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Can carabidologists spot a pitfall? The non-equivalence of two components of sampling effort, the number of sampling units and sampling period in pitfall-trapped ground beetles (Carabidae)

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Abstract

Sampling effort in pitfall trapping sessions is routinely calculated as a product of trap numbers and time period, and expressed in units of trap-days or trap-weeks. This assumes that these two components contribute equally to the catch, so that the catch from 2*n* traps run for *z* days is equivalent to the catch of *n* traps run for 2*z* days. We tested this equivalence relationship by comparing two pitfall trapping sessions, representing a similar trapping effort, performed in the same habitat (an apple orchard in Hungary), using the same pitfall trap design and spatial arrangement. The two trapping sessions were nested in time. The "Time Series" session had 20 traps operating for 28 weeks (560 trap-weeks), while the "Spatial Series" session had 100 traps operating for 4 weeks (400 trap-weeks). The Time Series session caught 1823 individuals of 51 species, while the Spatial Series session had fewer (757) individuals but 52 species. The virtual structure of the two carabid assemblages was different, although the major species were the same. Rarefaction curves clearly indicated that the Spatial Series indicated a significantly more species-rich ground beetle assemblage than the "Time Series" sample. The "common currency" for trapping effort needs to be re-examined because its two components, number of traps and length of operation do not contribute to the final catch in the same way. This has an important consequence for the design of biodiversity monitoring: trapping effort allocation for monitoring is better when the number of traps is at the possible maximum and the time of sampling shortened rather than the other way around.

Key Words: sampling, carabid assemblages, pitfall trapping, apple orchards, diversity

Introduction

Pitfall trapping is a frequently used field collecting method in the study of organisms active on the soil surface. A pitfall trap is a container dug into the soil so that its rim is usually flush with the soil surface, and captures organisms that walking on the soil surface, fall into it (but a trap can be set to catch from the top or within litter, soil, grass, etc.). Pitfall trapping is thus a "passive" sampling method where the activity of the target organism is necessary for capture. The trap can contain an attractant, a killing/preserving liquid, or nothing – each of these has its own modifying effect on the catch (Southwood and Henderson 2000). The method, commonly attributed to Barber (1931), has become very popular, and the variation of pitfall trap design is vast, using different material, shape, and size (Southwood & Henderson 2000). The use of pitfall traps and their biases have been hotly debated without bringing about many generally accepted ways of standardization (Lövei & Sunderland 1996), but see (Niemelä *et al.* 1990); (Digweed *et al.* 1995); (Koivula *et al.* 2003)). One of the few accepted standards is the expression of the sampling effort, which is usually reported as "trap-nights" or "trap-weeks". and is seen as a universal currency for comparisons of different pitfall trapping projects. However, while different aspects of this technique, the distance, design, material of the traps, and the influence of habitat and the preservative fluid has been studied and discussed (for a recent review see (Woodcock 2005), there is no similar evaluation of the equivalence of the two components of this trapping effort unit.

Sampling effort has two components: the number of sampling units (often the number of traps) and the length of sampling time (days, nights or weeks) during which the traps are in operation. Consequently, sampling effort is routinely calculated as a product of these two components (trap

numbers x time period, in units of trap-days or trap-weeks). This characterization of the trapping effort, however, contains an important assumption. It is generally assumed that two catches are equivalent if they result from an effort of the same number of trap-days, irrespective whether this is derived as '*n* traps x *z* days' or '*n*/2 traps x 2*z* days'. This assumption remains untested, although it could critically influence our sampling of the assemblage under study, as well as the comparisons we make among different locations, assemblages and habitats. Some commonly used inventory/monitoring methods that face this dilemma include pitfall trapping for collecting ground-active arthropods (Barber 1931) and mist nets for catching birds (Bub 1996). In the current contribution, we examine the relationship between the two sampling components using pitfall trapping as an example.

In the present contribution, we tested the assumption that the product of the two components of trapping effort, trapping time and the number of traps are equivalent. We compared two trapping sessons made at the same time, in the same habitat, and with the same trapping effort, but differing in the relative contribution of their two components. The results showed that the two components are not equivalent, and the unified currency of trapping effort cannot always be used.

Material and Methods

The study site was at the field station of the Plant Protection Institute (PPI) at Julianna-major, near Budapest, central Hungary. This area is hilly, with various broad-acre crops in the valley

bottom, orchards on the lower slopes of hills, and a modified oak-hornbeam forest at higher elevations. The study was done in an apple orchard of ca. 6ha, divided into two parts. Half of the orchard received pesticide treatments, usually two times during the first half of the season, while the other half had no such treatments. The first spraying was before the traps were deployed, and overall, the treatments had little influence on the catch. A more complete description of the study site, management and the surroundings see in (Lövei 1981) and (Mészáros 1984).

Pitfall traps were 500 ml glass jars, with 70% ethylene glycol as killing agent and preservative, placed under the south-eastern corner of an apple tree, about 2 m from the trunk. Twenty such traps were established at randomly selected trees (but not allowing any traps located closer than 10 m), half of them in the non-treated, the other half in the adjoining "treated" block. All traps were covered with a galvanized iron square mounted on pegs, to prevent bycatch and to protect the catch from scavengers. Traps were checked weekly, when the catch was removed, and kept in 70% ethyl alcohol until identification. Identification was made by using keys by (Freude *et al.* 1976); voucher specimens are kept in the arthropod collection at the PPI Department of Zoology, Budapest. Traps were run from early March to late October 1980. This trapping session was run for 28 weeks, i.e. 560 trap-weeks, and was called the “Time Series sampling”.

A second set of data was collected during the autumn (18 September – 21 October 1980), when, an additonal, non-overlapping grid of 100 pitfall traps was set up (50 traps in the unsprayed, 50 in the sprayed block) and run for 4 weeks (400 trap-weeks), called the “Spatial Series sampling”. The distance of these traps was 10 m (both between rows and between trees).

Sample- and individual-based rarefaction curves were constructed according to the recommendations by (Gotelli & Colwell 2001): we used repeated re-sampling and set the patchiness parameter to 0.8 to emphasize the effect of spatial aggregation. For calculations, the program EstimateS Version 8 (Colwell 2006) was used. Special values of the estimated species richness were compared by unpaired *t*-tests with Welch's correction, using two-tailed *p* values.

Results

The Time Series Sampling Session

The catch by the 20 traps over the season was 1823 individuals of 51 identified species (35 individuals, 1.9% of the catch was not identified to species; 28 of these were individuals belonging to the genus *Amara,* and 7 to the genus *Harpalus*). The most common species (Table 1) in the catch were *Platynus dorsalis* Pont., *Poecilus cupreus* L, *Harpalus rufipes* De Geer, *Brachinus explodens* Duft. and *H. tardus* Panzer. The five most common species combined constituted 75.0% of the total catch. The Berger-Parker dominance index was d = 0.25. There were 8 singletons in this sample (*Asaphidion flavipes* L., *Calathus melanocephalus* L., *Badister meridionalis* Puel, *Pterostichus oblongopunctatus* F., *Trechus quadristriatus* Schrank, and 3 unidentified *Harpalus* spp.*),* as well as 4 more species with 2 individuals each. Thus 26.7 % of the species found can be considered rare.

The Spatial Series Sampling Session

This trapping arrangement, over four weeks in autumn, collected 757 individual beetles of 52 species. The most common species were: *P. cupreus*, *Metabletus truncatellus* L., *Bembidion lampros* Herbst, *Amara familiaris* Duft., and *H. tardus*. These five species combined constituted

65.4% of the total catch. The Berger-Parker dominance index was d=0.29, less diverse than the time series. There were 18 singletons (*Acuplapus inerstitialis* Reitter, *Abax parallelepipedus* Pill. & Mitt., *Amara apricaria* (Payk.), *A. municipalis* (Duft.), *A. similata* (Gyll.), *Badister lacertosus* Sturm, *B. meridionalis* Puel, *Bradycellus harpalinus* (Serville), *Carabus hortensis* L., *Dolichus halensis* (Schaller), *Harpalus signaticornis* (Duft.), *H. picipennis* (Duft.), *Leistus rufomarginatus* Duft., *Panageus crux-major* (L.), *Parophonus complanatus* (Dejean), *Poecilus striatopunctatus* (Duft.) and *Stomis pumicatus* Panzer). From a further 6 species, 2 individuals each were captured. A higher share (46.2%) of the species were rare than in the time sample.

Comparing the Two Trapping Series

The "Time Series" session had a higher trapping effort, collected more individuals and the assemblage showed a higher activity density (Table 1). It yielded nearly as many species as the "Spatial Series" sampling. The rank-abundance curves (Fig. 1) indicated that the time sample overall had a less diverse assemblage than the spatial sampling series. There are several differences in the species lists, too (Table 1). Thirty-one species were shared, which made up 97.7% of the total number of individuals captured in the time series, while the shared species made up 81% of the total in the "Spatial Series". Consequently, the time series can loosely be considered a sub-sample of the "Spatial Series", because an overwhelming majority of the individuals belonged to species that were also captured by the spatial sampling series – but not the opposite. Nevertheless, the time sample had 14 unique species, while the spatial sample had 21 such species. This latter only included 3 species of *Amara* and thus the difference cannot fully be attributed to the unidentified *Amara* species in the time series sample.

The differences in the two curves become obvious in the rarefaction curves (Figs. 2, 3). The sample-based rarefaction curve of the "Time Series" runs above that of the "Spatial Series" (Fig. 2a). This is caused by the higher number of individuals caught (overall more than double) in the "Time Series" sampling (Table 1). The difference between the two curves is significant (Welch-corrected t=36.31, d.f.=81, p<0.0001).

This, however, is biased and was corrected as suggested by Gotelli and Colwell (2001): „When sample-based rarefaction curves are used to compare taxon richness at comparable levels of sampling effort, the number of taxa should be plotted as a function of the accumulated number of individuals, not accumulated number of samples, because datasets may differ systematically in the mean number of individuals per sample." After re-scaling the x –axes of the sample-based rarefaction curves to individuals (based n the number of individuals per sample), the Spatial Series sample was significantly more species-rich than the "Time Series" sample: the estimated species number at equal sample size (762 individuals) was significantly (Welch-corrected t =20.15, d.f.=90, p<0.0001) higher in the Spatial sample (Fig. 2b). The individual-based rarefaction curves (Fig. 3) confirmed this difference: the estimated species richness for 755 individuals of the Spatial Series was significantly (Welch-corrected t =23.58, d.f.=50, p<0.0001) higher than that of the "Time Series" sample.

Discussion

Our results indicated that the often recommended "common unit" for pitfall trapping, trap-days or trap-weeks, that express the sampling effort as the product of the number of traps and the

length of trapping time may not universally be used for comparisons of such sampling sessions.

Clearly, a lower number of traps cannot be compensated for by running them longer. The 20 traps may not have been representative of the variety of microhabitats in the orchard (which the 100 traps covered much better). This, however, is usually not seen as a problem, and even some current recommendations (e.g. Woodcock 2005) suggest fewer traps and longer trapping period, while a shorter–than-full-season trapping arrangement is often condemned (e.g. (den Boer 2002). Our results contradict this piece of advice.

Another possible limitation could be an inter-trap distance that does not allow the traps to be independent of each other. Such interference effect would be larger during a short trapping session when immigration and the appearance of new generation of adults is less significant, than for longer trapping sessions, during which termporal changes could compensate the depletion. Consequently, a depletion effect resulting from too close trap locations could be stronger during our 100-traps short session. In our case, the distance did not have a depletion effect on the catch. Edge traps of our 100-trap trapping grid, where the inter-trap distance was 10 m, captured neither more individuals, nor more species than the central ones (data not shown). This is additional indication that 10m inter-trap distance is suitable to generate independent sampling points when using pitfall traps.

We also have to be aware of several other conditions that are particularly relevant for constructing rarefaction curves, but also for comparing the diversity of different assemblages. It is the assumption of probability-based diversity methods (Tóthmérész 1994) as well as for a

valid rarefaction analysis that the spatial distribution of individuals is random (Kobayashi 1982), that their occurrence is independent of the occurrence of other species (Tóthmérész 1997), the sample sizes are sufficient, and that assemblages being compared have been sampled in the same way (Abele & Walters 1979). Most – but not all- conditions are fulfilled in our comparison.

The two components of the measurement unit, trap number and time, are usually considered equivalent. From this it would follow that the bias in a shorter trapping period can be counteracted by increasing the number of traps. Viceversa, if the number of traps is limited, the length of time can compensate for this. However, recommendations often emphasize that the length of the trapping period cannot be compromised and short pitfall trapping sessions are often criticized due to the lack of covering the whole period of ground beetle activity (den Boer 2002; Woodcock 2005, but see (Niemelä *et al.* 1990); (Sapia *et al.* 2006). Such criticism often argues that a short trapping series will miss species that do not appear during the period of trapping. Based on our (limited) comparisons, this aspect of the trapping error may have been overemphasized.

Our comparisons showed that the number of traps may have more influence on the final result than the length of the trapping period. This is a counterintuitive but important result. Niemela *et al.* (1990) claim: "shorter sampling periods may depict the fauna as accurately as a spatially limited sample". We suggest that the temporal and spatial axes are not equivalent during sampling, but we cannot yet establish their general relationship.

It seems that the "common currency" for pitfall trapping needs to be re-examined as sampling

results emerging from the same trapping effort, if resulting from different contributions of the two components, are not the same. We suggest that one needs to specify not only the product (number of traps x period of trapping) but also the components of the trapping effort.

When the focus of study is different or species identity is important, it is not easy to suggest a compromise. However, these considerations are valid if the aim is a general biodiversity survey to compare relative species richness or diversity – and this is indeed often the focus of study.

These findings may have implications for designing monitoring schemes that use pitfall traps or similar passive catching methods (for example light traps, or mist nets). If a compromise has to be made under a fixed total sampling effort in a biodiversity study, it is better to operate the maximum possible number of traps, and reduce the length of the trapping session rather than the opposite.

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Table 1. List of species captured by the two sampling regimes, the time sampling and the spatial sampling in an apple orchard, central Hungary. Only species with >5 individuals in at least one of the samples were included.

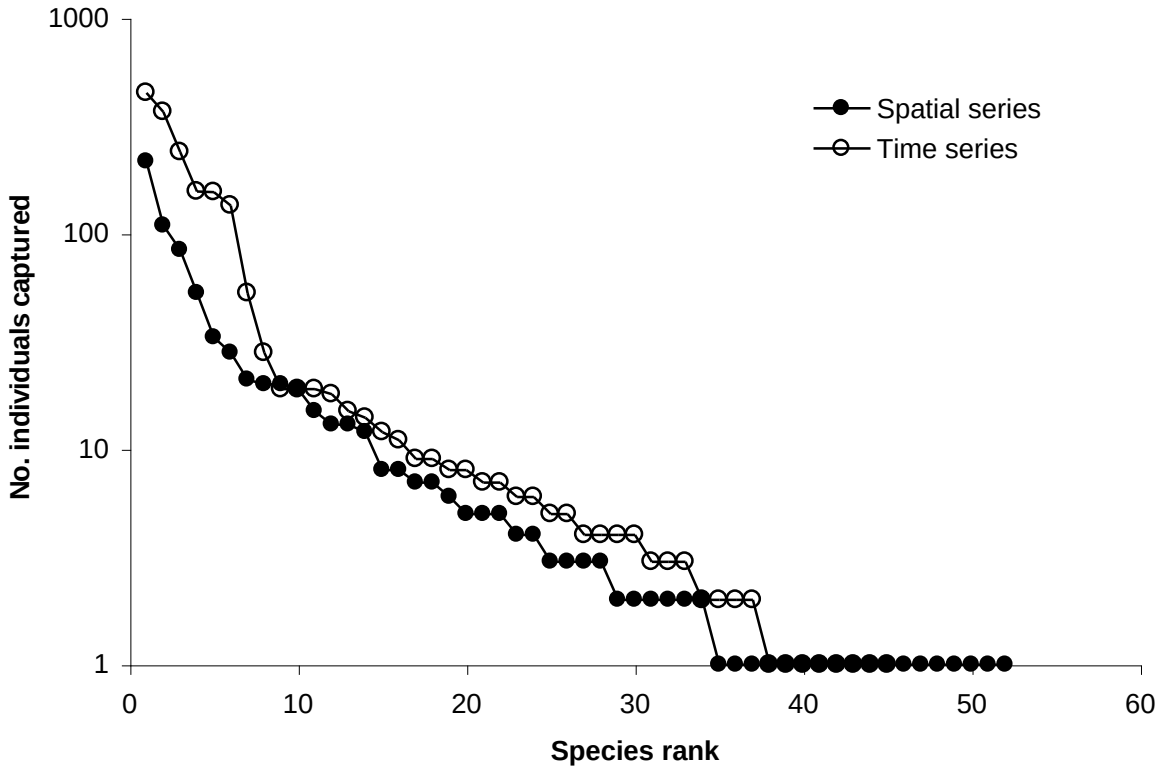
Species	**Time-sample**	**Spatial sample**
Platynus dorsalis	450	28
Poecilus cupreus	367	216
Harpalus rufipes	239	13
Brachinus explodens	157	5
Harpalus tardus	156	33
Harpalus distinguendus	135	20
Microlestes maurus	53	13
Amara consularis	19	7
Calathus erratus	19	5
Pterostichus melanarius	19	2
Amara anthobia	18	19
Broscus cephalotes	15	3
Amara similata	14	1
Amara ingenua	12	8
Amara aenea	11	6
Amara bifrons	9	15
Amara familiaris	9	53
Acupalpus meridionalis	8	7
Metabletus truncatulus	8	109
Carabus violaceus	7	-
Anisodactylus signatus	6	4
Bembidion properans	6	21
Bembidion sp 1	5	-
Panageus crux-major	5	1
Bembidion lampros	4	84
Calathus fuscipes	3	5
Poecilus versicolor	2	8
Calathus melanocephalus	1	12
Trechus quadristriatus	1	20
Trapping effort, trap-weeks	560	400
Total no. of individuals captured	1823	757
Overall activity density, no. of individuals/trap-week	3.26	1.89
Total no. of species captured	51	52
Berger-Parker dominance index	0.25	0.29
No. of unique species	14	21
No. of singletons	8	18

Figure legends

Figure 1. Rank-abundance curves of the carabid assemblage in an apple orchard at Juliannamajor, near Budapest, central Hungary, sampled by two different trapping arrangements: 20 traps for 28 weeks (Time Series) and 100 traps for 4 weeks (Spatial Series).

Figure 2. The rarefaction curves of the two pitfall trapping series collected at Juliannamajor (Hungary) based on the numbers of accumulated samples (a) and based on the accumulated number of individuals (b).

Figure 3. Individual-based rarefaction curves of the two pitfall trapping series collected at Juliannamajor, Hungary. The individual-based rarefaction curves were computed using the Coleman method (Coleman 1981).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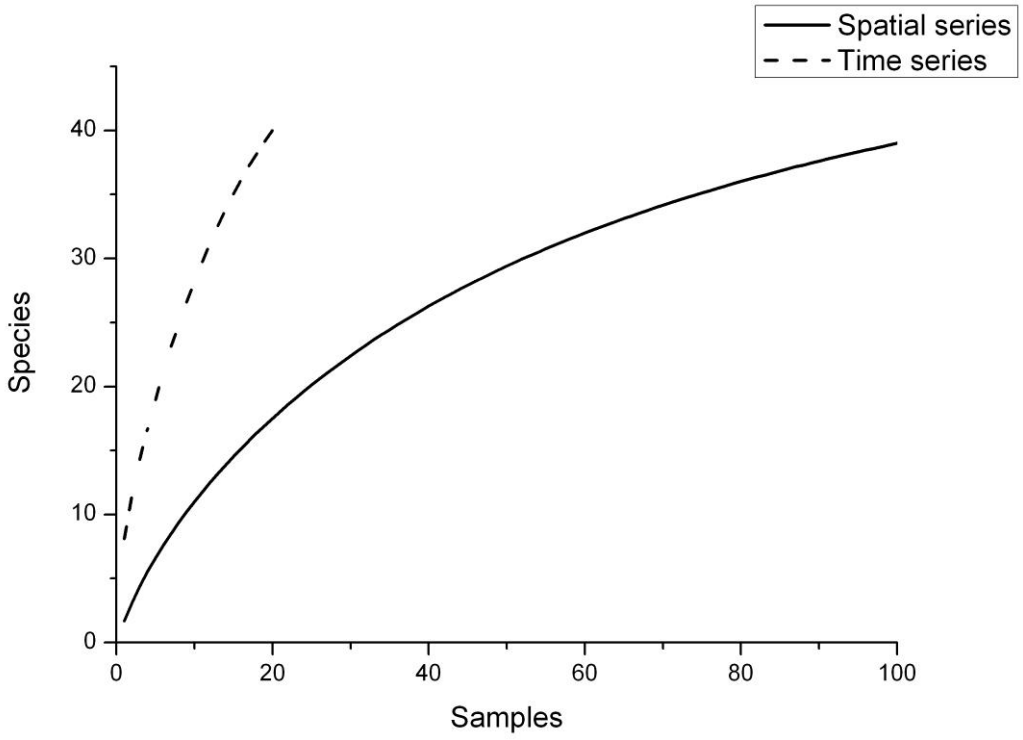
Species rank
Spatial series
Time series

Fig 1.



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316 Fig. 2a

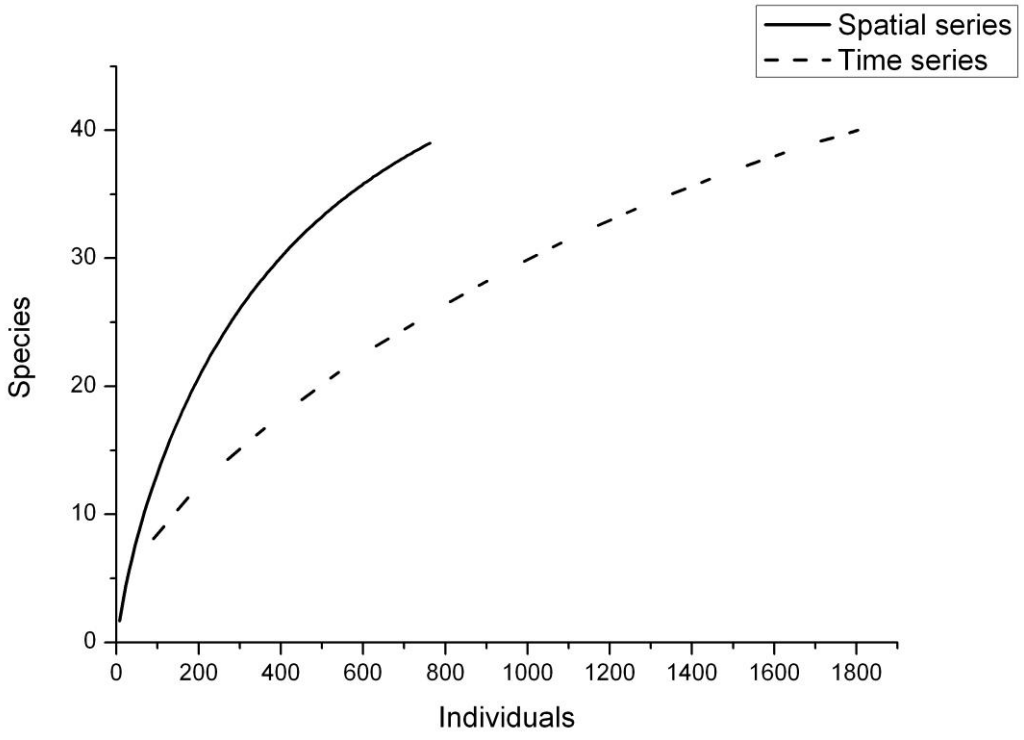
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Fig 2b

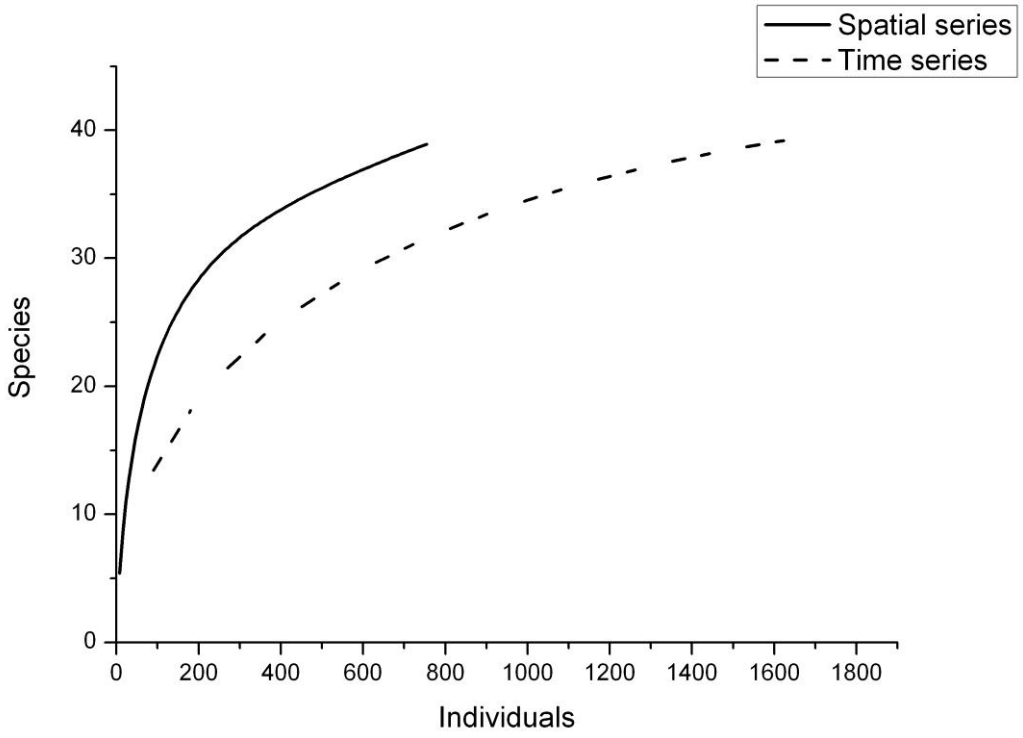
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Fig. 3