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Temporal asynchrony, spatial segregation and seasonal abundance of aphids on apple trees

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ABSTRACT

The species composition and seasonal abundance of aphids and their natural enemies were investigated in an apple orchard located in central Peloponnese. For that purpose shoots were collected at weekly intervals. The aphid species *Aphis pomi* De Geer (Hemiptera: Aphididae), *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae) and *Eriosoma lanigerum* (Hausmann) (Hemiptera: Eriosomatidae) were recorded. In both years of the study, *A. pomi* developed higher populations than the other two species. The population of *A. pomi* was high in June and July. *D. plantaginea* was present in April and May, with high numbers mainly in May, whilst *E. lanigerum* was recorded in low numbers from May to July. The number of aphids was not found to differ significantly between samples collected from the northern and southern part of the trees. The species composition of aphid population on each sampled shoot, documented spatial segregation between *A. pomi* and *D. plantaginea*. It was proved that the eggs were more commonly laid near the buds of the central part of the twigs. The natural enemies found were predators belonging to the families of Coccinellidae, Chrysopidae, Syrphidae and Anthocoridae. Generally, their numbers were low.

Introduction

Apple trees can be infested with more than 15 aphid species (Blackman and Eastop 1984). Among them, the green apple aphid (*Aphis pomi* De Geer) (Hemiptera: Aphididae), the rosy apple aphid (*Dysaphis* (*Pomaphis*) *plantaginea* (Passerini)) (Hemiptera: Aphididae) and the wooly apple aphid (*Eriosoma lanigerum* (Hausmann)) (Hemiptera: Eriosomatidae) are considered to be serious pests of apple orchards worldwide (Niemczyk 1988). In Europe, *D. plantaginea* and *A. pomi* and in Canada and U.S.A. *A. pomi* and *Aphis spiraecola* Patch are regarded as the most injurious aphids to apple trees (Dickler 1983, Carrol and Hoyt 1984, Bouchard et al. 1986, Grasswitzand and Burts 1995).

Aphis pomi colonizes the young shoots causing leaf curling and producing honeydew which results in fruit discoloration (Oatman and Legner 1961, Madsen et al. 1961, Blommers 1994). It causes significant losses in yield if not suppressed (Hagley 1989). *D. plantaginea* causes malformation of fruits even at low populations (Blommers 1994), longitudinal leaf rolling and formation of red leaf-galls (Forrest and Dixon 1975). Finally, *E. lanigerum* infests trunk, branches and shoots causing cancer-like swellings. Also, its populations on roots may affect significantly the growth of young apple trees (Brown and Smitt 1990).

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Dysaphis plantaginea and *A. pomi* share identical feeding niches (young shoots) and thus might face competitive interactions. In the cereals, the aphids *Rhopalosiphum padi* L. and *Sitobion avenae* (F.), temporal and spatial separation diminishes the severity of competition (Gianoli 2000). However, in the apple aphids *A. pomi* and *A. spiraecola* the exploitation of identical feeding niche (young growth), coupled with no separation in their temporal emergence, resulted to the partial displacement of the first by the latter species (Brown et al. 1995).

Studies on species composition and abundance of aphids and their natural enemies are required for the development of an integrated management program in apple orchards. Under this concept the aim of the present work was to study the species composition and seasonal abundance of aphids as well as to record the populations of their natural enemies. In addition, this work aimed at investigating spatial and temporal distribution of aphids as factors that may contribute in the understanding of the factors that could influence the occurrence and distribution of the aphid pests on apple trees.

Materials and Methods

The work was conducted in an apple orchard of 0.15 ha located in the plateau of Tegea (approximately 700m altitude) near Tripolis in central Peloponnese, Greece. In this orchard 80 apple trees, of the cultivar "Delicious Pilafa Tripoleos", 4m high with a canopy base diameter 3-4m, about 20-years-old were grown in 4 rows. The distance of the trees on the row was 5m and the distance between the rows was 7m. The two exterior rows were excluded from the samplings, serving as protecting barriers against sprayings which normally took place in two of the neighboring fields. During the study and in the preceding year the orchard had not received any management.

The temporal abundance of aphids was studied by taking samples from 10 trees selected using random numbers. The sampling unit was the upper part of a growing shoot, bearing six leaves. As first leaf was considered the last leaf which had not been completely unruffled and its length was about 2cm. The examination of the first six leaves offers an adequate estimation of the population level of aphids on the tree, since according to Hull and Grimm (1983) 90 and more than 90% of the total aphid population collected from the top or the lower part of the tree, respectively, develops on those leaves.

From each tree, 4 shoots (2 from the northern side and 2 from the southern side of the tree's periphery) at a height of 1.8-2.0m were collected. The aphid populations were not estimated by sampling at a higher level, since Hull and Grimm (1983) concluded that "despite of some loss of prediction when sampling only the lower part of the tree to predict the density at the top or over the entire tree, this loss may be compensated for by the more convenient use of the sampler's time". The sampling sites within the northern or southern side of the tree, were about 1-1.5m apart.

Samples were collected weekly, from April 12 to November 18 in 1992 and from April 18 to December 5, in 1993. Each shoot was put separately in a polyethylene bag and brought to the laboratory. The examination was usually completed in two days and during this time the samples were kept at 5°C. Samples were examined under a stereomicroscope and aphids collected were kept in plastic vials filled with preserving fluid (2 volumes ethyl alcohol 90-95% and 1 volume lactic acid 75% w/w) (Eastop and van Emden 1972). Nymphs of each aphid species were separated in instars, and adults in alate and apterous.

In each sampling date the numbers of each instar or adult of each aphid species found on samples collected from the

northern part of the tree was compared with the respective one from the southern part using *F-test*. The separation of the nymphal instars within each aphid species was based on the differentiation of the number and relative length of the antennal segments (Lykouressis et al. unpubl. data).

In an effort to record the number and distribution of aphid eggs laid on twigs of apple trees, the upper part (1m long) of twigs was collected, from March 14 to April 11 in 1993 and from December 5 in 1993 to February 27 in 1994, at weekly intervals. In each sampling date 4 twigs from each of 10 trees were collected (2 from the northern and 2 from the southern side of its periphery) while trees were selected by using random numbers. The twigs were examined under stereomicroscope for the presence of aphid eggs. The number of eggs and the bud close to which they were found, were recorded. Differences between the number of eggs found on twigs collected from the northern and the southern side were tested for significance using 2-way ANOVA with factors the side of the tree and the sampling date. The relationship between the number of eggs and the position of the bud close to which each egg had been recorded, was described using a quadratic curve equation after data had been square root transformed.

Natural enemies found in the samples were kept in plastic vials without preserving fluid. Adults of the family Anthocoridae of Hemiptera were identified into species using appropriate keys (Stichel 1962, Wagner 1952).

Statistical analyses were conducted using the statistical package JMP (v. 6.0.2, SAS Institute).

Results

Aphis pomi, *D. plantaginea* and *E. lanigerum* were found to develop populations on the apple trees and their population trends are shown in Fig. 1. In 1992, *A. pomi* appeared on May 24 and it was present in the samples until the end of September. Its population peaked on June 14 (37.3 individuals/stem) and decreased sharply after June 28. In 1993, *A. pomi* appeared firstly on June 13 and it was present in the samples till September 12. Its population peaked on July 4 (40.43 individuals/shoot) and thereafter it gradually decreased.

In 1992, *D. plantaginea* was recorded from the first sampling on April 12 till end of June reaching a peak on May 17 (18.6 individuals/shoot). A small number of aphids appeared in November. In 1993, individuals were observed from May 2 until July 11 and its population peaked on June 6 (21.60 individuals/shoot). Generally, this species developed high populations from May 30 to June 13, and was also present in November in very small numbers.

A small number of individuals of *E. lanigerum* was recorded both in 1992, from April 29 to July 13, and in 1993, from April 24 to June 13, reaching a peak on April 29 (0.65 individuals/shoot) and on May 16 (2 individuals/shoot) in each year respectively. In 1993, a small number of individuals of this species was recorded in November.

The population structure of *A. pomi* and *D. plantaginea* in 1992 and 1993 is shown in Fig. 2 and 3, respectively. The first instar generally, was the most numerous followed by the second and the third instar, in both aphid species in both years. The number of aphids was not found to differ significantly between samples collected from the northern and southern part of the trees.

The percentage of each aphid species in the total population on each sampling date in 1992 and 1993, is shown in Fig. 4. In 1992 *D. plantaginea* and *E. lanigerum* were the only species recorded from the beginning till May 17, with the first species reaching much higher densities than the second. From May 24 till June 7 *D. plantaginea* and *A. pomi*

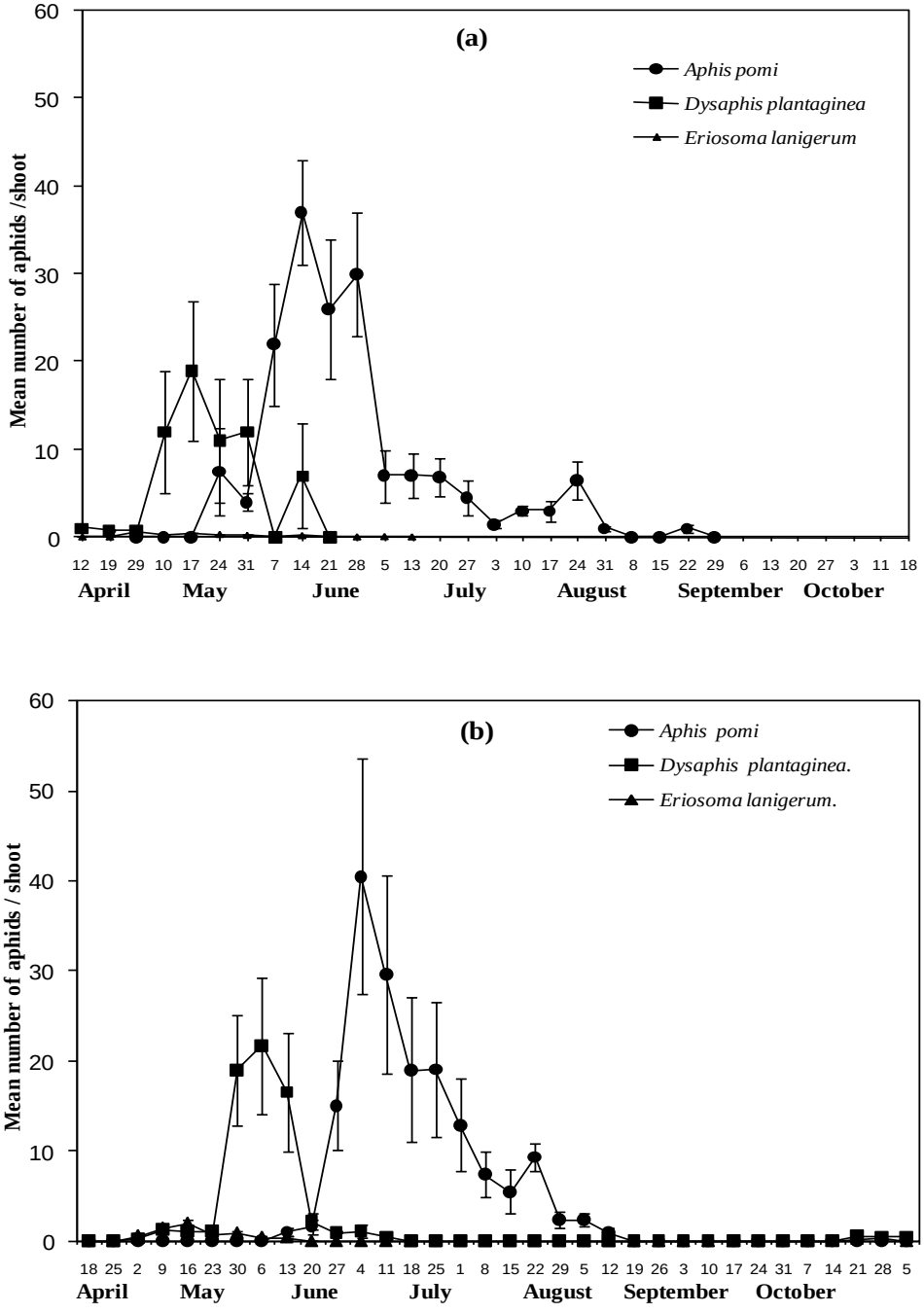

FIG. 1. Number per shoot (mean ± SE) of *Aphis pomi*, *Dysaphis plantaginea* and *Eriosoma lanigerum* individuals in an apple orchard in Tegea, Co. Arcadia central Peloponnese in 1992 (a) and in 1993 (b).

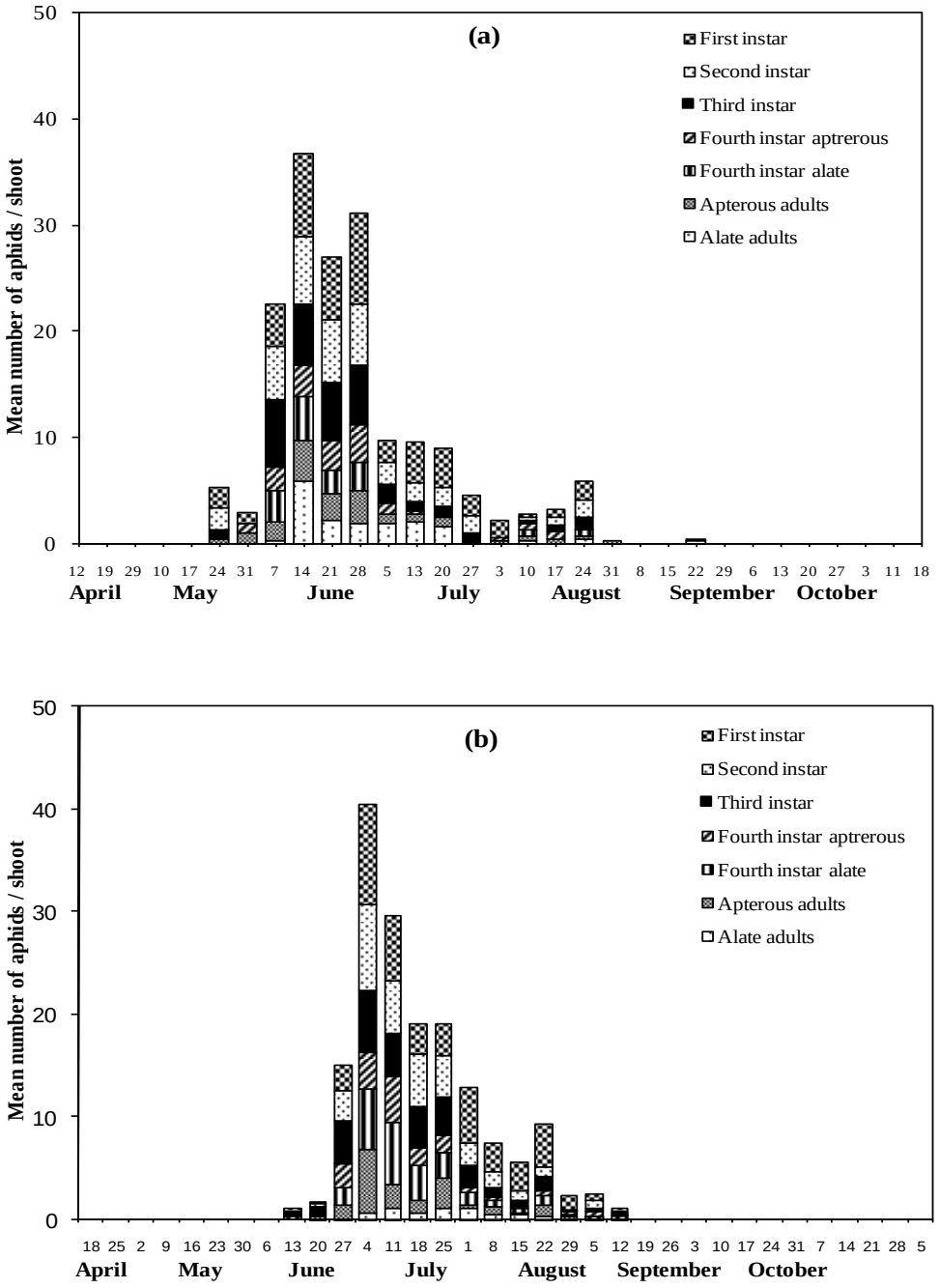

FIG. 2. Population structure (mean number per shoot) of *Aphis pomi* in an apple orchard in central Peloponnese in 1992 (a) and in 1993 (b).

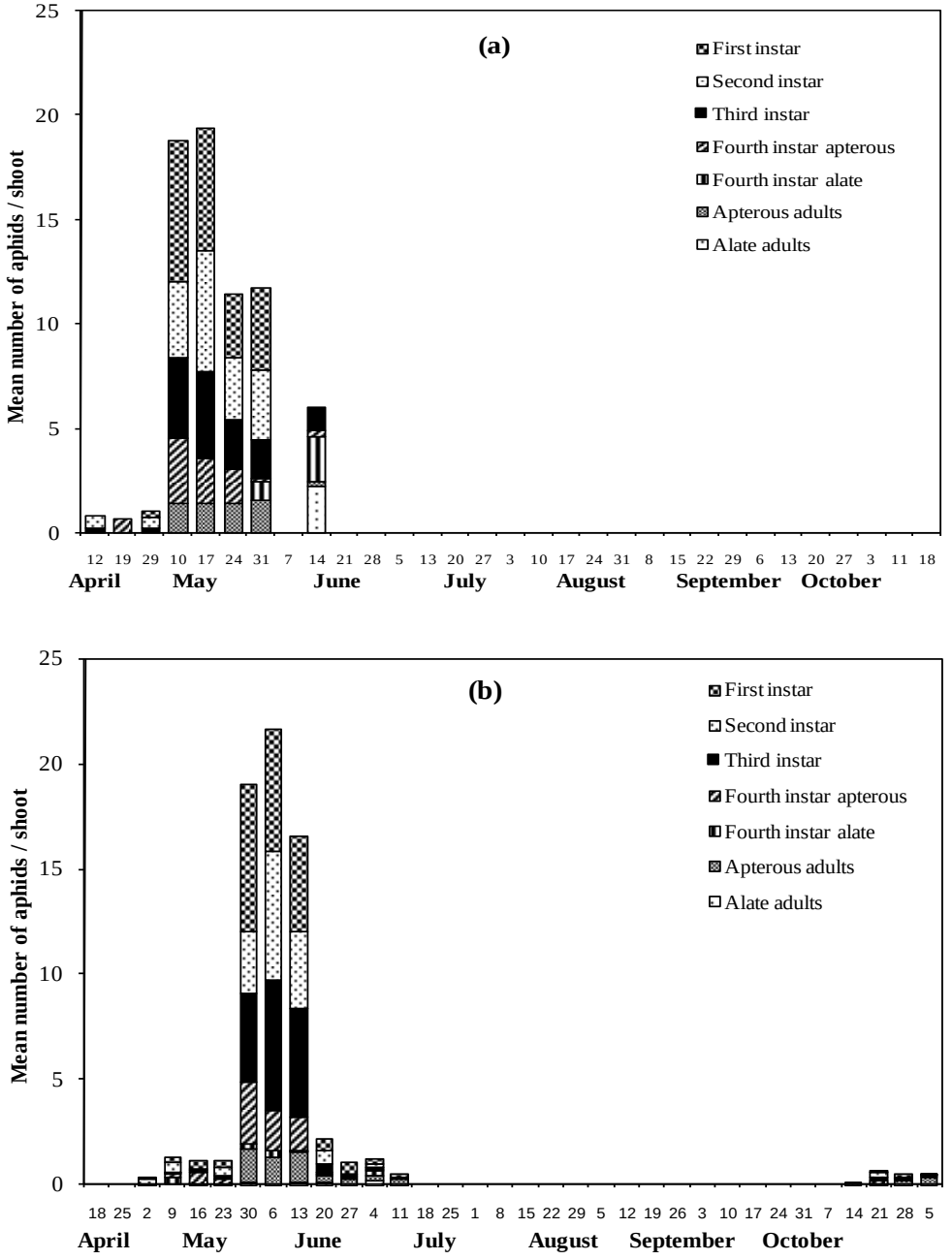

FIG. 3. Population structure (mean number per shoot) of *Dysaphis plantaginea* in an apple orchard in central Peloponnese in 1992 (a) and in 1993 (b).

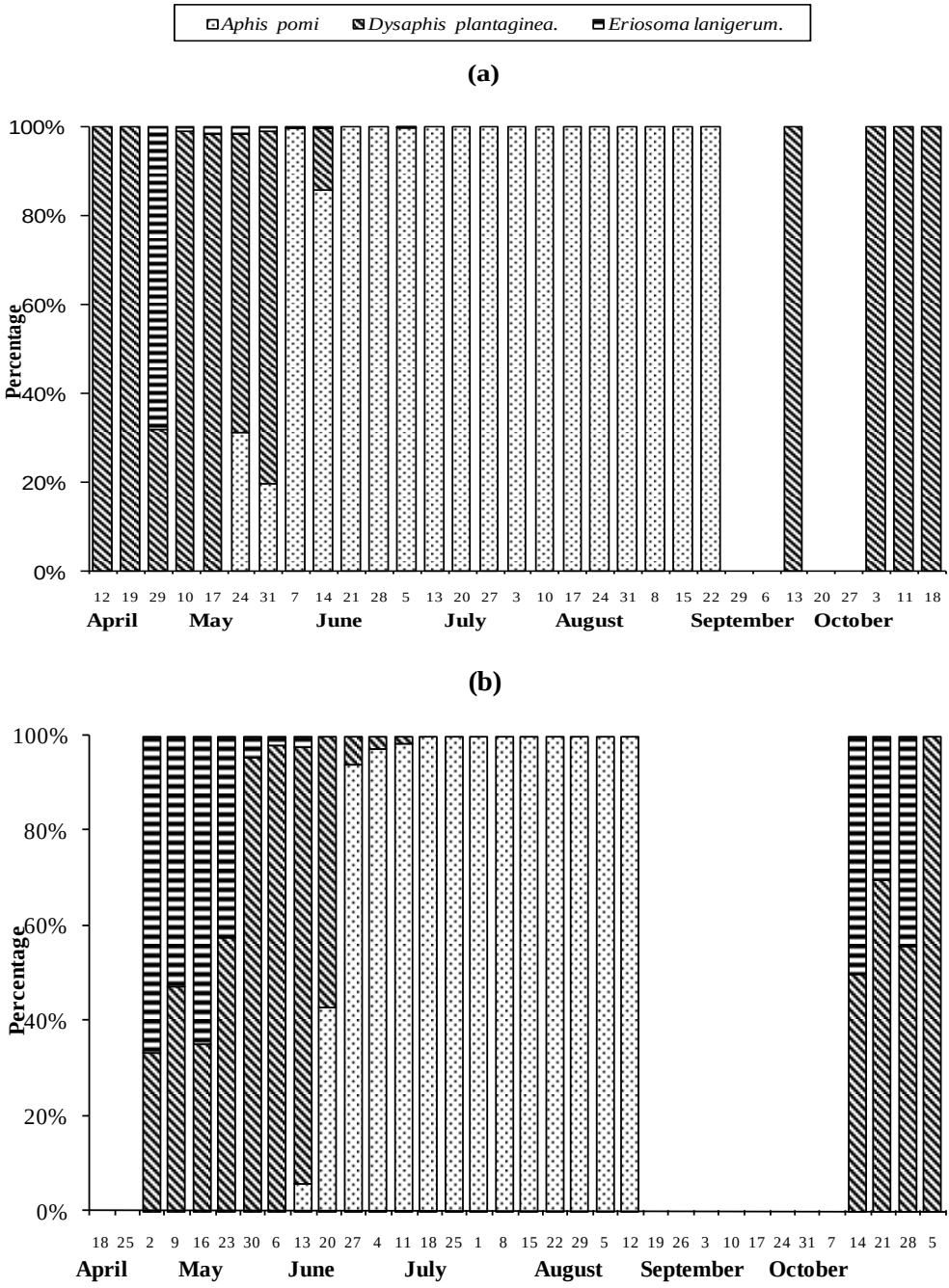

FIG. 4. Percentage (%) of the total aphid population found on shoots from an apple orchard in central Peloponnese in 1992 (a) and in 1993 (b) that belong to *Aphis pomi*, *Dysaphis plantaginea* and *Eriosoma lanigerum.*

were recorded together in the samples, with the first species at much higher densities than the second, till May 31. Later, from June 7 till September 22, *A. pomi* was the only aphid species found with the exception of the sampling date of June 14 when a small percentage belonged to *D. plantaginea*. In November the only species found was *D. plantaginea*.

In 1993, *E. lanigerum* was present in the samples from the beginning of the sampling period, May 2, until June 6. Its population consisted more than 50% of the total aphid population from May 2 to May 16. *D. plantaginea* first appeared on May 2, and on May 30 it had become the prevailing species, reaching almost 100% of the total aphid population from May 30 until June 13. On June 13, *A. pomi* made its appearance with a rather low percentage but from June 27 till September 12 it was the main species recorded in the samples. In fact *A. pomi* was the only species found in the samples till September 12 with the exception of a small percentage of aphids belonging to *D. plantaginea* that still existed till July 11. In November, *D. plantaginea* reappeared along with *E. lanigerum* but with higher percentages.

The number of the sampled shoots occupied by one or more aphid species in each sampling date in 1992 was expressed as percentage of the total number of shoots colonized by aphids (Fig. 5). *A. pomi* co-existed with *D. plantaginea* in 7 sampling dates, from May 17 to June 28 and in 5 sampling dates it was found to colonize shoots on which *D. plantaginea* had already developed population at a percentage ranged from 13% on May 17 to 5% on June 14. *A. pomi* co-occurred with *E. lanigerum* in 6 sampling dates, but both species were found together on shoots in 2 samplings at a percentage ranged from 11% on July 15 to 5% on June 7. *D. plantaginea* co-occurred with *E. lanigerum* in 8 sampling dates, but both species occupied common shoots in 3 samplings at percentages ranged from 25% on April 29 to 8% on May 10. All the three aphid species were present in 5 samplings but only on May 17 they were found to colonize the same shoot, at a percentage of 6%.

Aphis pomi was found to share the same shoot with *D. plantaginea* on shoots at a percentage of 5% of the total number of shoots collected on the sampling dates that both species were found to co-exist on the trees. In the case of *A. pomi* and *E. lanigerum* that percentage was 2%, in *D. plantaginea* and *E. lanigerum* 14% and finally, all three aphid species were recorded on the same shoot at a percentage of 1%.

The mean number of overwintering aphid eggs found per twig in each sampling date ranged from 0 (on the sampling dates of April 4 and 11) to 0.4 (on the sampling date of December 19). The maximum number of eggs found on a twig was 6, whilst the maximum number of eggs found near a single bud was 3. Statistical analysis showed that there was not a significant difference in the number of eggs between twigs collected from the northern and southern side of the tree ($F_{17,684} = 0.74$, $P > 0.39$). The total number of eggs found on a bud irrespectively of sampling date or side of the tree is shown in Fig. 6. Generally, eggs were recorded near buds between the 55^{th} and 18^{th} bud. Most eggs were laid on the 35^{th} and 22^{th} bud (9 and 10 eggs respectively). The distribution of eggs on the twigs could be described by a quadratic curve ($R^2 = 0.44$, $P< 0.001$; a = 1.68±0.22, $P < 0.01$; b = 0.015±0.005, $P < 0.01$; c = -0.0022±0.0003, $P < 0.001$) (Fig. 6).

The natural enemies recorded belonged to the families of Coccinellidae (Coleoptera), Chrysopidae (Neuroptera), Syrphidae (Diptera) and Anthocoridae (Hemiptera) but their population densities were generally low (Figs 7, 8). Among coccinellids the species

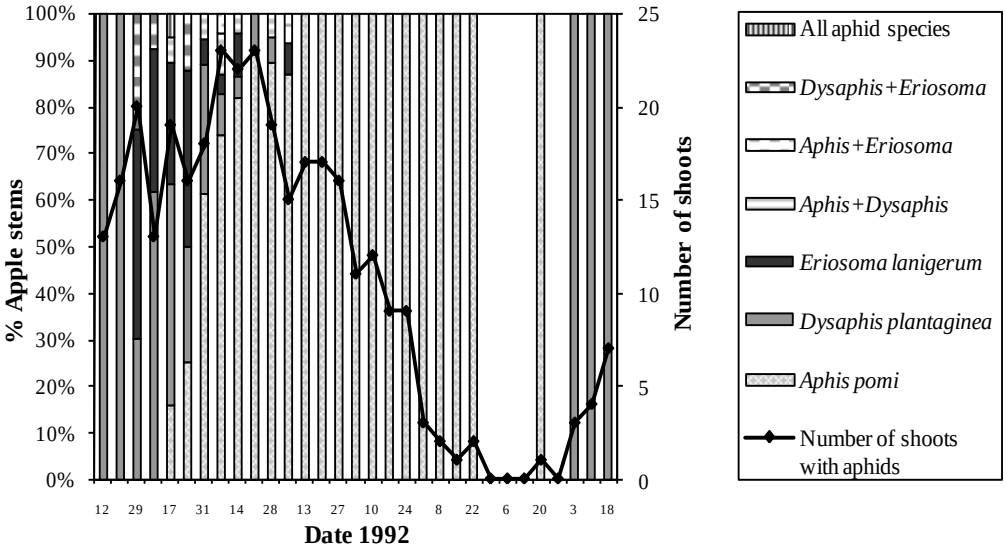

FIG. 5. Percentage of shoots bearing each aphid species of the total number of shoots bearing aphids in 1992.

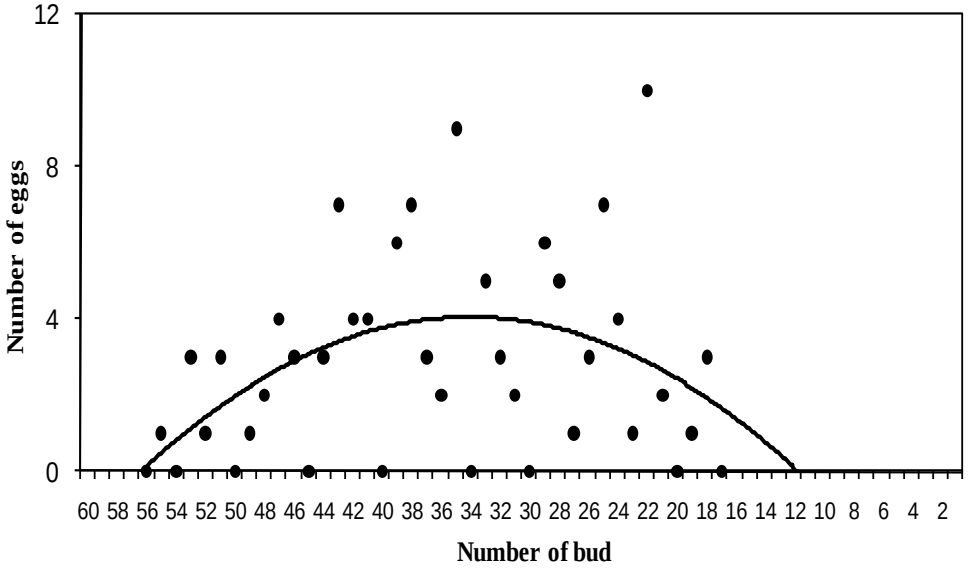

FIG. 6. Distribution of aphid eggs on twigs of apple trees in relation to the bud position on the twig.

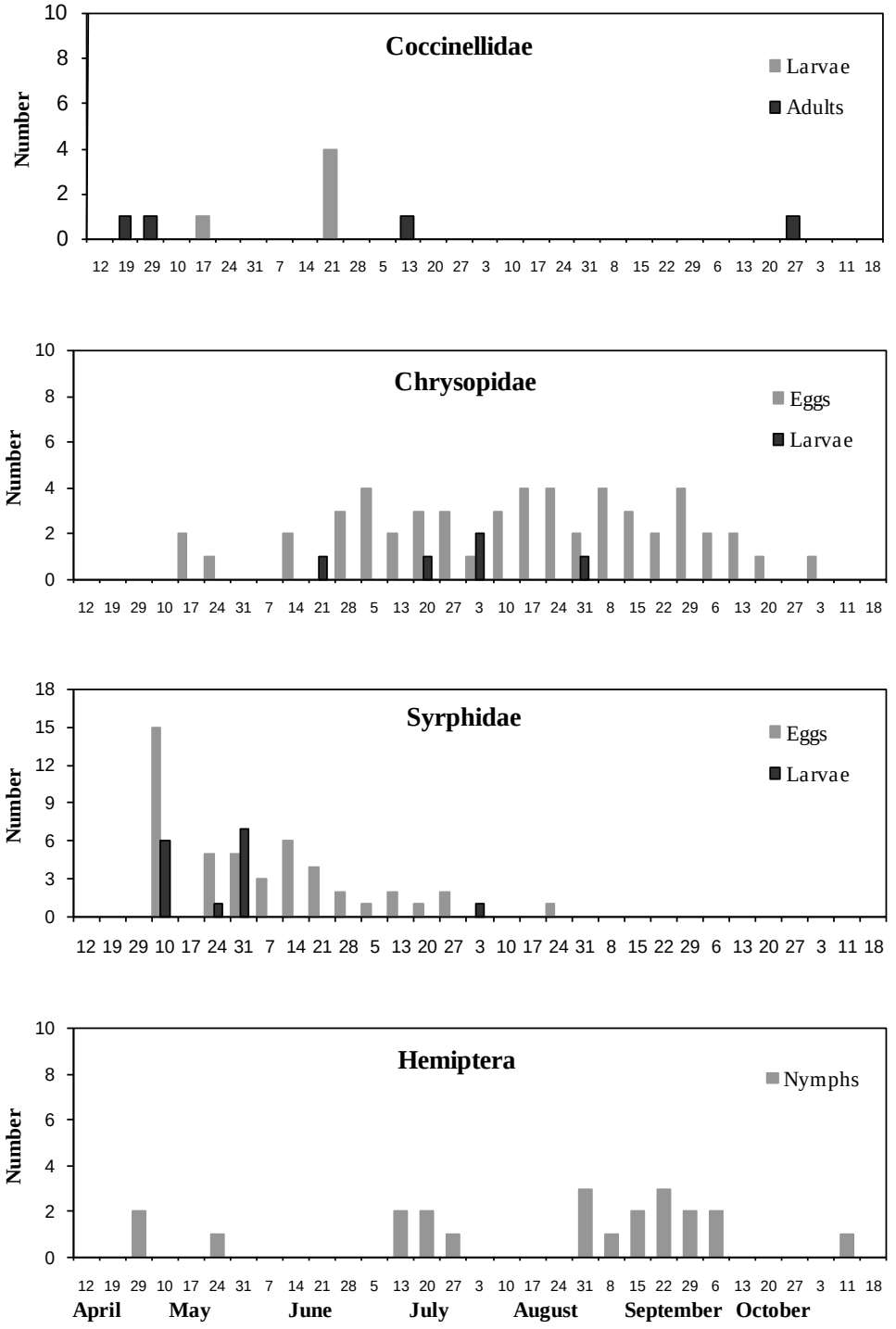

FIG. 7. Number of natural enemies found on samples from an apple orchard in central Peloponnese in 1992.

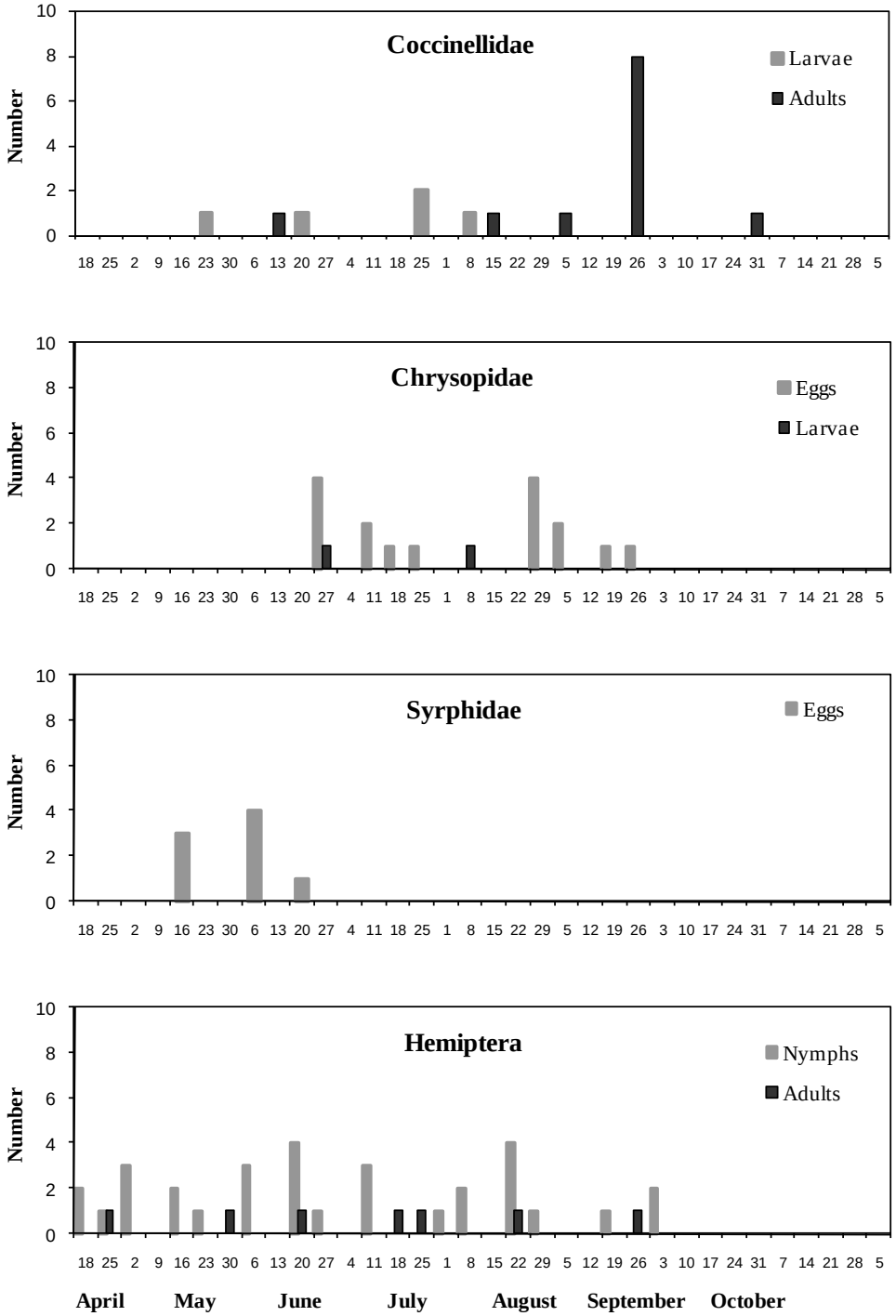

FIG. 8. Number of natural enemies found on samples from an apple orchard in central Peloponnese in 1993.

Coccinella septempunctata L. and *Adalia bipunctata* (L.) were identified but in very low numbers. Eggs and a small number of larvae of *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) were recorded almost throughout the sampling period in 1992 and from end of June until end of September in 1993. A small number of syrphid eggs and larvae was found in 1992 mainly in May and June. In Anthocoridae nymphs and adults of *Orius niger* (Wolff) and *Orius minutus* (L.) were recorded but in low numbers. In 1992, anthocorid nymphs were recorded mainly in July and in September and in the next year both nymphs and adults were found from the beginning of the sampling period till the beginning of October. Parasitised aphids were not recorded in the samples in both years of this study.

Discussion

The aphid species *A. pomi*, *D. plantaginea* and *E. lanigerum* were found to colonize apple trees. *A. pomi* was recorded in much higher population densities than *D. plantaginea* whilst *E. lanigerum* was present in very low numbers. *D. plantaginea* and *E. lanigerum* appeared in May and June while *A. pomi* appeared later (after mid-May) and it was present in the samples till the end of September. *D. plantaginea* and *E. lanigerum* reappeared in November but with in very small numbers.

In apple orchards in Wisconsin, California and Nova Scotia, *A. pomi* population showed a more or less similar fluctuation to that recorded in the present study (Oatman and Legner 1961, Westigard and Madsen 1965, Braun 1991, Stewart and Walde 1997). In Ohio apple orchards *A. pomi* population showed a peak in July as occured in our study, but *D. plantaginea* fluctuation was different than in our study, as it was conspicuous in June and reached a peak on August 1 (Holdsworth 1970). In another study (Braun 1991) the population of *D. plantaginea* became very low at the end of June in Nova Scotia. *D. plantaginea* occurred only in May, in an apple orchard in west Virginia, whilst *Aphis* spp. population densities were higher in June-July (Kozar et al. 1994).

Aphis pomi and *D. plantaginea* population development depends on the presence of new growth of apple trees. The second peak of *A. pomi* population at the end of August in both 1992 and 1993 seems to be correlated with the availability of new growth on the trees during that period. The strong correlation between *A. pomi* population trends and the presence of new growth has been stated by several researchers (Cutright 1930, Westigard and Madsen 1965, Hull and Grim 1983).

The occupation of the same feeding niche could be an indirect evidence of a possible interspecific competition between *A. pomi* and *D. plantaginea*. Interspecific interactions may lead to temporal and /or spatial separation. These two species show temporal separation as co-occur on apple trees only for a rather short period, as it was also mentioned by other researchers (Bonnemaison 1972, Graft et al. 1985). This could be attributed to the lower temperature threshold for development and the smaller thermal constant of *D. plantaginea* than *A. pomi* (Graf et al. 1985). Differences in thermal requirements have been also proved to prevent the simultaneous presence of competitive species, lowering substantially the adverse effects of competition (Denno et al. 1995).

Apart from temporal separation, *A. pomi* and *D. plantaginea* show also spatial segregation since they co-existed only on a very low percentage of infested shoots, during the period that both species co-occurred on apple trees (Fig. 5). Likely, competition might force aphids to colonize all the available shoots on tree periphery and

this could be a reason, not to show a preference for a particular side of the tree. *D. plantaginea* infestation may cause a significant deterioration of host plant quality, deterring a subsequent *A. pomi* infestation. In cereal aphids, *S. avenae* reproductive rate was reduced when fed on wheat plants previously infested with *R. padi* (Gianoli 2000).

Conversely, *D. plantaginea* and *E. lanigerum* co-occupy a high number of shoots indicating a low degree of competition. This could be attributable to their different feeding niches (leaf and wood respectively). The high within-tree dispersal of *E. lanigerum* (Hoyt and Madsen 1960) might contribute to lessen competition effects. Later in the season, *E. lanigerum* should also co-exist with *A. pomi*, but, the population densities of *E. lanigerum* are rather low possibly due to the high temperature and intense light which affect adversely *E. lanigerum* (Hoyt and Madsen 1960).

The natural enemies found were predators belonging to a wide range of taxa. Bouchard et al. (1986) referred 60 predators and parasitoids active against *A. pomi* while in California apple orchards, the main predator was the coccinellid *Coccinella novemnotata* Herbst. (Oatman and Legner 1961) and in Quebec the midge *Aphidoletes aphidimyza* (Rondani) (Stewart and Walde 1997). In central Washington 39 predators and 2 parasitoids were recorded (Carrol and Hoyt 1984) and in Ohio apple orchards, syrphids, hemerobiids, coccinellids and in low numbers the anthocorid *Orius insidiosus* (Say) (Holdsworth 1970). In the course of the current study, parasitized aphids were not recorded, as it was also the case in other studies (Oataman and Legner 1961, Westigard and Madsen 1965, Stewart and Walde 1997). However, aphid parasitoids have been reported in other studies (Carrol and Hoyt 1984, Bouchard et al. 1986).

Generally, the natural enemies were recorded in low numbers and very likely they had a limited suppressing effect on aphid populations. A similar weak effect of natural enemies' activity against aphids has been reported by Holdsworth (1970) and Wyss (1995). Possible causes for this result could be the intensive sprays and also, the reduction of the native vegetation in intensively managed orchards which if conserved, could substantially support natural enemies persistence and population increase (Carrol and Hoyt 1984, Altieri and Schmidt 1986, Haley and Hogue 1990).

In conclusion, the data obtained could contribute in the development of an effective management program against aphids in apple orchards. Early in the season the target pest will be *D. plantaginea* and due to its severe damage potential, sprayings might be required. Later in the season, the predominant species is *A. pomi*, which is considered less harmful, and very likely, sprayings could very seldom needed. Natural enemies were recorded in low numbers and this indicates that likely, cultural practices applied in apple orchards and surrounding habitats may adversely affect natural enemies' abundance and should be reconsidered.

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Εποχική αφθονία και κατανομή των πληθυσμών ειδών αφίδων σε δένδρα μηλιάς

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ΠΕΡΙΛΗΨΗ

Η σύνθεση των ειδών και η εποχική διακύμανση των πληθυσμών των αφίδων και των φυσικών τους εχθρών μελετήθηκαν σε μηλεώνα ποικιλίας "Delicious Pilafa Tripoleos", στην περιοχή της Τρίπολης. Για το σκοπό αυτό στελέχη κλάδων συλλέγονταν σε εβδομαδιαία διαστήματα καθ' όλη τη βλαστική περίοδο των ετών 1992 και 1993. Στα δείγματα βρέθηκαν το *Aphis pomi* De Geer (Hemiptera: Aphididae), το *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae) και το *Eriosoma lanigerum* (Hausmann) (Hemiptera: Eriosomatidae). Κατά τα δύο έτη της μελέτης αυτής το *A. pomi* ανέπτυξε υψηλότερους πληθυσμούς από τα άλλα δύο είδη. Ο πληθυσμός του ήταν υψηλότερος κατά τους μήνες Ιούνιο και Ιούλιο και παρουσίασε ένα μικρότερο μέγιστο στον Αύγουστο. Η περίοδος εμφάνισης του *D. plantaginea* ήταν κυρίως τον Απρίλιο και τον Μάιο, με υψηλότερους πληθυσμούς τον Μάιο. Το *E. lanigerum* παρατηρούνταν από τον Μάιο έως τον Ιούλιο αλλά σε πολύ μικρούς πληθυσμούς. Οι πληθυσμιακές πυκνότητες των αφίδων δεν βρέθηκε να διαφέρουν σημαντικά μεταξύ της νότιας και της βόρειας πλευράς των δένδρων. Παρατηρήθηκε ότι επί του ίδιου στελέχους δεν σημειώνονταν το *A. pomi* μαζί με το *D. plantaginea*. Σε δειγματοληψίες στελεχών πριν την έκπτυξη των φύλλων μελετήθηκε η κατανομή των χειμερινών ωών των αφίδων σε σχέση με τη θέση των οφθαλμών επί του στελέχους. Βρέθηκε ότι τα περισσότερα ωά είχαν εναποτεθεί πλησίον των οφθαλμών που βρίσκονταν περί το μέσο του στελέχους. Οι φυσικοί εχθροί που βρέθηκαν ήταν αρπακτικά Coccinellidae, Chrysopidae, Syrphidae και Anthocoridae. Γενικά όμως οι πληθυσμοί τους κυμάνθηκαν σε χαμηλά επίπεδα.