect the dynamics of WNS. Sociality and group formation in vespertilionid bats differ among seasons and between sexes. In general, both sexes occur in winter hibernation sites, but in spring females move to maternity colonies, where synchronized births of young occur. Males tend to spend spring and summer away from females and roost alone or in smaller groups at cooler sites (Weller et al. 2009). The sexes reunite during autumn swarming, when mating begins and multiple species of bats often congregate and interact at cave entrances before hibernation (Barbour & Davis 1969). Bats generally have lower survival in their first year, after which adult survival is high relative to similarly sized mammals (Frick et al. 2010*b*). High annual adult survival and low fecundity result in modest population growth rates and abundances that do not fluctuate widely over time (O'Shea et al. 2010). Although most adult females breed, they typically have only one offspring per year (Tuttle & Stevenson 1982). In addition to survival effects, reproduction may be adversely affected by WNS (Frick et al. 2010*b*). Volant mammals have a high capacity to spread and transmit infectious disease. Many of the species affected by WNS migrate tens to hundreds of kilometers between winter and summer habitats and can travel tens of kilometers per night (Barbour & Davis 1969; Griffin 1970). The seasonal sex differences in behaviors of hibernating bats, life-history characteristics that favor longevity and low fecundity, and the extreme vagility of bats may strongly influence WNS disease dynamics.

Knowledge Gaps

Although knowledge of WNS disease ecology is accumulating, it is unknown whether *G. destructans* is the only pathogen involved and, if so, how it causes mortality. Means of transmission and spread are unknown, and there is no information on management actions that might reduce mortality and be specific to hibernating bats.

Ecology of Bats and *G. destructans*

Locations of most roost sites and details of the movement of individuals are largely unknown for many species of bats. Other gaps in knowledge include in-depth information on feeding and roosting behaviors; nightly, seasonal, and annual flight distances; population carrying capacities; age-specific survival and reproductive rates, and potential thresholds for Allee effects. There are few long-term data on abundance, and even fewer data collected with mark-recapture methods or that account for age classes and recruitment (sensu O'Shea et al. 2004).

Little is known about *G. destructans*, but it is the only species of the genus known to infect the living skin tissues of bats (Cryan et al. 2010). Congeners, such as *G. pannorum* (which infects fur and feathers of various species), *G. sulphureus*, and *G. asperulatus* are saprophytic. It is not known whether *G. destructans* coevolved virulence with bats and requires an animal host or whether it originated as a saprophyte in cold environments but had virulence factors facilitating host infection ("accidental virulence") (sensu Casadevall & Pirofski 2007). The residence time of the fungus in North America is unknown. Nevertheless, recent sampling of sediments from caves and mines within and beyond the area affected by WNS revealed DNA of *G. destructans* only in regions where WNS had been observed (Lindner et al. 2010). The breadth of its host tropism, whether it has vectors, how long it survives without a host, how it interacts with soil or host microbiota, and many other details of its ecology are unknown.

Investigation of Outbreaks

An outbreak investigation framework (Gordis 2000) helps prioritize information needs specific to disease. The first step in such an investigation is to synthesize existing information and address logistical considerations, including biosecurity for field workers. The second step is to verify the diagnosis. Histopathologic examination is used to diagnose WNS (Meteyer et al. 2009). Blehert et al. (2009) used histopathologic methods to confirm the presence of the fungus in 105 of 117 bats with clinical signs of WNS (89.7%). Histopathologic examination, however, is time consuming, expensive, and most useful for diagnosing disease in dead bats. Biopsy lacks sensitivity (the ability to detect characteristic lesions if present) because relatively large samples are required for diagnosis. Culture and polymerase chain reaction (PCR) are less useful as diagnostic tests because the presence of viable fungus or fungal DNA does not equate to disease caused by *G. destructans*. Nevertheless, Lorch et al. (2010) report that PCR detected 96% histopathology-positive samples, whereas culture detected 33%. In their study, specificity was 100% for both methods. The low success rate of culturing is due in part to the difficulty of excluding other fungi from cultures. Published PCR primers for *G. destructans* react with other species of *Geomyces* found in cave sediments (Lindner et al. 2010). Nevertheless, PCR as a diagnostic test is 100% specific for *G. destructans* when bat tissues are tested. Until more-specific primers are found, PCR samples that are positive for *G. destructans* should be genetically sequenced to confirm that *G. destructans* is involved. Establishing guidelines to ensure consistency across laboratories in protocols and interpretation of results is critical.

The third step of an outbreak investigation is to establish what constitutes a suspect or confirmed case (i.e., case definitions). Draft case definitions for suspect and confirmed cases of WNS have been developed (http://www.nwhc.usgs.gov/disease_information/white-nose_syndrome/wns_definitions.jsp). During hibernation, WNS is suspect if consistent clinical signs are observed or an individual bat is found emaciated or dead in the vicinity of bats with confirmed WNS. Cases are presumptive if there are consistent clinical signs with positive *G. destructans* fungal culture or PCR, and cases are confirmed on the basis of histopathologic examination. Whether WNS is present in a hibernation site or other location can also be analyzed as a "case." Suspected case hibernacula have animals with apparent WNS clinical signs. Confirmed hibernacula have at least one dead, histopathology-positive bat.

On the basis of case definitions, an outbreak can be confirmed by determining whether suspected cases of a disease are real, that there is an actual increase in cases above previous baseline mortality, and that cases are related to each other or some causal factor. It is possible that unidentified WNS cases existed prior to 2007. WNS qualifies as an outbreak because mass mortality from this disease did not occur until recently and strong evidence indicates most cases are real (i.e., a diagnosis has been made) and that they are related in time and space.

Descriptive and analytical epidemiological statistics have not yet been compiled for individual bats and for bat populations and hibernacula. We suggest that data be collected from individual cases on sex, species, site, age class, clinical signs, ectoparasite load, season, and other possible factors that increase the probability of differences in susceptibility and transmission. Hibernacula can be classified by such characteristics as WNS prevalence, bat density, species richness of bats, location, and microclimate (e.g., humidity, temperature). A case-control epidemiologic study could be performed at the hibernaculum level if randomly chosen uninfected sites were evaluated. In contrast, bats and hibernacula evaluated to date have been ad hoc and have not been compared rigorously with controls. Final steps in the outbreak investigation are to implement control and prevention measures and communicate findings.

Establishing Causation of WNS

The evidence that WNS is associated with *G. destructans* implies but does not prove that this fungus is causal, and other factors likely contribute to disease. In addition to establishing causation of WNS by *G. destructans*, we recommend assessing the causation of the common clinical findings, such as emaciation and dehydration. Hill's nine criteria for causation are applicable in this situation, and

Table 1. Application of epidemiologic framework and Hill's (1965) criteria to assess *Geomyces destructans* as the cause of white-nose syndrome in bats.

Criterion	*Definition*	*Evidence whether criterion is met*
Strength of association	Stronger association implies agent under study is more likely to be causal for disease.	There is ample evidence for a strong association of *G. destructans* with WNS in North America. This may not be the case in Europe.
Consistency	Repeated observations of causal factors by "different persons, in different places, circumstances, and times."	As reports of WNS accumulate and affected bats are evaluated histopathologically and through PCR and culture, the relation between *G. destructans* and disease appears increasingly consistent.
Plausibility	Association under study is consistent with currently accepted understanding of pathological processes.	Skin infection by *G. destructans* is a plausible primary cause of mortality associated with WNS. Fungal infection of bat wings may disrupt the energy balance or cause life-threatening disruption of homeostasis.
Coherence	Association under study is compatible with existing theory and knowledge.	The postulated relation of *G. destructans* and WNS fits well with "known facts of the natural history and biology of the disease" (Hill 1965).
Experimental evidence	Disease can be prevented or ameliorated by an experimental regimen.	Very early experimental attempts to prevent or ameliorate effects of WNS were not successful.
Analogy	For analogous disease agents and diseases, similar outcomes have occurred.	Several diseases similar to WNS have emerged rapidly, been attributed to a fungus or oomycete, and resulted in substantial declines in abundance of their host species. These include the amphibian disease chytridiomycosis, attributed to the fungus *Batrachochytrium dendrobatidis,* sudden oak death, caused by *Phytophthora ramorum*, chestnut blight, caused by *Cryphonectria parasitica*, and crayfish plague, caused by *Aphanomyces astaci.*
Specificity	Factor or disease agent specifies a particular outcome or condition.	*G. destructans* has been implicated in essentially all cases of WNS evaluated to date.
Temporality	Exposure to disease agent precedes disease.	The temporal relation between *G. destructans* and WNS is not well established.
Biological gradient	Disease occurs after a threshold pathogen level is exceeded or disease is more severe if there is a higher dose of pathogen.	This has not been established for WNS.

we suggest they would be useful because they are general and flexible. Hill's criteria are strength of association, consistency, plausibility, coherence, experimental evidence, analogy, specificity, temporality, and biological gradient (Table 1). No single criterion is definitive, but evidence in support of each increases the probability that a factor is causal (Hill 1965; Plowright et al. 2008). In light of Hill's criteria, existing knowledge of WNS is consistent with *G. destructans* as the causal agent, but we think additional contributing factors need to be assessed (Table 1).

WNS Disease Ecology

The population dynamics of bats drive enzootic and epizootic WNS. Nevertheless, almost all critical details (or, in a modeling framework, parameter values) needed to understand and model the ecology of WNS in bats are unknown. We outline a WNS model, consider relevant parameters, and determine gaps in knowledge that can be filled through research.

Compartment modeling is commonly used to model disease dynamics. In such models groups of host individuals move among compartments designated as susceptible (S), infected or infective (I), and recovered or resistant (typically immune, R) to a disease (Kermack & McKendrick 1927; Bailey 1982). If recovered individuals can lose immunity and become susceptible again, the disease model is denoted as SIRS. If there is no immunity but animals recover, then the disease model is SIS. If infection persists without recovery, the disease model is SI. Differential equations describe how individuals move among the compartments with the parameters infection rate, recovery rate, and rate at which immunity is lost. If the time span of disease dynamics is long relative to host life span, then it is necessary to include functions for dynamics of host population growth independent of disease. Depending on the duration of the disease relative to host life spans, parameters for host birth, death, and population regulation (e.g., density dependence) may be included. Other modifications to compartment models allow for addition of parameters on demographic and environmental stochasticity, exposed but not yet infective (e.g., fungus not reproducing) classes (E), vector transmission, and an environmental reservoir (e.g., fungus persists in hibernacula without a bat host). A generic set of SIRS differential equations is

$$\frac{dS}{dt} = bN - \beta SI - dS,$$

$$\frac{dI}{dt} = \beta SI - \gamma I - dI,$$

and

$$\frac{dR}{dt} = \gamma I - dR,$$

where N is the total population size (= S individuals $+I$ individuals $+R$ individuals), b is host birth rate, d is host death rate, β is the rate of disease transmission, and γ is the rate of host recovery. These equations assume disease transmission is density dependent (i.e., each infected individual transmits infection to an a priori proportion of the available S individuals). It alternatively could be assumed that disease transmission is frequency dependent, in which case I individuals transmit to an a priori number of S individuals. Frequency-dependent transmission can lead to the infection of every S animal in a population. Whether WNS is frequency or density-dependent is unknown.

It is also unknown whether individuals that are exposed to, or recover from, the disease are resistant and whether individuals that recover become susceptible to or act as a source of infection. The existence of recovered individuals might seem unlikely, given the apparent high mortality observed to date. Nonetheless, some animals may recover if they had a mild case of the disease late in the winter (C. Meteyer, personal communication) or if mild winter weather increases probability of survival. The accumulation of recovered individuals could constitute herd immunity. All parameter values must be estimated, which also means the routes and rates of transmission must be determined, such as whether *G. destructans* is spread by direct contact among bats, through contact with contaminated roost sites, or through exposure to human or other animal vectors. The model may require substructuring that includes different bat species or age classes if bats have different levels of disease susceptibility, mortality, and recovery. Because males roost individually or in small groups in colder locations than females, they may function as reservoirs. Substructuring according to species or age could cause the model to predict longer-lasting endemic disease (Bolker & Grenfell 1996). The presence of reservoirs or vectors of WNS (which could include bat ectoparasites) may need to be included in the model. If animals can be medically treated, then recovery parameters can be adjusted.

Spatial modeling also may be useful for examining the pattern, rate, and direction of spread of WNS. The locations of some hibernacula of bats with WNS are known. We recommend that cases confirmed pathologically be considered separately from those identified through either culture- or PCR-only evidence of infection. This differentiation will allow for testing of two hypotheses: WNS and *G. destructans* infection are synonymous and thus overlap in time and space and *G. destructans* is already present in caves or perhaps spreading ahead of WNS. Spatial modeling with, for example, nearest-neighbor or moving-window analyses (Alexander & Boyle 1996) would facilitate examination of potential clusters of WNS and patterns of spread. Because bats often occur in groups, cluster analysis should be conducted at the hibernaculum level and separately for winter hibernacula and summer roosts. Such analyses would help determine whether the disease is spreading locally in clusters typical of regional contagion or more erratically, with new infections far from known infections. Approaches used to examine diffusion of, for example, plague (Noble 1974; Adjemian et al. 2007) and rabies (Moore 1999) also might be appropriate for determining the directions in which WNS is spreading, whether the speed of the diffusion front is increasing, and whether expansion of the disease is constrained by geological features (e.g., Appalachian Mountains with their associated caves and abandoned mines).

Network theory and cellular automaton models (del Rey et al. 2006) might also be useful in exploring possible patchiness and lack of spatial homogeneity of the probability of the spread of WNS. If limited data are available, individual-based simulation models may be useful (e.g., Kindlmann & Burel 2008; Lookingbill et al. 2010). Simulation models have been used to examine spread of rabies virus (Deal et al. 2000).

Science-Based Strategies for Adaptive Management of WNS

In the absence of well-validated strategies to reduce the spread of WNS and its effects on bat populations, we considered the following: disease surveillance, treatment of individuals, increasing population resistance to WNS (through vaccines, immunomodulators, or other methods), improving survival from starvation and dehydration associated with WNS, modifying hibernacula environments to eliminate *G. destructans*, culling individuals or populations, controlling anthropogenic spread of WNS, conserving genetic diversity of bats, and educating the public about bats and bat conservation.

Targeted epidemiological surveillance programs to detect disease occurrence that reduce bias from passive detection of disease are optimal, but data can also be acquired through judicious use of convenience samples (e.g., suspected rabid bats submitted to public health departments) and reports from citizens. Ideally, surveillance is minimally invasive and does not disturb bats. Regardless of the approach, surveillance is improved by clear and consistent case definitions, consistent sampling protocols, and centralized data entry, management, analysis, and reporting. Descriptions of ideal sample quality and storage, including storage of voucher specimens, should be standardized. There are currently no targeted epidemiological surveillance programs for WNS, but such surveillance is essential for knowing where and when to take actions to minimize WNS effects.

Treatment of infected bats may prevent death and reduce the incidence of fungus. Treatment options under consideration include chemical or biological agents, especially fungicides. *G. destructans* is susceptible to treatment in vitro, but treatments (e.g., drugs) and delivery mechanisms proven safe for bats have not been developed. A major obstacle is delivery of treatment. Fogging caves with fungicide almost certainly would affect microbial flora in the cave. Unless bat populations decline to very low abundances, hand delivery of treatment to individual bats would not be feasible. It is unknown whether bats would require repeated treatment. Treatment with fungicide during passage in and out of hibernacula or roosting sites may be possible. Affected bats could be treated in captivity but issues of quarantine, handling, and release would need to be addressed. The proportion of a population that would need to be treated to reduce sufficiently the "infected" compartment of a population to reduce enzootic disease levels and spread is unknown.

Focusing recovery actions on increasing population resistance to *G. destructans* may be a useful component of WNS management. Little is known about immunity to WNS, whether some bats become resistant after exposure and to what extent immunity could be induced (e.g., through vaccination). If one assumes WNS is maintained and spread primarily bat to bat, it is possible to calculate the fraction of the population that, if immune, would lead to local abatement of the disease. Increased resistance in local populations of bats might interrupt transmission from infected to susceptible populations and curtail spread. There are precedents for vaccination against fungal disease, including recombinant vaccines for humans against fungal disease (Wuthrich et al. 2000), novel vaccines against valley fever for humans (caused by *Coccidioides immitis*), a vaccine for cats to speed recovery from ringworm (caused by dermatophyte fungi), and a phosphorus prophylactic treatment for oak trees against sudden oak death (Garbelotto et al. 2007). All possible means to ensure the good health of bat populations should be applied, such as maximizing habitat quantity and quality and reducing the effects of synergistic stressors (e.g., toxins) that reduce resistance.

Reducing starvation and dehydration during hibernation may reduce mortality. The cause of death in WNS is thought to be either starvation, major disruption of homeostatic balance, or impaired survival due to wing damage. Some obvious actions to prevent death, for example supplemental feeding or watering, pose challenges because hibernating insectivorous bats will likely not learn to feed from novel food sources during winter and their gut physiology may not adjust to availability of winter food.

Treatment of or modification of hibernacula may eliminate *G. destructans*. WNS treatments have been proposed that would deliver chemical or biological control agents into a cave or mine. There are several likely obstacles to this approach. First, many affected caves and mines occur on private land, where access may be restricted. Second, many caves and mines used by bats have great internal volume and structural complexity that would render complete coverage extremely difficult. Third, treatment may not meet its objectives if transmission is from bat to bat, rather than from cave surfaces to bats. Fourth, antifungal treatment in caves would almost certainly change resident species composition, possibly even increasing the probability of WNS if resident invertebrates or microbes are already competing with or somehow limiting transmission of *G. destructans*. It may be possible to manipulate the temperature and humidity of hibernacula so that they are less conducive to growth or transmission of *G. destructans* or to mitigate the effects of fungal infection on bats. Although a model suggests that localized warm areas within hibernacula could increase survival of infected bats (Boyles & Willis 2010), this approach has yet to be tested. Certain hibernating bats have evolved to survive winter in the very conditions at which *G. destructans* grows (Davis 1970; Cryan et al. 2010), and altering hibernacula to discourage growth of the fungus could also reduce survival of bats.

Although culling of infected individuals or populations may seem a viable approach to reducing pathogen load, the incidence of WNS within populations, and the probability of transmission to other populations, we suggest its potential effectiveness must be considered carefully and critically. For culling to be effective, the following are necessary: little or none of the pathogen should originate from fomites (objects that may be contaminated with the pathogen); most cases should be clinical or diagnosed after death; a sufficiently high proportion of affected individuals should be removed (this proportion can be calculated with SIRS models once a realistic model and model parameters are obtained); and the remaining population of individuals must be isolated to prevent spread and reintroduction. Culling in wild animal populations is less successful than culling of livestock because of difficulties and delays in diagnosis; vagility of animals, particularly in volant and potentially migratory species such as bats; and inability to control environmental factors and ongoing disease exposure. Culling of animals in the wild for disease control has been either ineffective (e.g., control of Tasmanian devil [*Sarcophilus harrisii*] facial disease [Lachish et al. 2010]) or implicated in the exacerbation of disease (e.g., badger [*Meles meles*] tuberculosis [Jenkins et al. 2010]). Culling also may be perceived negatively by the public, may remove individuals with resistance to the disease because field indications of WNS are ephemeral (e.g., white noses) and often difficult to detect; and may lead to local extinction. For bats, culling to separate affected from unaffected bat populations (i.e., construction of a *cordon sanitaire*) would be difficult. Recent data document extensive spread of WNS, which increases the likelihood that a *cordon sanitaire* would be breached. Should culling be considered, we believe population and disease models should inform and justify decisions to cull, and concurrent research should assess key features of WNS disease ecology, such as the presence of reservoirs and alternate hosts, means and levels of disease transmission, possibilities of disease recovery and immunity, and different levels of susceptibility among different host species.

Even though the spread of WNS probably occurs mostly through contact among bats and possibly among bats and other animals, preventing the anthropogenic spread of *G. destructans* from cave to cave (most likely explanation for intercontinental spread) and from bat to bat during capture and handling could prevent some disease transmission. We think it is reasonable to require humans entering uninfected sites to disinfect their clothes and equipment. People studying or monitoring bats can also implement strict protocols for disinfecting equipment and preventing cross-species infection (Constantine 1986). In places where large numbers of humans and bats are likely to co-occur, caves could be closed to humans. If bats in a cave are uninfected, prohibiting human entry might slow *G. destructans* introduction, and if bats are infected, this prohibition might reduce spread from that cave as a nidus (center of infection).

Increased efforts to maintain genetic diversity of bats may become necessary to reduce spread of and mortality to bats from WNS. Decreases in the abundance of bats are likely to be followed by decreases in genetic diversity. Captive propagation or captivity during the winter could be initiated for critically endangered species; certain species of bats have been reared in captivity successfully (but see results of work with Virginia big-eared bats, http://www.fws.gov/WhiteNoseSyndrome). Nevertheless, such captive populations would only sustain relatively low levels of genetic diversity.

Monitoring populations of bats, although difficult (O'Shea & Bogan 2003), will provide important information on which species of bats are most susceptible to WNS and whether management actions are reducing mortality in bat populations. Newer quantitative methods, such as open population models (e.g., quantifying survival and reproductive rates [O'Shea et al. 2004]) and occupancy modeling (e.g., tracking occurrence of species over time at affected hibernacula [MacKenzie et al. 2006]), may offer promise for assessing the viability of bat populations exposed to WNS, prioritizing species on which to focus management, and gauging the effectiveness of management actions.

Education of the public may encourage people to report cases of WNS, avoid inadvertent spread of the fungus, and avoid disturbance of hibernacula. Education may also minimize reactive and ineffective killing. Public health departments responsible for surveillance of rabies could be educated about WNS, given they may be the first agencies to respond to bat-mortality events. State and federal land management agencies could opportunistically educate the public about bats and WNS. In situations such as high-traffic tourist caves with few hibernating bats, the potential benefits of educating the public about bats and WNS may be greater than the probability of human transmission of *G. destructans* to and from such sites.

In the 3 years since its discovery, WNS has changed the focus of bat conservation in North America. Prior conservation strategies for bats in North America sought to alleviate human-associated mortality (Weller et al. 2009), but WNS is a much less tractable natural threat. In contrast to diseases for which national response plans have been developed (e.g., chronic wasting disease, highly pathogenic avian influenza), WNS affects nongame species and poses no known direct threats to humans or domestic animals. Because WNS affects a number of species designated as endangered under the U.S. Endangered Species Act, some responsibility for coordinating a response to WNS rests with federal and state agencies charged with preventing extinction of listed species. Some of these agencies may have little or no experience dealing with epizootics. Our epidemiological roadmap is intended to supplement and inform emerging national and state plans for coordinating management activities directed at WNS in the United States.

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Diet of the Endangered Indiana Bat (Myotis sodalis) on the Northern Edge of Its Range

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Diet of the Endangered Indiana Bat (Myotis sodalis) on the Northern Edge of Its Range

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ABSTRACT.—Dietary preferences of Indiana bats were determined by analyzing 382 fecal pellets collected beneath roost trees in southern Michigan, over parts of 3 yr. Although terrestrial insects (Lepidoptera and Coleoptera) usually dominated the diet of Indiana bats in more southern states, those in Michigan consumed mostly insects associated with aquatic environments. Indiana bats in Michigan ate primarily Trichoptera (55.1% of volume) and Diptera (25.5%), followed by Lepidoptera (14.2%) and Coleoptera (1.4%). Consumption of Diptera was highest during lactation (48.2%), whereas consumption of Lepidoptera was least during this time (7.7%). Although most insectivorous bats do not prey on mosquitoes (Culicidae), these insects were a consistent component of the diet of Indiana bats and were eaten most heavily during pregnancy (6.6%).

INTRODUCTION

Knowledge of the diet can provide fundamental insights into the ecology and behavior of an animal, and dietary information is essential for proper management of any species. For example, the type of food predicts an animal's basal metabolic rate, which, in turn, determines aspects of the animal's population ecology and home-range size (McNab, 1980). In addition, knowledge of the diet may reveal where, when, how, and how often an animal forages. Understanding the foods eaten by an endangered species is particularly important, because a population's decline may be related to the diet; for example, lack of suitable prey (MacKenzie and Oxford, 1995) or exposure to pollutants obtained through contaminated prey (Clark, 1981, 1996; Wiemeyer *et al.*, 1984; Clawson and Clark, 1989; McLachlan and Arnold, 1996) have been implicated in the decline of many species.

The Indiana bat (*Myotis sodalis*) is a small, 7–10 g, insectivorous species that ranges throughout much of the eastern United States (Thomson, 1982). At one time, 90% of the known population hibernated in only three caves and one mine (Brady *et al.*, 1983). Because of large declines in population size and the apparent lack of critical habitat in winter, the species was declared endangered in the United States in 1967. The primary focus of the original recovery plan for this species (Brady *et al.*, 1983) was to prevent disturbance to hibernating bats, yet despite current protection of all major hibernacula, the species continues to decline. The magnitude of the problem, however, varies across the species' range, with some areas showing little, if any, decline in population, while others report alarming losses. The population in Missouri, for example, has decreased by 80% over the last 13 yr (Indiana Bat Recovery Team, 1996; Clawson, 1987).

The continued decline of the Indiana bat, despite protection in winter, suggests that there also are problems during spring and summer when females gather in maternity colonies and actively forage. However, the only available information on diet of this species during the maternity season is from unpublished thesis research in Indiana (Belwood, 1979; Brack,

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1983; Lee, 1992). Because many aspects of the roosting ecology and behavior of Indiana bats in northern areas differ from those observed in more southern states (Kurta *et al.*, 1993, 1996), it is essential that the diet of this endangered species be examined in all parts of its range (Indiana Bat Recovery Team, 1996). The purpose of the present report is to document the diet of Indiana bats at the most northern maternity colony known for the species and to summarize and make comparisons with unpublished studies from more southern locations.

METHODS

Study animals.—We determined diet by examining fecal pellets collected from a maternity colony of Indiana bats that roosted under the exfoliating bark of dead trees, near Vermontville, Eaton Co., Michigan (Kurta *et al.*, 1993, 1996). These bats used at least 23 trees over 3 yr and as many as 18 different trees in 1 yr; no tree was continually used throughout any year. We did not know where these bats foraged, but it was not in the immediate vicinity of the roosts; radiotagged individuals left the roosting area every night, and some individuals were captured up to 2 km from their dayroost. This population of Indiana bats consisted of 20–25 adult females, most of which gave birth to a single young in late June (Kurta *et al.*, 1993, 1996).

Fecal analysis.—To obtain feces, we placed a nylon screen on wooden supports below the preferred entrance/exit of six of the most commonly used roost trees. Maximum distance between roosts from which we collected feces was less than 150 m. Overall, we collected 27 samples, containing 2 to 125 pellets each; 18 samples were from 6 June to 17 July 1993, six were from 22 July to 28 August 1994, and three from 2 to 10 June 1995. After collection, pellets were dried and stored in vials, and later, up to 30 pellets from any one sample were randomly selected and examined under a dissecting microscope; examination of 30 pellets is sufficient to document all major dietary items in a sample of the feces of insectivorous bats (Whitaker, 1999). Insect remains were identified to order, and occasionally family, and the percent-volume of each taxon in each pellet was estimated visually (Whitaker, 1988). Differences among samples from bats in different reproductive conditions were examined using Kruskal-Wallis tests, followed by Bonferroni-adjusted Wilcoxon tests for multiple comparisons (SAS Institute, 1990).

RESULTS

A total of 382 pellets were examined. Indiana bats in Michigan ate mainly Trichoptera (caddisflies; 55.1% of volume) and Diptera (true flies; 25.5%), followed by Lepidoptera (moths; 14.2%) and Coleoptera (beetles; 1.4%—Table 1). The remaining 3.8% consisted of six other insect orders, as well as spiders (Araneae). On occasion, we were able to identify the foods to lower taxa (Table 1). Numerically, the most important of these were the dipteran families Chironomidae (midges; 4.1%) and Culicidae (mosquitoes; 2.7%). Although mosquitoes are not an important food for most species of bats (Whitaker and Lawhead, 1992), these small insects were consistently present in the diet of Indiana bats in Michigan, appearing in 22 of 27 collections.

The most extensive samples were from 1993, and the last date of collection in that year (17 July) coincided with the earliest date that we encountered volant juveniles (Kurta *et al.*, 1996). Assuming 3–4 wk from birth to first foraging flight, as in *Myotis lucifugus* (Buchler, 1980; Fujita, 1986), parturition by Indiana bats began ca. 19–26 June. Consequently, we divided the sample from 1993 into three groups, representing pregnancy (6–17 June, 94 pellets), a transition from late pregnancy to early lactation (19–30 June, 100 pellets), and lactation (2–17 July, 39 pellets). We analyzed the data for the four most common orders

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TABLE 1.—Percent-volume of foods eaten by Indiana bats in Michigan based on analysis of fecal pellets. When separate families are listed, their percent-volume is included in the value indicated for the whole order. Values for orders within columns do not add to 100 because of rounding errors

	Percent-volume			
Taxon	1993 (n = 233)	1994 (n = 101)	1995 (n = 48)	Total (n = 382)
Trichoptera	47.7	71.4	56.5	55.1
Diptera (all families)	31.8	15.0	17.0	25.5
Chironomidae	2.6	7.8	2.7	4.1
Culicidae	4.2	0.6	0.4	2.7
Tipulidae	0.3	0	1.6	0.4
Dolichopidae	0.02	0	0	0.01
Lepidoptera	16.6	8.8	14.8	14.3
Coleoptera (all families)	0.7	1.5	4.8	1.4
Scarabaeidae	0.9	0	2.0	0.3
Curculionidae	0.3	0	0	0.02
Dytiscidae	0	0.5	0	0.1
Hymenoptera (all families)	1.3	0.5	1.3	1.1
Ichneumonidae	1.3	0.1	1.2	1.0
Formicidae	0	0.2	0	0.07
Neuroptera (Hemerobiidae)	0.2	0.9	4.6	0.9
Araneae	1.0	0.3	0	0.7
Unidentified insects	0.2	0.7	0.7	0.4
Hemiptera (all families)	0.3	0.05	0.3	0.3
Lygaeidae	0.06	0	0	0.04
Homoptera (all families)	0.2	0.4	0	0.2
Cicadellidae	0.2	0.4	0	0.2
Aphididae	0	0.1	0	0.04
Plecoptera	0	0	0.4	0.05
Ephemeroptera	0.04	0	0	0.03
Total for orders	100.04	99.6	100.4	100

and found no significant differences among the three groups for Trichoptera or Coleoptera (Table 2). However, the percent-volume of Lepidoptera was highest in pregnancy and transition and lowest in lactation, whereas all Diptera combined were greater in lactation than in pregnancy or transition. Chironomid flies did not vary across reproductive conditions, but mosquitoes were consumed in highest amounts during pregnancy.

DISCUSSION

To date, there have been four unpublished surveys of the diet of Indiana bats (Fig. 1); each of these was similar to the present study in that each reported the percent-volume of various foods, based on analysis of fecal samples that were collected from May or June through August. Brack and Laval (1985), for example, examined fecal pellets from 140 male Indiana bats, captured as they entered a cave in Missouri, and found 83% Lepidoptera and 7% Coleoptera. Brack and Laval (1985) also indicated that the diet did not vary across the night; they compared the composition of pellets from individuals captured during the postsunset foraging period and those captured during predawn foraging and found no significant differences. In another study, Belwood (1979) analyzed pellets from individual females and juveniles and also pellets collected beneath a maternity roost in southern In-

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TABLE 2.—Mean percent-volume of the most common foods eaten by Indiana bats in Michigan during pregnancy, transition from pregnancy to lactation, and lactation, in 1993. The indicated probability is for differences among the three groups as indicated by Kruskal-Wallis tests, each with 2 deg freedom. For each taxon, means with different superscripts were significantly different based on Bonferoni-adjusted Wilcoxon tests (alpha = 0.025); actual probabilities for significant Wilcoxon tests were all ≤0.01

	Percent-volume				
Taxon	Pregnancy (n = 94)	Transition (n = 100)	Lactation (n = 39)	χ^2	P
Trichoptera	55.6[a]	43.6[a]	39.4[a]	3.94	0.14
Diptera	22.4[a]	34.3[a]	48.2[b]	17.02	0.002
Chironomidae	1.2[a]	3.6[a]	3.1[a]	1.84	0.40
Culicidae	6.6[a]	2.9[b]	1.5[b]	10.94	0.004
Lepidoptera	16.0[a]	20.7[a]	7.7[b]	9.24	0.01
Coleoptera	0.9[a]	0.5[a]	0.5[a]	0.85	0.65

diana; she reported 57% Lepidoptera, 18% Diptera, and 9% Coleoptera. Similarly, Brack (1983), working at sites throughout Indiana over 3 yr, found Lepidoptera (48%) and Coleoptera (24%) to be major components of the diet, followed by Diptera (8.5%) and Trichoptera (9.8%); although the exact proportions differed, moths and beetles predominated in samples taken from mist-netted individuals of each sex and age (adult vs. juvenile), and these insects also were the most common taxa in pellets collected from beneath a maternity roost. Lepidoptera dominated the diet in every year of his study (Brack, 1983), and the percent-volume of Lepidoptera in the diet did not differ significantly among years; Brack

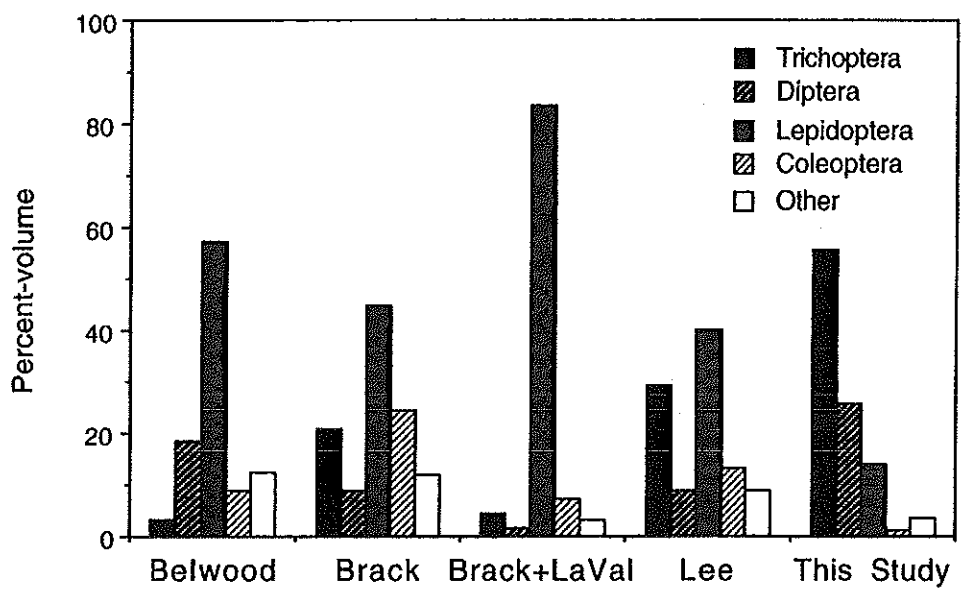

FIG. 1.—Percent-volume of various insect taxa in the diet of the Indiana bat, as reported by Belwood (1979), Brack, (1983), Brack and LaVal (1985), Lee (1993) and the present study

(1983) also indicated no significant differences in the diet of males (the only group tested) that were captured early or late in the night. Finally, Lee (1993) collected pellets from 23 female Indiana bats that were mist-netted in central and northern Indiana and found 40% Lepidoptera, 29% Trichoptera, 13% Coleoptera, and 9% Diptera. Hence, previous studies at more southern sites consistently showed that the diet of Indiana bats was dominated by Lepidoptera (Fig. 1). This dominance of Lepidoptera occurred throughout the night and across years and was evident in pellets collected from individuals of varying age and sex, as well as pellets obtained from maternity roosts.

Although our study was similar to previous reports in showing that the diet of the Indiana bat consisted primarily of soft-bodied insects (Table 1), our results indicated that the diet of females and young at a northern colony was not dependent upon moths. In Michigan, Indiana bats took prey from 10 insect orders, as well as spiders, but these bats concentrated on Trichoptera and Diptera. These two orders comprised ca. 81% of the foods eaten, and their dominance was evident both among and within years (Tables 1–2); Lepidoptera, in contrast, contributed only ca. 14%, or less than half the amount found in any previous study (Fig. 1).

Overall diet in Michigan was not only different from that in southern locations; trends within a year also differed. Brack (1983), for example, reported that consumption of Lepidoptera increased from May through August, while Trichoptera decreased. Such a pattern was not evident in our study; there was no statistical difference in the abundance of caddisflies during pregnancy, transition or lactation, whereas moths actually decreased during lactation (Table 2). In addition, if the same trend occurred in Michigan, our sample from 1994, which was gathered late in the season (22 July to 28 August), should have had a very low proportion of caddisflies, yet those pellets actually yielded the greatest percentage of Trichoptera (71%, Table 1).

Similarly, Belwood (1979) reported a significant increase (from 31% to 70%) in moth consumption and a significant decrease (from 41% to 16%) in fly consumption during lactation compared to pregnancy. She hypothesized that the shift to moths during lactation was an attempt by females to obtain prey that were energetically or nutritionally more rewarding. Such speculation was logical considering the huge increase in energy required by bats during lactation (Kurta *et al.*, 1989), but if her hypothesis were correct, one would have expected Indiana bats in Michigan to follow the same pattern. However, moth consumption in Michigan actually declined, while flies substantially increased, during lactation (Table 2). We suspect that these conflicting reports of seasonal changes in diet simply reflect availability of insects in the habitats in which the bats chose to forage, and such changes may not necessarily have an adaptationist explanation.

Small myotine bats, such as the Indiana bat, are generally believed to be opportunistic foragers (Belwood and Fenton, 1976; Fenton and Morris, 1976; Vaughan, 1980). The speed of a flying bat and the short detection range inherent in the use of echolocation make discrimination among different types of prey difficult (Barclay and Brigham, 1994). Selectivity in terms of prey, to a large degree, likely results from selection of a particular habitat to forage in, rather than selection of a particular type of insect *per se*, and once the habitat is chosen, the bats may simply feed on whatever appropriate-size insect is most abundant (Brack, 1983; Aldridge and Rautenbach, 1987; Brigham, 1990; Barclay and Brigham, 1994; Whitaker, 1995). Consequently, consumption of insects associated with terrestrial environments (Lepidoptera and Coleoptera) by Indiana bats in southern states indicates that these bats often foraged in upland habitats (Belwood, 1979; Brack, 1983; Lee, 1993), whereas the consumption of insects generally associated with aquatic environments (Trichoptera and

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Diptera) by Indiana bats in Michigan indicates that these bats foraged primarily in wetland habitats.

Differences between Indiana bats in Michigan and more southern areas are not restricted to dietary and foraging patterns; previous work also indicates substantial differences in roosting behavior. For example, those that summer in Michigan consistently form smaller colonies, use different species of trees, choose trees in sunnier locations, and roost more frequently in wetlands than do southern populations (Gardner *et al.*, 1991; Callahan, 1993; Kurta *et al.*, 1993, 1996). These differences in roosting and foraging behavior may reflect regional differences in availability of habitats or insects (Brack, 1983; Price, 1984; Dunn, 1996), increased or decreased competition from other species (as membership of the local chiropteran community changes across the continent, Findley, 1993), or perhaps true regional preferences by different populations of bats.

Whatever its cause, such variation is potentially important to the management and recovery of this and other endangered species and indicates that any sound management plan must consider the behavior of an animal in all parts of its range. This is particularly true for the Indiana bat, because not only does this species show apparent regional differences in foraging and roosting behavior, but population declines of the Indiana bat also show regional variation. The Indiana bat in some areas of its range, such as Missouri, is on the verge of extinction, while other populations are holding steady (Clawson, 1987; Indiana Bat Recovery Team, 1996); hence future solutions to the decline of the Indiana bat likely will reflect regional differences in the behavior and ecology of the species. In any event, suggestions for aiding any endangered species of bat by facilitating the diversity and abundance of a particular type of insect prey (*e.g.*, Rydell *et al.*, 1996) should be viewed with caution, until diet is sampled throughout the range of the species.

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