

# Estimating species richness of pitfall catches by non-parametric estimators

Ulrich Brose\*

Centre for Agricultural Landscape and Land-Use Research, Institute of Land-Use Systems and Landscape Ecology, Eberswalder Str. 84, D-15374 Muencheberg, Germany

Submitted: May 31, 2001  
Accepted: August 23, 2001

## Summary

In consequence of accelerated applications of new land-use systems, agricultural landscape research is challenged to provide results on their sustainability. Studies on biodiversity that are carried out with minimal sampling programs have become increasingly popular. However, concerning insects, the observed number of species in these studies underestimates the true species richness. In such studies, the non-parametric estimators might provide a more reliable tool to gain information about the true species richness. The objective of this paper is to evaluate how accurately and precisely estimates of species richness in studies with few pitfall samples correlate with those of studies with higher sampling intensity. This indicates how much effort could be saved in collecting data on species richness of insect communities.

The species richness of carabid beetles at ten temporary wetlands in the East-German agricultural landscape was surveyed by nine pitfall traps per site. Estimates of species richness were calculated in scenarios with four, five or six pitfall traps per site. The observed number of species and the non-parametric estimators, Chao2, Bootstrap, Jackknife1 and Jackknife2, were included in the study to estimate species richness in each scenario, respectively. The estimates in the scenarios were compared with estimations based on the whole data set. While Chao2 was the most accurate and precise estimator, the Bootstrap estimator performed only slightly better than the number of observed species. Jackknife1 and 2 performed intermediately. Only Chao2 performed more precisely than the observed number of species. In conclusion, the number of samples might be reduced to five or six pitfall traps per site in studies carried out in small habitats with minimal sampling programs. The non-parametric estimators pro-

---

\*E-mail corresponding author: [ulrich\\_brose@web.de](mailto:ulrich_brose@web.de)

vide possibilities to carry out studies on species richness with reduced sampling efforts as well as, to gain more reliable information on species richness re-analyzing studies already carried out.

**Key words:** Biodiversity, non-parametric estimators, pitfall trapping, Carabidae, evaluation

---

## Introduction

In consequence of the ongoing process of species loss in agricultural landscapes, maintaining biodiversity has become an important challenge. In particular, recent developments – like the use of transgenic organisms, which could have far-reaching consequences for the habitats' communities – require further research on biodiversity. In agricultural landscape research much emphasis has been placed on the communities of predaceous insects like carabid beetles due to the fact that (1) they contribute a substantial part to overall diversity and (2) they gain importance as natural pest control agents (Kromp 1999). As a result of the discussion about sustainable land-use, numerous studies were conducted challenging the correlation between various land-use parameters and the diversity of carabid beetle communities (review in Kromp 1999). However, while species richness is a central aspect of biodiversity, it is generally not as easily measurable as it seems (Gaston 1996). In arthropod communities, this measurement is seldom achieved due to the requirement of an enormous sampling intensity (e.g. Standen 2000). Furthermore, empirical studies in agricultural landscapes face the influence of various parameters of land-use systems and landscape characteristics on the species studied. This leads to the requirement of sufficiently replicated experiments with a substantial number of cases. On this basis, economical constraints place researchers in the dilemma to choose between either sufficient cases or adequate sampling intensity per site. Accordingly, many studies are carried out with minimal sampling programs using few pitfall traps per site (Duelli 1997). If such studies require reliable information about species richness, they will either be restricted to vascular plant, bird or vertebrate animal communities, or they will depend on estimators. Concerning the estimation of species richness, most interest has been directed towards data-analytic methods (species accumulation curves and parametric models of species relative abundances) and sampling-theoretic methods (non-parametric estimators) (review in Bunge & Fitzpatrick 1993). However, the data-analytic methods require additional information about the underlying models of either species accumulation or species abundances. Such models are generally not easily chosen and the subsequent extrapolations multiply biases and case-to-case errors (Colwell & Coddington 1994; Gaston 1996; Wilson et al. 1998). This might explain the fact that in empirical comparisons in simulated as well as in real data sets of plant communities the non-parametric estimators performed better than the other methods (Palmer 1990, 1991; Baltanás 1992; Colwell & Coddington 1994). Accordingly, these non-parametric methods are most promising in extrapolating observed species numbers to true species numbers (reviews in Bunge & Fitzpatrick 1993; Colwell & Coddington 1994). The reliability of five methods (Bootstrap, Jackknife 1 and 2 and Chao 1 and 2) has so far been tested for plant communities (Palmer 1990, 1991; Colwell & Coddington 1994) and

simulated data sets (Heltshe & Forrester 1983; Baltanás 1992; Chao & Lee 1992). There is, however, still a lack of such tests for more diverse insect communities; this fact stresses the general importance of further studies which compare the accuracy and precision of the estimators (Gaston 1996).

The non-parametric estimators might provide a tool to achieve reliable estimates of species richness in studies with minimal sampling programs that are often carried out in agricultural landscape research. The present study is a first step towards the evaluation of potential benefits for pitfall trapping projects. The pitfall catches of temporary wetland carabid beetle communities were chosen as an example of predaceous insects caught by standardized sampling methods in a semi-natural habitat. The objective of this study is to determine how accurately and precisely the estimates in studies with few pitfall samples correlate with those of studies containing higher sampling intensity.

## Materials and Methods

### *Site description*

The study was carried out in 1999 and the data were collected at ten temporary wetlands in the agricultural landscape of East-Germany (52° 27' N., 14° 08' E.). The area of the sites ranged between 850 and 1600 m<sup>2</sup>. Temporary wetlands are characteristic habitats of this younger pleistocene landscape. As parts of conventionally used fields, the temporary wetlands are cultivated and typically produce crops in the driest years. During years of average or above-average precipitation, temporary wetlands retain water until spring or summer. In these years, they are inhabited by highly diverse carabid beetle communities, which consist of a mixture of typical field species with numerous wetland species. There was a gradient of species richness that ranges from sites with a species richness resembling those of conventional parts of the fields to highly diverse sites, which might be characterized as diversity hot spots in the agricultural landscapes. This gradient was the main reason why the project was carried out at the temporary wetlands.

### *Sampling techniques*

The carabid beetles were recorded by pitfall trapping (white cups: Ø=9.2 cm, 55% Iso-propanol with added Glycerin and detergent). The traps, which were covered by transparent plastic lids to avoid damage by animals or precipitation, were placed with a minimal distance of four meters to each other. Nine pitfall traps were installed on each site in a stratified random design (Krebs 1999). The sampling took place between the beginning of April and mid-July, when harvesting and soil tillage began. A further trapping season in autumn was not included in the study, because after the sites had dried out and were ploughed, they lost their wetland characteristics which account for the gradient of species richness. The species caught were removed every week and identified to the species level. The catches were pooled for the respective pitfall samples.

### *Evaluation of the estimators*

I evaluated the potential of four non-parametric estimators (Jackknife 1 and 2, Bootstrap, Chao2) to predict the true species richness  $S_{\text{true}}$  of the ten study sites. As the estimators are based on the observed species richness  $S_{\text{obs}}$ , it was included as a reference in the analysis. Due to the fact that  $S_{\text{true}}$  can hardly be determined in highly diverse communities, I used a surrogate variable,  $S_{\text{true}*}$ ,

which was measured as the arithmetic mean of the four estimators based on the data of nine samples per site. This method was chosen as a result of a preliminary study in the previous year which demonstrated that (1)  $S_{\text{obs}}$  will approach  $S_{\text{true}^*}$  if more than nine pitfalls are used, and (2)  $S_{\text{true}^*}$  will not increase strongly if more than nine pitfall samples are used for the calculation.

The performance of the estimators was compared in three scenarios with four, five and six pitfall traps per site (scenario<sub>4,5,6</sub>). These scenarios represent minimal sampling procedures. In each scenario, I took 25 randomized subsamples of the nine pitfall samples in each habitat. The estimated species richness  $S_{\text{est}}$  of the sites was calculated with each estimator at every site by the mean of the estimations in the 25 subsamples. This procedure provided respective values of  $S_{\text{est}}$  for each estimator in each scenario and at each site.

The estimators were subsequently analyzed concerning their accuracy and precision in terms of the true number of species  $S_{\text{true}^*}$ . The accuracy of the estimators was measured by relative bias as the ratio of  $S_{\text{est}}$  to  $S_{\text{true}^*}$ , i.e. percent of true richness (PTR):  $\text{PTR} [\%] = (S_{\text{est}}/S_{\text{true}^*}) * 100$ . The closer PTR is to 100 % the more accurate is the estimator. PTR will be above 100 % if the estimator overestimates and below 100 % if the estimator underestimates  $S_{\text{true}^*}$ . I calculated the mean PTR of each estimator across all study sites in order to compare the estimators. Precision was measured as the standard deviation of the PTR. In general, the lower the standard deviation is, the higher the precision of the estimator is. Furthermore, the estimators were evaluated by linear regressions (Type I) of  $S_{\text{est}}$  on  $S_{\text{true}^*}$ .

## Results

In this study 48,087 individuals of carabid beetles were captured, yielding a total of 123 species. Site species richness ( $S_{\text{obs}}$ ) ranged between 42 and 79 species. In contrast to the collector curves of  $S_{\text{obs}}$ , the accumulation curves of  $S_{\text{true}^*}$  indicated a beginning saturation showing that the sampling program with nine pitfall traps per site should have been adequate to determine total species richness.

In the three scenarios, all mean PTRs were below 100 % (Table 1), which indicates that all estimators had negative biases. However, the bias was constantly reduced with increasing number of samples.  $S_{\text{obs}}$  showed the slowest approach towards  $S_{\text{true}^*}$  and even in scenario<sub>6</sub> a mean PTR of only 63 % was reached. The Bootstrap estimator performed only slightly better, reaching a mean PTR of 72 % in this scenario. The remaining estimators reduced the bias substantially. Chao2 performed best in all scenarios and reached a mean PTR of 96 % in scenario<sub>6</sub>. While the precision of  $S_{\text{obs}}$  was highest in scenario<sub>4</sub>, Chao2 performed more precisely in the other scenarios (Table 1). The remaining estimators were in all scenarios less precise than  $S_{\text{obs}}$ .

In the regression analyses, Chao2 performed best, reaching the highest significance level in all scenarios (Table 1). In the scenarios with five and six samples the coefficient of determination reached 94 % and 85 %, respectively. While in scenario<sub>4</sub> the remaining estimators did not perform much better than  $S_{\text{obs}}$ , they did, however, reach higher coefficients of determination in the other scenarios. In scenario<sub>6</sub> Jackknife2 performed obviously better than Jackknife1 and the Bootstrap estimator.

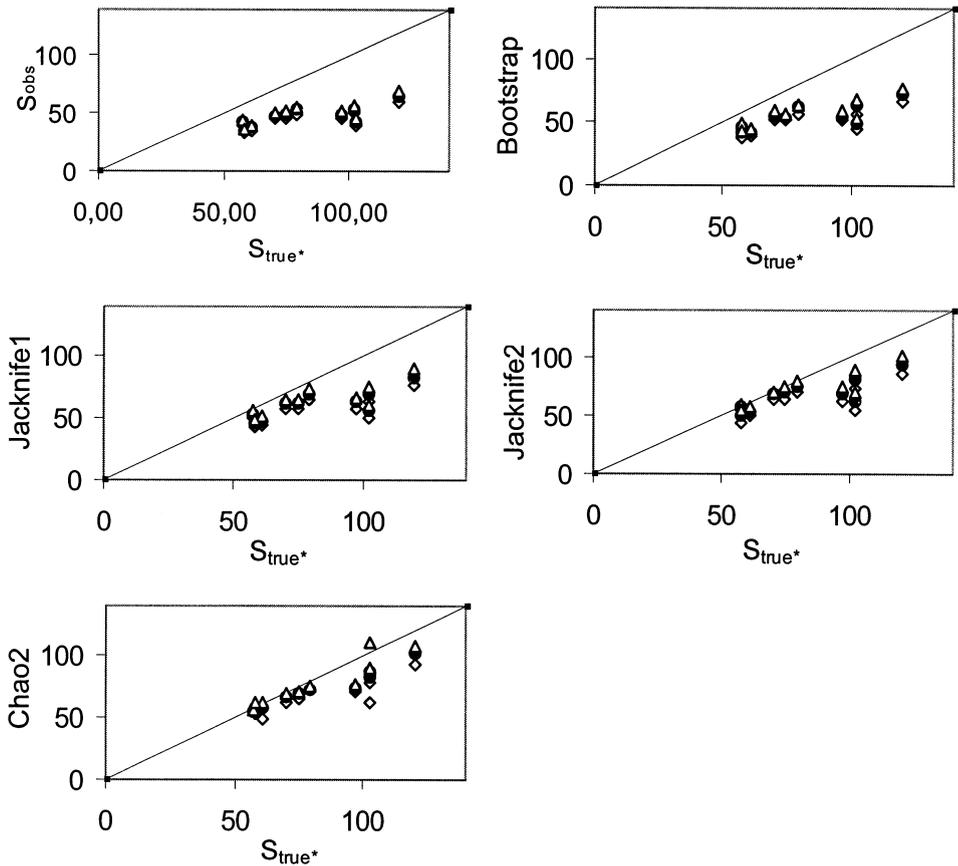
Figure 1 shows the relation between the estimators and  $S_{\text{true}^*}$ . Points under the diagonal line represent underestimation and points above indicate overestimation. It is obvious that Chao2 has the closest approximations toward the diagonal. Jackknife2 has the second best results. While the other estimators and  $S_{\text{obs}}$  get close to the diagonal in the habitats with low  $S_{\text{true}^*}$ , they seriously underestimate  $S_{\text{true}^*}$  in the species-rich habitats.

**Table 1.** Performance of the estimators of species richness. Accuracy (mean PTR), precision (SD PTR) and regression of estimated on true species richness, PTR = percent of true richness, SD = standard deviation,  $S_{obs}$  = observed species richness

	<i>accuracy (mean PTR)</i>	<i>precision (SD PTR)</i>	$r^2$	$p$
<b>4 pitfall traps:</b>				
$S_{obs}$	55.46	9.41	0.563	*
Chao 2	81.99	10.34	0.768	**
Jacknife 1	71.01	11.99	0.554	*
Jacknife 2	78.08	13.14	0.559	*
Bootstrap	63.04	10.55	0.568	*
<b>5 pitfall traps:</b>				
$S_{obs}$	59.57	9.75	0.591	**
Chao 2	89.44	7.44	0.938	***
Jacknife 1	76.45	12.11	0.614	**
Jacknife 2	84.84	12.55	0.653	**
Bootstrap	67.57	11.06	0.57	*
<b>6 pitfall traps:</b>				
$S_{obs}$	62.97	10.03	0.615	**
Chao 2	96.13	8.89	0.854	***
Jacknife 1	81.19	12.04	0.665	**
Jacknife 2	90.56	11.42	0.752	**
Bootstrap	71.71	10.85	0.653	**

## Discussion

It is almost impossible to measure  $S_{true}$  for highly diverse arthropod communities (Colwell & Coddington 1994). This could be a possible explanation for the lack of studies testing the efficiency of the non-parametric estimators in arthropod communities. In the present study, the use of  $S_{true*}$  instead of  $S_{true}$  might eventually cause errors, because  $S_{true*}$  is based on the non-parametric estimators. However, the accumulation curves of  $S_{true*}$  indicated beginning saturation, which is supported by the results of a previous study. Accordingly,  $S_{true*}$  should closely match  $S_{true}$ . Furthermore, the considered estimators produce results with negative bias in studies with few samples (Palmer 1990, 1991; Colwell & Coddington 1994). Therefore, it is most likely that  $S_{true}$  is higher than  $S_{true*}$ . This conclusion is supported by the results of a previous study. In the present study, all mean PTRs indicated negative bias of  $S_{est}$ . Accordingly, the use of  $S_{true}$  with higher values would have produced a stronger negative bias of the estimators; however, it is very unlikely that it would have changed the ranking of the methods. The results of the present study should therefore, be interpreted qualitatively rather than quantitatively. As a result, the ranking of the estimators in the present study reflects their ability to match the results of studies with higher sampling intensity. The results of the comparison in the present paper are in accordance with Colwell & Coddington (1994), which also concluded that Chao2 produces the least biased estimations. Palmer (1990) compared various parametric methods, the extrapolation of species-area curves, and non-parametric estimators in a study on species richness of



**Fig. 1.** Relation between  $S_{est}$  and  $S_{true*}$ . Points under the diagonal line represent underestimation and points above indicate overestimation. Open rhombus: scenario<sub>4</sub>, closed circles: scenario<sub>5</sub>, open triangle: scenario<sub>6</sub>

plants in a forest. The non-parametric estimators performed much better than the other methods. Jackknife1 and 2 produced the best results, but Chao2 was not included. These results were generally confirmed by Baltanás (1992) in computer simulations. Colwell & Coddington (1994) summarized the discussion stating that the non-parametric estimators are most promising in estimating species richness in highly diverse communities. In the present study, the estimators significantly reduced the bias compared to the results of  $S_{obs}$ . However, a minimum of five samples is apparently necessary to achieve fairly accurate and precise estimations. In general, the estimators Chao2 and Jackknife2 performed best. They are both based on the number of species that occur in only one sample, as well as the number of species that occur in exactly two samples. It seems that this approach is more promising in studies with a low number of samples than the other estimators.

The present results are based on a pitfall trapping program of carabid beetles in a small habitat. This represents a first step towards the evaluation of the non-parametric estima-

tors. Further work is needed to determine if the results are transferable to sampling programs of other taxonomic groups with different sampling methods in larger habitats. However, the present study was carried out on study sites having a strong gradient of species richness, which is supposed to be the most important factor influencing the performance of the non-parametric estimators (Colwell & Coddington 1994). Accordingly, it is very likely that the present results can be transferred to other sampling programs. In summary, Chao2, though negatively biased, was the most accurate estimator in the present study. Furthermore, it was the only estimator which was more precise than  $S_{\text{obs}}$ . In the scenarios with five or six samples, the estimations of Chao2 were fairly close to  $S_{\text{true}}$ . Accordingly, in studies with the objective to compare the species richness of various sites using pitfall traps, the effort can most likely be reduced to five or six samples. Due to the higher precision, the comparison of sites is more reliable using Chao 2 than  $S_{\text{obs}}$  or any other of the estimators.

## Acknowledgements

The study was supported by a grant from the state of Brandenburg. I am grateful to S. Samu, T. Dennard, M. Schädler, D. Wrase, M. Glemnitz, U. Stachow, A. Werner, G. Berger and I. Wolf.

## References

- Baltanás, A. (1992) On the use of some methods for the estimation of species richness. *Oikos* 65, 484–492.
- Bunge, J., Fitzpatrick, M. (1993) Estimating the number of species: a review. *Journal of the American Statistical Association* 88, 364–373.
- Chao, A., Lee, S. M. (1992) Estimating the number of classes via sample coverage. *Journal of the American Statistical Association* 87, 210–217.
- Colwell, R. K., Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. In: Hawksworth, D. L. (ed) *Biodiversity: measurement and estimation*. The Royal Society, London, pp. 101–118.
- Duelli, P. (1997) Biodiversity evaluation in agricultural landscapes: an approach at two different scales. *Agriculture, Ecosystems and Environment* 62, 81–91.
- Gaston, K. J. (1996) Species richness: measure and measurement. In: Gaston, K. J. (ed) *Biodiversity: a biology by numbers and difference*. Blackwell Science, Oxford, pp. 77–113.
- Heltsh, J. F., Forrester, N. E. (1983) Estimating species richness using the Jackknife Procedure. *Biometrics* 39, 1–11.
- Krebs, C. J. (1999) *Ecological methodology*. Addison-Welsey, Menlo Park.
- Kromp, B. (1999) Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. *Agriculture, Ecosystems and Environment* 74, 187–228.
- Palmer, M. W. (1990) The estimation of species richness by extrapolation. *Ecology* 71, 1195–1198.
- Palmer, M. W. (1991) Estimating species richness: the second-order Jackknife reconsidered. *Ecology* 72, 1512–1513.
- Standen, V. (2000) The adequacy of collecting techniques for estimating species richness of grassland invertebrates. *Journal of Applied Ecology* 37, 884–893.
- Wilson, J. B., Gitay, H., Steel, J. B., King, W. M. (1998) Relative abundance distributions in plant communities: effects of species richness and of spatial scale. *Journal of Vegetation Science* 9, 213–220.