Linzer biol. Beitr.	50/1	845-854	27.7.2018

Distribution patterns of selected insect populations on their host plants – an ecological study

Robert STURM

A b s t r a c t : Main objective of the study consists in the detailed investigation of the distribution patterns of three insect species (greenfly, mealybug, and sap beetle) on their preferential habitat plants (common hazel, chervil, and nettle). For this purpose, respective counting data of the animals (N = 100) were analyzed statistically. Sap beetles and greenflies colonizing the upper leaves of the nettle and the common hazel, respectively, are commonly marked by an aggregated distribution of single individuals. According to advanced computations carried out in this context both species bespeak an intermediate to high grade of animal clustering. Those sap beetles colonizing the lower leaves of the nettle exhibit a completely different distribution of their individuals. In this case an increased tendency towards a regular dispersion of the animals may be observed. Mealybugs are distinguished by a random distribution of single individuals on the leaves of the chervil.

K e y w o r d s : Distribution pattern, random distribution, aggregated distribution, regular distribution, population, habitat.

Introduction

Knowledge of habitat-specific distribution patterns of a given animal population are of high ecological value in several respects: Firstly, such skills establish an essential basis for the development of sampling strategies and associated methods of data analysis (ROJAS 1964). Secondly, they also find their use for a determination of effective population size and for a reliable description of the condition of an animal community (SOUTHWOOD 1978). Each modification of the distribution pattern of a given animal species is commonly indicative of a related change of effective population size. If, for instance, a mortality factor significantly reduces the tendency of a sessile organism towards the aggregation of single individuals, it may be concluded that this factor has its highest impact in the case of enhanced population densities. If, on the other hand, the regularity of a distribution pattern is successively increased, the suspicion of an intensification of intrasubject competition becomes obvious (IWAO 1970). Finally, comprehension of animal distributions in specific habitats may be also regarded as essential for the analysis of predator-prey and host-parasite interactions (CROFTON 1971, MURDIE & HASSEL 1973, HASSEL & MAY 1974, ANDERSON 1974).

In principle, modern ecology distinguishes between three types of distribution patterns (Fig. 1a): In the case of random distribution colonization of each point within the considered habitat area occurs with equal probability. Presence of one individual does not have any effect on the spreading of another. The regular or uniform distribution is characterized by almost identical distances between single individuals. This highly idealized type, however, does not find frequent realization in the animal world. This is by far not applicable to the aggregated distribution of an animal population, which is distinguished by its high abundance in nature and the converging of individuals to cohesive clusters of variable size. The last-named distribution pattern can be frequently found among insect communities, with the intensity of individual aggregation underlying remarkable variations (BLISS & OWEN 1958, ROJAS 1964, SOEMARGONO et al. 2008, STURM 2000, 2001, 2003, 2004, 2005, 2007, 2010, 2012, 2016).

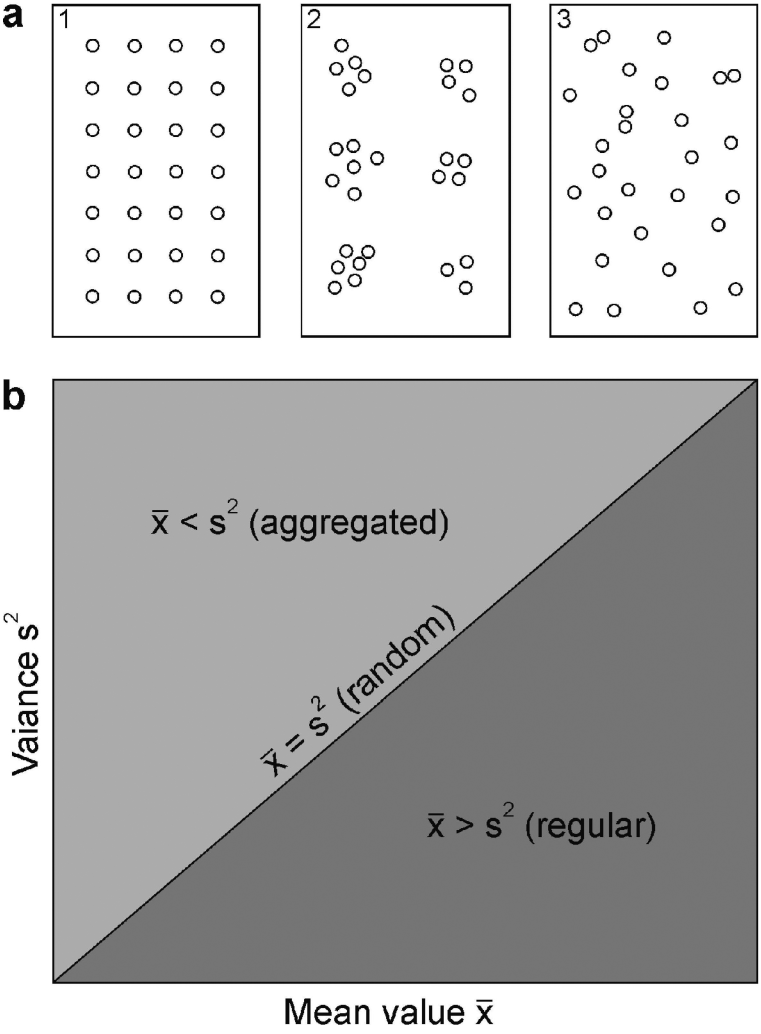

Fig. 1: (a) Basic types of distribution patterns in the animal kingdom: (**1**) regular distribution, (**2**) aggregated (clotted) distribution, (**3**) random distribution; (**b**) graphical method for the determination of the distribution pattern produced by a given animal population.

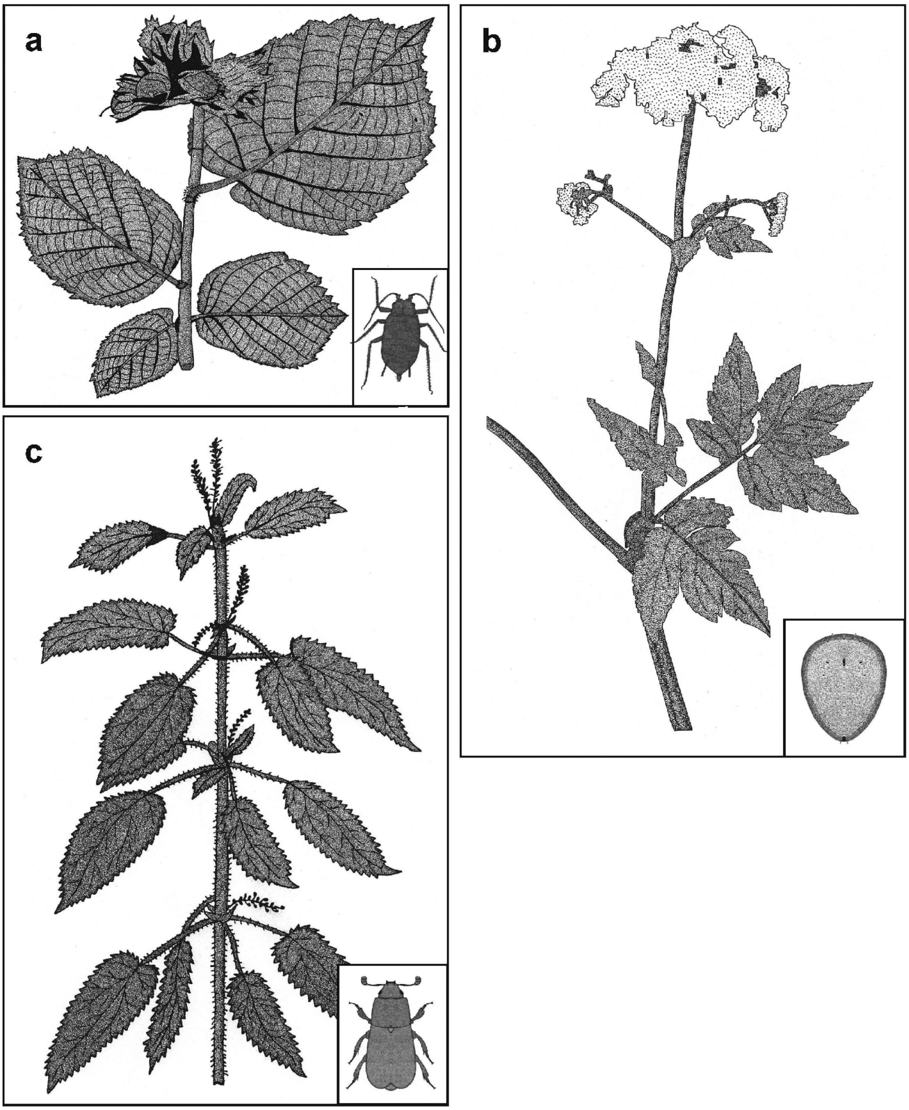

Fig. 2: Illustration of those insects with their preferred host plants studied in the present contribution: (**a**) greenfly on the leaves of the common hazel, (**b**) mealybug on the leaves of the chervil, (**c**) sap beetle on the leaves of the nettle.

From a theoretical perspective, random animal dispersion is most adequately represented by a Poisson distribution, where the data-related variance (s^2) corresponds to the mean value (x_m) (GOULDEN 1952, BLISS & CALHOUN 1954, BAILEY 1959). This function of the form $p_x = \exp(-x_m)\cdot x_m^x/x!$ describes the probability (p), with which a specific number of individuals (x) can be found in a sample of a population with a given mean value (x_m). Regular distributions of individuals are commonly characterized by the circumstance that the variance declines with respect to the mean value, whereas aggregated distributions exhibit a contrary effect. The mathematical ratio between variance and mean value can be used for a coarse differentiation of the distribution type (SOUTHWOOD 1978). For a more detailed analysis application of more complex mathematical techniques becomes unavoidable.

Main objective of the present contribution is the investigation of individual distributions of selected insect populations on respective habitat plants. Eventual discrepancies between the obtained distribution patterns are submitted to a comprehensive debate.

Material and Methods

For the study of population distribution patterns occurring among different insects three animal species and their preferred habitats were subjected to a detailed analysis. For this purpose, spreading (1) of the greenfly (family Aphididae) on leaves of the common hazel (*Corylus avellana*), (2) of the sap beetle (family Nitidulidae) on upper and lower leaves of the nettle (*Urtica dioica*), and (3) of the mealybug (family Pseudococcidae) on leaves of the chervil (*Chaerophyllum hirsutum*) was extensively investigated (Fig. 2). Collection of counting data took place in a pasture wood in the south of the city of Salzburg, where the habitat plants noted above commonly occur with high frequencies. This circumstance allowed the creation of a large sample ($N = 100$) for each species.

In the course of data collection almost equally sized leaves of the host plants were analyzed for their stock with respective individuals. For each plant included in the investigation the mean value x_m and variance s^2 of the individual number per leaf were calculated. In order to obtain a course estimation of the distribution pattern produced by a given insect population, both statistical measurements were plotted into the diagram with x_m defining the abscissa and s^2 defining the ordinate (Fig. 1b). In the case of an aggregated distribution of the insect population, an advanced mathematical analysis for a more detailed differentiation of the spreading pattern was carried out (ANSCOMBE 1949, GOULDEN 1952, BLISS & CALHOUN 1954, BAILEY 1959). It has to be mentioned in this context that any clotted dispersion pattern can be adequately expressed by a binomial distribution (ROJAS 1964, ANDERSON 1974) of the form $p(k) = (n\ k)\cdot p^k\cdot(1-p)^{n-k}$, where the exponent k may be regarded as measure for the grade of clustering. High values of k indicate a tendency towards random distribution of individuals, whereas low values of k ($k < 1$) additionally underline the extent of aggregation. The parameter k has not to be assumed as constant for the studied population, but frequently increases with the average individual number per sampling area (ANSCOMBE 1949, 1950, BLISS & FISHER 1953, WATERS & HENSON 1959, DEBAUCHE 1962, LEGAY 1963, ROJAS 1964, ANDERSON 1974). Estimation of k takes place according to two independent methods: In the first approach, the parameter is quantified with the formula $k = x_m^2/(s^2-x_m)$ [20], whereby useable accuracy of this equation can be only attested for low values of x_m. An alternative quantification of k takes place by using the formula $\log(N/n_0)= k\cdot\log(1+x_m/k)$. In this mathematical expression N denotes the total number of samples, whilst n_0 represents the amount of samples without any recording of individuals (KATTI & GURLAND 1962). As easily recognizable from the equation, k can be only approximated iteratively, with 2 representing an appropriate starting value of the related procedure.

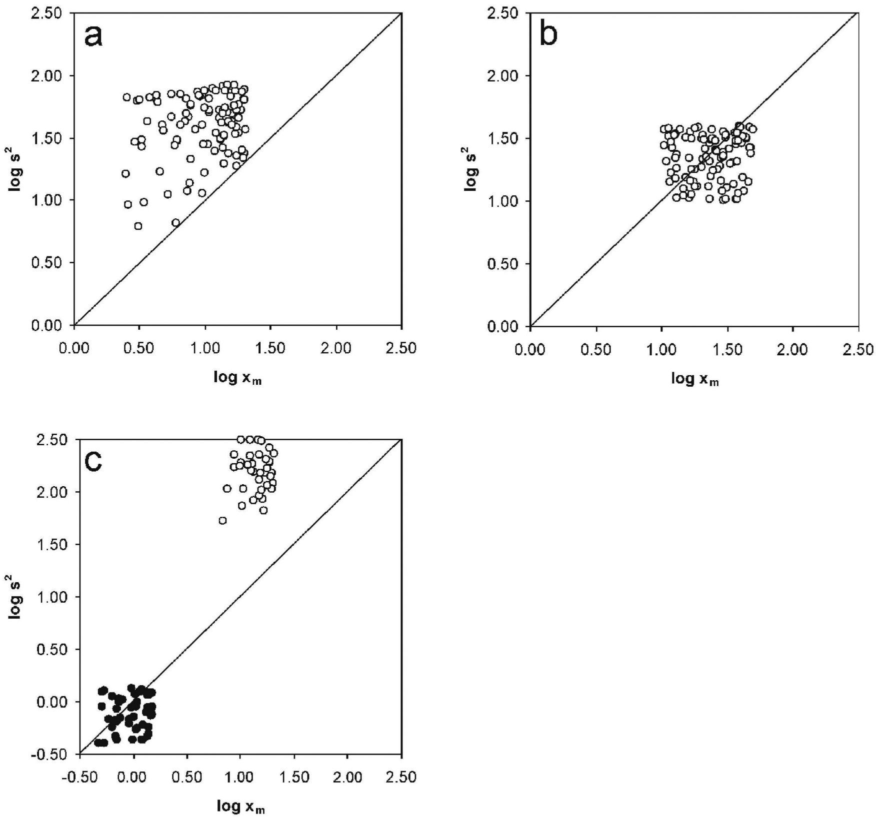

Fig. 3: Graphical determination of the distribution patterns of those species introduced in Fig. 2: (**a**) greenfly on the common hazel, (**b**) mealybug on the chervil, (**c**) sap beetle on the nettle.

Results

Main results of the study are summarized in the graphs of Fig. 3 and 4. In general, distribution patterns of the three insect species investigated in this contribution are characterized by partly significant differences. According to this, greenflies colonizing the leaves of the common hazel exclusively show aggregated distribution patterns, with the x_m/s^2 ratios adopting values < 1. A completely different picture is provided for the mealybugs on the leaves of the chervil, which are mainly distinguished by random distribution patterns ($x_m/s^2 \sim 1$). An interesting phenomenon may be observed with regard to the colonization of nettle leaves by the sap beetle: Individuals residing in the upper part of this host plant exclusively exhibit a clotted distribution, with x_m/s^2 ratios assuming values << 1. On the other side, sap beetles colonizing the lower part of their host plant are marked by respective aggregation only in very specific cases. According to the related graph they increasingly tend towards more regular distribution patterns.

In the case of greenflies and sap beetles residing on the upper leaves of the nettle clotted distribution patterns could be found, which were subsequently analyzed more in detail by computation of the parameter k (Fig. 5). Estimation of the grade of aggregation according to the first mathematical method (Fig. 5a, b) for both species results in a steep ascent of k with increasing x_m. For $x_m < 10$, k commonly adopts values < 1, which indicates a rather pronounced clustering behavior. For $x_m > 10$, k is characterized by values between 1 and 100 in the case of greenflies, but by values between 1 and 10 in the case of sap beetles. Summing up, no clear picture with regard to the intensity of aggregation can be drawn. According to the related graphs larger populations of these two species increasingly tend towards random distribution patterns, whereas smaller populations are marked by local accumulations of individuals. This impression, however, is additionally underlined after calculation of the parameter k according to the second mathematical method (Fig. 5c, d). In the respective double-logarithmic plots k exhibits an ideal linear increase with x_m. For $x_m > 10$, k generally varies between 1 and 3 and, therefore, can be attributed to a much smaller interval. The graphs of Fig. 5c and d recommend a distribution of greenflies and sap beetles with intermediate to high grade of clustering.

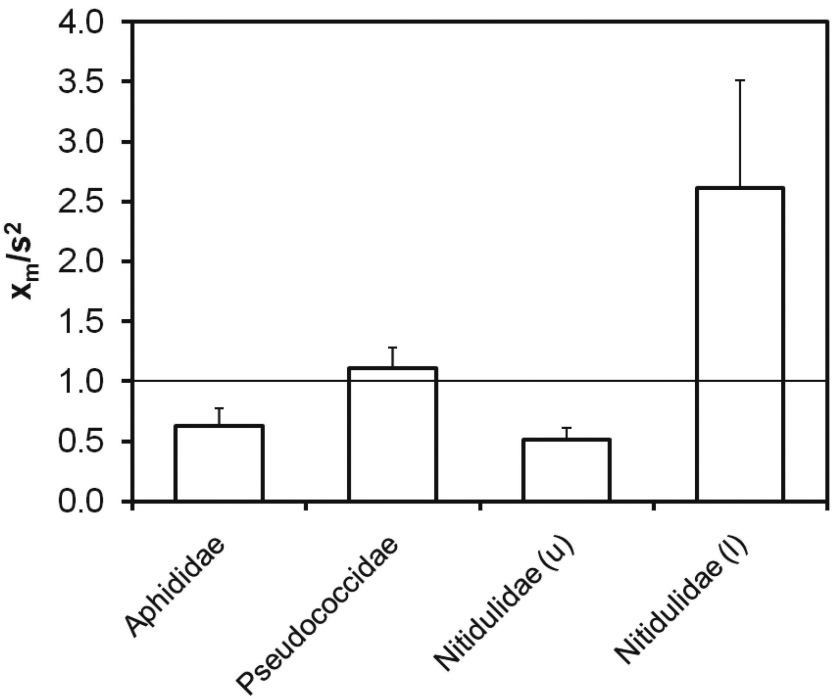

Fig. 4: Mean values and standard deviations of the x_m/s^2 ratios for a more detailed differentiation of the animal distribution patterns. According to the results greenflies and sap beetles colonizing the upper parts of the nettle are distinguished by aggregated distribution patterns, whilst sap beetles residing on the lower parts of the nettle are characterized by a more regular distribution. Mealybugs tend to develop random distribution patterns.

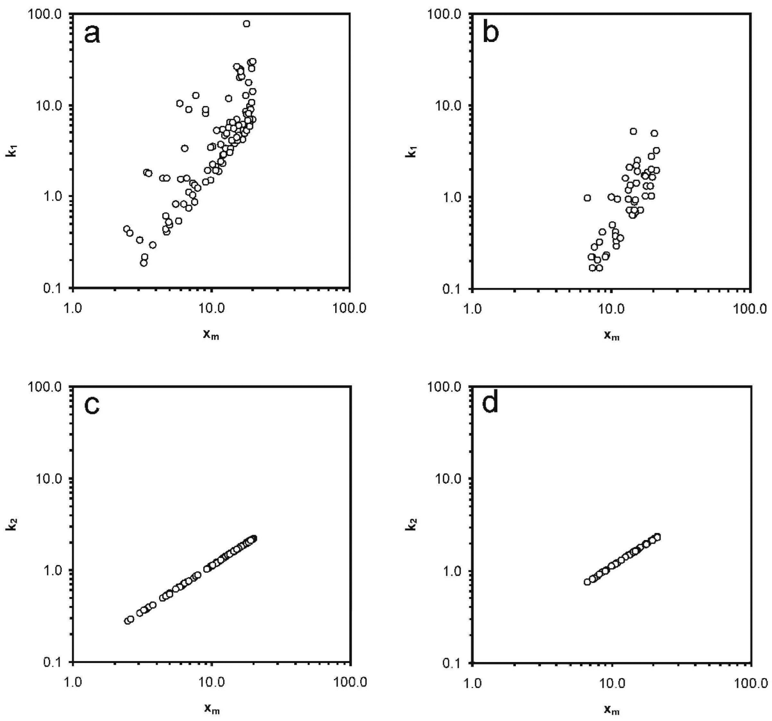

Fig. 5: Determination of the grade of aggregation (**k**) according to two independent methods (see text) and illustration of the relationship between k and x_m: (**a**) greenflies (first method), (**b**) sap beetles (first method), (**c**) greenflies (second method), (**d**) sap beetles (second method).

Discussion and Conclusions

Based upon the results presented in this contribution it could be demonstrated that distribution patterns of single insect species may not be regarded as uniform, but may adopt very different shapes. Besides the differentiation of individual distribution by species also a dependence of specific dispersion patterns on spatial positions of the colonized leaves could be reported in the case of the sap beetle. Here, the upper and lower parts of the same host plant are characterized by completely different settling strategies. Principally, the distribution of insects on their host plants is mainly controlled by a multiplicity of ecological factors and the way of life of the species (solitary or in colonies) (SOUTHWOOD 1978). Hence, it is not very surprising that the greenfly exhibits a clotted distribution of its individuals with enhanced grade of clustering; this insect is marked by increased colony-forming activities (KLAUSNITZER 1997).

Regarding the mealybug a random distribution of single individuals could be calculated on basis of the sampling data. Although ecology of this species has not been enlightened in detail hitherto, this result seems to be well explicable. The computed type of distribution pattern ensures an optimal exploitation of the food resources offered on the host plant. If, for comparison, the distribution of crop pests is considered more explicitly, also a random spreading of single animals can be observed, which change into another distribution type in the case of specific events (e.g., reproduction) (SOUTHWOOD 1978).

The locally different distribution patterns generated by individuals of the sap beetle seem to rest upon complex causes at first sight, but can be rather easily explained, too. In principle, this insect species pursues the attempt of colonizing those positions of the habitat, which offer the highest supply of nutriments. In the case of the nettle, these positions are located in the apical area of the plant. A resulting increase of the population density on the upper leaves (Fig. 3-5) forcibly implies the phenomenon of clustering. Aggregation in the upper part of the host plant causes a massive thinning of the population in the lower part and, as consequence of that, the generation of a random distribution of animals.

The study of insect distribution patterns houses several sources of inaccuracy. Most of all, the method of sampling and the size of the sample area may cause a significant falsification of the results. There exists a remarkable difference, if the whole host plants (as carried out in this contribution) or only parts of them are sampled. Previous scientific investigations arrived at the unequivocal assessment that any increase of the sample area may frequently result in a modification of the distribution pattern (SOUTHWOOD & LESTON 1959, KATTI & GURLAND 1962, SOUTHWOOD 1978, SOEMARGONO et al. 2008). In order to obtain high certainty with regard to the distribution of single insect species, besides application of the classical methods also the use of more refined mathematical techniques (nearest-neighbor method) is recommended (SOUTHWOOD & LESTON 1959).

The results introduced in this contribution lead to the conclusion that the mode of life of the studied animal population on the one hand and the quality of the habitat on the other represent two main control parameters of the distribution of single individuals. Within the large group of the insects, a certain variety of distribution patterns may be observed. Thereby, single phases of the life-cycle (embryonic stage, nymph, larva, adult) are often characterized by different distribution structures, which partly result from very individual colonizing strategies.

Zusammenfassung

Verteilungsmuster von ausgewählten Insektenpopulationen auf deren Wirtspflanzen – eine ökologische Studie. – Das hauptsächliche Ziel der Studie besteht in einer detaillierten Untersuchung der Verteilungsmuster von drei Insektenarten (Blattlaus, Schildlaus, Glanzkäfer) auf deren bevorzugten Habitatpflanzen (Hasel, Kälberkropf und Brennnessel). Zu diesem Zweck wurden entsprechende Zähldaten der Tiere statistisch ausgewertet. Glanzkäfer und Blattläuse, welche die oberen Blätter der Brennnessel und Hasel besiedeln, zeichnen sich gemeinhin durch eine geklumpte Verteilung der einzelnen Individuen aus. Gemäß erweiterter in diesem Kontext durchgeführter Computerberechnungen lassen beide Spezies einen mittleren bis hohen Grad der Clusterbildung erkennen. Jene Glanzkäfer auf den unteren Blättern der Brennnessel zeigen eine vollständig unterschiedliche Verteilung ihrer Individuen. In diesem Fall kann eine erhöhte Tendenz in Richtung regelmäßiges Verteilungsmuster der Tiere beobachtet werden. Schildläuse sind durch eine zufällige Verteilung einzelner Organismen auf den Blättern des Kälberkropfes charakterisiert.

References

ANDERSON R.M. (1974): Population dynamics of the cestode *Caryophyllaeus laticeps* (PALLAS, 1781) in the bream (*Abramis brama* L.). — J. Anim. Ecol. **43**: 305-321.

ANSCOMBE F.J. (1949): The statistical analysis of insect counts based on the negative binomial distribution. — Biometrics **5**: 165-173.

ANSCOMBE F.J. (1950): Sampling theory of the negative binomial and logarithmic series distributions. — Biometrika **37**: 358-382.

BAILEY N.TJ. (1959): Statistical methods in biology. — 200 pp., London (English Universities Press).

BLISS C.I. & R.A. FISHER (1953): Fitting the negative binomial distribution to biological data and note on the efficient fitting of the negative binomial. — Biometrics **9**: 176-200.

BLISS C.I. & D.W. CALHOUN (1954): An outline of biometry. — 366 pp., New Haven (Yale co-operative corp.).

BLISS C.I. & A.R.G. OWEN (1958): Negative binomial distributions with a common k. — Biometrika **45**: 37-58.

CROFTON H.D. (1971): A quantitative approach to parasitism. — Parasitology **62**: 179-193.

DEBAUCHE H.R. (1962): The structural analysis of animal communities of the soil. — In: MURPHY P. W. (ed.), Progress in soil zoology. pp. 10-25, London (Butterworths).

GOULDEN C.H. (1952): Methods of statistical analysis. — 467 pp., New York (Wiley).

HASSELL M.P. & R.M. MAY (1974): Aggregation of predators and insect parasites and its effect on stability. — J. Anim. Ecol. **43**: 567-594.

IWAO S. (1970): Analysis of contagiousness in the action of mortality factors on the western tent caterpillar population by using the $\dot{m}-$m relationship. — Res. Pop. Ecol. **12**: 100-110.

KATTI S.K. & J. GURLAND (1962): Efficiency of certain methods of estimation for the negative binomial and the Neyman type A distributions. — Biometrika **49**: 215-226.

KLAUSNITZER B. (1997): Aphidina, Blattläuse. — In: WESTHEIDE, RIEGER (ed.), Spezielle Zoologie Teil 1: Einzeller und wirbellose Tiere. — pp. 653-654, Stuttgart (Gustav Fischer Verlag).

LEGAY J.M. (1963): A propos de la répartition de la cecidomyie du Hêtre, *Mikiola fagi*. Un exemple de distribution binomiale négative. — Annales des Epiphytes **14**: 49-56.

MURDIE G. & M. P. HASSELL (1973): Food distribution, searching success and predator-prey models. — In: Bartlett M. S. & R. W. Hiorns (Ed.): The Mathematical Theory of the Dynamics of Biological Populations. — pp. 87-101, London (Academic Press).

ROJAS B.A. (1964). La binomial negativa y la estimación de intensidad de plagas en el suelo. — Fitotecnia Latinamericana **1**: 27-36.

SOEMARGONO A., YUSOF I., ROHANI I. & S. O. MOHAMMAD (2008): Spatial distribution of the Asian citrus psyllid, *Diaphorina citri* KUWAYAMA (Homoptera, Psyllidae) on citrus and orange jasmine. — J. Biosci. **19**: 9-19.

SOUTHWOOD T.R.E. (1978): Ecological Methods. — 634 pp., London, Glasgow etc. (Chapman & Hill).

SOUTHWOOD T.R.E. & D. LESTON (1959): Land and Water Bugs of the British Isles. — 521 pp., London (Frederic Warne).

STURM R. (2000): Die Süßwassermollusken in Gewässern und Kleinmooren des Postalmgebietes. — Linzer biol. Beitr. **32** (2): 1235-1246.

STURM R. (2001): Süßwassermollusken in ausgewählten Gebirgsseen der Kalk- und Zentralalpen Salzburgs und Oberösterreichs. — Beitr. Naturkde. Oberösterreichs **10**: 209-226.

STURM R. (2003): Species diversity and abundance of freshwater molluscs (Gastropoda et Bivalvia) in selected mountain lakes of the Central Alps in Austria. — Malak. Abh. **21**: 49-57.

STURM R. (2004): Freshwater Molluscs (Gastropoda et Bivalvia) in Selected Mountain Lakes of the Hohe Tauern, Austria: A Contribution to the Faunistic Mapping of the Eastern Alps. — Malak. Abh. **22**: 23-36.

STURM R. (2005): Modelling optimum ranges of selected environmental variables for habitats colonized by the spring snail *Bythinella austriaca* (v. FRAUENFELD 1857) (Gastropoda, Prosobranchia). — Malakologische Abhandlungen, **23**: 67-76, Dresden.

STURM R. (2007): Freshwater molluscs in mountain lakes of the Eastern Alps (Austria): relationship between environmental variables and lake colonization. — J. Limnol. **66**: 160-169.

STURM R. (2010): Untersuchung der Verteilungsmuster von Tierpopulationen am Beispiel ausgewählter Insektenarten. — EZ **120**: 56-63.

STURM R. (2012): Aquatic molluscs in high mountain lakes of the Eastern Alps (Austria): Species-environment relationships and specific colonization behaviour. — Chinese Journal of Oceanography and Limnology, **30**: 59-70.

STURM R. (2016): Modelling ecological specificities of freshwater molluscs: the exemplary case of *Bythinella austriaca* (v. FRAUENFELD, 1857) (Gastropoda, Prosobranchia). — J. Limnol. **75**: 626-633.

WATERS W.E. & W.R. HENSON (1959): Some sampling attributes of the negative binomial distribution with special reference to forest insects. — Forest Science **5**: 397-412.

Anschrift des Verfassers: MMMMMMag. Dr. Robert STURM
Brunnleitenweg 41
5061 Elsbethen, Austria
E-mail: sturm_rob@hotmail.com