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Sampling Acyrthosiphon pisum Harris in pea fields

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Pea aphid *(Acyrthosiphon pisum* HARRIS) densities per tiller were estimated with successive samples in two pea fields. Based on the mean crowding statistics (LLOYD, 1967) decision rules are proposed for estimating parameters in population models or for validation purposes, and for less intensive sampling in pest management programs. The work is based on investigations made by IWAO (1977), KUNO (1977) and CHRISTENSEN *et al.* (1977).

Pea aphids, *Acyrthosiphon pisum* HARRIS, affect the yield of Swiss pea fields (MEIER, 1955, 1976, 1981; SUTER & KELLER, 1977). Adequate sampling methods are of primary importance both for decisions in pest management programs and for parameter estimation in population models (RUESINK & KOGAN, 1975). Farm advisers rely on efficient sampling methods to estimate population densities relative to economic thresholds and to decide on possible control measures. Ecologists are interested in conservative methods to estimate population densities with some predetermined degree of reliability including confidence intervals (CHRISTENSEN *et al.,* 1977; RUESINK, 1980). As a part of the ongoing analysis of the pea agroecosystem (DELUCCHI *et al.,* in prep.), this paper proposes sampling methods for both purposes described above.

MATERIAL AND METHODS

Experimental fields and sampling procedures

During 1980 and 1981 the total number of *A. pisum* was estimated on several sampling dates (tab. 1, fig. 1) in 2 pea fields located at Rickenbach (Canton Zürich). The fields (1980: 35 x 80 m, 1981: 55 x 165 m) were subdivided in blocks (1980: 5 x 5 = 25, 1981: 5 x 10 = 50 m) to avoid errors in population estimates that may arise whenever the samples are taken at random in heterogeneous areas (LE ROUX & REIMER, 1959; SOUTHWOOD, 1978). The block size is based on a sampling plan for gall midges *(Contarinia pisi* WINN.) that takes into account a density gradient caused by ovipositing gall midges invading the pea field from an area nearby (DELUCCHI *et al.,* in prep.).

A pea plant may have tillers and branches in addition to the main stem. Tillers are axillary shoots originating from the lower nodes whereas branches arise higher on the stem (MILBOURN & HARDWICK, 1968). The variety «Mars» used in this study can produce fertile tillers but hardly any flower bearing branches. Because it is often difficult to separate a stem from a tiller and both are contributing to the yield as influenced by aphids, no distinction was made between them in sampling procedures and the term «tiller» was applied to both.

Three (1981) to four (1980) tillers per block and sampling date were bent carefully on a plastic trough (length: 50 cm) and cut at the base (BIERI *et al.,* in

Tab. 1: Analysis of the distribution of *Acyrthosiphon pisum* on successive samples (S) in 2 pea fields (1980, 1981). The significance of F is given for differences in rows of horizontal (R) and perpendicular (C) blocks (a: in S6 and S7 only 2 perpendicular block rows were sampled: DF: degrees of freedom).

Source of variation	1980								1981							
	DF	S1	S2	S3	S4	S5	S6	S7	DF	S1	S2	S3	S4	S5	S6	S7
Main effects																
R	4	.718	.925	.636	.332	.002	.369	.004	9	.001	.016	.880	.004	.087	.135	.024
C	4	.238	.008	.605	.426	.650	.738	.734	4[a]	.002	.643	.215	.022	.688	.123	.089
2-way interactions																
R * C	16	.575	.331	.597	.932	.042	.019	.040	36	.001	.583	.684	.761	.418	.874	.671
Total	99								149							

prep.). Each tiller was then put with the dropped aphids in a plastic bag and brought to the laboratory. The total number of aphids, the virginoparous alatae, and dead or mummified aphids were counted on each tiller.

The air temperature was recorded with a thermohygrograph located in a shelter 2 m above the crop. The physiological time (GILBERT *et al.,* 1976) was calculated by integrating a sine wave forced through daily maximum and minimum temperatures above the developmental threshold (5.7 °C) for *A. pisum* (BIERI *et al.,* in prep.). This method is detailed by FRAZER & GILBERT (1976) and GUTIERREZ *et al.* (1977).

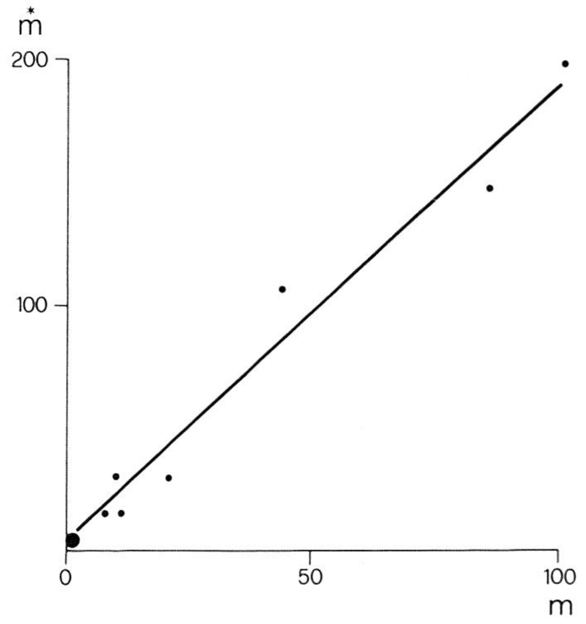

Fig. 1: Mean crowding ($\overset{*}{m}$) against the mean (m) density of *Acyrthosiphon pisum* in successive tiller samples from two pea fields (1980, 1981) ($\overset{*}{m}$ = 2.75 + 1.86 m, r^2 = 0.98).

Statistical analysis

LLOYD (1967) described the distribution of a given species in its habitat by the mean crowding parameter $\overset{*}{m}$

$$\overset{*}{m} = m + [(VAR/m) - 1] \qquad (1)$$

In this formula m is the population density and VAR its variance.

Based on this statistic IWAO (1968, 1977), KUNO (1976, 1977) and IWAO & KUNO (1968, 1971) developed a comprehensive method to analyze spatial distribution patterns and sampling strategies. Their method was applied for one-stage sampling problems (CHRISTENSEN *et al.,* 1977; GUTTIEREZ *et al.,* 1980) or for the analysis of multi-stage distribution patterns (KUNO, 1976; DOWELL & CHERRY, 1981; ZAHNER & BAUMGÄRTNER, in prep.). For a certain density range $\overset{*}{m}$ can be described as a linear function of m in various theoretical and biological distributions (IWAO, 1968)

$$\overset{*}{m} = \alpha + \beta m \qquad (2)$$

while α = intercept, indicating the basic population component

β = slope, indicating the distribution pattern of the basic population component.

IWAO & KUNO (1968) present a transformation method to stabilize the variance in the analysis of population counts (x). For $\alpha > -1$ and $\beta > 1$ the following transformation to $\dot{x}$ is recommended (IWAO, 1977)

$$\dot{x} = \ln \left(\sqrt{x\left(\frac{\beta - 1}{\alpha + 1}\right)} + \sqrt{x\left(\frac{\beta - 1}{\alpha + 1}\right) + 1} \right) \tag{3}$$

Based on the $\overset{*}{m}/m$-ratio (LLOYD's patchiness index, 1967) CHRISTENSEN *et al.* (1977) derived an optimum sampling plan for the Egyptian alfalfa weevil *(Hypera brunneipennis* BOHEMAN)

$$n = t^2/D_F^2\,(\overset{*}{m}/m - 1 + 1/m) \tag{4}$$

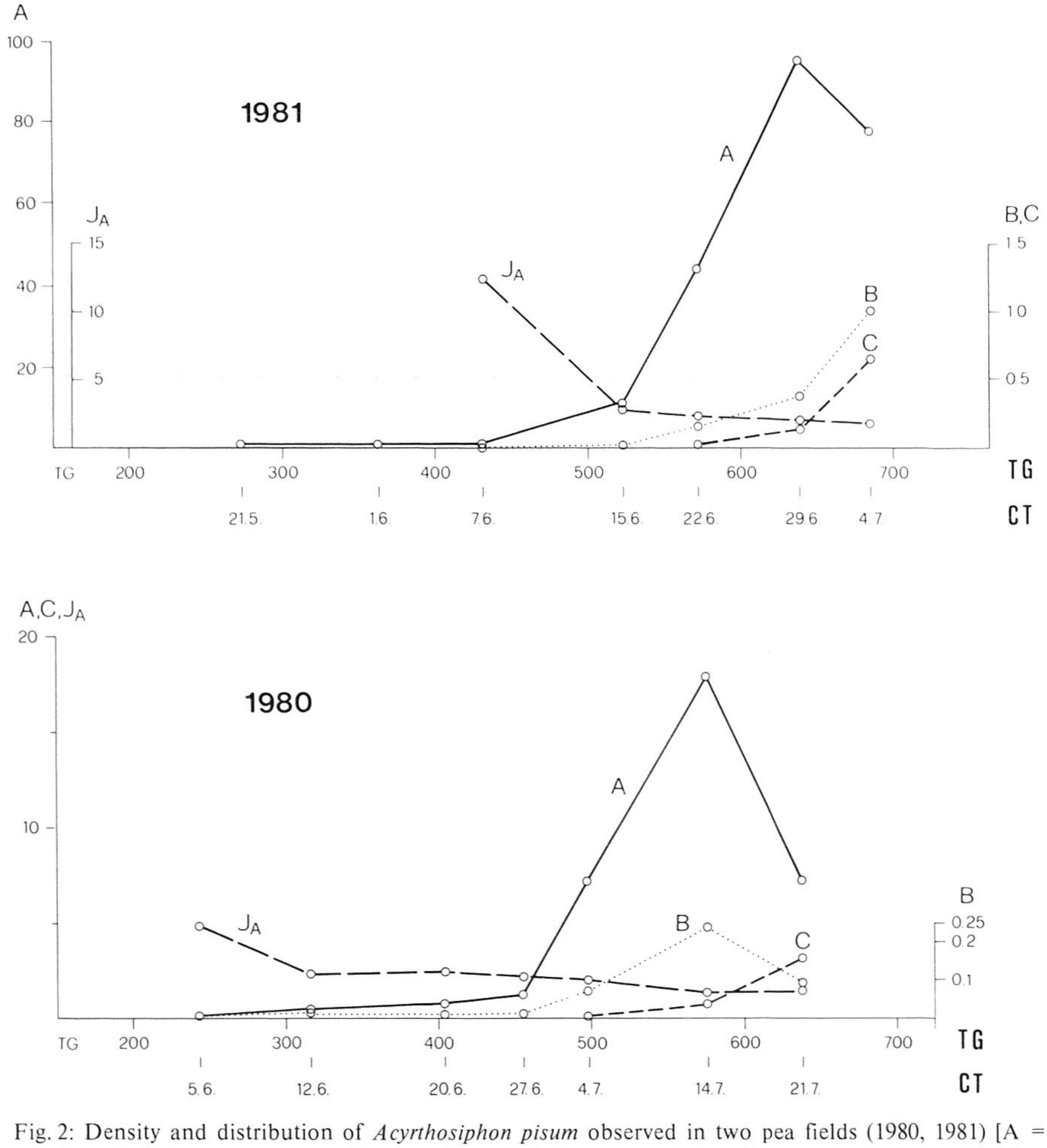

Fig. 2: Density and distribution of *Acyrthosiphon pisum* observed in two pea fields (1980, 1981) [A = number of virginoparous aptera, B = number of virginoparous alatae, C = number of parasitized or dead aphids, JA = patchiness index, CT = Sampling dates (calendar time), TG = corresponding day degrees above 5.7 °C].

while n = number of samples
t = Student's t (approximated by 2 for P = 95%)
D_F = precision defined as fraction of the mean (m).

An efficient method to estimate population densities is based on sequential sampling plans (WATERS, 1955). The size of each sample (T_n) is defined as variable to be determined through continuous feed-back of the data so far obtained (KUNO, 1969). KUNO (1969, 1977) developed a sequential sampling plan on the mean crowding statistics

$$T_n = \frac{\alpha + 1}{D_E^2 - (\beta - 1)/n} \tag{5}$$

while T_n = cumulative total number
n = number of samples
D_E = precision defined as the ratio of the standard error to the mean (m).

IWAO (1975, 1977) and COGGIN & DIVELY (1982) used a sequential sampling method for grading population levels in relation to a critical density (c). The upper and lower boundary lines $T_{u,1}$ for decision making are given by

$$T_{u,1} = nc \pm t \sqrt{nc\,(\alpha + 1) + c^2\,(\beta - 1)} \tag{6}$$

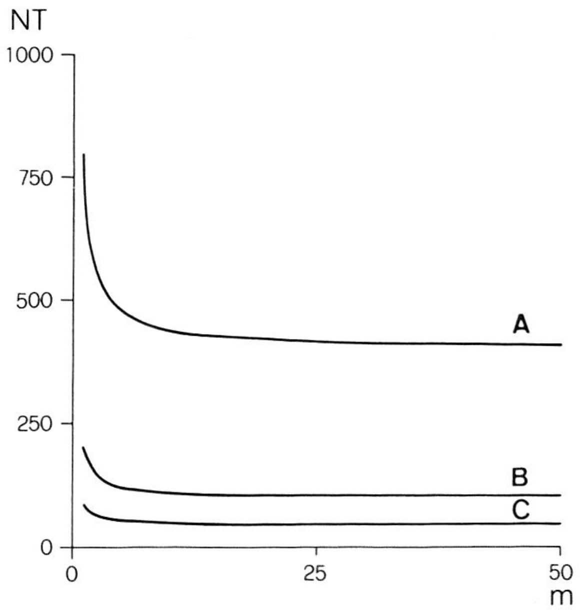

Fig. 3: Number of tillers (NT) required to estimate the density of *Acyrthosiphon pisum* with a precision level of 0.1 (A), 0.2 (B) and 0.3 (C) defined as a fraction of the mean (m) with a 95% confidence probability.

In this paper we analyze between block differences with the transformed (eq. 3) aphid counts in using the SPSS-ANOVA program (NIE *et al.,* 1975). Based on an average patchiness index for both fields ($\overset{*}{m}/m$ = 2, fig. 2) we use eq. 4 to propose an intensive sampling program for parameter estimates in population models and for validation purposes. Less intensive sampling programs may be based on eq. 4 and also on eq. 5, while eq. 6 may be an efficient method to relate aphid numbers to critical densities (c) in any pest management program. For c the value 7.5 has been chosen because MEIER (1981) recommends chemical treat-

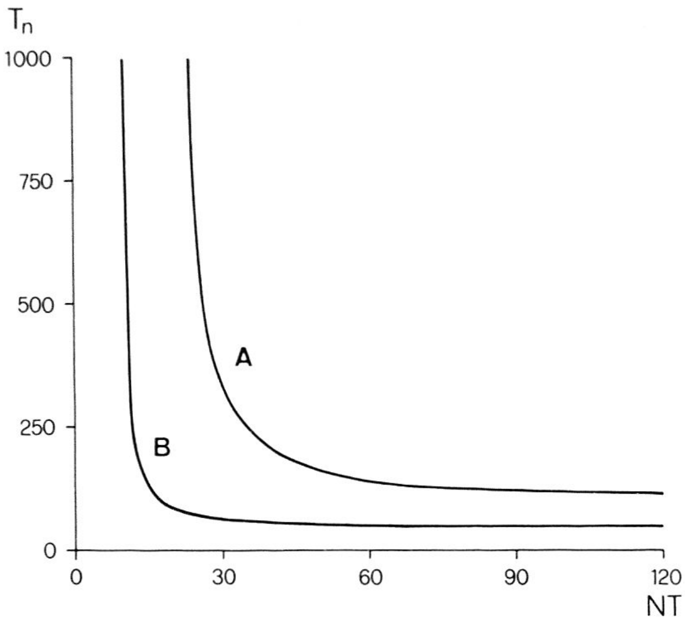

Fig. 4: Sequential sampling plan to estimate the density of *Acyrthosiphon pisum* with a precision level of 0.2 (A) and 0.3 (B) defined as the ratio of the standard error to the mean. The number of tillers (NT) to be sampled stops whenever the cumulative aphid number (T_n) reaches or exceeds the stop line.

ments if a «critical threshold» of 5–10 aphids per tiller on a date is exceeded any time up to 3 weeks before harvest. The decision rules (eq. 5, 6) are given in fig. 3 and 4 for less than 120 tillers sampled per field. This number is considered as the upper limit for tiller samples because of time constraints in an aphid-monitoring program.

RESULTS AND DISCUSSION

After the analysis of variance based on transformed aphid counts (eq. 3) there are only few significant ($P \leqq 0.01$) within-field differences in the two fields (tab. 1). This, however, may be unique to the two experimental conditions and to the design of the sampling procedures. Therefore other fields subdivided in blocks of different sizes should be investigated before any general recommendation on stratification can be made. A design for stratified random sampling is discussed by Iwao (1977). With equal aphid densities in the blocks and with the variance usually related to the mean (Southwood, 1978) the block counts were pooled to form one sample per date and field (fig. 2). Mean crowding ($\overset{*}{m}$, eq. 1) calculated on the pooled aphid numbers per sample appears to be linearly related to the mean m (fig. 1). The intercept does not differ significantly from O ($P \leqq 0.19$). Hence, a single aphid may be taken as the basic population component (Iwao & Kuno, 1971).

The intercept is greater than calculated for other aphids as for example *Myzus persicae* Sulzer on beet plants and for *A. pisum* in Japanese alfalfa fields (Iwao & Kuno, 1971). In Californian alfalfa, however, Gutierrez *et al.* (1980) found generally higher intercepts for three aphid species. Their distribution as described by the slope of $\overset{*}{m}$ to m (eq. 2, fig. 1) was affected by predation. In this study no attempt was made to investigate predator activity. Therefore the influence of predation on the slope in fig. 1 cannot be evaluated here. The distribution observed in this study appears to be more aggregated than found for *M. persicae* and *A. pisum* in Japan (Iwao & Kuno, 1971), but lower than for aphids in Californian alfalfa fields (Gutierrez *et al.*, 1980).

The ratio of $\overset{*}{m}$ to m (LLOYD's patchiness index, 1967) was rather high when aphids started colonizing the pea fields (fig. 2) but stabilized at less than 2 by mid June (fig. 2). Considering this value in a conservative sampling plan (eq. 4, fig. 3) about 100 tillers are required to estimate the total aphid density with a precision of 0.20 defined as the fraction to the mean with a confidence probability of 95%. The same sampling plan was used successfully by CHRISTENSEN *et al.* (1977) for parameter estimates in the population model of *H. brunneipennis.*

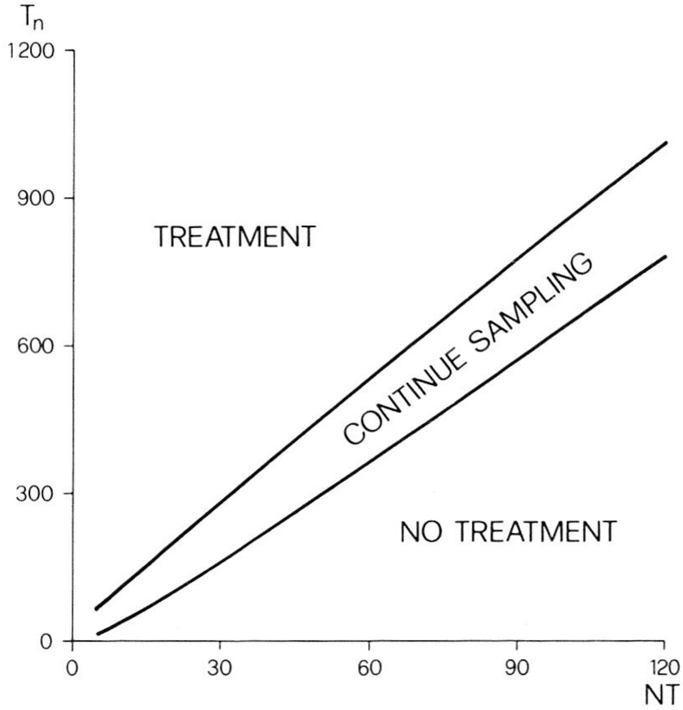

Fig. 5: Sequential sampling plan to estimate the density of *Acyrthosiphon pisum* relative to a critical number of 7.5 aphids per tiller with a 95% confidence probability (T_n = cumulative number of aphids in the sample, NT = number of tillers sampled).

While population models may require detailed information on the structure of the herbivore and the interacting natural enemy component (GUTIERREZ & BAUMGÄRTNER, in prep.; GUTIERREZ & GETZ, in prep.) the monitoring of aphid development can be based on less intensive sampling programs. For such a purpose a different precision than above can be used in eq. 4 (see KARANDINOS, 1976). More efficient sampling plans, however, can be based on sequential sampling rules (fig. 4, 5). They may be particularly useful if estimates are to be made in relation to a critical number that calls usually for chemical control measures. Whenever changes in accepted aphid numbers are justified, new decision rules can easily be generated with eq. 6. In both fields the total aphid number exceeded MEIER's (1981) critical number (fig. 2).

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ZUSAMMENFASSUNG

Stichprobenpläne für Acyrthosiphon pisum HARRIS *in Erbsenfeldern* - In mehreren Erhebungen wurden in 2 Erbsenfeldern die Dichten der Erbsenblattlaus *(Acyrthosiphon pisum* HARRIS) pro Trieb ermittelt. Auf der Grundlage der «mean crowding»-Statistik (LLOYD, 1967) werden Regeln vorgeschlagen, mit denen Parameterschätzungen in Populationsmodellen vorgenommen, eine Validierungsgrundlage erstellt und Stichprobeentnahmen in weniger intensiven Schädlingsbekämpfungsprogrammen durchgeführt werden können. Die Arbeit ist aufgebaut auf Untersuchungen von IWAO (1977), KUNO (1977) und CHRISTENSEN *et al.* (1977).

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