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A prospective power analysis and review of habitat characteristics used in studies of tree-roosting bats

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We identified 25 studies published between 1988 and 2001 that measured characteristics of roosting sites of tree-roosting bats, and where measures were compared to characteristics of random or available locations. The most frequently measured habitat characteristics were roost-tree diameter ($n = 23$), roost-tree height (21), roost-tree canopy cover (16), roost height (14), and slope (10). Habitat characteristics of the roost tree itself were measured more frequently than stand or landscape characteristics; a total of 31 different habitat characteristics was used to describe stand or landscape conditions as opposed to 23 different habitat characteristics used to describe features of the roost tree. The overall mean (± SE) number of habitat characteristics examined per study was 8.0 ± 1.1, with an average of 4.2 ± 0.7 characteristics reported to be significant ($P < 0.05$). Mean estimated effect size, or the absolute value of the difference between means divided by the population standard deviation, of habitat characteristics ranged from 0.83 to 1.52. A sample size of 11 radio-tagged bats was sufficient to achieve acceptable power, i.e., 0.80, for all habitat characteristics examined when only using the upper limit of the 95% confidence intervals for estimated effect sizes. In contrast, a sample size of 39 radio-tagged bats was sufficient in achieving the same level of power for only 50% of the habitat characteristics evaluated at the lower end of the 95% confidence intervals. We encourage researchers to conduct pilot studies, and estimate effect sizes and variances to assess the level of sampling effort required to evaluate habitat characteristics in studies of tree-roosting bats.

Key words: bats, effect size, habitat, power analysis, sample size, tree roosts, variance

INTRODUCTION

Application of power analysis to clarify inference drawn in statistical analysis of data has found favor in the fields of wildlife management and conservation biology (e.g., Taylor and Gerrodette, 1993; Reed and Blaustein, 1995; The Wildlife Society, 1995; Hayes and Steidl, 1997; Steidl *et al.*, 1997). Most attention has centered on the use or misuse of retrospective power analysis (Steidl *et al.*, 1997; Thomas, 1997; Gerard *et al.*, 1998), which is calculation of power after the data are already collected and where a significant difference was not found relative to some effect or standard of comparison. One purpose of retrospective power analysis is to help investigators qualify or temper their conclusions. This is true when a statistical test shows no difference or other type of effect in the data and where power of the test is estimated to be low and the chance of committing a Type II error is high (Steidl *et al.*, 1997; Thomas, 1997; Gerard *et al.*, 1998). In prospective power analysis, effect size and the variance for the parameter in question are estimated and power of the test calculated before the study takes place (Eberhardt and Thomas, 1991; Steidl *et al.*, 1997). Prospective power analysis also can be used to estimate the sample size needed to meet a specified level of power given a fixed effect size and estimate of the variance before testing a parameter of interest (Cohen, 1988; Thomas, 1997). This information could facilitate the study of tree-roosting bats, where data collection often is costly and labor intensive and where no recommendations presently exist on the amount of sampling required to detect biologically meaningful differences in use of forest habitat by bats.

A heightened awareness of the importance of above ground habitat for tree-roosting bats has resulted in an increasing demand for data and recommendations by agencies charged with responsible use of forest lands and by private land owners that actively manage forests. Recent symposia on forest bats (Brigham and Barclay, 1996) and the tree-roosting Indiana bat, *Myotis sodalis* (Lacki, 2002), attest to the level of attention being paid to uncovering critical habitat requirements of tree-roosting bat species. A unified goal of all these efforts should be identification of habitat characteristics or construction of predictive habitat models that effectively discriminate habitats used by bats from random or available habitats at the stand or landscape scale (Fenton, 1997). Such information would be helpful in the planning stage where the implementation of different forest management prescriptions is evaluated and where existing data on bats could possibly sway the outcome of the decision-making process (Pierson, 1998). Presently there is little agreement as to how to quantify habitat, the scale at which habitat characteristics should be measured (i.e., tree, stand or landscape), whether habitat characteristics should be examined separately or in a multivariate context, and the level of sampling effort necessary to achieve a specified level of precision for the habitat characteristics measured. The purposes of this paper are: 1) to review the existing literature and identify habitat characteristics that appear to be best suited to the study of tree-roosting bats, and 2) to develop recommendations for estimating sampling effort that will achieve a high probability of detecting meaningful biological effect sizes.

METHODS

We reviewed literature published between 1988 and 2001 for studies that examined habitat characteristics associated with roost site selection in tree-roosting bats. We specifically identified studies where habitat characteristics were measured at roosting sites and then compared to random or available conditions, or where habitat characteristics were compared among species. Finally, we identified 25 published studies that met desired habitat comparison requirements, and were used in calculating power analyses. These include (in alphabetical order): Barclay *et al.* (1988), Betts (1996, 1998), Boonman (2000), Brigham *et al.* (1997), Callahan *et al*. (1997), Campbell *et al*. (1996), Crampton and Barclay (1998), Cryan *et al.* (2001), Foster and Kurta (1999), Grindal (1999), Hutchinson and Lacki (2000), Lacki and Schwierjohann (2001), Lunney *et al*. (1995), Mattson *et al.* (1996), Menzel *et al.* (1998), Ormsbee and McComb (1998), Rabe *et al*. (1998), Sasse and Pekins (1996), Sedgeley and O'Donnell (1999*a*, 1999*b*), Vonhof (1996), Vonhof and Barclay (1996), Waldien *et al.* (2000), and Weller and Zabel (2001). For each paper we determined the number of habitat characteristics quantified, number of habitat characteristics found to be significant, whether nominal (i.e., categorical) habitat characteristics were examined, and whether habitat characteristics were tested using a multivariate approach, tested separately, or both.

Rather than rely on power curves based on a range of possible effect sizes to evaluate the sample size needed to detect a biologically significant effect size for a habitat characteristic (Steidl *et al.*, 1997), we used differences reported to be statistically significant in the published literature and, thus, interpreted as if they were biologically significant by the authors to estimate effects. For habitat characteristics where differences were reported across three or more studies, we calculated the mean estimated standardized effect size, i.e., the absolute value of the difference between means divided by the population standard deviation, and 95% confidence intervals, based on the estimated or measured effects reported in the studies reviewed (Cohen, 1988). Standardized effect sizes are helpful in the planning phase of studies because they are unitless and can be compared among studies (Steidl and Thomas, 2001). We estimated the sample size of radio-tagged bats needed to achieve minimally acceptable power (i.e., 0.8; Steidl *et al.*, 1997), and a power level (0.95) where alpha and beta are equal and the chance of committing a Type I or Type II error equal (0.05), using upper and lower limits of the 95% confidence intervals associated with mean estimated standardized effect sizes for habitat characteristics and tables provided in Cohen (1988). For all comparisons we used tables assuming a two-tailed *t*-test and an $\alpha = 0.05$.

We combined habitat characteristics across studies that we thought measured like attributes and organized the variables into two categories: those associated with the roost tree and those measured at the stand or landscape scale. Habitat characteristics for study of tree-roosting bats were evaluated based on their frequency of success, i.e., % of time found significant, and the sample sizes of radio-tagged bats projected to achieve measured levels of precision with sufficient power for these characteristics.

Results

We identified 25 published studies from 1988 to 2001 that met desired habitat comparison requirements. The mean (± SE) number of habitat characteristics measured per study was 8.0 ± 1.1, with 4.2 ± 0.7 habitat characteristics found on average to be significant. Ten (40%) of the studies also measured nominal habitat characteristics. Thirteen (52%) of the studies used a multivariate approach to evaluate habitat characteristics, with the mean number of habitat characteristics examined being 9.2 ± 1.8. In these papers, 4.2 ± 1.0 habitat characteristics were found to be significant on average. Logistic regression was the most common multivariate approach used in evaluating habitat characteristics.

Authors tested an average of 6.7 ± 1.2 habitat characteristics in studies where measures were examined separately, with 4.3 ± 1.0 habitat characteristics found to be significant. Student's *t*-test and Wilcoxon nonparametric test were the most frequently used approaches when evaluating habitat characteristics independently.

Roost-tree diameter was the most frequently measured habitat characteristic, followed by roost-tree height, roost-tree canopy cover, roost height, and slope, respectively (Table 1). Habitat characteristics of the roost tree itself were measured far more often than stand or landscape characteristics; however, there was a total of 31 different habitat characteristics used to describe stand or landscape habitat features as opposed to only 23 habitat characteristics used to describe features of the roost tree (Table 1; Appendix). For stand or landscape characteristics, a significant difference was reported at least once for 61.3% (n = 19) of the habitat characteristics reported, whereas habitat characteristics measured at the roost tree were found significant in at least one instance for 82.6% (n = 19) of the measures reported.

Of the studies surveyed, 68% (n = 17) provided sufficient data for power analysis, i.e., mean, an estimate of variance, and sample size, of at least one or more habitat characteristic. Mean estimated standardized effect size of habitat characteristics ranged from 0.83 for stand basal area to 1.52 for tree/snag height (Table 2). A sample size of 11 radio-tagged bats was sufficient to achieve acceptable power, i.e., 0.80, for all habitat characteristics evaluated based on the upper limit of the 95% confidence intervals for estimated mean standardized effect sizes. In contrast, a sample size of 39 radio-tagged bats was sufficient in achieving the same level of power for only 50% of the habitat characteristics evaluated at the lower end of the 95% confidence interval. Habitat characteristics found to have low estimated effect sizes and, thus, are likely to be poor choices for modeling habitat conditions of tree-roosting bats included

TABLE 1. Quantitative habitat characteristics most frequently measured in studies of tree-roosting bats. The percentage of studies in which a habitat characteristic was found significant at $P < 0.05$ and the direction of the measured characteristic from random or available trees in the habitat are presented

Habitat characteristic	No. studies measured	% different	Direction of difference
	Roost-tree characteristics[a]		
Tree/snag diameter (cm)	23	65.2	Roost > random
Tree/snag height (m)	21	52.4	Roost > random
Tree/snag canopy cover (%)	16	56.2	Roost < random
Roost height (m)	14	21.4	Roost > random
Snag bark cover (%)	9	22.2	Roost > random
Roost aspect (°)	7	14.3	Roost ≠ random[c]
Distance to nearest tree (m)	6	33.3	Roost > random
Canopy height (m)	5	20	Roost > random
Distance to nearest tree > roost tree in height (m)	5	80	Roost > random
Height of nearest tree (m)	5	0	–
Difference between roost tree height and canopy height (m)	4	50	Roost < random
Distance to nearest available tree (m)	4	25	Roost < random
Branches remaining (%)	3	33.3	Roost > random
	Stand/landscape characteristics[b]		
Slope (%)	10	30	Roost > random
Aspect (o)	8	0	–
Mean stem diameter (cm)	8	75	Roost > random
Distance to forest edge (m)	7	28.6	Roost > random
Distance to open/lentic water (m)	7	14.3	Roost < random
Mean snag density (no. snags/ha)	7	42.9	Roost > random
Elevation (m)	6	33.3	Roost ≠ random
Mean stand density (no. trees/ha)	5	60	Roost ≠ random
Stand basal area (m^2/ha)	5	80	Roost > random
Basal area of large diameter (≥ 25 cm) trees (m^2/ha)	5	80	Roost > random

[a] — Ten additional characteristics were measured in ≤ 2 studies
[b] — Twenty-one additional characteristics were measured in ≤ 2 studies
[c] — Direction of difference (≠) varied across studies

tree/snag canopy cover, mean snag density, and stand basal area. An explanation for poor performance of these habitat characteristics in our analysis probably lies in an inherently larger variation within the data collected to assess these measures, resulting in smaller estimated effect sizes.

DISCUSSION

Although not exhaustive, we do believe that our sample of available literature reflects the variety of habitat characteristics being examined and variability in the data collected across studies of tree-roosting bats. Further, we restricted our analysis to quantitative habitat characteristics only, so recommendations here cannot be applied to nominal measures of habitat characteristics. Regardless, we believe the results of this analysis can be used to aid in designing habitat studies of tree-roosting bats. For example, based on the findings presented (Tables 1 and 2), we could hypothesize that forest bats should typically choose roost trees larger in diameter, taller in height, lower in canopy cover, further from the nearest tree ≥ roost tree in height, and smaller in distance between roost-tree height and canopy height than random or available trees in the

TABLE 2. Mean estimated standardized effect sizes for quantitative habitat characteristics measured in studies of tree-roosting bats and associated sample sizes (shown in LCI and UCI columns) required to achieve indicated power levels. Based on α = 0.05, using two-sample *t*-test (Cohen, 1988). LCI and UCI: lower and upper ends of confidence interval, respectively

Habitat characteristics	Effect size			Power level			
				0.8		0.95	
	n[a]	Mean	95% CI	LCI	UCI	LCI	UCI
Roost-tree characteristics							
Tree/snag diameter (cm)	18	1.19	0.94–1.44	19	9	31	14
Tree/snag height (m)	7	1.52	0.92–2.12	21	9	33	14
Tree/snag canopy cover (%)	7	0.95	0.40–1.50	99	9	163	14
Distance to nearest tree ≥ roost tree in height (m)	4	1.37	0.65–2.09	39	9	64	14
Roost height (m)	3	1.1	0.79–1.41	27	9	43	14
Stand/landscape characteristics							
Mean snag density (no. snags/ha)	6	0.85	0.45–1.25	82	11	134	18
Mean stem diameter (cm)	4	1.22	-1.30–3.74	–	9	–	14
Stand basal area (m^2/ha)	4	0.83	-0.10–1.77	–	9	–	14

[a] — Indicates the number of comparisons in which sufficient data (i.e., mean, variance, and sample size) were provided to allow calculation of estimated standardized effect size

habitat. Further, forest bats should choose roost trees on steeper slopes, in stands greater in basal area, higher in snag density, and closer to open water relative to random stands in the landscape. We suggest that these variable combinations represent baseline models that could be tested across landscapes to identify patterns common to bat species. Anderson *et al*. (2001) have encouraged authors to develop biological theories for testing prior to undertaking empirical studies leading toward the development of predictive models. The results presented here provide a baseline from which biological theory on roost-site selection of tree-roosting bats could begin to be formulated.

It should be anticipated that some habitat characteristics will be more or less important to some bat species than others, and that species may respond differently to the same habitat characteristic; thus, reciprocal effects in models of habitat use for some characteristics are plausible among different bat species (e.g., elevation and stand density; Table 1). The difference in canopy closure observed between roost trees of northern bats (*Myotis septentrionalis*), which select higher closure (Foster and Kurta, 1999; Lacki and Schwierjohann, 2001), and *M. sodalis*, which select more open canopies (Callahan *et al.*, 1997; Foster and Kurta, 1999), is a case in point. In turn, habitat characteristics important to foliage-roosting species, such as the lasiurine bats (e.g., Menzel *et al.*, 1998; Hutchinson and Lacki, 2000), cannot be expected to mimic those required of snag or cavity-roosting bats (Hayes, In press).

It is well documented that tree-roosting bats switch roosts frequently (Lewis, 1995), and it is hypothesized that low roost-site fidelity of tree-roosting bats is in response, in part, to the ephemeral nature of tree roosts (Kurta *et al.*, 1993). Temporal shifts in energetic demands of tree-roosting bats, especially among pregnant, lactating, and post-lactating females, also is likely to be a contributing factor in roost switching over the course of the summer maternity season (Kurta *et al.*, 1996), rendering development of predictive habitat models difficult at best (Millspaugh *et al.*, 1998). Because of such anticipated variability in roost-site selection by bats, we recommend that authors continue to explore other options for habitat characteristics, including characteristics little used in the studies reviewed here.

Prospective power analyses revealed that sample sizes of radio-tagged bats ranging from 11–39 would be sufficient to achieve some probability of detecting biologically significant effects for several of the variables tested. As was pointed out to one of us (MJL) by an anonymous reviewer (Lacki and Schwierjohann, 2001), the actual sample size upon which statistical inferences should be based in studies of tree-roosting bats is the number of bats fitted with radio-transmitters. This is because multiple bats can and do use the same roost tree and, therefore, individual roosts are not necessarily independent samples. Further, analysis of resource selection assumes that sampling of resource units is random and independent (Millspaugh *et al.*, 1998). Because roost trees are selected by the bats, and not the researcher, and that bats often use the same roost trees at various points in time, roost trees are not biologically or statistically independent. As such, the sample sizes reported here should reflect the number of bats radio-tagged for study and not the number of roost trees identified, because it is the bats that are presumed to be collected randomly and independently.

We also encourage researchers to consider planning when determining the sample size necessary for the number of random or available habitat plots or trees to be measured. Guidelines for determining sampling effort of random plots or trees exist (Ramsey *et al.*, 1994), with a recommendation of no more than 4:1 random to used samples, because of the limited increase in statistical power beyond this ratio relative to the expense of obtaining additional samples (Breslow and Day, 1980). The effect of scale also should not be overlooked. Although estimated sample sizes varied among the habitat characteristics examined (Table 2), there appeared to be greater variability in projected sample sizes associated with stand and landscape habitat characteristics than with measures used to describe the roost tree. Thus, the need for prior planning is even more critical when landscape-scale inferences are being examined.

Exactly how preexisting data should be used to calculate statistical power during the planning phase of studies remains a point of discussion (Steidl *et al.*, 1997; Thomas, 1997; Gerard *et al.*, 1998). To begin with, statistical significance does not always reflect biological significance (Tacha *et al.*, 1982; Yoccoz, 1991; Johnson, 1995), and use of preexisting data to measure the effect and variance can lead to biased estimates of power with low precision (Gerard *et al.*, 1998). Further, when analyses are based on actual data collected in the field, power becomes a random variable and the measures of power reported are 'estimates' of statistical power (Gerard *et al.*, 1998). Thomas (1997) recommended that when field data are used to estimate power, a sensitivity analysis should be performed that examines a range of Type II error levels.

Through an examination of Type II error levels at the upper and lower bounds of the confidence intervals of estimated standardized mean effect sizes, we provide a foundation for sensitivity analysis of power for studies planning to evaluate habitat characteristics of tree-roosting bats (Taylor and Muller, 1995; Thomas, 1997). By using data collected and previously analyzed across a series of studies, or a meta-analysis approach (Johnson, 2002), we believe that estimated standardized mean effect sizes can be calculated and used as a potential tool for estimating power or sample size for a given power level. This approach is in lieu of the development of a range of 'hypothetical' power curves; curves that represent a wide range of possibilities and are based on limited forethought of the potential biological effect sizes in question. We believe this latter approach can be troublesome, especially for researchers who have limited experience with the species of bat or geographic region they intend to study.

We chose to use data from published studies to reflect biologically significant effect sizes and variances under the supposition that the authors' of these papers deemed the effects to be biologically significant, because differences were interpreted to be biologically meaningful. We qualify analyses in this paper with the understanding that in each comparison that we evaluated, reality lies somewhere between biological and statistical significance; the larger the effect and/or the smaller the sampling variance the greater the likelihood that a 'difference' will be reported (Johnson, 1995; Hayes and Steidl, 1997). Conversely, studies for which no significant effect is observed are less likely to be published; thus, any evaluation based on published findings, including this one, has the potential for bias due to the method of sampling used (Dear and Begg, 1992). Ultimately, it is the responsibility of the researcher to decide if the observed effect is biologically significant given their understanding of the species of bat under study. Proper planning beforehand that produces a sampling design with sufficient power should minimize ambiguity in interpreting the outcome of the data collected. By no means do we imply that non-significant results are unimportant. They are more difficult to interpret, particularly when the study design used has low statistical power.

The results of our analysis, along with the synthesis provided in Hayes (In press), suggests that sufficient data exist to begin formulating biological theories that could be tested in empirical studies of tree-roosting bats. Regardless, we encourage researchers to provide the mean, an estimate of variance, and the sample size for each habitat characteristic measured in all published studies of tree-roosting bats. This alone will help in the design and analysis of future studies of tree-roosting bats. We support the use of pilot studies during the planning phase (Steidl *et al.*, 1997). Developing a priori hypotheses on how bats might respond to habitat characteristics, supplemented with estimates of effect size and variance from pilot study data, should provide useful comparisons with published data. Lastly, there can be no shortage of care taken to minimize sampling error in the field while studying tree-roosting bats. By minimizing error due to the collection technique, investigators should produce smaller estimates of variance via more efficient sampling protocols, and, ultimately, increased statistical power.

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Literature Cited

Anderson, D. R., K. P. Burnham, W. R. Gould, and S. Cherry. 2001. Concern about finding effects that are actually spurious. Wildlife Society Bulletin, 29: 311–316.

Barclay, R. M. R., P. A. Faure, and D. R. Farr. 1988. Roosting behavior and roost selection by migrating silver-haired bats (*Lasionycteris noctivagans*). Journal of Mammalogy, 69: 821–825.

Betts, B. J. 1996. Roosting behavior of silver-haired bats (*Lasionycteris noctivagans*) and big brown bats (*Eptesicus fuscus*) in Northeast Oregon. Pp. 55–61, *in* Bats and forests symposium (R. M.

R. Barclay and R. M. Brigham, eds.). British Columbia Ministry of Forests, Victoria, British Columbia, 292 pp.

Betts, B. J. 1998. Roosts used by maternity colonies of silver-haired bats in northeastern Oregon. Journal of Mammalogy, 79: 643–650.

Boonman, M. 2000. Roost selection by noctules (*Nyctalus noctula*) and Daubenton's bats (*Myotis daubentonii*). Journal of Zoology (London), 251: 385–389.

Breslow, N. E., and N. E. Day. 1980. Statistical methods in cancer research. Volume 1: The analysis of case control studies. International Agency for Research on Cancer Scientific Publication, Lyon, 32: 1–350.

Brigham, R. M., and R. M. R. Barclay. 1996. Bats and forests. Pp. xi –xiv, *in* Bats and forests symposium (R. M. R. Barclay and R. M. Brigham, eds.). British Columbia Ministry of Forests, Victoria, 292 pp.

Brigham, R. M., M. J. Vonhof, R. M. R. Barclay, and J. C. Gwilliam. 1997. Roosting behavior and roost-site preferences of forest-dwelling California bats (*Myotis californicus*). Journal of Mammalogy, 78: 1231–1239.

Callahan, E. V., R. D. Drobney, and R. L. Clawson. 1997. Selection of summer roosting sites by Indiana bats (*Myotis sodalis*) in Missouri. Journal of Mammalogy, 78: 818–825.

Campbell, L. A., J. G. Hallett, and M. A. O'Connell. 1996. Conservation of bats in managed forests: use of roosts by *Lasionycteris noctivagans*. Journal of Mammalogy, 77: 976–984.

Cohen, J. 1988. Statistical power analysis for the behavioral sciences. Second ed. Lawrence Erlbaum, Hillsdale, New Jersey, 567 pp.

Crampton, L. H., and R. M. R. Barclay. 1998. Selection of roosting and foraging habitat by bats in different-aged aspen mixedwood stands. Conservation Biology, 12: 1347–1358.

Cryan, P. M., M. A. Bogan, and G. M. Yanega. 2001. Roosting habits of four bat species in the Black Hills of South Dakota. Acta Chiropterologica, 3: 43–52.

Dear, K., and C. Begg. 1992. An approach for assessing publication bias prior to performing a meta-analysis. Statistical Science, 7: 237–245.

Eberhardt, L. L., and J. M. Thomas. 1991. Designing environmental field studies. Ecological Monographs, 61: 53–73.

Fenton, M. B. 1997. Science and the conservation of bats. Journal of Mammalogy, 78: 1–14.

Foster, R. W., and A. Kurta. 1999. Roosting ecology of the northern bat (*Myotis septentrionalis*) and comparisons with the endangered Indiana bat (*Myotis sodalis*). Journal of Mammalogy, 80: 659–672.

Gerard, P. D., D. R. Smith, and G. Weerakody. 1998. Limits of retrospective power analysis. Journal of Wildlife Management, 62: 801–807.

Grindal, S. D. 1999. Habitat use by bats, *Myotis* spp., in western Newfoundland. Canadian Field-Naturalist, 113: 258–263.

Hayes, J. P. In press. Habitat ecology and conservation of bats in western coniferous forests. *In* Conservation of small mammals in western coniferous forests (C. J. Zabel and R. G. Anthony, eds.). Island Press, Covela, CA.

Hayes, J. P., and R. J. Steidl. 1997. Statistical power analysis and amphibian population trends. Conservation Biology, 11: 273–275.

Hutchinson, J. T., and M. J. Lacki. 2000. Selection of day roosts by red bats in mixed mesophytic forests. Journal of Wildlife Management, 64: 87–94.

Johnson, D. H. 1995. Statistical sirens: the allure of nonparametrics. Ecology, 76: 1998–2000.

Johnson, D. H. 2002. The importance of replication in wildlife research. Journal of Wildlife Management, 66: 919–932.

Kurta, A., D. King, J. A. Teramino, J. M. Stribley, and K. J. Williams. 1993. Summer roosts of the endangered Indiana bat (*Myotis sodalis*) on the northern edge of its range. The American Midland Naturalist, 129: 132–138.

Kurta, A., K. J. Williams, and R. Mies. 1996. Ecological, behavioural, and thermal observations of a peripheral population of Indiana bats (*Myotis sodalis*). Pp. 102–117, *in* Bats and forests symposium (R. M. R. Barclay and R. M. Brigham, eds.). British Columbia Ministry of Forests, Victoria, British Columbia, 292 pp.

Lacki, M. J. 2002. Conference summary. Pp. xi–xii, *in* The Indiana bat: biology and management of an endangered species (A. Kurta and J. Kennedy, eds.). Bat Conservation International, Inc., Austin, TX, 253 pp.

Lacki, M. J., and J. H. Schwierjohann. 2001. Day-roost characteristics of northern bats in mixed mesophytic forest. Journal of Wildlife Management, 65: 482–488.

Lewis, S. E. 1995. Roost fidelity of bats: a review. Journal of Mammalogy, 76: 481–496.

Lunney, D., J. Barker, T. Leary, D. Priddel, R. Wheeler, P. O'Connor, and B. Law. 1995. Roost selection by the north Queensland long-eared bat *Nyctophilus bifax* in littoral rainforest in the Iluka World Heritage Area, New South Wales. Australian Journal of Ecology, 20: 532–537.

MATTSON, T. A., S. W. BUSKIRK, and N. L. STANTON. 1996. Roost sites of the silver-haired bat (*Lasionycteris noctivagans*) in the Black Hills, South Dakota. Great Basin Naturalist, 56: 247–253.

MENZEL, M. A., T. C. CARTER, B. R. CHAPMAN, and J. LAERM. 1998. Quantitative comparison of tree roosts used by red bats (*Lasiurus borealis*) and Seminole bats (*L. seminolus*). Canadian Journal of Zoology, 76: 630–634.

MILLSPAUGH, J. J., J. R. SKALSKI, B. J. KERNOHAN, K. J. RAEDEKE, G. C. BRUNDIGE, and A. B. COOPER. 1998. Some comments on spatial independence in studies of resource selection. Wildlife Society Bulletin, 26: 232–236.

ORMSBEE, P. C., and W. C. MCCOMB. 1998. Selection of day roosts by female long-legged myotis in the Central Oregon Cascade range. Journal of Wildlife Management, 62: 596–603.

PIERSON, E. D. 1998. Tall trees, deep holes, and scarred landscapes: conservation biology of North American bats. Pp. 309–325, *in* Bat biology and conservation. (T. H. KUNZ and P. A. RACEY, eds.). Smithsonian Institution Press, Washington, D.C., 365 pp.

RABE, M. J., T. E. MORRELL, H. GREEN, J. C. DEVOS, JR., and C. R. MILLER. 1998. Characteristics of ponderosa pine snag roosts used by reproductive bats in northern Arizona. Journal of Wildlife Management, 62: 612–621.

RAMSEY, F. L., M. MCCRACKEN, J. A. CRAWFORD, M. S. DRUT, and W. J. RIPPLE. 1994. Habitat association studies of the northern spotted owl, sage grouse, and flammulated owl. Pp. 189–209, *in* Case studies in biometry (N. LANGE, L. RYAN, L. BILLARD, D. BRILLINGER, L. CONQUEST, and J. GREENHOUSE, eds.). John Wiley & Sons, Inc., New York, 462 pp.

REED, J. M., and A. R. BLAUSTEIN. 1995. Assessment of 'nondeclining' amphibian populations using power analysis. Conservation Biology, 9: 1299–1300.

SASSE, D. B., and P. J. PEKINS. 1996. Summer roosting ecology of northern long-eared bats (*Myotis septentrionalis*) in the White Mountain National Forest. Pp. 91–101, *in* Bats and forests symposium (R. M. R. BARCLAY and R. M. BRIGHAM, eds.). British Columbia Ministry of Forests, Victoria, British Columbia, 292 pp.

SEDGELEY, J. A., and C. F. J. O'DONNELL. 1999*a*. Roost selection by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate New Zealand rainforest and its implications for the conservation of bats in managed forests. Biological Conservation, 88: 261–276.

SEDGELEY, J. A., and C. F. J. O'DONNELL. 1999*b*. Factors influencing the selection of roost cavities by a temperate rainforest bat (Vespertilionidae: *Chalinolobus tuberculatus*) in New Zealand. Journal of Zoology (London), 249: 437–446.

STEIDL, R. J., and L. THOMAS. 2001. Power analysis and experimental design. Pp. 14–36, *in* Design and analysis of ecological experiments (S. M. SCHEINER and J. GUREVITCH, eds.). Oxford University Press, New York, NY, 415 pp.

STEIDL, R. J., J. P. HAYES, and E. SCHAUBER. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management, 61: 270–279.

TACHA, T. C., W. D. WARDE, and K. P. BURNHAM. 1982. Use and interpretation of statistics in wildlife journals. Wildlife Society Bulletin, 10: 355–362.

TAYLOR, B. L., and T. GERRODETTE. 1993. The uses of statistical power in conservation biology: the Vaquita and northern spotted owl. Conservation Biology, 7: 489–500.

TAYLOR, D. J., and K. E. MULLER. 1995. Computing confidence bounds for power and sample size of the general linear univariate model. The American Statistician, 49: 43–47.

THE WILDLIFE SOCIETY. 1995. Journal news. Journal of Wildlife Management, 59: 196–198.

THOMAS, L. 1997. Retrospective power analysis. Conservation Biology, 11: 276–280.

VONHOF, M. J. 1996. Roost-site preferences of big brown bats (*Eptesicus fuscus*) and silver-haired bats (*Lasionycteris noctivagans*) in the Pend d'Oreille Valley in southern British Columbia. Pp. 62–80, *in* Bats and forests symposium (R. M. R. BARCLAY and R. M. BRIGHAM, eds.). British Columbia Ministry of Forests, Victoria, British Columbia, 292 pp.

VONHOF, M. J., and R. M. R. BARCLAY. 1996. Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. Canadian Journal of Zoology, 74: 1797–1805.

WALDIEN, D. L., J. P. HAYES, and E. B. ARNETT. 2000. Day-roosts of female long-eared myotis in western Oregon. Journal of Wildlife Management, 64: 785–796.

WELLER, T. J., and C. J. ZABEL. 2001. Characteristics of fringed myotis day roosts in northern California. Journal of Wildlife Management, 65: 489–497.

YOCCOZ, N. G. 1991. Use, overuse, and misuse of significance tests in evolutionary biology and ecology. Bulletin of the Ecological Society of America, 72: 106–111.

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Appendix

Supplemental list of quantitative variables to describe habitat characteristics of tree-roosting bats that were used in ≤ 2 studies. Significance met if $P \leq 0.05$

Habitat characteristics	Significant	Direction of difference
Roost-tree characteristics		
Canopy depth (m)	No	–
Distance to nearest vegetation (m)	Yes	Roost > random
Height of nearest tree as tall or taller than roost tree (m)	Yes	Roost > random
Number of cavities (*n*)	Yes	Roost > random
Percent bare trunk (bole — %)	No	–
Percent crown remaining (%)	Yes	Roost > random
Percent obstruction near roost entrance (%)	No	–
Percent of roost tree obscured by vegetation (%)	Yes	Roost < random
Trunk (bole) height (m)	Yes	Roost > random
Trunk (bole) surface area (m^2)	Yes	Roost > random
Stand characteristics		
Basal area of snags (m^2/ha)	Yes	Roost > random
Density of available trees (no. trees/ha)	No	–
Density of conifer trees (no. trees/ha)	No	–
Density of deciduous trees (no. trees/ha)	No	–
Density of large diameter snags (no. snags/ha)	Yes	Roost > random
Downed log density (no. logs/ha)	Yes	Roost > random
Height of overstory (m)	No	–
Height of understory vegetation (m)	Yes	Roost < random
Mean stem diameter of trees ≥ 25 cm in diameter	No	–
Number of canopy layers (*n*)	No	–
Number of sapling (*n*)	No	–
Number of shrubs (*n*)	No	–
Number of stumps (no. stumps/ha)	No	–
Number of trees in overstory (*n*)	No	–
Percent understory cover (%)	Yes	Roost < random
Richness of understory (no. species)	Yes	Roost > random
Standard deviation of tree diameter (cm)	Yes	Roost > random
Stand height (m)	Yes	Roost > random
Landscape characteristics		
Distance to capture site (m)	Yes	Roost < random
Distance to nearest roadway (m)	No	–
Distance to nearest stream channel (m)	Yes	Roost < random