Short Articles

Standard Errors of Survey Estimates: What Do They Mean?

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Few journals would accept an estimate of density or population size without a corresponding measure of variability, and most computer programs that provide estimates of population size also provide estimates of standard errors. It is part of the prevailing scientific culture to demand "error" estimates even when they do not aid communication (Magnusson, 2000a). In my experience, most students and many professionals do not understand what those "errors" represent or the relationship between the question and the sampling design. Primatologists often use "standardized" survey techniques that depend on repeated sampling of the same transect and the use of line transect methods to estimate population size (Peres, 1999). I will show below that these provide standard errors with extremely limited utility. Wildlife courses should spend more time explaining what standard errors mean and less time showing how to calculate them.

The terms "standard error" (SE) and "standard deviation" (SD) were originally synonymous. However, SE is currently used to indicate an estimate of the standard deviation of a parameter such as the mean, or total population size, and SD is used to describe the primary data. The SE gives an estimate of the variability expected if many independent estimates of the parameter were made using the same methodology. Usually, only one estimate of the parameter is made, and the SE estimated from statistical theory based on variability among the observations.

In the simplest case, the SE relates to the expected variability caused by sampling only a small proportion of the area occupied by the population. Sampling units are spread randomly over the area and all of the target organisms are counted within each sampling unit (Pielou, 1984). If some of the targets in each unit are counted, the SE may give a useful index of the variability expected if the methodology is repeated, but the SE does not relate to the uncertainty in the estimate of population size. In many cases, the trend in population size, rather than the absolute value of population size, is not of interest, and it may be more efficient to use regularly spaced sampling units. This results in smaller SEs (Caughley and Sinclair, 1994).

Alternatively, the whole area may be surveyed and corrections made for the number of animals not seen. This is the basis of the mark-recapture and line-transect methods. Line-transect methods depend on the construction of a sighting function that estimates the relationship between the number of targets recorded and the distance from the transect line. Mark-recapture methods estimate the mean proportion of targets registered over the whole area. The SE of these methods relates to the uncertainty in the proportion of targets seen.

The two types of methods can be combined with incomplete sampling of individual sampling units that do not cover the whole area of interest. If the correction for targets missed within the sampling units is unbiased, then the SE of the estimate based on geographical variation effectively includes the variability due to incomplete counts within the sampling units. It is best to seek help from a statistician before using these hybrid methods because the standard errors for density corrections may not be symmetrical (Caughley and Sinclair, 1994). Students often do not realize that the "expected value" of a parameter for a statistician is the mean of a very large number of estimates of that parameter. If the distribution of estimates is asymmetrical, then the "expected value" may be far from the values you expect to obtain from most samples. Other sources of variability, such as seasonal or random fluctuations in population density, may contribute to variability, but our model is already sufficiently complicated.

Let us consider the standard method suggested by Peres (1999), which is similar to standard methods recommended by many primatologists. Two 4.5 km transects are placed at 90º to each other, forming an "L" shape. Each transect is surveyed many times until a minimum number of primate groups is recorded, or a minimum distance covered. Peres (1999) suggested that more than 300 km should be walked. A computer program such as DISTANCE (Buckland *et al.*, 1993) is used to estimate population density and its SE. This estimate relates to the area effectively sampled by the transects, which depends on vegetation density. However, in most forests, it is unlikely that mammals can be detected at more than 50 m from the transect line. Therefore, the area effectively surveyed would be of the order of 90 ha or less.

Population estimates obtained by line-transect methods are greatly affected by the sighting function. The distribution of primates around a 300 km transect should give a reasonably precise idea of the sighting function for that region. However, if the sighting function is based only on repetitions of the same 9 km, then it may depend on the behavior of a few groups of monkeys. A large fruiting tree near the transect line that regularly attracts primates will result in a very different sighting function than a similar large tree further from the transect line. When no large trees are fruiting, the sighting function for the same area will change again as the same monkeys do not accumulate in the same place on different days. Line-transect methods were designed for analyzing independent observations. Sampling 100 km of transects (e.g., 10 separate 10 km or 20 separate 5 km transects) once would give a much more accurate estimate of primate density and its SE than repeatedly walking along the same 9 km of trails until a total of 300 km is attained. It is very unlikely that the time gained by not cutting extra transects compensates for the uncertainty in what the SEs represent.

Densities are used to compare sites, habitats or areas subject to different disturbances, such as hunting. If the units being compared are of similar size to the transects, then the SEs are meaningful and can be used to calculate 95% confidence intervals (95% CI). If the areas are much larger, as they usually are, it is impossible to estimate the SE of the density based on a single dog-leg transect; there is no replication. The SE calculated, which may relate to uncertainty in the absolute density in that transect, gives no information as to likely variation in other transects. However, given that the line-transect methods give unbiased density estimates for transects, the SE based on between-transect variability would effectively include variability due to incomplete sampling within transects. Therefore, it is not usually necessary to calculate the SEs for densities in individual transects, and meaningful conclusions can be made without consideration of the within transect uncertainty (e.g., Peres, 1997).

Hurlbert (1984) alerted biologists to the dangers of pseudoreplication decades ago. However, university courses do not prepare students to deal with practical sampling problems. At the most basic level, this just means stating clearly what is being sampled. Editors should require that authors clearly state what is being studied on three distinct scales. The *first scale* is the universe of interest. A researcher may be interested in "big" questions such as the mortality patterns of a species over its entire range, or the physiology of all species within a family. The reader should know this, but it is almost always impractical to carry out studies at that scale. Therefore, authors should state their sampling universe, the *second scale*, which will generally be something smaller, such as mortality patterns in Wisconsin or all species in the family that occur in Mexico. The greater the overlap between the sampling universe and the universe of interest, the greater the generality, but only a pedant with no field experience would require that the whole universe of interest be sampled in every study.

The level of interest in relation to pseudoreplication is the sampling universe. Sampling units (the *third scale*) are usually best distributed randomly (or at least uniformly or arbitrarily) over the whole sampling universe. The greater the coverage of the sampling universe, the greater the generality. Variability among sampling units affects the accuracy of parameter estimates for the sampling universe, and this is reflected in the SEs. Variability within sampling units (as given by line-transect SEs) does not allow evaluation of accuracy or precision of parameters.

I have focussed on problems in surveying primates, but the same problems of linking the questions to the analyses and avoiding pseudoreplication are general for wildlife studies (e.g., Magnusson, 1999). Courses in wildlife management, and biology in general, need to give more emphasis on the basic concepts of sampling design, and less on the mathematical manipulations (Magnusson, 2000b).

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Primatas da Região do Rio Tapajós, Pará, Brasil

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Introdução

Vários naturalistas visitaram o Tapajós, porém, foi Henry W. Bates, no século XIX, quem melhor descreveu a região. Na obra *The Naturalist on the River Amazons* (Bates, 1863), ele dedicou um capítulo inteiro a descrição de uma excursão que fez ao local, entre junho e outubro de 1852.

Alfonso M. Olalla continua sendo o responsável pela maior e mais importante coleção de mamíferos já formada na área de Tapajós. As coletas feitas, entre 1931 e 1971, reúnem exemplares de diversas localidades de ambas as margens, principalmente, Santarém (junho-julho de 1934), Caxiricatuba (maio de 1931; janeiro-setembro de 1935; março, maio, novembro e dezembro de 1936; janeiro, fevereiro, setembro, novembro e dezembro de 1937), Piquiatuba (maio de 1931; maio-agosto e dezembro de 1936; março de 1937), Marai, Tapaiuna, Aveiro e Fordlândia, entre outras. No Brasil, o material colecionado pelo Sr. Olalla encontra-se depositado no Museu Nacional/Universidade Federal do Rio de Janeiro (UFRJ) e no Museu de Zoologia/Universidade de São Paulo (USP).

Em 1938, aproveitando a abertura de áreas para a implantação de seringais pela Companhia Ford Industrial do Brasil, em Belterra e Fordlândia, o Ministério da Educação e Saúde, através do Serviço de Estudos e Pesquisas sobre a Febre Amarela (SEPSFA), com a cooperação da Divisão de Saúde da Fundação Rockefeller, realizou investigações envolvendo