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Multivariate statistical analyses of visual arthropod counts on apple leaf clusters

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Cluster analysis and correspondence analysis were applied to visual arthropod counts from an apple orchard near Zurich. The arthropods were classified as members of various trophic guilds with different degrees of associations. The multivariate analyses showed that among predators only syrphid eggs and larvae had a close relationship to the three apple aphids *Rhopalosiphum insertum* (Pass.), *Dysaphis plantaginea* (Walk.), and *Aphis pomi* (De Geer). Coccinellid adults and eggs were not closely related and other predatory arthropods, such as chrysopids, anthocorids and spiders, may have been attracted by other prey than aphids, such as thrips and tetranychid mites (not recorded), and didn't have a close association with aphids. There was, however, a close relationship between apple aphids and ants which are known to be able to interfere with biological control agents.

Simulation models have long been recognized as a powerful tool for studying ecologial relationships (Gilbert *et al.,* 1976) and for designing pest management programs (Huffaker 1980, Getz & Gutierrez 1982, Conway 1984). Graf *et al.* (1985) used this approach for analyzing the dynamics of the apple aphids *Rhopalosiphum insertum* (Pass.), *Dysaphis plantaginea* (Walk.), and *Aphis pomi* (De Geer). Their investigation confirmed empirical evidence of the importance of predation in influencing aphid infestation patterns in Swiss apple orchards. However, a simple method with little explicative capability was used to model predation and more detailed studies were concluded to be necessary both for improving and generalizing the population models. The presence of aphid antagonists and their reduction potential can describe the situation in a particular orchard (Graf *et al.* 1985) but provides little insight into the dynamics of the species under consideration. In classical biological control many workers have attempted to define attributes of successful natural enemies (Hassell 1978). In recent years spatial heterogeneity and differential responses to patchily distributed prey have been identified as crucially important factors affecting population's dynamics (Hassell 1982) and an analysis of mathematical models suggested that differential exploitation of patches of a pest in a spatially heterogeneous environment provides the most likely mechanism to account for known successes in biological control (Beddington *et al.* 1978). A study of aphid-antagonist dynamics, however, goes far beyond the scope of this work which merely attempts to describe the degree of association between leaf cluster inhabiting arthropod groups. Such an analysis may help to clarify the ecological background for the dynamics of aphids and their natural enemies and to create at the same time a base for evaluating biological control agents by stressing some of their important attributes such as the ones identified by Beddington *et al.* (1978).

Arthropod counts

In 1980 GRAF (1984) counted weekly the number of *D. plantaginea*, *R. insertum*, *A. pomi*, and *Dysaphis* sp. on apple leaf clusters in an orchard near Zurich, Switzerland. His sample unit was called leaf cluster although it consisted of various tree organs which emerge from an opening bud. In addition he recorded the number of spiders, ants, and of insects belonging to various families. The latter were furthermore divided into eggs, postembryonic immature life stages and adults. By making this distinction GRAF (1984) obtained the number of individuals in each of several arthropod groups that are called trophic guilds in this work. When selecting the 384 leaf clusters per week GRAF (1984) used a stratified two-stage sampling plan detailed by LE ROUX & REIMER (1959). In this work three infestation periods were identified (Fig. 1) and arthropod counts were combined in each to form a sample-guild matrix analyzed as presented below.

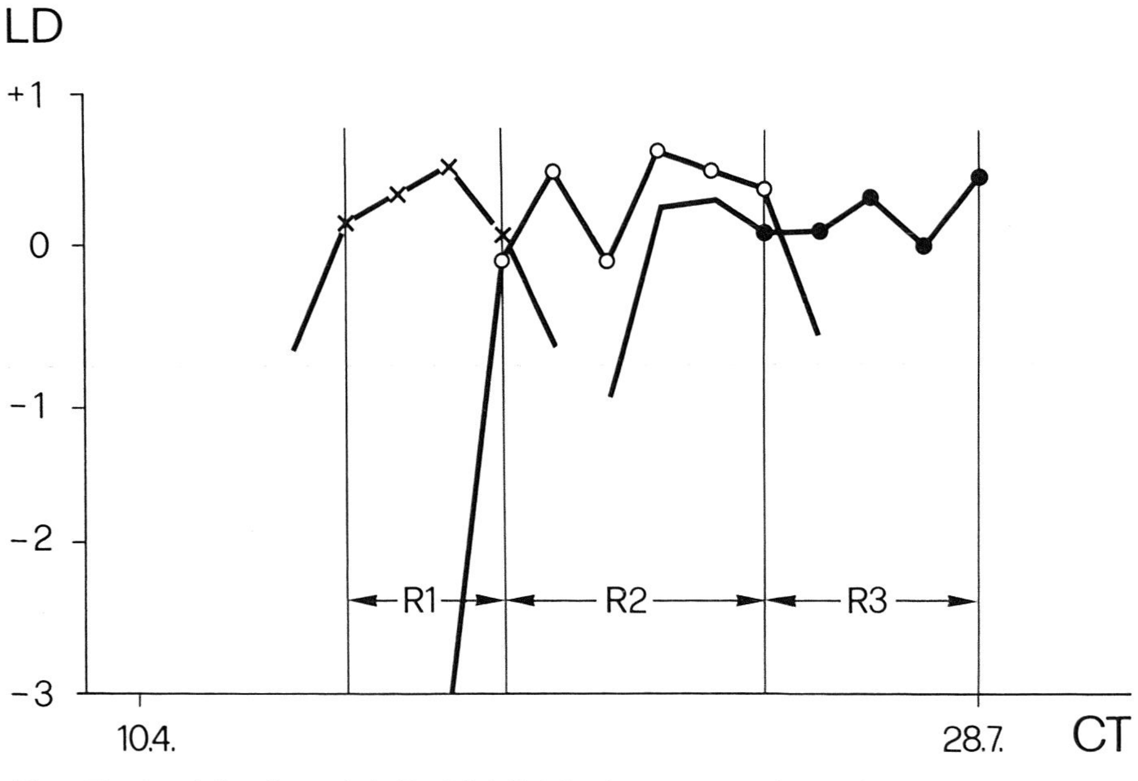

Fig. 1: The three infestation periods (R1, R2, R3) defined by the log density of *Rhopalosiphum insertum* (x), *Dysaphis plantaginea* (o), and *Aphis pomi* (•) calculated on a per leaf cluster basis (CT = calendar time).

Statistical analyses

BOCK (1980) and ATHIAS-BINCHE (1983) recommended the use of both cluster analyses and oridnation procedures for analyzing the structure of multidimensional data. A cluster analysis was carried out first and aphid numbers were transformed according to x' = log(x + 1). Because empirical evidence predicted the existence of clusters a pragmatic procedure was selected for discovering them (BOCK 1980). Thereby the coefficient of correlation was chosen as the appropriate measure of similarity and dendrograms were constructed with HARTIGANS' (1981) BMDP 1 M-algorithm. In Figs. 2, 3, 4 the correlation coefficient r ε (–1,1), however, appears as the similarity measure

SI ε (0,100). Each trophic guild was initially considered as a seperate cluster, than the two most similar variables were joined with the average distance as amalgation criterion. For ordination purposes correspondence analysis was chosen. The method enables to represent the variability of multidimensional data in a space of reduced dimensions. The contribution of the different axes to the explanation of the total variance is described by their eigenvalues (LEGENDRE & LEGENDRE 1979). For GAUCH *et al.* (1977) the approach is an eigenvalue technique which uses chi-square distances instead of correlation or covariance distances which are employed in the more widely used principal component analysis. For a detailed description of the method and for interpreting the results it is also referred to BINET *et al.* (1972), HILL (1974) and GAUCH *et al.* (1977). According to the amount of contribution the eigenvalues provide for explaining the variance the corresponding axes are numbered. GAUCH *et al.* (1977) recommend using the first two axes only because they tend to influence higher axes which makes them more difficult to interprete. In this work, however, the eigenvalues for the third axes are close to values calculated for the second axes and the first three were therefore selected for analyzing. The computations were performed with the SPAD-program by LEBART & MORINEAU (1982) and some guilds that were represented by a few individuals only were ommitted.

RESULTS AND DISCUSSION

Biological considerations

The rosy apple aphid *D. plantaginea* has the lowest threshold among the apple aphids under study and apple growers are recommended to tolerate only 1%–3% of tree organs infested (OILB 1974). The highest infestation level in GRAF's (1984) orchard was 2.1% and didn't appear to change much in the three years under study. During the observation phase of three years no insecticides were applied, parasitism was observed only occasionally and there was no indication of entomopathogens. This leaves the predators as the only natural enemies present which contributed to rather stable infestation patterns by aphids in the three years under study. Coccinellids occured in low numbers only (GRAF *et al.* 1985) and both eggs and adults are less associated with aphid prey than expected from their biology (Figs. 2, 3, 4). Likewise chrysopid eggs and larvae were rare and both life stages appear generally unrelated to aphids (Figs. 2, 3, 4). This is not unexpected because they are general predators. Anthocorid adults and larvae were found in the second and third infestation period only and may have been attracted to other prey such as thrips and tetranychid mites which were also observed in low numbers. This may explain the low degree of association with any of the aphids under study (Figs. 2, 3, 4). Spiders were restricted to the first infestation period (Fig. 2) and don't have a close relationship to the dominant aphid species and its associated arthropods. As opposed to all trophic guilds discussed so far syrphid eggs are clearly associated with aphids in the first two infestation periods (Figs. 2, 3, 4) and adult syrphids are thought to respond to the patch size of the prey when selecting oviposition sites. Because larvae were found in relatively high numbers and have a high prey consumption potential GRAF *et al.* (1985) considered them the most active aphid predators in the orchard under study. A similar conclusion was drawn by REMAUDIERE *et al.* (1973) working in french apple orchards. Because of all these qualities particular attention should be given to this family when further exploring the apple aphid population ecology. In all three infestation periods there was a

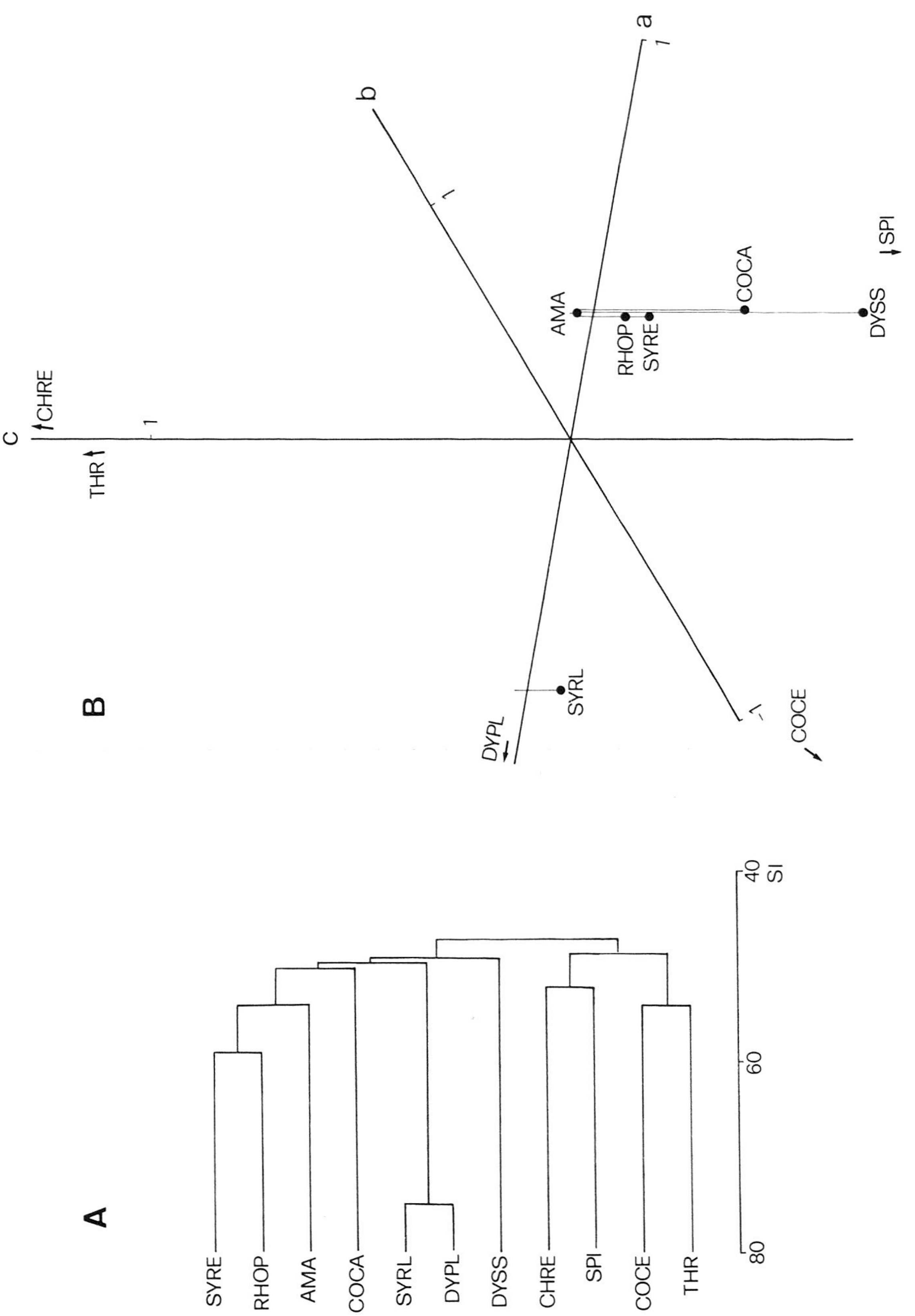

Fig. 2: Cluster analysis (A; SI = Index of similarity) and correspondence analysis (B; a, b, c = first, second, and third axis) for the first infestation period (R1, Fig. 1) with different trophic guilds (AMA = ants, CHRE = chrysopid eggs, COCA = coccinellid adults, COCE = coccinellid eggs, DYPL = *Dysaphis plantaginea*, DYSS = *Dysaphis* sp., RHOP = *Rhopalosiphum insertum*, SPI = spiders, SYRE = syrphid eggs, SYRL = syrphid larvae, THR = thrips).

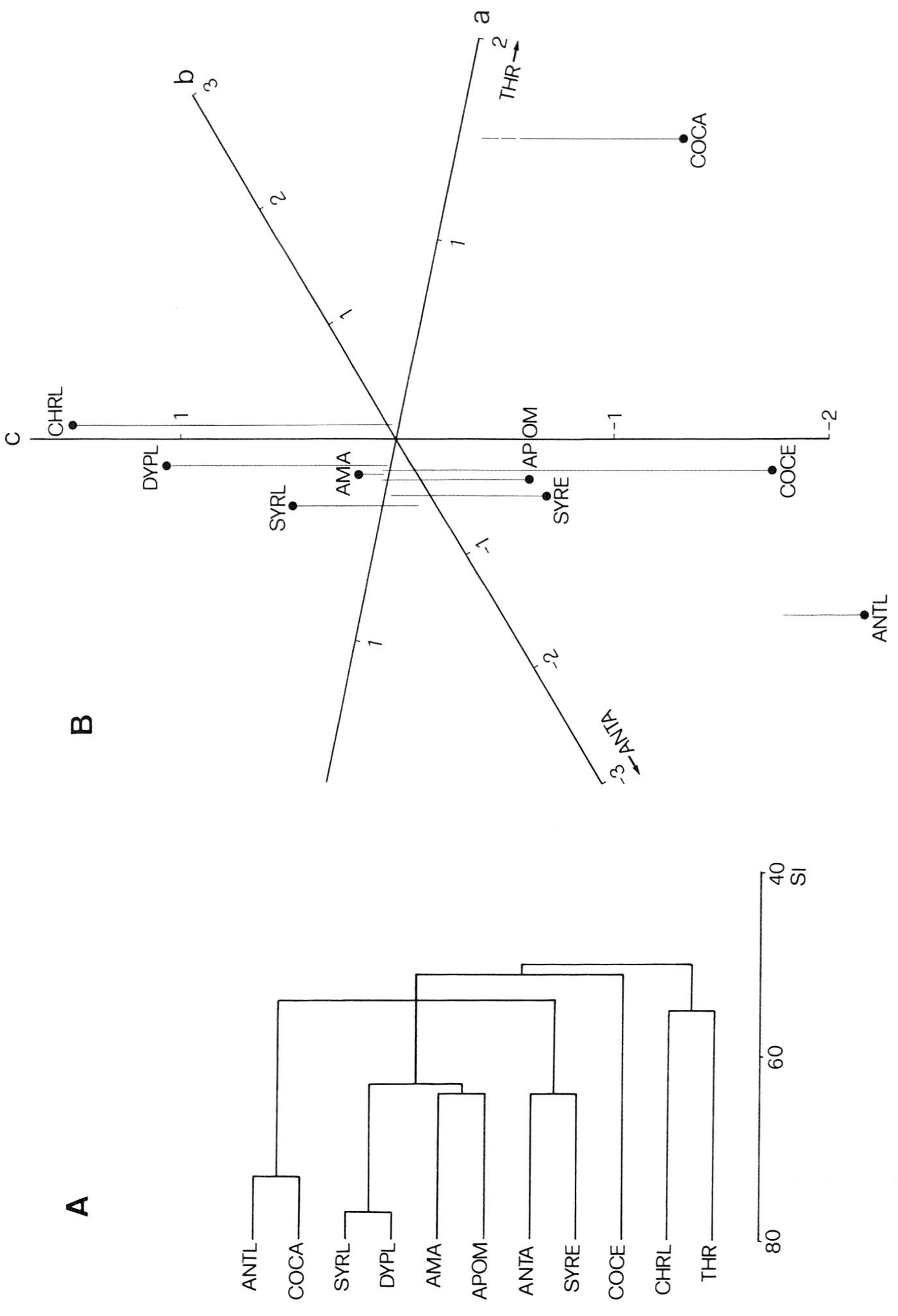

Fig. 3: Cluster analysis (A; SI = Index of similarity) and correspondence analysis (B; a, b, c = first, second, and third axis) for the second infestation period (R2, Fig. 1) with different trophic guilds (AMA = ants, ANTA = anthocorid larvae, ANTL = anthocorid adults, APOM = *Aphis pomi*, CHRE = chrysopid eggs, CHRL = chrysopid larvae, COCE = coccinellid eggs, DYPL = *Dysaphis plantaginea*, DYSS = *Dysaphis* sp., RHOP = *Rhopalosiphum insertum*, SYRE = Syrphid eggs, SYRL = syrphid larvae, THR = thrips).

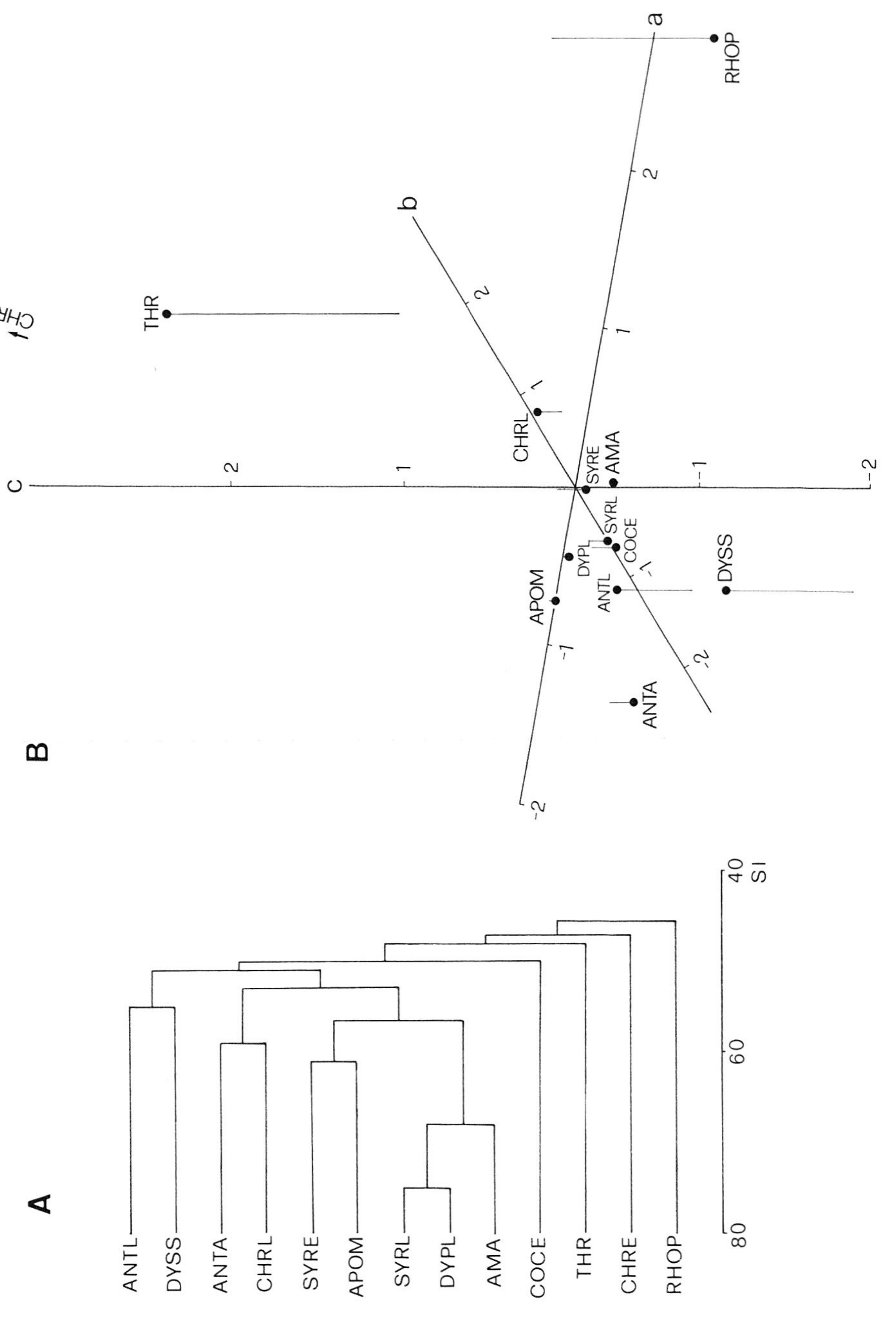

Fig. 4: Cluster analysis (A; SI = Index of similarity) and correspondence analysis (B; a, b, c = first, second, and third axis) for the third infestation period (R3, Fig. 1) with different trophic guilds (AMA = ants, ANTA = anthocorid adults, ANTL = anthocorid larvae, APOM = *Aphis pomi*, CHRL = chrysopid eggs, COCA = coccinellid adults, COCE = coccinellid eggs, DYPL = *Dysaphis plantaginea*, SYRE = syrphid eggs, SYRL = syrphid larvae, THR = thrips).

close relationship between aphids and ants (Figs. 2, 3, 4), which are known to interfere with the activity of aphid antagonists (VAN DEN BOSCH & TELFORD 1964). Therefore they should be considered carefully in future attempts to get more insight into the apple aphid life system. ASGARI (1966) found that forficulids were very important predators in German apple orchards. He may have shown in fact some limitations of this analysis which relies heavily on visual arthropod counts. Forficulids are active at night and their activity is easily overlooked when working during the day. In northern America other insect families such as cecidomyiids and chamaemyiids were identified as additional predators of some importance (PARADIS 1981, CARROLL & HOYT 1984, TRACEWSKI *et al.* 1984). In GRAF's (1984) orchard they were either missing or occurred in negligeable numbers only. As stressed above this analysis is restricted to a one year observation phase in one particular orchard. Further studies will show how the association of trophic guilds and species changes with geographical zones and management practices.

Statistical considerations and general conclusions

Different types of trophic interactions between the various guilds and possible influences of time (Fig. 1) and space (GRAF 1984) are likely to produce a great variability in the sample-guild matrix. But some correlation coefficients are high and the contribution of the first three eigenvalues for explaining the variance was as high as 47.0% in the first, 43.4% in the second, and 65.9% in the third infestation period. Despite the fact that cluster analysis is based here on correlation coefficients while the correspondence analysis uses chi-square distances the results of the former analysis appeared generally be confirmed by the latter (Figs. 2, 3, 4) and both approaches support empirical evidence on associations in apple orchards. The analysis performed in this work has made efficient use of a complicated data set collected even for other purposes than for multivariate analyses (GRAF *et al.* 1985) and was able to point to some important relationships easily overlooked by a less objective study of the data base. Although of limited use for providing insights into the dynamics of interactions between arthropods in an apple orchard it is recognized a valuable tool for generating hypotheses and for setting priorities in future research work.

ZUSAMMENFASSUNG

Die Clusteranalyse und die Korrespondenzanalyse sind für die Untersuchung von visuellen Stichproben aus einer Apfelanlage in der Nähe von Zürich verwendet worden. Die Arthropoden wurden dabei verschiedenen trophischen Gruppen zugeordnet, die sich durch verschieden ausgeprägte Assoziierungsstufen unterscheiden. Die multivariaten Verfahren haben gezeigt, dass unter den Räubern lediglich Syrphideneier und -larven eine enge Beziehung zu den Blattläusen *Rhopalosiphum insertum* (PASS.), *Dysaphis plantaginea* (WALK.) und *Aphis pomi* (DE GEER) haben. Coccinellideneier und Adulte waren nicht eng verbunden und andere räuberische Arthropoden, wie Chrysopiden, Anthocoriden und Spinnen, sind möglicherweise von anderer Beute als Aphiden, wie Thripsen und Spinnmilben (nicht gezählt), angelockt worden und haben keine enge Beziehung zu den Blattläusen. Es wurde hingegen eine enge Beziehung zwischen Apfelblattläusen und Ameisen festgestellt, welche bekanntlich mit biologischen Kontrollfaktoren interferieren können.

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