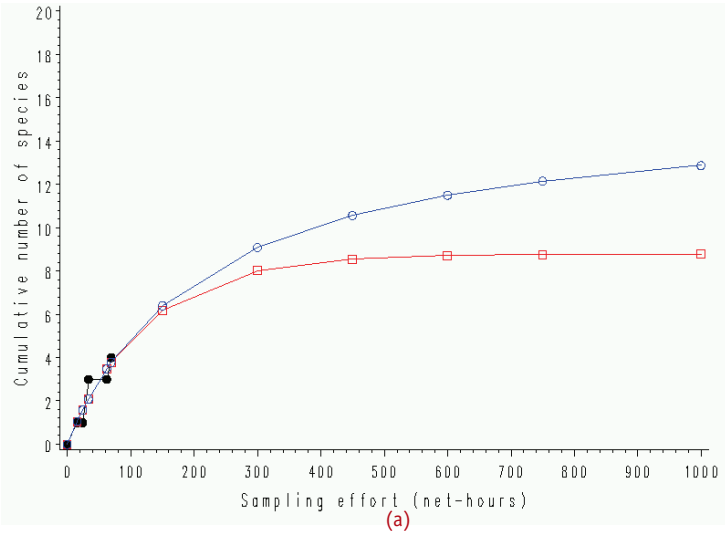
Estimation of sampling effort for catching enough bats

How many bats must you catch to find out how many species of them are flying around? South Dakota is evidently well infested with small flying mammals. **Weiming Ke** and **Brandon T. Bales** of South Dakota State University spent many happy night-time hours with their nets....

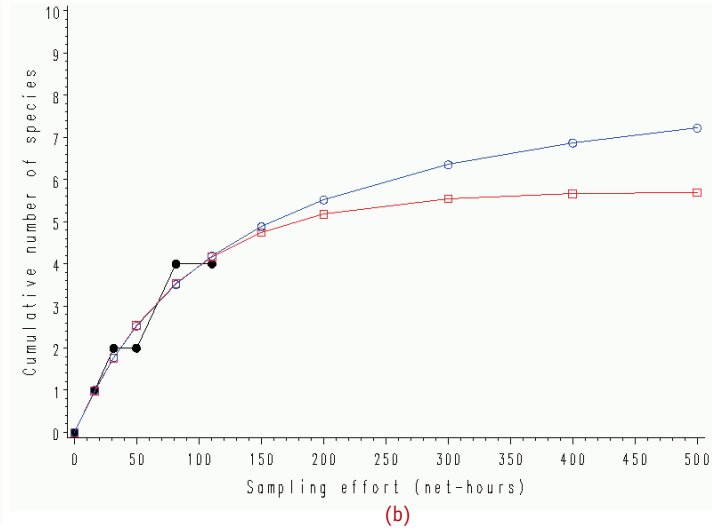
Bats are one of the most beneficial mammals in the world. Like all mammals, bats have hair, are warm blooded and nurse their young. Bats are the only mammals that truly fly. As the primary predators of night-flying insects, bats play a vital role in maintaining the balance of nature. And, as consumers of vast numbers of pests, they rank among humanity's most valuable allies. One bat can eat between 600 and 1000 mosquitoes and other insect pests in just an hour. Bats are extremely important members of a healthy rainforest, and by dispersing seeds they help to regenerate the forest after clear-cutting or fires. There are over 950 species of bats worldwide. Only 0.5% of all bats have rabies, and there are only three species of vampire bat that feed on blood. Bats eat tons of millions of insect pests each night around the world. They are extremely important for the overall well-being of the ecosystem.

Lasiurus borealis (red bats) are widely distributed in forested regions, occurring from southern Canada through Central America and into Chile and Argentina. Red bats migrate to warmer regions during winter. They capture insects while flying like many other insectivorous bats. They play an important ecosystem role as insect consumers. Photo by Timothy Brown

To understand better and to preserve bats and their habitats, we need to catch samples of various species of bat to study their distribution, foraging habits, roosting sites, migratory patterns, reproductive strategies, population structure, genetic structure and the problems they face. Bats can be captured by mist nets. The sampling effort can be measured by net-nights or net-hours, etc. When making effort to take samples of bats, the most frequently asked questions are how many species of bats are living in this area? And how much sampling effort is needed to catch enough species of bats, say 90% of the total fauna in this area?



(a)



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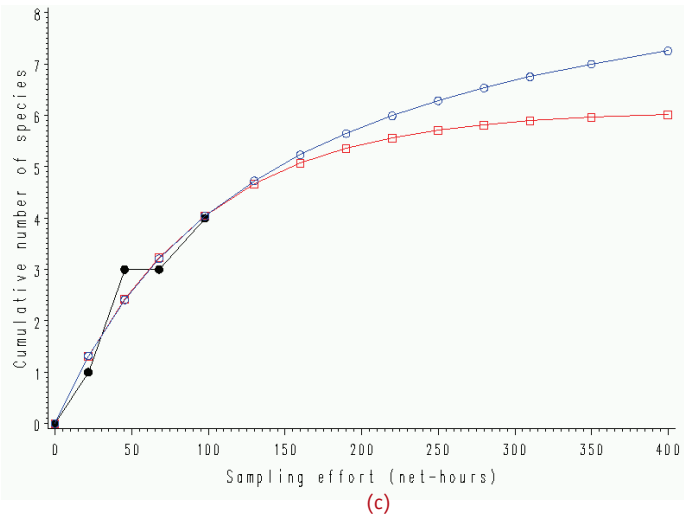

(c)

Figure 1. Original and fitted bat species accumulation curves for three locations: (a) Farm Island, (b) West Bend and (c) Lewis and Clark boy scout camp. ●, observed data; □, prediction of the linear dependence model; ○, prediction of the Clench model

Species accumulation models

Species accumulation models can be used to estimate the total number of species in an area and to estimate the sampling effort required to reach a satisfactory level of completeness. On the basis of the available data, we can draw a species accumulation curve in which the cumulative number of species is plotted against some measure of the sampling effort it takes to obtain that sample. By fitting the species accumulation models to species accumulation curves, the total number of species in an area can be estimated, which is the asymptote of the model. By using the estimated parameters of the model, the sampling effort needed to reach a proportion of the total fauna can be estimated. The species accumulation models provide a predictive tool for biodiversity studies, and also provide a planning tool for designing sampling protocols.

In this article, we introduce and use two species accumulation models to fit the bat species accumulation data: the linear dependence model and the Clench model.

The linear dependence model

The linear dependence model is given by

$$S(t) = \frac{a}{b}\{1 - \exp(-bt)\},$$

where t is a measure of sampling effort (in our case, it is the number of net-hours), $S(t)$ is the predicted number of species at t, a represents the rate of increase at the beginning of the sampling, b is a parameter related to the shape of the accumulation of new species during the sampling, a/b is the asymptote which is the total richness of the site that can be obtained when t goes to infinity. This model assumes that the probability of adding a new species to the list depends linearly on the size of the list. As the species list grows, the probability of adding a new species to the list decreases proportionally to the current size of the list: hence the name of the linear dependence model.

On the basis of this model, the sampling effort t_q required to register a proportion of the total fauna $q = S(t)/(a/b)$ is given by

$$t_q = -\frac{1}{b}\ln(1 - q)$$

where q is the desired proportion of the total fauna for which the required time t_q is estimated. Soberon and Llorente[1] recommended this model for situations where the study area is relatively small and could theoretically reach an asymptote over a finite period of time.

The Clench model

Another species accumulation model is called the Clench model. This model is given by

$$S(t) = \frac{at}{1 + bt}.$$

On the basis of this model, the sampling effort t_q required to register a proportion of the total fauna $q = S(t)/(a/b)$ is given by

$$t_q = \frac{q}{b(1 - q)}$$

In this model, Clench[2] assumed that the probability of adding species to the list decreases with the number of species already recorded, but increases over time. Soberon and Llorente[1] recommended this model for larger areas than those where the linear dependence model would be applied, or for situations where the probability of adding new species will increase as more time is spent in the field, until an upper limit is reached.

Considering the nature of the two models, Moreno and Halffter[3] recommended using the linear dependence model to predict the "floor" or lower limit, and using the Clench model to predict the "ceiling" or upper limit;

Table 1. Estimation of parameters and asymptotes for linear dependence model

Location	Linear dependence model			
	a	b	a/b	r^2
Farm Island	0.0715	0.0081	8.8	0.8789
West Bend	0.0677	0.0119	5.7	0.9542
Lewis and Clark boy scout camp	0.0681	0.0112	6.1	0.9549

Table 2. Estimation of parameters and asymptotes for Clench model

Location	Clench model			
	a	b	a/b	r^2
Farm Island	0.0721	0.0046	15.7	0.8787
West Bend	0.0704	0.0077	9.1	0.9536
Lewis and Clark boy scout camp	0.0704	0.0072	9.8	0.9540

the true species accumulation curve should lie somewhere between them.

Model fitting and parameter estimation

To determine the distribution, seasonal activity pattern, habitat selection and migratory behaviours of bats in South Dakota, USA, specifically those that may use the Missouri river drainage as a corridor, samples of bats were taken from several locations along the Missouri river. On the basis of the sampling effort and the number of bat species recorded prior to this study, the species accumulation curves were made for each location. The sampling effort was measured by net-hours, which is the sum of the number of nets used each day multiplied by the number of hours used for that day. The two species accumulation models were used to fit the data from three locations. The total number of species was estimated for each location and the sampling effort required to catch a proportion of the total fauna in a site was estimated.

Achieving 100% richness would require infinite effort. We select 90% as satisfactory.

We used the non-linear regression procedure of SAS[4] to fit the two models to the observed data, which were cumulative number of species and the corresponding sampling effort. Both models fit the observed data very well at all locations (r^2 >0.87; r^2 is called the coefficient of determination, which is used in regression analysis to measure the effectiveness of a model. Its value is between 0 and 1. The larger the r^2, the better the model fits the data.) The linear dependence model predicted a lower asymptote and the Clench model predicted a higher asymptote than the observed species richness. The observed species accumulation curves and the fitted models are shown in Figure 1 for three different locations. The parameters a, b, and r^2 as well as the asymptote values a/b were estimated for the two models and the results are listed in Table 1 and Table 2.

Table 3. Estimated sampling effort required to record 90% of the total fauna

Location	Proportion of the asymptote, q	Linear dependence model Sampling effort required (minimum net-hours) $tq = -1/b \ln(1 - q)$	Clench model Sampling effort required (maximum net-hours) $tq = q/[b(1 - q)]$
Farm Island	90%	284.3	1956.5
West Bend	90%	193.5	1168.8
Lewis and Clark boy scout camp	90%	205.6	1250.0

Prediction of the sampling effort

The sampling effort, t_q, required to register a desired proportion of the total fauna can be estimated given q, the desired proportion of the total fauna and b, a parameter which was estimated when fitting the species accumulation models to the observed data. By definition, achieving 100% richness would require an infinite effort. We select 90% of the total fauna as a conservative, but satisfactory, level of completeness and estimate the sampling efforts required to reach this level. The sampling efforts estimated from the linear dependence model were used as lower limits, or minimum efforts; those estimated from the Clench model were used as upper limits, or maximum efforts. The results are listed in Table 3 for three locations.

Discussion

In this article, we use species accumulation models to fit the observed species accumulation curves of bats. These models can be used to predict the richness of the fauna of a site, given the known accumulation curve. They can also be used to predict the sampling effort required to record a satisfactory proportion of the total fauna. This will help us to estimate the cost of our future field work to record enough species of bats. From the results listed in Tables 1 and 2, with rounding down the lower limit and rounding up the upper limit, the estimated total fauna is 9–16 at location (a), 6–9 at location (b) and 6–10 at location (c). So we predict that, of the three locations, (a) is the most diversified with bat species. From Table 3, the minimum sampling efforts required to record 90% of the total fauna are 284.3 net-hours at location (a), 193.5 net-hours at location (b) and 205.6 net-hours at location (c). The use of species accumulation models can help us to predict the richness of bat biodiversity. It can also result in better sampling protocols by providing reliable estimates of the sampling effort required to obtain an efficient number of species and, consequently, can result in notable savings in time and field expenses. Thus, application of these models is highly recommended when comparing species diversity from different locations and planning further sampling field work.

References

1. Soberon, J. and Llorente, J. (1993) The use of species accumulation functions for the prediction of species richness. *Conservation Biology*, **7**, 480–488.
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4. SAS Publishing (2004) *SAS 9.1 User's Guide*. Cary, NC: SAS.

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