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Estimating the herpetofaunal species richness of Pangkor Island, Peninsular Malaysia

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Abstract. Herpetological surveys of Southeast Asian tropical ecosystems rarely, if ever, result in complete inventories. This is due to the fact that surveying to completion requires huge investments in terms of search effort. As a result, the presented species lists usually represent subsets of the total herpetofaunal assemblage and consequently do not shed light on the total species richness of the investigated area. This is regrettable as species richness is an elementary measure of biodiversity that underlies many ecological models and conservation strategies. By recording not just species but species per unit of search effort, an extended dataset results which can be used to generate estimates of total species richness. In this study, the herpetofauna of Pangkor Island, Peninsular Malaysia is used as an example. In 2009 and 2010, the first herpetological surveys were carried out on this small, 18 km^2, island. Those surveys recorded 43 species of reptiles and 13 species of amphibians. In this study, total reptile species richness was estimated by fitting several models to the sample-based rarefaction curve as well as by application of the nonparametric Chao-I estimator. Of the applied models, the 4-parameter Weibull function was shown to be superior, a finding that is in line with several other studies. Consequently, the use of this model is recommended. On the basis of the fitted 4-parameter Weibull-function, 69 reptile species are expected to occur on Pangkor Island. As for amphibians, total species richness was estimated to be 17. As such, a remarkably extensive herpetofaunal assemblage inhabits this small island.

Key words. Pangkor Island, Malaysia; amphibians, reptiles, species-richness, sample-based rarefaction curve, negative exponential function, 3-parameter Weibull function, 4-parameter Weibull function, Chapman-Richards model, Chao-I estimator

INTRODUCTION

Herpetological surveys of species-rich tropical ecosystems rarely result in complete inventories (e.g. Lloyd et al. 1968; Murphy et al. 1994; Hofer & Bersier 2001; Van Rooijen 2009). This is due to the asymptotical nature of the species accumulation process in combination with limited survey-investments. As a consequence, the use of estimation techniques is unavoidable when the intended objective is to assess species richness, an elementary measure of biodiversity that underlies many ecological models and conservation strategies. One such estimation technique consists of fitting an appropriate function to the species accumulation curve. The asymptote of the fitted functions can then be regarded as an estimate of total species richness. Species accumulation curves are regularly applied in herpetofaunal surveys but they are mostly used to arrive at qualitative judgements about the exhaustiveness of the survey (e.g. Murphy et al. 1994; Zug et al. 1998; Ziegler 2002). However, extensive and sophisticated literature exists pertaining to methods and models used to quantitatively estimate species richness, on the basis of either rarefied species accumulation curves or abundance patterns (e.g. Colwell & Coddington 1994; Flather 1996; Gotelli & Colwell 2001; Longino et al. 2002; Brose et al. 2003).

The offshore archipelagos of Peninsular Malaysia have been the subject of increasing interest in recent years. Many of these islands have never been surveyed and recent explorations are only beginning to uncover the hidden diversity and endemism that they shelter (Chan et al. 2009a; Grismer 2008; Grismer & Norhayati 2008; Grismer & Pan 2008; Grismer et al. 2008, 2009a, b). One such

Fig. 1. A: View into the primary forest of Pangkor Island; B: *Boiga drapiezii* (Boie, 1827); C: *Cnemaspis shahruli* Grismer et al., 2010; D: *Dryophiops rubescens* (Gray, 1835).

island is Pulau Pangkor, approximately 18 km^2 and situated 3.5 km from the west coast of Peninsular Malaysia. The island's interior remains heavily forested and maintains a river system, Sungai Pinang, which supplies a significant source of permanent fresh water in the form of multiple streams. Chan et al. (2010) provided the first report on the (non-marine) herpetofauna of this island and documented 43 reptiles and 13 amphibians. A few illustrations are provided in figures 1 and 2.

The study described in this paper had a dual objective. First, data collected by Chan et al. (2010) were used to evaluate the performance of several estimators. Second, the most appropriate estimator was used to estimate the total herpetofaunal species richness harboured by Pangkor Island, West Malaysia.

MATERIAL AND METHODS

The data underlying this study were based on the surveys carried out by Chan et al. (2010). These were conducted in the periods March 15–17, May 4–8, June 13 to July 8, 2009, and February 22 to March 8, 2010. During the latter two periods, only reptiles were surveyed. Marine reptiles were ignored altogether. The predominantly applied survey method corresponds to visual encounter survey (VES), a simple method which has been shown to be effective for surveying rainforest herpetofauna (Doan, 2003). VES was carried out both during day and night (e.g. Coddington et al., 1996; Doan, 2003) in a way similar to that applied by Minh (2007). Existing trails as well as several trails made by the Department of Forestry of Perak and Peninsular Malaysia were used. These trails traversed dipterocarp forest, mangrove forest and cultivated areas and provided ample access to forest streams. The second collection method consisted of searching for road-kills. The third entailed turning logs, fallen tree bark and similar objects in order to uncover animals hiding underneath. Sampling effort was expressed in terms of search-days where one search-day was defined as roughly 4.5 search-hours. As two of the surveys underlying the data collected by Chan et al. (2010) focused solely on reptiles, substantially more information was available regarding reptiles allowing for more thorough analyses. Therefore, this study focuses predominantly on reptiles, amphibians being treated separately and in less detail.

Sample-based rarefaction curves (Gotelli & Colwell 2001) were generated with the program EstimateS (Colwell

Fig. 2. A: *Heosemys spinosa* (Gray, 1831); B: *Kaloula pulchra* Gray, 1831; C: *Naja sumatrana* (Müller, 1890); D: *Tropidolaemus wagleri* (Boie, 1827).

2005). Four models were fitted to the rarefaetion eurve. The first eorresponds with a negative exponential model (Colwell & Coddington 1994; Flather 1996; Van Rooijen 2009). It is based on the assumption that the number of new speeies found per seareh day is proportional to the number of as yet undiseovered speeies, in mathematieal terms: $dY/dt = c\,(A–Y)$ where A is the total number of speeies present in the area under investigation, Y is the total number of speeies found and c is a eonstant. This equation can be represented as a negative exponential funetion (e.g. Van Rooijen 2009): $Y = A\,(1–e^{-ct})$. The basic assumption underlying the negative exponential model (heneeforth NE) may be overly simplistie given that abundanee patterns are usually strongly skewed (e.g. Lloyd et al. 1968; Coddington et al. 1996; Limpert et al. 2001; Longino et al. 2002; Thompson et al. 2003). In order to model more eomplex speeies aeeumulation proeesses, the NE ean be refined in various ways by adding one (d) or two parameters (d and p), resulting in the Chapman-Riehards model (heneeforth CR), 3- and 4-parameter Weibull eumulative distribution funetions (heneeforth 3pW and 4pW):

$$Y = A\,(1–e^{-ct})^{d}\ \text{(CR)},$$
$$Y = A\,(1–e^{-(ct)^{d}})\ \text{(3pW)},$$
$$Y = A\,(1–e^{-(c(t-p))^{d}})\ \text{(4pW)}$$

The four models were fitted to the sample-based rarefaetion eurve using nonlinear regression analysis (e.g. Norusis and SPSS 1994) with SPSS (release 14 February 1996; SPSS Inc.).

Extrapolation using different models for the speeies aeeumulation proeess ean provide different asymptotes and thus prediet different values of species riehness (e.g. Colwell & Coddington 1994; Flather 1996). Therefore, eare has to be taken to seleet the most appropriate model in order to minimize bias. In this study, the appropriateness of eaeh model was evaluated on the basis of three eriteria. The first eriterion was goodness-of-fit. The seeond eriterion entailed the behaviour of the riehness-estimate with inereasing eumulative seareh effort. The final eriterion was the differenee with the nonparametrie Chao-I estimator (Chao 1984; Coddington et al. 1996; Hofer & Bersier 2001; Veith et al. 2004). This estimator is an often applied representative of a elass of estimators that uses a different approaeh as they are based on abundanee patterns instead of the aeeumulation eurve. The Chao-I estimator is based on the observed number of rare speeies, $A = Y + (a^2/2b)$, where A is the total number of speeies, Y is the observed number of speeies, a is the number of observed speeies represented by a single specimen and b

is the number of observed species represented by exactly two specimens.

RESULTS

Figure 3 depicts the deviations of the fitted functions from the sample-based rarefaction curve (residuals) for reptiles. As expected, the NE exhibits a very poor goodness-of-fit. At first, the fitted curve is situated beneath the rarefaction curve, then above and finally drops beneath the rarefaction curve again. The suboptimal fit of the NE as well as the pattern of residuals are in agreement with results obtained with regard to avian diversity (Flather 1996) as well as snake diversity (Van Rooijen 2009). Although the RC and 3pW fit substantially better than the NE, they exhibit a similar pattern of residuals. The 4pW function obviously exhibits a superior, near-perfect, fit.

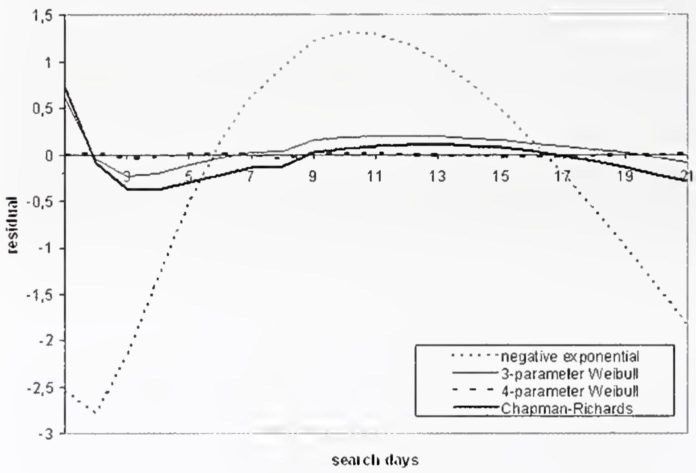

Fig. 3. Deviations of the fitted models from the sample-based rarefaction curve (residuals).

Figure 4 depicts the sample-based rarefaction curve as well as the fitted 4pW. The only noticeable deviation of the fitted 4pW from the rarefaction curve lies in the fact that it passes through (p,0) instead of the origin (0,0). The close fit of the 4pW is in agreement with results obtained in studies of avian diversity (Flather 1996), snake diversity (Van Rooijen 2009) and diversity of small reptiles (Thompson et al. 2003). The progression of the rarefaction curve clearly indicates that an asymptote has not yet been reached, thus the surveys have not been exhaustive.

Figure 5 shows how the richness estimates (as opposed to observed richness or fitted model-values) develop with increasing search days during the second half of the survey. The NE is neglected due to its poor fit. Evidently, the 3pW- as well as CR-based estimates are still increasing at the end of the survey whereas the 4pW-based estimate

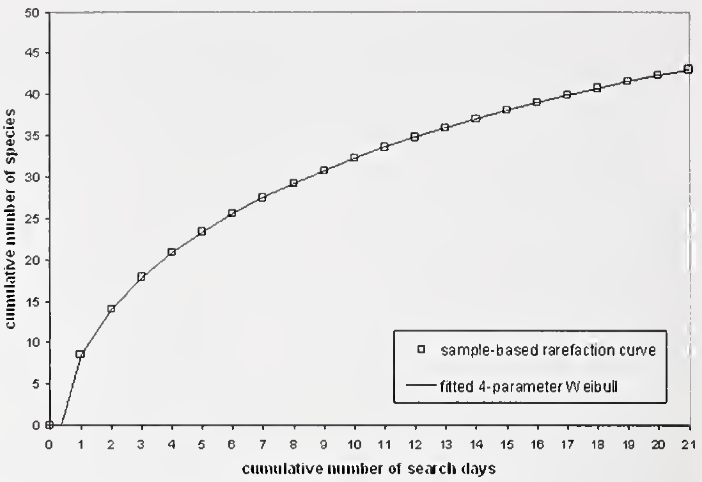

Fig. 4. Reptile species sample-based rarefaction curve with fitted 4-parameter Weibull function.

has reached a more or less stable level. A similar result (unpublished) was obtained on the basis of a dataset that underlies a study of Bornean snakes (Van Rooijen 2009): the 4pW-based estimate reached an approximately stable plateau rather early with the CR- and 3pW-based estimates approaching the 4pW-based estimate with increasing search days.

On the basis of these results, the 4pW-based estimate, 69, is assumed to be the least biased. Finally, the estimate based on the nonparametric Chao I estimator, 62, agrees reasonably well with the 4pW-based estimate. Taking the average, 65 reptile species are expected to inhabit Pangkor Island. As for amphibians species richness, the fitted 4pW and Chao I estimator both resulted in an estimate of 17 species.

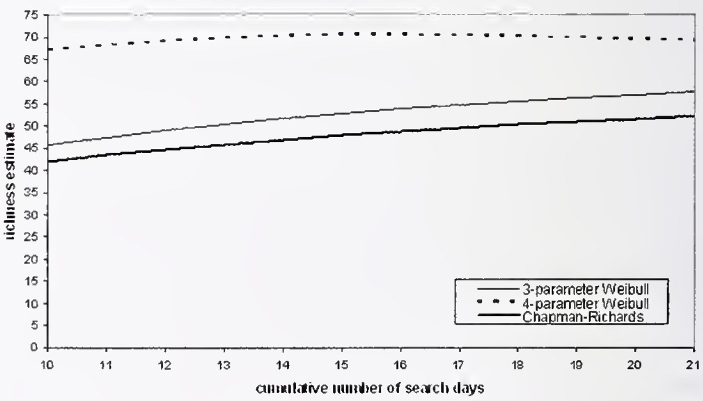

Fig. 5. Richness estimates in relation to cumulative search effort.

DISCUSSION

Estimation by extrapolation, as opposed to interpolation, into the unknown entails a high degree of uncertainty. However, the alternative, surveying until completion, is simply unfeasible when the survey is aimed at the herpetofauna of a Southeast Asian rainforest ecosystem (Van Rooijen 2009). As such, there simply is no alternative. Thus, further refinement of estimation methods is of importance. That said, approximately complete species lists are obviously still crucial for many zoogeographic studies. Such species lists can be (and are) compiled by combining results of various surveys. However, this usually entails the combination of species lists pertaining to different locations. As such, completeness comes at a price as one has to accept a huge decrease in spatial resolution. In most zoogeographic studies however, a high resolution is not essential as species compositions of major land masses are compared (e.g. In Den Bosch 1985; How and Kitchener 1997; Inger and Voris 2001). At the spatial scale which is relevant for conservation though, complete species lists are a utopia in the majority of cases and estimation will therefore gain in importance (Van Rooijen 2009). This study underscores the notion that a combination of criteria needs to be applied to select the most appropriate estimator. The 4-parameter Weibull function exhibited the highest goodness-of-fit. Moreover, it produced the most stable estimate near the end of the survey (figure 5). Finally, it resulted in a richness-estimate that agreed well with the estimate based on the nonparametric Chao-I estimator. Even then, the estimate may be downwardly biased due to suboptimal sampling. First of all, although searches were carried out during both day and night, no searches were performed in the early morning (before dawn). Secondly, sampling of canopy-microhabitat was obviously unfeasible. Finally, as true species richness is underestimated by most estimators when sample size is small (Colwell & Coddington 1994; Canning-Clode et al. 2008), the estimate of amphibian species richness may be downwardly biased since it was based on only five search days. Nevertheless, the amphibian species richness appears to be rather low which is in agreement with the impression of herpetologists who carried out the surveys (Chan et al. 2010).

The fact that the 4-parameter Weibull function exhibits such a good fit when applied to diverse ecological communities such as small reptiles in desert habitat (Thompson et al. 2003), birds (Flather 1996) and reptiles in rainforest habitat (Van Rooijen 2009 and this report) is striking. Two explanations can be put forward. First, relative species abundances follow very similar patterns over a wide range of ecological communities: relatively few species are abundant whereas most are rare (e.g. Hughes 1986). Thus, the shape of the species accumulation process may also be expected to be rather uniform. Second, the higher the number of parameters of a model, the better the fit. Thus, the 4pW may simply be expected to fit better than similar functions with fewer parameters, irrespective of the field of application.

65 reptilian species are estimated to inhabit Pangkor Island, 43 of which have been recorded (Chan et al. 2010). A major part of the as yet unrecorded species will concern snakes as members of this taxon are notoriously hard to find due to their elusive habits and low densities (e.g. Lloyd et al. 1968; Inger & Colwell 1977; Hofer & Bersier 2001; Orlov et al. 2003; Van Rooijen 2009). This notion is strengthened by several indirect observations. Locals provided accounts regarding observations of *Boiga dendrophila* (Boie, 1827), *Cryptelytrops purpureomaculatus* (Gray, 1832), *Ophiophagus hannah* (Cantor, 1836) and *Maticora bivirgata* (Boie, 1827). In addition, there has been a visual record of a *Coelognathus radiatus* (Boie, 1827) (Schultz, pers. comm.). As amphibian species richness is estimated to be at least 17, herpetofaunal species richness is expected to equal at least 82 species, which is quite impressive given the fact that Pangkor Island encompasses merely 18 km^2. On the other hand, whether Pangkor Island harbours a comparatively extensive herpetofauna is impossible to determine at the moment as species richness on other Malaysian islands has not yet been estimated.

Estimating species richness of specific sites such as islands obviously has added value as species richness is an elementary criterion a conservationist may use when selecting sites and is crucial for many ecological studies. However, the function fitted to the rarefaction curve not only provides an estimate of total species richness but also provides insight in expected return on further investment: how many previously unrecorded species may be expected to be found with additional search effort? For instance, on the basis of the fitted 4-parameter Weibull function, ten previously unrecorded reptiles are expected to be found on Pangkor Island when 20 additional search days are invested. Such statistical expectations can be used as input for a cost-benefit evaluation when choices have to be made between different sites for the investment of survey-capacity. Alternatively, one might determine how much search effort would have to be invested to bring the survey to some specified level of completeness.

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