PLANT SPECIES DIVERSITY AND ABUNDANCE AFFECTS THE NUMBER OF ARTHROPOD PESTS IN RESIDENTIAL LANDSCAPES

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Abstract. An analysis of data collected from 212 residential landscapes in suburban Maryland, U.S., revealed significant positive relationships between the number of insect and mite pests in the landscape and the total number of plants and plant species at the site. The number of pests in a landscape increased very little in relation to the number of plants found in the landscape. However, the number of arthropod pests increased at a much greater rate as more species of plants were added. Two explanations for these results are likely. Relatively few plants harbored arthropod pests throughout the course of the season. Adding more plants of the same species had little effect on altering the number of pest species in a landscape. Arthropod pests tend to be relatively specialized in their host range. When different species of plants are added to a landscape, more opportunities are created for specialized insects and mites to colonize the site and increase the richness of the arthropod fauna. When used in conjunction with previous investigations involving monitoring approaches, these results help IPM and PHC monitors plan and conduct site inspections more efficiently and effectively.

Key Words. Landscape diversity; pest diversity; Integrated Pest Management; Plant Health Care.

One of the pillars of both Integrated Pest Management (IPM) and Plant Health Care (PHC) programs is the regular inspection of plant material in the managed landscape (Raupp et al. 1985; Ball 1987, 1994; Ball and Marsan 1991). This process, known as monitoring, forms the basis for making decisions regarding corrective actions such as the application of pesticides or ameliorative and restorative actions such as pruning, fertil-

izing, mulching, or irrigating (Lloyd and Miller 1997; Ball et al. 1999; Harris et al. 1999).

During the past two decades, several advances have helped arborists understand the relationships between landscape plants and their pest complexes. Not the least of these has been the recognition that a relatively small number of pests (called key pests) are responsible for the majority of biotic problems found in the landscape (Raupp and Noland 1984; Nielsen et al. 1985; Raupp et al. 1985, 1992; Harris et al. 1999). There are now several well-developed lists of key pests for different regions of the United States. These lists have been generated in two general ways. Some are compilations of large surveys conducted with groups such as municipal foresters on regional and national scales (Nielsen et al. 1985; Wu et al. 1991). Others were compiled from monitoring records gathered by IPM and PHC technicians during their visits to the landscapes of clients (Holmes and Davidson 1984; Raupp and Noland 1984). Both types of data have been extremely valuable in helping arborists and landscapers prepare bids, train employees, and focus their monitoring and intervention activities.

With the evolution of IPM and PHC programs for landscapes came refinements in our understanding of methods to make monitoring more effective and efficient. Authors such as Holmes and Davidson (1984) demonstrated that the amount of time spent monitoring was directly related to the size of the property under management. Next came the recognition that monitoring activities could be made more efficient if actions

centered on plants that were exceptional in their value to the landscape and propensity for problems. This led to the emergence of the concept of key plants in landscapes (Nielsen 1983; Raupp et al. 1985; Lloyd and Miller 1997; Harris et al. 1999). In an important paper, Ball (1987) used this concept to demonstrate that landscapes containing greater numbers of key plants required significantly longer amounts of time for technicians to monitor. By enumerating key plants in residential landscapes, arborists could more accurately estimate the amount of time necessary to monitor and treat plants and thereby estimate jobs more effectively (Ball 1987). Recently, Ball et al. (1999) have linked levels of plant injury to intervention responses of arborists using a system called the Appropriate Response Process. That paper expanded the role of monitors by developing five plant health injury classes that demonstrate appropriate responses monitors should take at each level of plant injury.

Our objective was to gain further insights into the relationships between the abundance and types of plant materials found in landscapes and the diversity of associated insect and mite pests. Relatively few studies have attempted to quantify the diversity of pests found in landscapes (Hellman et al. 1982; Raupp and Noland 1984; Nielsen et al. 1985; Raupp et al. 1985; Ball 1987; Raupp and Shrewsbury 2000). In particular, we were interested in determining if relationships existed between the number of arthropod pests and abundance and diversity of the plant material found in the landscape. It was our goal to provide arborists and landscapers with information that could be used to estimate the magnitude of pests likely to be encountered in home landscapes.

MATERIALS AND METHODS

Data were gathered from suburban home sites in central Maryland, U.S., that were part of demonstration landscape IPM programs conducted by the University of Maryland in 1981 and 1982. Beginning in April of both years, trained IPM monitors visited each landscape and recorded the identity and number of each woody plant species found in the landscape. Samples from plants that could not be identified in the field by monitors were brought to the Plant Diagnostic Laboratory at the University of Maryland where they were identified by plant taxonomists. In the case of woody ground covers such as *Vinca minor* or *Euonymus fortunei*, single plants could not be readily enumerated, and plants with coalesced canopies were recorded as single plant units as reported by Raupp and Noland (1984). Starting in May and continuing through September at biweekly intervals, all plants in each landscape were examined and all occurrences of insect and mite infestations were recorded. When monitors were unable to identify pests in the field, samples were returned to the University of Maryland where entomologists assisted with the identification.

The average size of the home landscapes ranged from slightly less than one-quarter acre to slightly more than one-half acre and was typical for homes found in and around the suburbs of Washington, D.C. The composition of landscape plants found in these landscapes has been discussed in greater detail elsewhere (Hellman et al. 1982; Raupp and Noland 1984; Raupp et al. 1985, 1999; Raupp and Shrewsbury 2000).

To examine the relationships between the number of arthropod pests encountered and various attributes of plant diversity, regression analyses were performed as in Shrewsbury and Raupp (2000). Linear regression analyses were used to investigate the relationship between the number of arthropod species found in a landscape and the number of plants, plant species, species diversity (H'), and relative diversity or evenness (J'). Plant species diversity was estimated using a Shannon-Wiener Diversity Index (Zar 1999). Plant species diversity was calculated as follows:

$$H' = \left(n \log n - \sum f_i \log f_i\right)/n$$

where n = total number of plants; f_i = number of plants of each species; and log = natural log.

Plant species evenness or relative diversity was calculated as follows:

$$J' = H'/H'\max$$

where $H'\max = \log K$, and K = the total number of plant species and was the maximum possible diversity.

To determine which components of diversity best predicted the number of arthropod pests in the landscape, a regression analysis was performed on the number of pests and the number of plants, number of plant species, plant diversity (H'), and plant evenness (J') (SAS 1988).

RESULTS AND DISCUSSION

The number of home landscapes examined in this study was 100 and 112 in 1981 and 1982, respectively. The total number of plants and plant units sampled was 13,395. The best predictor of arthropod pest diversity was the number of plants found in the landscape (Table 1, Figure 1). This variable explained about 18% of the variation in the number of insect and mite species observed during the course of the growing season (Table 1). Almost as predictive as the total number of plants was the number of plant species in the landscape (Table 1, Figure 2). This variable independently predicted about 17% of the variation observed in the number of arthropod pests found (Table 1). Although there was a significant relationship between plant diversity, H', and the number of pests observed, this relationship was weak and explained less than 3% of the variation in the number of pests found (Table 1). There was no relationship between plant evenness, J' (that is, the observed diversity

relative to the maximum diversity), and the number of pests observed (Table 1).

A correlation analysis of all independent variables revealed a high and significant relationship between the number of plant species and the total number of plants found in the landscape ($r = 0.728$, $p < 0.001$). This is not altogether surprising, for often in many of the landscapes only a single specimen of a plant species was found at the site. Therefore, increasing the number of plant species in a site concomitantly increased the total number of plants at the site.
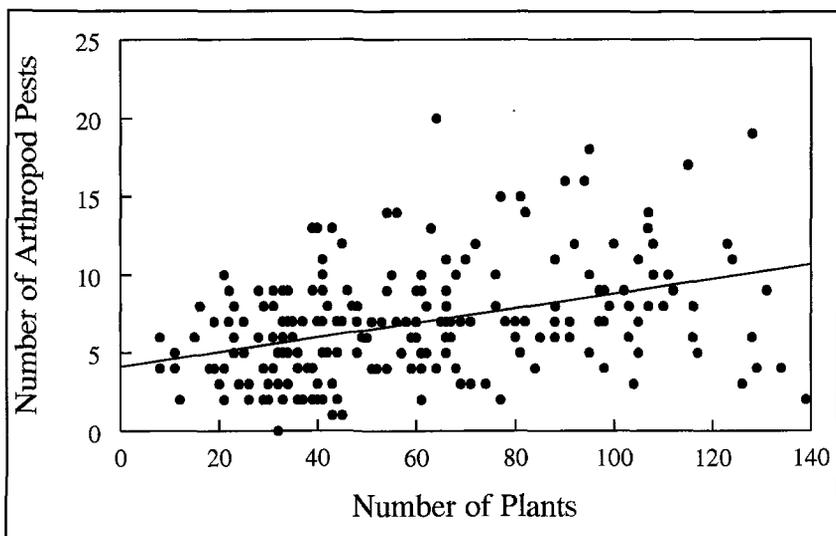
The relationships between the number of arthropod pests and the number plants and plant species in a landscape are both interesting and important. The slopes of regression equations for total number of plants and number of plant species on number of pests both differ significantly from one (numbers of plants versus number of pest species, $Z = 6.554$, $p < 0.0001$; number of plant species versus number of pest species, $Z = 6.198$, $p < 0.0001$). Therefore, the rate at which the number of pests accrues in a landscape is less than the rate at which numbers of plants are added (Figure 1). This relationship confirms the observation that there were numerous plants in every landscape that lacked any noticeable insect or mite pests for the entire duration of the study.

Adding additional plants of the same species to a landscape is unlikely to increase the number of resident arthropod pests for at least two reasons. First, most plants never become infested with insects or mites or achieve pest status during the course of the growing season (Raupp and Noland 1984). Adding an additional plant of the same species is unlikely to change this situation; hence, the slope of the regression of number of pest species on number of plants is far less than one. Second, once a pest has successfully colonized a landscape and

Table 1. Summary of regression analyses of number of arthropod pests and the number of plants, plant species, diversity (H'), and evenness (J') encountered in 212 suburban Maryland landscapes monitored in 1982 and 1983.

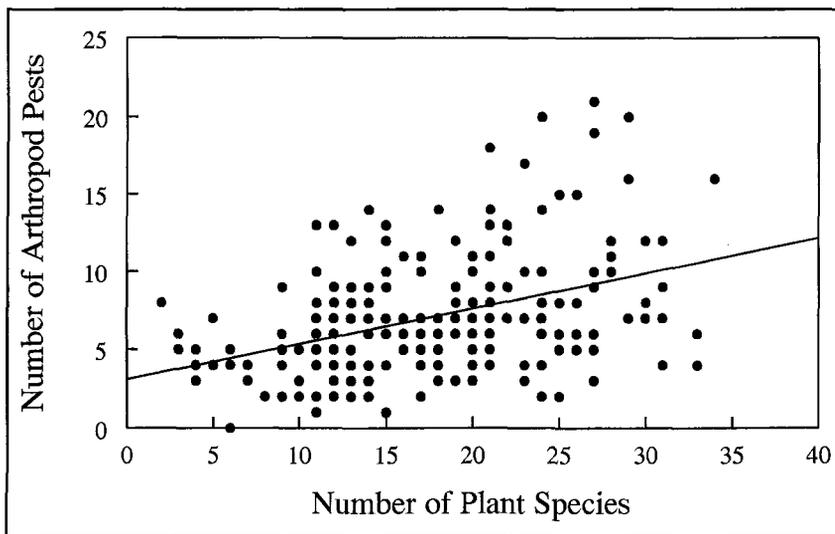| Attribute of plant diversity	n	F	P	r^2	Slope (se)	Intercept (se)
Number of plants	212	46.16	0.001	0.18	0.047 (0.007)	4.14 (0.494)
Number of plant species	212	41.01	0.001	0.17	0.227 (0.036)	3.08 (0.669)
Diversity (H')	212	5.38	0.021	0.02	1.002 (0.432)	4.66 (1.074)
Evenness (J')	212	0.97	0.327	0.00	-0.54 (0.549)	7.56 (0.555)

Figure 1. Relationship between the number of plants in a landscape and the number of arthropod pest species associated with them. The linear regression was significant at $P = 0.001$, and the regression equation was $y = 0.047x + 4.14$, where y = number of pest species and x = total number of plants.

of the same species. This pattern likely reflects at least two important relationships between arthropod pests and their host plants. Several earlier studies established the fact that certain plants—key plants—were likely to be attacked by pests, while others were less likely to be (Raupp and Noland 1984; Holmes and Davidson 1984; Raupp et al. 1985; Ball 1987; Raupp et al. 1999; Raupp and Shrewsbury 2000). The relative absence of arthropod pests on many common woody plants likely causes the relationship between number of plant species and number of pest species to be less than one to one. Species of plants can be added to a landscape without simul-

achieved pest status, adding a plant of the same species will not alter the species richness of pests in the landscape unless a second pest species accompanies or colonizes the second plant. This phenomenon suppresses the rate at which pests accrue in landscapes as plants are added.

Adding additional species of plants to a landscape has a somewhat different effect on the numbers of arthropod pests found there. The rate at which the number of pests increased in relation to the number of plant species added was less than one (Figure 2). However, adding plant species quintuples the rate at which pest species increase relative to adding more individuals

Figure 2. Relationship between the number of plant species in a landscape and the number of arthropod pest species associated with them. The linear regression was significant at $P = 0.001$, and the regression equation was $y = 0.227x + 3.08$, where y = number of pest species and x = number of plant species.

taneously increasing the number of arthropod pests because most herbivorous arthropods are relatively specialized in their diets and eat relatively few taxa of plants (Bernays and Chapman 1994). There is strong evidence for this trend in landscapes where many of the key pests such as lace bugs, armored scales, aphids, defoliating caterpillars and sawflies, and borers tend to have relatively restricted host ranges (Holmes and Davidson 1984; Raupp and Noland 1984; Ball 1987; Johnson and Lyon 1988). Therefore, adding a new species of plant to a landscape will provide new opportunities for additional pest species to colonize and become resident. This will cause pest species richness to increase at a greater rate relative to the rate observed when additional individuals of the same species are added. Hence, numbers of arthropod pests increase at a greater rate when species of plants rather than individual plant specimens are added to a landscape.

Increasing the taxonomic diversity of plants in a landscape increases the number of pests that will be found in a site. However, the rate at which pests accumulate is far less than the rates at which plants or plant species are added. While diversifying landscape plantings may increase the absolute number of pests, recent studies have shown that diversification may actually reduce the severity of pest outbreaks in landscape systems (Hanks and Denno 1993; Trumble and Denno 1995; Shrewsbury 1996; Shrewsbury and Raupp 2000).

The findings of previous researchers and those presented here can be incorporated into IPM and PHC schemes in the following way. Arborists gain valuable insight into how long it will take to monitor a property simply by knowing the absolute size of the landscape. Holmes and Davidson (1984) clearly demonstrated a direct relationship between the size (acreage) and amount of time required to monitor a property. As we have shown, landscapes containing many plant species tend to have more pests than ones with fewer plants or species of plants. We caution that while we demonstrated relationships between

numbers of pests and plants and species, we did not attempt to quantify the levels of damage pests were causing. In most cases where pest species were observed, they were not at levels that warranted intervention (Holmes and Davidson 1984; Raupp and Noland 1984). On the contrary, there is mounting evidence that the severity of pest damage will be reduced as plant diversity in landscapes is increased (Hanks and Denno 1993; Trumble and Denno 1995; Shrewsbury 1996; Shrewsbury and Raupp 2000).

Arboricultural and landscape management firms will need well-qualified Plant Health Care monitors to inspect plants at sites composed of highly diversified plant materials as a greater diversity of pest species is found at these sites. Landscapes with many individuals of the same type of plant will have fewer species of arthropod pests than landscapes with many types of plants. The diagnostic skills of sales representatives and Plant Health Care technicians may require consideration when work assignments are made. Technicians monitoring diverse landscapes need to recognize a wider variety of plants and their associated arthropod pests than those monitoring simple landscapes.

Finally, as Ball (1987) clearly demonstrated, the amount of time spent monitoring and controlling pests will be strongly influenced by the number of key plants found in a landscape. The propensity of key plants to harbor damaging levels of pests and intensities of pest damage may override other factors such as the size of the property or diversity of the landscape planting (Ball 1987; Ball et al. 1999).

Using information including the size of the property, number of plants and plant species, number of key plants, and intensity of plant care, arborists and landscapers gain considerable insight into the number of pest problems and amount of time that will be required to monitor and intervene in landscapes (Holmes and Davidson 1984; Raupp et al. 1985; Ball 1987; Ball et al. 1999). This information will be useful in making work estimates more accurate and monitoring activities ef-

ficient, effective, and reflective of the intensity of intervention.

LITERATURE CITED

Ball J., 1987. Efficient monitoring for an urban IPM program. J. Arboric. 13:174–177.

Ball, J. 1994. Plant health care and the public. J. Arboric. 20:33–37.

Ball, J., and P. Marsan. 1991. Establishing monitoring routines and action thresholds for a landscape IPM service. J. Arboric. 17:88–93.

Ball, J., J.E. Lloyd, and D.F. Marion. 1999. The appropriate response process (ARP) and its role in Plant Health Care. J. Arboric. 25:24–30.

Bernays, E., and R.F. Chapman 1994. Host–Plant Selection by Phytophagous Insects. Chapman and Hall, New York, NY.

Hanks, L.M., and R.F. Denno. 1993. Natural enemies and plant water relations influence the distribution of an armored scale insect. Ecology 74:1081–1091.

Harris, R.W., J.R. Clark, and N.P. Matheny. 1999. Arboriculture: Integrated Management of Landscape Trees, Shrubs, and Vines. Prentice-Hall, Inc., Upper Saddle River, NJ.

Hellman, J.L., J.A. Davidson, and J. Holmes. 1982. Urban integrated pest management in Maryland, pp 68–74. In Niemczyk, H.D., and B.G. Joiner (Eds.). Turfgrass Entomology. Hammer Graphics, Picqua, OH.

Holmes, J.J., and J.A. Davidson. 1984. Integrated Pest Management for arborists: Implementation of a pilot program. J. Arboric. 10:65–70.

Johnson, W.T., and H.H. Lyon. 1988. Insects That Feed on Trees and Shrubs (2nd ed.). Cornell University Press, Ithaca, NY.

Lloyd, J., and F. Miller. 1997. Introduction to Plant Health Care, pp 1–5. In Lloyd, J. (Ed.). Plant Health Care for Woody Ornamentals. University of Illinois and International Society of Arboriculture, Champaign, IL.

Nielsen, D.G. 1983. Integrated Pest Management (IPM). Brooklyn Botanic Garden Record 40(1):7072.

Nielsen D.G., E.R. Hart, M.E. Dix, M.J. Linit, J.E. Appleby, M. Ascerno, D.L. Mahr, D.A. Potter, and J.A. Jones. 1985. Common street trees and their pest problems in the North Central United States. J. Arboric. 11:225–173.

Raupp M.J., and R.M. Noland, 1984. Implementing plant management programs in residential and institutional settings. J. Arboric. 10:161–169.

Raupp M.J., J.A. Davidson, J.J. Holmes, and J.L. Hellman, 1985. The concept of key plants in Integrated Pest Management for landscapes. J. Arboric. 11:317–322.

Raupp M.J., C.S. Koehler, and J.A. Davidson, 1992. Advances in implementing Integrated Pest Management for woody landscape plants. Annu. Rev. Entomol. 37:561–585.

Raupp, M.J., P.M. Shrewsbury, and S. Gill. 1999. Advances in managing insect pests of urban trees. Acta Hortic. 496:47–153.

Raupp, M.J., and P.M. Shrewsbury. 2000. Defining key pests, key plants, and their relationship to vegetational diversity in residential landscapes, pp 41–46. In Backhaus, G.F., H. Balder, and E. Idczak (Eds.). International Symposium on Plant Health Care in Urban Horticulture. Parey Buchverlag Berlin, Berlin, Germany.

SAS Institute Inc., 1988. SAS/STAT User's Guide, Release 6.03. Cary, NC.

Shrewsbury, P.M. 1996. Factors influencing the distribution and abundance of the azalea lace bug, *Stephanitis pyrioides*, in simple and complex landscape habitats. PhD dissertation, Department of Entomology, University of Maryland, College Park, MD. 146 pp.

Shrewsbury, P.M., and M.J. Raupp. 2000. Evaluation of components of vegetational texture for predicting azalea lace bug, *Stephanitis pyrioides* (Heteroptera: Tingidae), abundance in managed landscapes. Environ. Entomol. 29(5):919–926.

Trumble, R.B., and R.F. Denno. 1995. Light intensity, host plant irrigation, and habitat-related mortality as determinants of the abundance of the azalea lace bug (Heteroptera: Tingidae). Environ. Entomol. 24:898–908.

Wu, Z., S. Jamieson, and J. Kielbaso. 1991. Urban forest pest management. J. Arboric. 17:150–158.

Zar, J. 1999. Biostatistical Analysis. Prentice-Hall, Upper Saddle River, NJ.

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Résumé. Une analyse des données recueillie auprès de 212 aménagements paysagers résidentiels dans les banlieues du Maryland a révélé des relations significativement positives entre le nombre d'insectes et d'acariens parasites présents dans l'aménagement d'avec le nombre total de plantes ainsi que d'espèces de plantes présentes sur le site. Le nombre de parasites dans un aménagement s'accroît très peu par rapport au nombre de plantes retrouvées dans l'aménagement. Cependant, le nombre d'arthropodes parasites s'accroît d'autant que des espèces différentes de plantes sont ajoutées dans l'aménagement. Deux explications à ces résultats sont possibles. Relativement peu de plantes abritent des arthropodes parasites à travers toute une saison. Ajouter plus de plantes d'une même espèce n'a que peu d'effet sur l'altération du nombre d'espèces parasites dans un aménagement. Les arthropodes parasites tendent à être relativement spécialisés dans leur choix d'hôtes. Lorsque différentes espèces de plantes sont ajoutées dans un aménagement, des opportunités supplémentaires sont créées pour des insectes et des acariens spécialisés qui colonisent le site et augmentent ainsi la richesse de la faune en arthropodes. Lorsque employé en conjonction avec les recherches précédentes impliquant des méthodes de suivi, ces résultats permettent d'aider à élaborer des plans de gestion intégré des insectes et des maladies ainsi que des plans de soins à la santé des végétaux, de même que d'aider à mener des inspections sur le terrain de façon plus efficace et efficiente.

Zusammenfassung. Eine Analyse der Daten, die von 212 besiedelten Landschaften in Stadtrandzonen von Maryland gesammelt wurden, enthüllte deutliche positive Beziehungen zwischen der Anzahl der Insekten und der Milben in der Landschaft und der absoluten Anzahl der Pflanzen und Pflanzenarten auf dem Standort. Die Anzahl der Schädlinge in einer Landschaft steigt nur gering in Relation zu der Anzahl der Pflanzen, die am selben Standort vorgefunden wurden. Trotzdem stieg die Zahl der Gliederfüßer weit stärker, wenn mehr Pflanzenspezies zugefügt wurden. Zwei Erklärungen sind für diese Ergebnisse möglich. Relativ wenige Pflanzen beherbergten Gliederfüßer während der ganzen Saison. Das Zufügen von mehr Pflanzen der gleichen Art hatte wenig Einfluß auf die Anzahl der vorgefundenen Schädlinge einer Landschaft. Gliederfüßer tendieren dazu, relativ wirtsspezifisch aufzutreten. Wenn unterschiedliche Pflanzenarten einer Landschaft zugefügt werden, ergeben sich mehr Möglichkeiten für spezialisierte Insekten und Milben den Standort zu kolonisieren und die Gliederfüßerfauna zu bereichern. Wenn diese Erkenntnisse mit den vorangegangenen Untersuchungen und Überwachungsversuchen in Verbindung gebracht werden, können diese Ergebnisse dazu beitragen, dass IPM und PHC eine Standortinspektion effektiver planen und ausführen können.

Resumen. Un análisis de datos colectados de 212 áreas residenciales en los suburbios de Maryland, reveló una relación positiva entre el número de plagas de insectos y ácaros en el sitio y el número total de plantas y especies de plantas. El número de plagas en el lugar incrementó muy poco con relación al número de plantas encontradas. Sin embargo, el número plagas de artrópodos aumentó a una velocidad mayor a medida que se agregaban más especies de plantas. Parecen haber dos explicaciones para estos resultados. Relativamente pocas plantas son habitadas por plagas de artrópodos a través de la estación. Al Agregar más plantas de las mismas especies, se tuvo poco efecto en la alteración del número de especies de plagas en el paisaje. Las plagas de artrópodos tienden a ser relativamente especializadas en su rango de hospedaje. Cuando diferentes especies de plantas son agregadas a un escenario, se crean más oportunidades para que insectos y ácaros especializados colonicen el sitio e incrementen la riqueza de la fauna de artrópodos. Usados en combinación con otros estudios anteriores de monitoreo, estos resultados ayudan a los monitores de IPM y PHC a planear y conducir más eficiente y efectivamente las inspecciones del sitio.