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Sampling Biodiversity in Bornean Frogs

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ABSTRACT.–Analysis of biodiversity is attracting increasing interest within the public arena, with many articles appearing in newspapers and popular magazines. This change is understandable because of the relationship of biodiversity to conservation in an increasingly stressed global environment. There is equal interest in biodiversity and related issues in scientific circles because of their relationship to questions in ecology, evolutionary biology, and conservation biology. The term biodiversity is often used as though it meant only the numbers of species (species richness), but the diversity of life is much more complex than that.

The scientific literature on biodiversity is centered on three main subjects: lists of species occurring in a small region, comparisons of the species occurring in different environments within a region, and comparisons of the species occurring in different regions. Unfortunately, the scientific literature on biodiversity is frequently marred by errors in sampling.

This paper will illustrate some aspects of biodiversity drawing upon work on the frogs of Borneo. My studies of the frogs of Borneo were designed to explore local and regional diversity, the impact of environmental differences on regional diversity, and the variation between species in the patterns of life cycles. Examples of these aspects of biodiversity are given.

KEY WORDS: biodiversity; sampling; Borneo; frogs

INTRODUCTION

Suddenly, it seems as if the entire world is talking about biodiversity. Certainly this is a very significant topic because it relates so directly to our growing interest in conservation in a stressed global environment. But what do we mean by biodiversity? Do we all mean the same thing? How do we study it? Are all the studies of biodiversity useful? In this paper I hope to provide some, at least partial, answers to those questions.

By biodiversity, most people mean simply the number of species at some place. In other words, they mean local or regional species richness. But there are many more faces to biodiversity. In addition to species richness, biodiversity also encompasses diversity in habitat relations, in life cycles, and various aspects of behavior. The focus in this paper will be on the patterns within one group of animals in one general environment: frogs of the rain forests of Borneo, a large island straddling the equator and having North-South and East-West dimensions greater than 1100 km.

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SAMPLING WEAKNESSES

Before reporting the results of the work in Borneo, I wish to make a few comments about sampling weaknesses. My experience as a

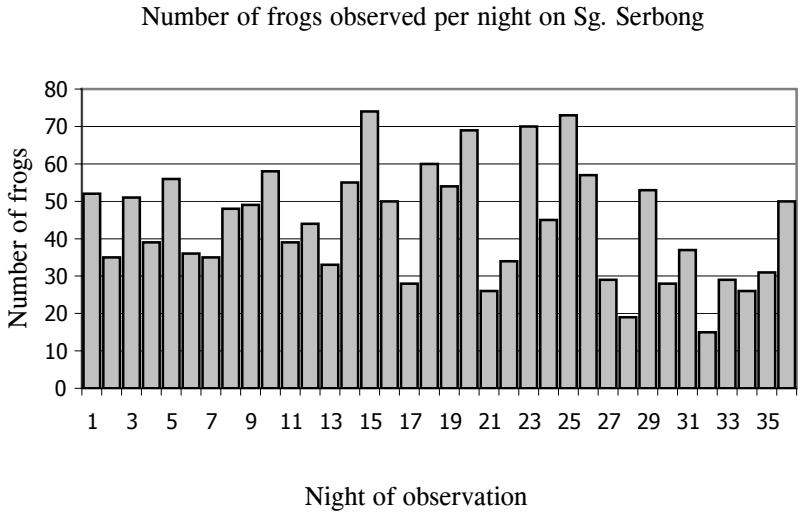

FIGURE 1. Variation in numbers of frogs observed (all species combined) on 36 nights over the same 620-meter transect on Sungai Serbong, Nanga Tekalit, Sarawak, during the course of 12 months (1962/63).

reviewer of manuscripts and reader of published papers tells me that many of the published statements about biodiversity cannot be supported because of very poor sampling procedures. Let me cite a few examples.

A recent study of a nature reserve in Madagascar (Raxworthy et al., 1998) compiled an inventory of the amphibians and reptiles on the eastern and western slopes of a massif. The authors concluded that " 30 species are restricted to a single slope only (between 1000 and 1700 m elevation)…suggesting significant differences in community composition." Sampling on the eastern slope took place 18 October - 28 November, 1994, while sampling on the western slope took place 25 January - 11 February, 1995. Amphibians are known to vary activity in response to variations in rainfall and temperature, but the authors give no indication of these variables of weather. No one would challenge the observation that 30 species were not found on both slopes, but the conclusion that 30 species are "restricted to a single slope" must be challenged. We may ask if the observed differences between the species lists are artifacts of differences in sampling periods. Would the observed differences have appeared if sampling had been carried out on both slopes during the same period or on both slopes at several times of the year? Unfortunately, this type of sampling deficiency is not uncommon, rendering a portion of the literature on biodiversity unreliable.

Ignoring important sources of variation is another common sampling error. Several students at a university proudly told me about a class exercise they had conducted to determine the differences in the frog species using ponds in two environments: open fields and adjacent rain forest. They showed me their results and asked my opinion. I asked them how many ponds they had sampled in each environment the answer was one! I then asked them if they thought their results would have been the same if they had sampled two ponds in each environment. That question puzzled them. Unfortunately, it also puzzled their professor who was standing next to us. These students and their professor had assumed that every pond in the forest would have the same species, that there was no variation within habitat types, that the species in each environment were essentially uniformly distributed within environments, like jam spread over a slice of bread. Although this example is drawn from my

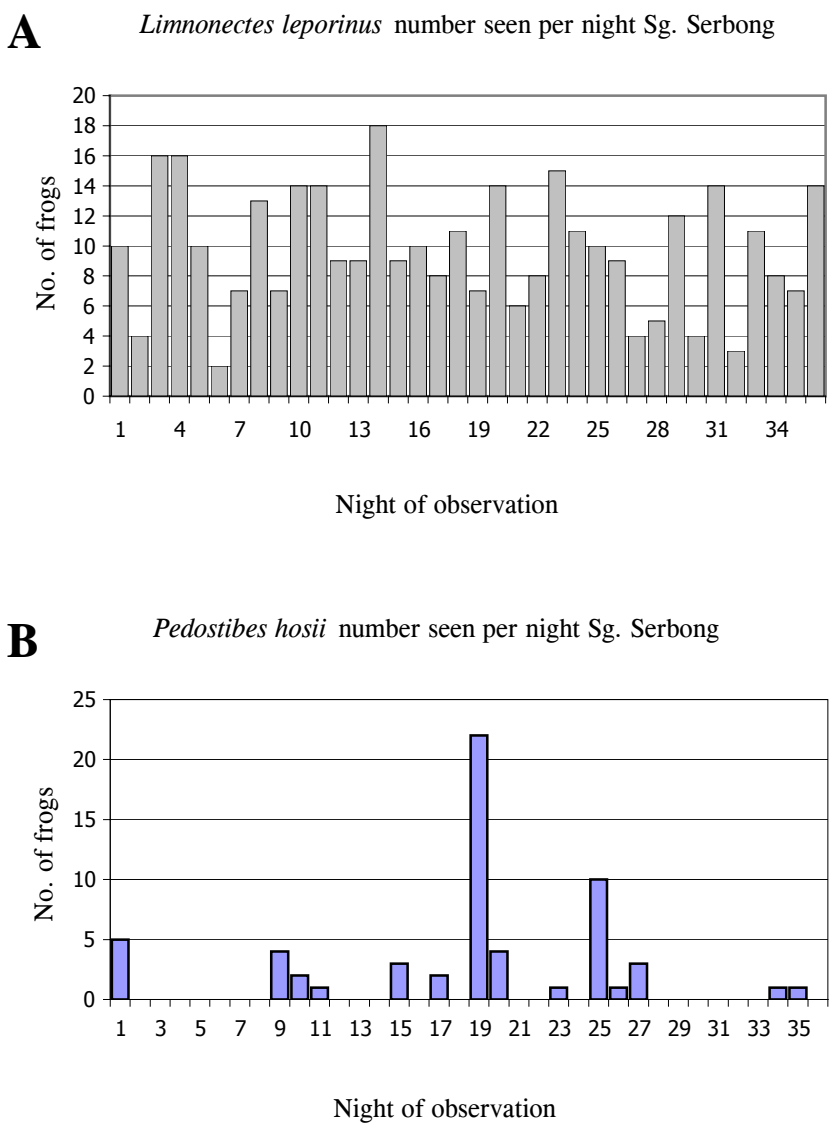

FIGURE 2. Numbers of individuals of each of two species seen on Sungai Serbong, Nanga Tekalit, Sarawak, on 36 nights spread over 12 months (1962/63). A. *Limnonectes leporinus* (Andersson). B. *Pedostibes hosii* (Boulenger).

personal experience, it can be duplicated, unfortunately, by looking at the published literature.

A common type of publication is a paper listing species of frogs (or other animals) occurring in some small region, a national wildlife reserve or an administrative district. Reading the methods section of such papers, one often sees that the authors collected on three nights within a five day interval, or some similar short period. Papers of this sort assume that all species of frogs present in the region are active on all nights, without variation between species in activity patterns. However, it is known that some species of frogs call and breed, and are therefore exposed to observation, only at the beginning of a rainy season whereas others call and breed over most of the season (vide

Heyer, 1973). Even in some aseasonal rain forest environments, breeding activity of some species is episodic whereas it is continuous in others (Inger and Tan, in prep.). An example of variation in activity of frogs in an aseasonal climate is shown in Figure 1. The data in Figure 1 include all species of frogs observed on a 600-meter transect along an 8-m wide stream in Sarawak, Borneo, over a period of one year. Differences between species in activity patterns along the stream dealt with in Figure. 1 are sharp (Fig. 2). A sampling period of three nights along the Sungai Serbong, Sarawak, would certainly include *Limnonectes leporinus* but probably omit *Pedostibes hosii* from the fauna of that stream. Clearly, to estimate species richness of any tropical region of any size it is essential that the sampling period be designed to cover interspecific variation in activity patterns and seasonal patterns in weather.

EXPLORING BIODIVERSITY OF FROGS OF BORNEO

Borneo is a very large island, approximately 1200 km from north to south and from east to west, with great variation in topography and maximum elevation of 4100 m. The island straddles the equator and climate is essentially aseasonal. Until relatively recently, the entire island was covered with evergreen forest, though economic development has now cleared large portions of the forest. Field studies of the frog fauna were designed to explore local and regional diversity, the impact of environmental differences on regional diversity, fluctuations in local population sizes, and diversity in life cycles and behavior. Most of my data come from 10 sites distributed in Sarawak and Sabah; sampling at each of these sites extended for at least four weeks (Inger and Voris, 1993), with additional sampling at four additional sites.

Local and regional species diversity.–Work was carried out at Nanga Tekalit, Sarawak (1°38'N/113°34'E), a site of lowland (100-230 m), hilly primary rain forest at three periods: 366 days in 1962/63, 93 days in 1970, and 30 days in 1984. Fifty four species of frogs were observed during 1962/63. From the species accumulation curve for that year (Fig. 3), it is obvious that additional species of frogs were to be expected. During the shorter period of field work in 1970, 45 species of frogs were found, including six species that were not seen in 1962/63. In the still shorter period of work in 1984, only 35 species were observed, all of them species that had been seen in 1962/63 but three that had not been seen in 1970.

Field work was also carried out at Segaham, Sarawak (2°44'N/113°55'E), an area of hilly primary rain forest with slightly steeper topography than that at Nanga Tekalit, 128 km distant. During the 61 days at Segaham, 47 species of frogs were found, all but four of

TABLE 1. Relation between topography and breeding patterns of frogs at Bornean localities. The number of days of sampling were: Labang–128 days; Segaham–61 days; Nanga Tekalit–366 days. Geographic coordinates of the three localities are given in the text.

Locality	Topography	Breeding microhabitat			
		Streams			
		In current[1]	Out of current[2]	Ponds[3]	Uncertain
		No. of species			
Labangflat		0	10	23	1
Segaham	Steep, hilly	10	14	14	5
N. Tekalit	hilly	13	19	24	5

Notes : [1] In riffles and torrents.
[2] In side pools, leaf drifts, and bank potholes.
[3] Pools on forest floor as well as water containing tree holes.

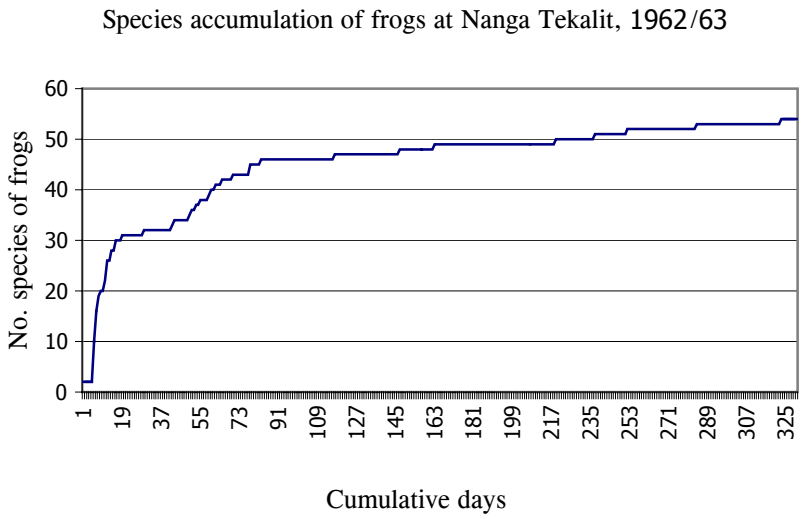

FIGURE 3. Species accumulation curve of frogs observed at Nanga Tekalit, Sarawak, during 12 months in 1962/63.

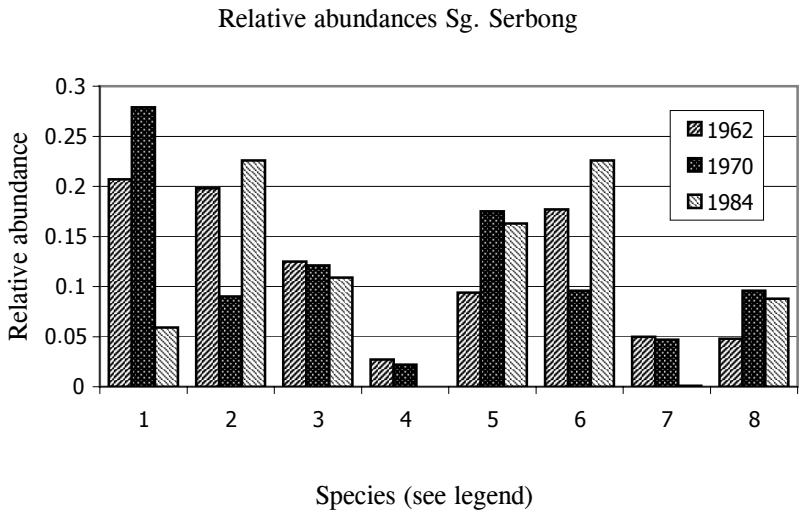

FIGURE 4. Year to year fluctuation in observed relative abundances of eight dominant species of frogs on Sungai Serbong, Nanga Tekalit, Sarawak. Adapted from Voris and Inger 1995.

them also found at Nanga Tekalit. Significantly, the samples from the two areas shared all the species that are known to breed in streams having moderate to strong currents. The significance of topography on the species composition of these faunas is evident when one compares the frogs found at Segaham with those found at Labang, Sarawak (3°21'N/113°27'E), 77 km distant. The forest at Labang is developed on very flat land < 100 m asl and the streams there have very slow current and silty bottoms. During the 128 days spent at Labang, 35 species of frogs were found, none of them species that breed at riffles or torrents; on the other hand, species with these habits were common at Nanga Tekalit and Segaham (Inger

and Voris, 1993). Two-thirds of the species found at Labang breed in rain pools on the forest floor, but less than a third of the species found at Segaham (Table 1).

Fluctuations in numbers.–At Nanga Tekalit three streams (8-15 m wide) were set aside as "experimental" streams, and frogs were not removed from those streams during 1962/63. Frogs were recorded over a stretch of 600 m on 36 nights on each of these three streams. In each of the next two periods of work at Nanga Tekalit, each of these streams was surveyed five nights; specimens were removed and preserved during these two years. Although no two streams can be exactly identical in channel shape, bottom types, etc., the same species of frogs dominated the assemblages on all three streams, suggesting that the environments were generally similar. The similarity in terms of the species occurring on the streams was quite high–0.73-0.89 (1.0 = complete identity) –for between stream, within year comparisons. Indeed, the similarity was as high as the between year, within stream comparisons –0.73-0.90 (Inger and Voris, 1993).

The relative abundances of species on these streams was also quite similar. The between stream, within year similarities were 0.68-0.96 and the between year, within stream similarities 0.72-0.88 (Inger and Voris, 1993). However, variation in relative abundances within species over time was significant (Voris and Inger, 1995). Figure 4. shows this temporal variation in eight common species on one stream.

Movements of individuals.–The fluctuations in abundances shown in Figure 4. are strong indication that over long periods of time local populations of any species may go extinct. However, the existence of some species at many sites scattered over large areas of Borneo suggest that either local extinctions have not affected these species at those sites or that immigration from other sites has restored any populations that may have gone extinct in the past. If the latter phenomenon has occurred, then extent of movements of individuals is an important factor. Information on movements is also important for assessing the likelihood of long range dispersal affecting geographic distribution of species (Inger and Voris, 2001). Movements of individual frogs of a number of species have been explored at Nanga Tekalit, Sarawak.

The home ranges of several large (snout-vent > 80 mm) species of frogs –*Limnonectes ibanorum,* and *L. leporinus* –at Nanga Tekalit were small: median values 5.2-9.8 m for both species (Inger, 1969). These ranges were determined by observations of marked individuals made over a period of 12 months. For these two species, the net movement (that is, the distance between the points of first and last captures) for those individuals we had under observation for at least six months (180 days) varied from 1 to 151 meters, with 10 of 19 being less than 11 m. In contrast, net movements of 18 individuals of *Bufo asper* (snoutvent of adults 80-125 mm) under observation for at least 180 days were larger, with only five of 18 less than 11 m and five ranging from 134 to 465 m.

Both *Limnonectes ibanorum* and *L. leporinus* are known only from Borneo, whereas *Bufo asper* is known from Borneo, Sumatra, and parts of Southeast Asia at least as far north as 15°N in western Thailand. The greater movement of individuals of *B. asper* may have enabled this species to disperse between the continent and Borneo during the relatively short periods of sea regression during the Pleistocene (see maps in Voris, 2000).

SUMMARY

My conclusion is a simple one. It is possible to obtain data that will permit one to make statements about biodiversity that encompass local and regional species richness, behavioral diversity, and even historical diversity. However, the validity of those statements, and the degree of confidence one may have in them, depend entirely on the appropriateness of the sampling procedures. It follows, of course, that conservation policies

and actions also depend on the quality of our sampling procedures.

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