El Colegio de la Frontera Sur

Influencia del paisaje urbano sobre poblaciones de áfidos y sus enemigos naturales: Implicaciones para la producción agroecológica

TESIS

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INTRODUCCIÓN

En la actualidad, la mitad de la población mundial vive en áreas urbanas, mientras que en el año de 1900 menos del 15% habitaba en ellas (UN-HABITAT, 2009). Este proceso de urbanización transforma los paisajes naturales cercanos a las ciudades, provoca una fuerte presión sobre el tipo de uso de suelo en la periferia de la ciudad y sobre las áreas verdes ubicadas alrededor y dentro de la misma.

Con el crecimiento de la población en zonas urbanas aumenta la necesidad de proveer alimento a las mismas, a la vez que los sistemas agrícolas adyacentes son aíslados, transformados o eliminados (Deelstra y Girardet, 2000; Premat, 2005; Thapa y Murayama, 2008). Lo que contribuye a la pérdida de biodiversidad, a la desaparición y fragmentación de habitats y a la reducción de servicios ecosistemicos.

Ante la expansión de la mancha urbana sobre las áreas agrícolas adyacentes y áreas de vegetación en su interior, los cultivos agrícolas en el interior o la periferia de las ciudades juegan un papel cada vez más importante para alimentar a su población. Sin embargo, pueden verse afectadas las redes tróficas que contribuyan a brindar servicios ecosistémicos como la regulación de plagas en estos huertos urbanos, por lo que es preciso explorar la interacción entre cultivos, insectos herbívoros y sus enemigos naturales (parasitoides y depredadores) en los huertos urbanos, la relación entre las características de estos sitios y la configuración del paisaje urbano en la que están embebidos. La presencia y el crecimiento poblocional de los insectos herbívoros puede estar influenciado tanto por características de los mismos huertos (ej. estructura y composición vegetal, prácticas de cultivo), como del entorno (ej. conectividad a otras áreas de vegetación, heterogeneidad del paisaje urbano). Asimismo, las poblaciones de insectos herbívoros pueden estar siendo contraladas por sus enemigos naturales (depredadores y parasitoides). Profundizar en el estudio de los factores que influyen en la respuesta de insectos herbívoros y sus enemigos naturales a escala local y de paisaje, tiene particular interés en el escenario mundial de la agricultura urbana.

Contexto de estudio

Las áreas agrícolas convencionales son producto de la transformación de los ecosistemas naturales en campos de cultivo con unas cuantas especies (Wood, et al., 2005). Dependen de insumos externos (ej. fertilizantes y plaguicidas) y maquinaria para mejorar el rendimiento y maximizar la producción agrícola dejan de lado los servicios que el propio ecosistema brinda a la agricultura. Entre dichos servicios figura la regulación -a partir de la biodiversidad- de plagas. Ésta depende de la diversidad de sus enemigos naturales, de la diversidad de especies dentro de los ecosistemas, así como de la distribución espacial de los tipos de agroecosistemas en el paisaje (Díaz, et al., 2005). En comparación con agroecosistemas convencionales, las áreas agrícolas con manejo agroecológico tienen la posibilidad de recibir mayores servicios ecosistémicos, entre ellos la regulación de plagas, debido a que se promueve la conservación, aumento y uso de la biodiversidad para reducir las poblaciones de organismos plaga. A través de la diversificación de la vegetación dentro y alrededor de los cultivos, la rotación y asociación de cultivos y la reducción en la aplicación de agroquímicos se estimula la conservación de insectos benéficos (enemigos naturales) (Altieri, l999; Altieri y Nicholls, 1999). Además, en áreas agrícolas inmersas en un paisaje heterogéneo, con áreas de vegetación próximas, cuerpos de agua, pastizales, entre otras, pueden ocurrir un intercambio de especies entre hábitats, lo que beneficia la diversidad en el paisaje y a la vez al incremento de la diversidad de enemigos naturales. Sin embargo, la reducción de la biodiversidad en ecosistemas agrícolas, al igual que la homogeneización de los paisajes agrícolas contribuye a una disminución en la capacidad de los ecosistemas para regular las poblaciones de plagas.

En el contexto de la agricultura urbana, para que estas áreas sean beneficiadas por servicios ecosistémicos, específicamente, la regulación de plagas, probablemente dependerá de la diversidad de enemigos naturales dentro de la ciudad y de cómo se constituye el paisaje urbano. Tanto la diversidad de cultivos en los huertos, su ubicación en distintos puntos de la ciudad, como el manejo de los mismos, pueden contribuir a que sean susceptibles al ataque de insectos herbívoros dañinos, siendo potenciales plagas. A pesar de que estas áreas representan parches de vegetación de diversas formas y tamaños que pueden ser hábitat o refugio para varias especies (Smith, et al., 2006; Fetridge, 2008), la matriz urbana puede reducir o suprimir la capacidad de desplazamiento de enemigos naturales (Gibb y Hochuli, 2002).

Agricultura Urbana en San Cristóbal de las Casas

La agricultura urbana se define como: "el cultivo de plantas y la cría de animales en o alrededor de las ciudades" (FAO, 2005). Este tipo de agricultura puede contribuir de forma efectiva a incrementar la seguridad alimentaria de diversas formas: produciendo alimentos en casa y reduciendo la escasez estacional de productos frescos (FAO, 2005). Actualmente, la agricultura urbana proporciona una parte de los alimentos cotidianos a aproximadamente 700 millones de residentes en ciudades, un cuarto de la población urbana mundial (FAO, 2005).

En la ciudad de San Cristóbal de las Casas (SCLC), Chiapas existen áreas de agricultura urbana y periurbana de autoconsumo. Se llevan a cabo en espacios por lo general reducidos, llamados “huertos de traspatio” o “sitio” (Figura 1). También hay áreas de mayor extensión que manejan establecimientos comerciales, instituciones públicas (de investigación y/o educativas) y terrenos privados-comunales (Vásquez, 2010).

Figura 1. Agricultura urbana y periurbana en la ciudad de San Cristóbal de las Casas. A) Cafetos y pequeños árboles frutales en macetas colocados como ornamentales en el jardín de un restaurante. B) Hortalizas en pequeñas camas de cultivo en la parte trasera de una casa del centro de la ciudad. C) Hortalizas en camas elevadas en la azotea de un restaurante. D) Aves de corral y árboles frutales en el patio de trasero de una casa en la periferia de la ciudad. **Fotos**: Vázquez-Cid, 2012.

Dentro de estas áreas los herbívoros más frecuentes son los áfidos o los pulgones (Vázquez-Cid 2012, observación personal). Debiso a la relativa facilidad del manejo de estos insectos herbívoros para su estudio y al potencial que tienen de ser dañinos para los cultivos (Cermelli, 1989; Cermelli, 2005; Ragsdale, et al., 2011), se decidió realizar el proyecto de investigación con estos insectos y sus enemigos naturales.

Biología general de los áfidos

La forma de alimentación de los áfidos (Hemíptera: Aphididae), su el alto ritmo de reproducción y la habilidad de los individuos alados para desplazarse a grandes distancias sitúan a los áfidos dentro de las plagas más abundantes e importantes de los cultivos hortícolas y forestales (Holman, 1974; Powell, et al., 2006). Los áfidos son insectos pequeños (1– 4 mm), ovalados, ápteros o alados, de exoesqueleto blando, desnudo o provisto de una cobertura de excreciones cerosas. Se alimentan de la savia; Sus partes bucales (estiletes) penetran hasta los vasos cribosos del floema, donde se adhieren para nutrirse (Holman, 1974). Aunque son activos, sus movimientos son lentos y sedentarios. Presentan una reproducción sexual y asexual (holocíclica), en la cual se alternan generaciones de reproducción sexual con aquellas, sincronizadas con la presencia de alta abundancia y diversidad de plantas herbáceas (Figura 2). Los áfidos alados se desarrollan y migran hacía otras plantas cuando la planta hospedera comienza a marchitarse o bien cuando la colonia tiene un exceso de individuos ápteros (Richards y Davis, 1984; Vergara y Galeano, 1994).

Existen especies de áfidos que dependen de una sola especie de planta para alcanzar su ciclo completo, lo que se conoce como ciclos monoécicos, mientras que otros áfidos necesitan migrar a otras especies de plantas para completar su (heteroicas). En el ciclo completo de generaciones, el desarrollo de áfidos sexuales y fundadoras ocurren generalmente en árboles, mientras que el desarrollo de varias generaciones de hembras ápteras y aladas ocurre comúnmente en herbáceas (Holman, 1974).

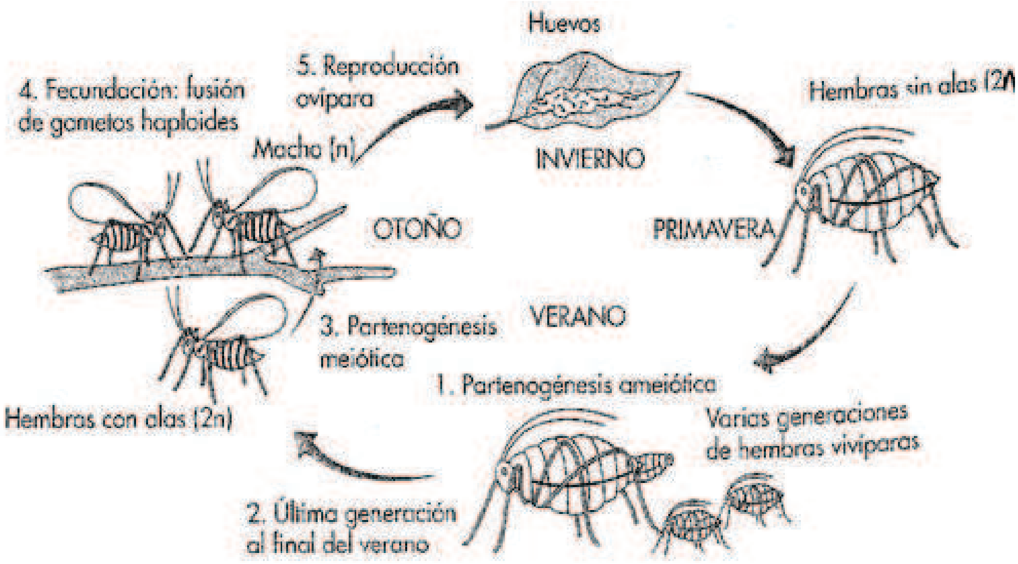

Figura 2. En zonas templadas los áfidos presentan una reproducción holocíclica, a la par de la temporada vegetativa. Pasando por un ciclo completo de generaciones que comprende cinco formas principales: fundadoras, vírgenes aladas, vírgenes ápteras, sexuales hembras y machos. La *fundadora* es una hembra partenogenética por lo general áptera que emerge en primavera a partir de un huevo invernal. Las *vírgenes* (hembras partenogenéticas) constituyen las generaciones siguientes que se desarrolla a través de la estación hasta el otoño, pueden ser aladas o ápteras dependiendo de las condiciones del ambiente. Las formas *sexuales* están representadas por hembras y machos que al copular producen huevos invernales. En muchas especies, estas formas se desarrollan durante el otoño como la última generación. **FUENTE**: Olmos, 2012.

La agricultura urbana desde un enfoque de ecología del paisaje

La abundancia de las plagas en la agricultura urbana puede depender de varios factores que dependen de la escala de análisis.

A escala local, la abundancia de insectos plaga depende directamente de la diversidad, composición y estructura de las plantas del huerto(Gliessman, 2002; Thevathasan y Gordon, 2004; Matienzo, et al., 2011). Estas características de la vegetación ocasionan variaciones en el microclima (ej. temperatura y humedad) que pueden afectar el desarrollo de poblaciones de insectos (Bailey, 1976; Ehrlich, et al., 1980; Kapos, 1989). La simplificación de la composición vegetal, como la observada en los monocultivos es uno de los factores de mayor importancia en el incremento de los insectos herbívoros (Altieri y Letourneau, 1982; Coll, 1998; Gurr, et al., 2000; Letourneau, et al., 2011). En áfidos esto puede favorecer el incremento de su abundancia por la disponibilidad prolongada del a alimento y posible ausencia de enemigos naturales (Horn, 1981; Kindlmann et al., 2007). Banks (1998) reportó que la abundancia y distribución de *Brevicoryne brassica* L. (áfido especializado a las plantas de la familia Brasicaceae) es influenciada principalmente por la composición de la vegetación sin importar las escala de fragmentación del paisaje.

Las técnicas de manejo de los sitios de cultivo influyen de diferente manera sobre las poblaciones de insectos. La fertilización por nitrógeno favorece el incremento en la abundancia de insectos herbívoros (Waring y Cobb, 1992) incluyendo los áfidos (McGarr, 1942; Pettit, et al., 1994). El uso de insecticidas favorece la resistencia en los áfidos, pero impactan negativamente a sus enemigos naturales (Bartllet, 1958; Stern y Van de Bosch 1959; Croft, 1989; Landis, et al., 2000).

A escala de paisaje, la heterogeneidad propiciada por la diversidad de fragmentos, tipos de coberturas y usos del suelo (Forman, 1995; Cousons y Ericsson, 2002; Pinkus, 2006) favorece la presencia de especies generalistas, menos sensibles a la fragmentación (van Rensburg, 2000; Atauri y de Lucio, 2001). Los parches de vegetación dentro del paisaje pueden ser utilizados por los insectos herbívoros para moverse de un sitio de cultivo a otro (Puszkar, et al., 2002; Banaszak y Cierzniak, 2002). Insectos herbívoros usan estos corredores de vegetación para obtener alimento o refugiarse (Czechowski, 1982; Schmitz, 1996). Sin embargo, a medida que las áreas de vegetación se encuentran alejados entre sí, la posibilidad de desplazarse y usar estas áreas se reduce (Bowne, et al., 1998; Tscharntke, et al., 2002; Tischendorf, et al., 2003). En áreas agrícolas tradicionales, las áreas adyacentes con vegetación leñosa y herbácea son usadas por los insectos plaga y enemigos naturales para hibernar. Varias especies de áfidos usan árboles y arbustos de la familia Rosaceae como hospederos en invierno (Leather, 1993). Coleópteros depredadores de la familia Coccinelidae (Zhou, et al.,1995) y avispas parasitoides (Corbett y Rosenheim, 1996) también usan hábitats leñosos y herbáceos para hibernar.

Por otro lado, los enemigos naturales reguladores de las poblaciones de insectos plaga, pueden ser afectados por los mismos factores que sus presas/huéspedes, aunque en diferente medida. A escala local, una mayor diversidad de plantas puede favorecer la reducción de la densidad de las poblaciones de insectos plagas en aproximadamente un 50% en comparación con monocultivos (Coll 1998; Gurr, et al., 2000), debido al aumento en la regulación de plagas por parte de enemigos naturales (hipótesis de los enemigos naturales de Root, 1973). La diversidad de plantas promueve condiciones microclimáticas favorables, ofrece presas o huéspedes alternos para depredadores o parasitoides respectivamente y otros recursos como polen y néctar que sirven de alimento (Landis, et al. 2000; Steffan-Dewenter, et al., 2001). Específicamente las poblaciones de parasitoides son favorecidas por las fuentes de néctar presentes en agroecosistemas diversos, al mejorar su tasa de reproducción e incrementar las tasas de parasitismo (Wratten, et al., 2003; Tylianakis, et al., 2004; Wackers, 2004; Heimpel y Jervis, 2005).

A escala de paisaje, los enemigos naturales tienen una área de desplazamiento menor que los herbívoros (Thies, et al., 2005; Rand, et al., 2006) y son más susceptibles a la fragmentación del hábitat (Zabel y Tscharntke, 1998; Kruess y Tscharntke, 2000; Hunter, 2002; Cronin 2004; Poveda, et al. 2012). En zonas urbanas, la reducción y degradación de áreas de vegetación influye particularmente en la diversidad de insectos de altos niveles tróficos (Gibb y Hochuli, 2002). Depredadores y parasitoides usan los fragmentos de vegetación de mayor tamaño y menor grado de disturbio dentro de la ciudad (Gibb y Hochuli, 2002). De igual forma, en paisajes agrícolas la fragmentación de hábitats afecta principalmente a insectos depredadores y parasitoides en comparación con sus presas o huespedes (Kruess y Tscharntke, 1994; Thies y Tscharntke, 1999; Hunter, 2002).

En áreas agrícolas, con la perdida de áreas de vegetación leñosa y/o herbácea adyacentes a los cultivos desaparecen hábitats para muchas especies que promueven distintos servicios ambientales tales como el control de plagas (Kruess, 2003, Tscharntke, et al., 2005). Bianchi y colaboradores (2006), al hacer una revisión de varios artículos sobre control biológico a nivel de paisaje en áreas agrícolas, señalaron que la actividad de enemigos naturales es asociada con hábitats herbáceos en 80% de los casos y con áreas de vegetación leñosas en un 71%. Por lo que dentro de las ciudades la presencia de áreas de vegetación leñosa puede favorecer la presencia de depredadores y parasitoides. Árboles y arbustos tales como *Vaccinium spp*., *Cornus spp*., *Ilex spp*. (Maier, 1981), *Fraxinus spp*. (Rieux, et al., 1999), *Crataegus spp*. (van Emden, 1965) y *Urtica spp*. (Perrin, 1975) pueden albergar hospederos y presas alternativas para depredadores y parasitoides. Además, proporcionan un microclima con temperatura estable (Rahim, et al., 1991; Hailemichael y Smith, 1994) y flores con néctar que promueve la longevidad y la temprana abundancia de parasitoides (Dyer y Landis, 1996, Cappuccino, et al., 1999).

Ante la expansión de la mancha urbana sobre las áreas agrícolas adyacentes y áreas de vegetación en su interior pueden verse afectadas las redes tróficas que contribuyan a brindar servicios ecosistémicos como la regulación de plagas. Al mismo tiempo que surgen huertos dentro de la ciudad como una estrategía para satisfacer parcialmente la necesidad de alimento. Por lo que es preciso explorar la interacción entre cultivos, insectos herbívoros y sus enemigos naturales (parasitoides y depredadores) en los huertos urbanos, la relación entre las características de estos sitios y la configuración del paisaje urbano en la que están embebidos.

A pesar del auge de la agricultura urbana y de las medidas de manejo de plagas en cultivos urbanos, son relativamente escasos los estudios realizados sobre control biológico de plagas en paisajes urbanos. Por lo tanto, considerando el sistema trófico áfidos – enemigos naturales, en este trabajo se plantea como hipótesis que el impacto de los áfidos (Aphididae: Hemíptera) sobre la agricultura urbana y periurbana depende de la composición vegetal de los sitios y del paisaje circundante. El objetivo fue evaluar la relación entre las especies vegetales cultivadas en los huertos y los tipos de coberturas del paisaje –Infraestructura urbana, vegetación leñosa, vegetación herbácea, áreas abiertas y cuerpos de agua– con la abundancia de áfidos y sus enemigos naturales en huertos urbanos de San Cristóbal de las Casas.

Landscape and site effects on aphids and their natural enemies in urban and periurban agriculture

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Abstract

As the proportion of the earth's people living in cities grows, urban agriculture is an increasingly important element of food security. However the ecological services that sustain agricultural production have not been well studied in urban settings. We studied aphids and their insect predators and parasitoids in a medium-sized city in the highlands of Southern Mexico to evaluate the influence of the urban and periurban landscape on potential for natural biological control. Using yellow pan traps, we sampled aphids, natural enemies and vegetation in 19 gardens. We classified the city's ground cover using a satellite image. Detrended correspondence analysis distinguished four groups of sites based upon their aphid and natural enemy communities. One group included only periurban sites, and another a small garden surrounded by cement and two rooftop gardens. Two other groups were mixes of urban and periurban sites. We used coinertia analysis to identify associations among plant species, aphids, natural enemies and groups of sites at the site level. Coinertia analysis and Aikake's information criteria found associations of aphid and natural enemy communities with land cover at scales of 10-1250 m around the gardens. With the exception of root feeders, aphids thrive throughout the urban landscape. Several genera were positively associated with woody and herbaceous vegetation, open areas and water bodies at the larges spatial scales analyzed. Natural enemies were also present throughout the landscape, except at the sites surrounded by cement. Predator populations appeared to depend on tree cover at the 20 and 40 m scales. Parasitoids were positively associated with areas dominated by open areas, as well as with several garden plant species. Our findings demonstrate the potential for conservation biological control in an urban setting, and its dependence upon land use and plant cover in gardens and surrounding landscapes.

Introduction

More than half of the world's population now lives in cities [1]. With rising transportation costs, many people, organizations and governments are turning to urban agriculture to help meet the rising food demand in urban areas [2]. Urban farming and gardening offer multiple benefits in addition to food provision [3, 4], including recreational and educational opportunities as well as many other ecological services that green spaces provide [5]. However growing food where we live requires increased attention to potential negative externalities, such as agrochemical contamination. For this reason, many urban agriculture initiatives emphasize organic and agroecological production strategies [6, 7]. Agroecological production itself relies on ecological services from surrounding landscapes, that regulate, for example, hydrology and microclimate. Of particular interest for agroecologists is the landscape-scale regulation of populations of potential pests and beneficial organisms [8]."Conservation biological control" refers to the management of fields and surrounding landscapes in order to minimize their permeability to pests and maximize habitat and movement of biological control agents [9, 10]. Urban farming takes place in mosaics of infrastructure, green spaces, and, in many cases, open water and wetlands. Plant communities include species that are planted for diverse purposes or that colonize spontaneously, and that are also diverse in their origins [11]. We know little about how these "novel ecosystems" [see 12, 13, 14] affect natural regulation of pest populations.

At the local scale, spatial homogeneity and temporal predictability in plant communities favor herbivore abundance [15, 16, 17]. In cities, herbivores specializing on ornamental or ruderal plants are particularly favored by continuous availability of food sources in gardens and vacant lots. [18]. Natural enemies of pests, in contrast, often rely on more than one type of food and habitat over the course of their life cycles, and therefore thrive under more heterogeneous conditions [19, 20, 21]. Furthermore, agroecosystem resilience to pests requires the maintenance in fields and surrounding landscapes of a diverse suite of natural enemies that can prevent and respond to outbreaks of different pests [19, 22]. Species and structural diversity in plant communities, provided by polycultures, hedgerows, cover crops, scattered shrubs and trees provide diverse habitats and food resources, fostering natural enemy diversity [16, 23, 24]. The abundance and diversity of plants with showy, insect-pollinated flowers favored by gardeners may provide nectar for parasitoids that oviposit in potential pest species. Agroecologists advocate planting combinations of species that flower in series as a strategy for maximizing natural enemy populations on farms [20, 23].

At the landscape level, cities are highly fragmented landscapes with distinct microenvironments that can affect potential insect pests and their natural enemies in different ways [18, 25, 26, 27, 28]. Herbivorous insects show little response to changes in landscape configuration [19, 29, 30], maintaining similar densities on small lots or large fields surrounded by urban infrastructure [31, 32]. Parasitoids and predators must forage more widely and their populations decline when hospitable patches of vegetation are few, small and isolated. [31, 33, 34]. High rates of parasitism have been associated with presence of uncultivated areas within 0.5 to 2 km of farms [30, 35]. Predaceous insects maintain their populations in diverse herbaceous vegetation adjacent to fields [36]. Predaceous insects are more abundant and diverse in landscapes with greater cover of uncultivated vegetation [37, 38]. In cities, populations of predators and parasitoids are concentrated in larger fragments of structurally diverse vegetation, such as in parks. [28].

Here, we explore patterns in populations of aphids and their natural enemies in San Cristóbal de Las Casas, a rapidly growing city in the highlands of Southern Mexico. Aphids are common in gardens and fields in and around San Cristóbal (pers. obs.), are easy to sample [39, 40] and have been reasonably well studied in the region [41, 42, 43] Many aphid species specialize in one or a few plant families, while others are generalists [44]. Some feed above-ground, others below. Their diversity and abundance depend principally upon the timing, extension, permanence and diversity of their host plants. [45]. Aphids can become important pests because of their rapid population growth and because they are vectors for plant pathogens [46]. Parasitoid wasps and predators such as ladybugs (Coleoptera: Coccinellidae) and Syrphid larvae (Diptera: Syrphidae) are the principal biological control agents of aphids. By studying this suite of insects, we sought to understand how landscape composition at a range of spatial scales influences potential for conservation biological control in cities.

Materials and Methods

Study area

The city of San Cristóbal de Las Casas (SCLC) in the highlands of Chiapas, Mexico is situated in a valley surrounded by karstic and volcanic hills [47] at 16°44'N y 92°38'W. It has a mean altitude of 2119 masl [48]. The climate is temperate and subhumid. Rainfall is concentrated in the summer months and the mean annual temperature is 14.4° C, with occasional winter frosts [49]. SCLC is traditionally a city of descendants of Spanish colonists. However it is among the fastest-growing cities in Mexico, and among the more recent arrivals are many Tseltal and Tsotsil Maya from the surrounding countryside, as well as people from other parts of Mexico and other countries [50]. At the same time, that the growing city has covered agricultural areas and filled in green spaces, this rich cultural mix brings with it a diversity of gardening traditions and innovations [51]. In addition to these family plots, some businesses and institutions maintain gardens [52]

Sampling sites

From among gardens with willing owners, we selected 19 gardens distributed from the city center to the edge (Fig.1A). These urban and periurban gardens are polycultures including some combination of ornamental plants, vegetables, kitchen herbs, and medicinal herbs and shrubs, and fruit trees. None of the owners apply agrochemicals (Table 1).

Vegetation sampling

Between February and May, 2012, we censused dominant plant species and their abundance on these sites. We identified plants visually, with the aid of their common names, and when necessary through identification of collections in the herbarium of El Colegio de la Frontera Sur (ECO-SC-H) The 120 species identified are listed in Appendix 1. We also registered presence or absence of vegetation in the herbaceous (0-1 m), shrub (1-5 m) and tree (5-20 m) layers.

Insect sampling

Between March 1 and June 6, 2012, we sampled insects 12 times in each garden. This period covers the dryest, warmest season, when aphids are most abundant [40]. At each site, we distributed uniformly 10 yellow plastic dishes 20 cm in diameter and 10 cm deep half filled with soapy water [39, 40]. Site owners added water when necessary. After a week we returned and collected insects from the traps in a separate jar for each site, preserving them in 70% etanol.

We later separated and counted aphids (Aphididae: Hemiptera) and their potencial natural enemies: parasitoid wasps from the Ichneumonoidea y Chalchidoidea superfamilies and predators from the Coccinelidae (Coleoptera) y Syrphidae (Diptera) families. R. Peña-

Martínez, director of the Mexican Colletion of Aphidoidea (Hemiptera:Aphididae) identified aphids to genera using photographs of winged individuals. We identified natural enemies to the family level using keys in Triplehorn and Johnson [53]

Land cover classification

We used a multispectral, high-resolution Geoeye-1 satellite image of SCLC taken in April 2011. We performed a supervised classification of the image in ArcGIS 9.2 [54] using five cover types: urban infrastructure (e.g. buildings, houses, paved streets), woody vegetation (forests, orchards, hedgerows, parks, and scattered trees), herbaceous vegetation (pastures, wetlands, and fields), open areas (unpaved roads, quarries, recently cultivated fields, and areas of sparse vegetation such as soccer fields), and water bodies (streams and ponds). Training sites were identified through ground-truthed data obtained through site visits, and visual interpretation of the image. The classification process was iterative. After creating a set of signatures representing all basic classes, we ran the classification and inspected the resulting thematic image for errors with reference to the satellite image. We corrected errors by editing the training sites of existing signatures and/or creating additional signatures. This iterative process continued until visual inspection of the classification revealed no further obvious errors. Images were classified using the nearest neighbour algorithm [55].

Statistical analysis

The first step was to identify spatial patterns in the composition of insect communities [56, 57]. We identified groups of sites with similar insect communities through detrended correspondence analysis (DCA) using the 'vegan' package [58] in R 2.15.1 [58]. We plotted site scores on the first two axes, and then identified groups of sites that lay together on this plane using K-means clustering [60, 61]. To decide how many groups to produce we: (1)

produced between three and six groups (Fig. 2, Table 2); and (2) used the ANOSIM R statistic [62] for each of these groups to look at the difference in mean ranks of Bray-Curtis dissimilarity between groups compared with within-group dissimilarity. The aim was to maximize between-group dissimilarity. We complemented this analysis with a visual inspection of the ordination diagram and expert judgement.

We calculated taxonomic richness and Shannon diversity índices [63] for aphids, natural enemies and plants at each site using the functions ‘specnumber’ and ‘diversity’ respectively, in the ‘vegan’ package [64]. We compared mean abundance, richness and diversity among the groups of sites previously identified using DCA (see above) with a boxplot graphic.

We looked for associations between the plant taxa and entomofauna by building and selecting among alternative models. We built the models with the 'vegan' function 'cca' in R 2.15.1 [59]. We began with a null model, then added every plant taxon, evaluating all possible additions (+) and removals (-) at each step using Akaike’s information criterion (AIC) [65] (Crawley, 2007). AIC addresses the trade-off between goodness of fit and parsimony by adding 2(p + 1) to the deviance to penalize superfluous parameters. Because the AIC used in model building is not based on a firm theory, we performed a permutation test at each step.

Using the selected plant taxa and the entomofauna databases we performed coinertia analysis (CIA) [65] to identify associations between insects and the plant taxa selected by AIC models. CIA is a multivariate method that allows simultaneous analysis of two tables with the same row weights. We performed CIA using the function ‘coinertia’ in R package ‘ade4’ [67].

Finally, we calculated mean abundance for each taxon across the 12 sampling periods per site sampled and performed separate models with 'cca' function for aphids and natural enemies to explore associations between land cover classes and insect communities at different scales. For each site we quantified proportion of the cover types in concentric circles or "circular landscape sectors" [35] with radii of 10, 20, 40, 80, 160, 320, 640 and 1250 m (Fig. 1B). In rural settings, Thies and colleagues [35] used circular landscape sectors of 0.5, 1.5, 2, 3, 4, 5 and 6 km. However given the finer grain of the urban landscape, we opted to start at a smaller scale and use exponentially increasing radii, but had to reduce the scale of analysis slightly to fit within the satellite image. For two sites (Lucy, Gaby) near the edge of the image we could only classify cover to the 640 m scale, and for a third (Albarrada) to 320 m. We used AIC to identify the best models as described above for the vegetation-entomofauna analysis.

Results

We collected a total of 7491 aphids from 15 genera and 3244 natural enemies that we identified to the level of family or superfamily (Appendix 2). Figure 4 presents abundance, species richness and Shannon indices for aphids and natural enemies for groups of sites identified by DCA. Aphid abundance was greatest in group FOUR (three urban sites with high cement cover), intermediate in groups THREE (three periurban sites; recently developed areas outside the city's ring road) and TWO (a mix of six urban and periurban sites), and lowest in group ONE (seven mixed urban and periurban sites). Natural enemy abundance was essentially equal in groups ONE, TWO, and THREE, and much lower in group FOUR. Mean Shannon diversity of aphids and natural enemies varied little among groups. Group ONE sites had the highest Shannon indices for vegetation (Table 1).

Vegetation vs Insects

AIC identified 30 plant species with significant associations with aphids and/or natural enemies (Table 2). The principal and secondary coinertia axes explained 40.3% and 22.4%, respectively, of total variation among sites in aphid-plant community composition (Fig. 5). The coinertia biplots suggests wide separation in aphid and plant communities among site groups ONE, TWO, and FOUR, while site group THREE (periurban sities) was intermediate between groups TWO and FOUR. Aphids were associated mainly with herbaceous and shrubby plants rather than trees. Site group ONE was not clearly associated with any aphid genera in the biplot (Fig. 5).

Coinertia analysis for natural enemy-plant communities explained 78% of variation among sites in insect-plant community composition (Fig. 5); 52.2% associated with the primary axis and 26.1% associated with the secondary axis. Site groups ONE and FOUR were not associated with particular natural enemy taxa, although group ONE was associated with three flowering plant taxa that are potential nectar sources. Groups TWO and THREE were closer together in the coinertia space and were associated with several of the same plant and natural enemy taxa. However group TWO was strongly associated with syrphid flies while group THREE was associated with ladybugs (Coccinellidae).

Land cover Vs Insects

The models created with CCA, found influence of land cover on communities of aphids and their natural enemies over a range of spatial scales (Table 4). Aphid communities were associated most strongly with land cover at the largest analysis scales. Water bodies, open areas, and woody and herbaceous vegetation were all positively associated with aphid abundance, with the tightest relationships at the 1250 scale. Infrastructure was most tightly associated with aphid abundance at the 640 m scale, but the sign of the relationship varied among aphid genera (Table 5). On the other hand, natural enemies were strongest associated with most land cover types at scales of 80 m or smaller (Table 5). Open areas had positive associations with parasitoids and negative associations with Coccinelids at the 10 and 20 m scales (Table 5). Coccinelids were positively associated with woody vegetation and 40 m as were Syrphids at 40 and 80 m. By contrast, associations with water bodies were only apparent at the 640 and 1250 m. These were positive for the parasitoids and Coccinelids, but negative for Syrphids. Infrastructure cover had no apparent influence on natural enemies (Table 5).

Discussion

Earlier works had found negative effects of urbanization on natural enemies [31, 67], in particular on parasitoid wasps [28]. By constrast, we found potential for regulation of aphid populations through biological control at most of the urban and periurban gardens sampled. Site groups ONE, TWO (both mixes of urban and periurban sites) and THREE (periurban sites) had relatively abundant populations of natural enemies, with relatively low (group ONE) to moderate (groups TWO and THREE) aphid abundance (Fig. 3). Only group FOUR sites (all surrounded by cement) had abundant aphids and few natural enemies.

Studies in rural settings demonstrate that both aphids and their potencial natural enemies respond positively to complexity in vegetation cover in landscapes surrounding fields [35, 38]. In our study, populations of aphids and their natural enemies were associated with several land cover classes at several spatial scales, but these relationships were both positive and negative (tables 4 and 5), Aphid abundance was most strongly related to land cover at the largest scales of land cover analysis, a finding congruent with earlier studies that have found landscape influences on aphid density at scales of one to three [69] and one to six km [30]. This pattern may be a product of aphids capacity for dispersal on wind currents over distances of several km [69, 70] and for rapid reproduction following colonization [44, 45]. However these relationships may also be to some extent artifacts of our sampling scheme, given that for the urban sites, agricultural and forested areas were located at greater distances.

Natural enemies responded most to land cover at local to intermediate scales [19, 21]. This may be because predators and parasitoids often require more then one type of habitat over the course of their lifetimes [71, 72]. However a previous study of aphid parasitoides found the strongest response at the 1 to 2 km scale [69].

Aphids seemed capable of colonizing anywhere in the urban-periurban landscape. Several generalist aphid genera (*Aphis, Dysaphis, Myzus*, and *Metopolopium*) were positively associated with the infrastructure cover class at the 640 m scale (Table 5), demonstrating their capacity to thrive in urban settings. *Aphis sp.* - the genus most found most frequently in our traps - and *Myzus sp.* are of particular importance as potential pests because of their role as vectors of plant virues [73]. However the abundance of the root aphids *Geopemphigus* and *Tetraneura* was negatively associated with urban infrastructure, and in the coinertia analysis (Table 5), these genera were closely associated with the periurban sites. An enigmatic finding of the coinertia analysis was the contrast in aphid communities between site groups ONE and TWO, both mixes of urban and periurban sites. Group TWO coincided in the coinertia diagram with both aphids, while group ONE fell on the other side of the principal axis, and was not associated with any aphid genera. This difference may be largely explained by the availability of host plants, a topic for further study. Aphids taxa were positively associated with woody and herbaceous vegetation, open areas, and water bodies at the largest scale of analysis. Some were also positively associated with herbaceous vegetation at intermediate scales.

By contrast, natural enemy populations, Syrphids and Coccinelids in particular, were most strongly associated with tree cover at 40 and 80 m (Table 5). Coinertia analysis (Fig. 6) suggested that tree and shrub cover at the site scale is also important. Periurban sites were most closely associated with Coccinelids and parasitoids. Trees and shrubs provide shelter and alternative food resources for insects at high trophic levels [17, 18, 36]. In rural areas, herbivores and their natural enemies move among cultivated and uncultivated areas [37, 38], and this also appears to be true in San Cristóbal de Las Casas. Patches of woody vegetation around the city likely harbor natural enemies and allow them to disperse to periurban gardens such as those in group THREE, where both aphids and their enemies were abundant (Fig. 4). However groups ONE and TWO, which included several sites in the city center, also had relatively high abundance and diversity of natural enemies (Fig. 4). Trees in parks and gardens may harbor these insects.

Open areas seemed to favor parasitoids at the most local scales (Table 5), perhaps because these areas also host nectariferous herbs and shrubs. Earlier studies demonstrate that generalist predators use areas of woody and weedy vegetation and vacant lots as corredors and foraging areas [18, 74]. In rural settings, herbaceous vegetation surrounding fields helps maintain Coccinelid populations [37, 38]. However we found that Coccinelids were negatively associated with both the open areas and herbaceous vegetation cover classes at the smallest scales of analysis (Table 4). Syrphids, by contrast, were positively associated with herbaceous cover at 20 m.

Coinertia analysis identified several plant taxa that were associated with natural enemy abundance. (Fig.6). These included common medicinal and kitchen herbs such as *epazote* (*Dysphania ambrosioides* (L.) Mosyakin & Clemants) and rue (*Ruta graveolons* L.), vegetables such as potato (*Solanum tuberosum* L.) and radish (*Raphanus sativus* L.), and ornamentals such as spider plant (*Chlorophytum comosum* (Thunb.) Jacques), *Pachystachys lutea* Nees, and poppy (*Papaver sp*.). The efficacy of these species for enhancing urban biological control may be a fruitful avenue for further research.

We also suggest that future studies use techniques similar to ours to explore the response of other groups of natural enemies, including birds, bats, spiders and other insects to urban environment. Studies directly documenting the function of these taxa in urban biological control will also be valuable.

Conclusion

Our findings are mostly good news for the viability of ecologically based urban food production and its potential contribution to food security in medium-sized cities like San Cristóbal. Urban infrastructure even seems to protect plants from root aphids. Most other aphid genera thrive in the city, but so do their natural enemies. Coccinelids and parasitoid wasps are present in the San Cristóbal, but are associated with woody vegetation and periurban sites. Rooftop and other gardens that are surrounded by cement host few natural enemies and are particularly vulnerable to pest outbreaks. In larger cities without sufficient tree cover, parasitoids and Coccinelids are likely to decline, leaving urban agroecosystems more vulnerable. Conservation biological control could be enhanced by increasing tree cover in gardens and parks, with positive effects experienced most strongly within 80 m. Increasing herbaceous cover may foster Syrphid populations at more local scales. These findings lend support to a "land-sharing" approach to urban planning [75], in which biodiversity-friendly areas are distributed throughout the city rather than concentrated in a few larger parks.

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Literature cited

1. UN-HABITAT (2009) State of the World´s Cities 2008/2009: Harmonius Cities. http://www.unhabitat.org/content.asp?cid=5964&catid=7&typeid=46
2. Deelstra T, Girardet H (2000) Urban agriculture and sustainable cities. In: Bakker N, Dubbeling M, Guendel S, Sabel-Koschella U, de Zeeuw H, editors. Growing cities, growing food: Urban agriculture on the policy agenda. Feldafing: DSE. pp. 43– 65.
3. Altieri MA, Companioni N, Cañizares K, Murphy C, Rosset P, Bourque M, Nicholls CI (1999) The greening of the “ barrios ”: Urban agriculture for food security in Cuba. Agriculture and Human Values 16:131–140.
4. Zezza A, Tasciotti L (2010) Urban agriculture, poverty and food security: Empirical evidence from a sample of developing countries. Food Policy 35: 265–273. doi:10.1016/j.foodpol.2010.04.007
5. De Zeeuw H, van Veenhuizen R, Dubbeling M (2011) The role of urban agriculture in building resilient cities in developing countries. The Journal of Agricultural Science 149: 153–163. doi:10.1017/S0021859610001279
6. Gonzalez-Novo M, Murphy C (2000) Urban agriculture in the city of Havana: a popular response to crisis. In: Bakker N, Dubbeling M, Guendel S, Sabel-Koschella U, de Zeeuw H, editors. Growing cities, growing food: Urban agriculture on the policy agenda. Feldafing: DSE. pp. 329–348.
7. Nugent R (2000) The impact of urban agriculture on the household and local economies. In: Bakker N, Dubbeling M, Guendel S, Sabel-Koschella U, de Zeeuw H, editors. Growing cities, growing food: Urban agriculture on the policy agenda. Feldafing: DSE. pp. 67–97.
8. Tscharntke T, Bommarco R, Clough Y, Crist TO, Kleijn D, Rand TA, Tylianakis JM, van Nouhuys S, Vidal S (2007) Conservation biological control and enemy diversity on a landscape scale. Biological Control 43: 294–309. doi:10.1016/j.biocontrol.2007.08.006
9. Ehler LE (1998) Conservation Biological Control: Past, present, and future. In: Barbosa P, editor. Conservation Biological Control.. San Diego: Academic Press. pp. 1-6.

10. Wyckhuys KAG, Lu Y, Morales H, Vazquez LL, Legaspi JC, Eliopoulos PA, Hernandez LM (2013) Current status and potential of conservation biological control for agriculture in the developing world. Biological Control 65: 152–167.
11. González-García A, Gómez-Sal A (2008) Private urban greenspaces or "Patios" as a key element in the urban ecology of tropical Central America. Human Ecology 36: 291–300. doi:10.1007/s10745-007-9155-0
12. Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, Ewel JJ, Klink CA, Lugo AE, Norton D, Ojima D, Richardson DM, Sanderson EW, Valladares F, Vila M, Zamora R, Zobel M (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography 15:1–7.
13. Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM (2008) Global change and the ecology of cities. Science 319: 756–60. doi:10.1126/science.1150195
14. Marris E (2009) Ragamuffin earth. Nature 460: 450–453.
15. Horn DJ (1981) Effect of the weedy backgrounds on colonization of collards by green peach aphids, *Myzus persicae*, and its major predators. Environmental Entomology 10: 285-289.
16. Altieri MA (1994) Biodiversity and pest management in agroecosystems., New York: Haworth Press 185 p.
17. Altieri M (1999). The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment 74:19–31. doi:10.1016/S0167-8809(99)00028-6
18. Denys C, Schmidt H (1998) Insect communities on experimental mugwort (*Artemisia vulgaris L.*) plots along an urban gradient. Oecologia 113: 269-277.
19. Thies C, Tscharntke T (1999) Landscape structure and biological control in agroecosystems. Science 285: 893-895.
20. Landis D, Wratten SD, Gurr GM (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual review of entomology 45: 175–201. doi:10.1146/annurev.ento.45.1.175

21. Steffan-Dewenter I (2002) Landscape context affects trap-nesting bees, wasps, and their natural enemies. Ecological Entomology 27: 631–637.
22. Kruess A, Tscharntke T (1994) Habitat fragmentation, species loss, and biological control. Science 264: 1581–1584. doi:10.1126/science.264.5165.1581
23. Nicholls CI, Parrella M, Altieri MA (2001) The effects of a vegetational corridor on the abundance and dispersal of insect biodiversity within a northern California organic vineyard. Landscape Ecology 16: 133–146.
24. Letourneau DK, Armbrecht I, Rivera BS, Lerma JM, Carmona EJ, Daza MC, Escobar S, Galindo V, Gutiérrez C, Duque S, López J, Acosta AM, Herrera J, Rivera L, Saavedra CA, Torres AM, Reyes A (2011) Does plant diversity benefit agroecosystems? A synthetic review. Ecological applications 21: 9–21.
25. Frankie GW (1978) Ecology of insects in urban environments. Annual review of entomology 23: 367–387.
26. Nuckols MS, Connor EF (1995) Do trees in urban or ornamental plantings receive more damage by insects than trees in natural forests? Ecol. Entomol. 20: 253-260.
27. McIntyre NE (2000) Ecology of urban arthropods: A review and a call to action. Annals of the entomological society of America 93: 825–835. doi:10.1603/0013-8746(2000)093
28. Ellis J, Walter D, Tooker JF, Ginzel MD, Reagel PF, Lacey ES, Bennett AB, Grossman EM, Hanks LM (2005) Conservation biological control in urban landscapes: Manipulating parasitoids of bagworm (Lepidoptera: Psychidae) with flowering forbs. Biological Control 34: 99–107. doi:10.1016/j.biocontrol.2005.03.020
29. Banks JE (1998) The scale of landscape fragmentation affects herbivore response to vegetation heterogeneity. Oecologia 117: 239–246. doi:10.1007/s004420050654
30. Thies C, Roschewitz I, Tscharntke T (2005) The landscape context of cereal aphid-parasitoid interactions. Proceedings biological sciences / The royal society 272: 203–10. doi:10.1098/rspb.2004.2902
31. Gibb H, Hochulli DF (2002) Habitat fragmentation in an urban environment: large and small fragments support different arthropod assemblages. Biological Conservation 106: 91–100. doi:10.1016/S0006-3207(01)00232-4

32. Raupp MJ, Shrewsbury PM, Herms D (2010) Ecology of herbivorous arthropods in urban landscapes. Annual review of entomology 55: 19–38. doi:10.1146/annurev-ento-112408-085351
33. Cronin JT, Reeve JD (2005) Host-parasitoid spatial ecology: a plea for a landscape-level synthesis. Proc. R. Soc. B 272: 2225–2235. doi:10.1098/rspb.2005.3286
34. Poveda K, Martínez E, Kersch-Becker MF, Bonilla M, Tscharntke T (2012) Landscape simplification and altitude affect biodiversity, herbivory and Andean potato yield. Journal of Applied Ecology 49: 513–522. doi:10.1111/j.1365-2664.2012.02120.x
35. Thies C, Steffan-Dewenter I, Tscharntke T (2003) Effects of landscape context on herbivory and parasitism at different spatial scales. Oikos 101, 18–25. doi:10.1034/j.1600-0706.2003.12567.x
36. Geiger F, Wäckers FL, Bianchi F (2009) Hibernation of predatory arthropods in semi-natural habitats. BioControl 54, 529-535.
37. Elliott NC, Kieckhefer RW, Lee J, French BW (1998) Influence of within-field and landscape factors on aphid predator populations in wheat. Landscape Ecology 14: 239–252.
38. Elliott N, Kieckhefer R, Beck D (2002) Effect of aphids and the surrounding landscape on the abundance of Coccinellidae in cornfields. Biological Control 24 214–220. doi:10.1016/S1049-9644(02)00036-1
39. Rabasse JM, Brunel R, Delecolle R, Rouzé-Jouan J (1976) Influence de ladimension despiégesá eau colorees en jaune sur les captures d'aphides dans une culture de carotte. Annales de Zoologie et Ecologie Animal 8: 39-52.
40. Melia A (1989) Utilización de trampas amarillas en el control de los pulgones (Homoptera, Aphididae) de los cítricos. Bol. San. Veg. Plagas 15: 175-185.
41. Ruiz-Montoya L, Núñez-Farfán J, Vargas J (2003) Host-associated genetic structure of Mexican populations of the cabbage aphid *Brevicoryne brassicae* L. (Homoptera: Aphididae). Heredity 91: 415–21. doi:10.1038/sj.hdy.6800338
42. Ruiz-Montoya L, Núñez-Farfán J, Domínguez CA (2005) Changes in morphological traits of the cabbage aphid (*Brevicoryne brassicae*) associated with

the use of different host plants. Ecological Research 20: 591–598. doi:10.1007/s11284-005-0076-3

43. Ruiz-Montoya L, Castro-Ramírez AE (2005) Riqueza y distribución de grupos funcionales de insectos en parcelas de maíz en Los Altos de Chiapas. In: González-Espinoza, Ramírez-Marcial y Ruiz-Montoya, editors. Diversidad biológica en Chiapas. México: Plaza y Vádez. pp. 441-473.
44. Holman J (1974) Los áfidos de Cuba. La Habana: Instituto Cubano del Libro. 304 p.
45. Dixon AFG (1998) Aphid ecology. London: Chapman & Hall. 300 p.
46. Kindlmann P, Jarosík V, Dixon AFG (2007) Population Dynamics. In: van Emden HF, Harrington R, editors. Crop Pests. London: CAB International. pp. 311-330.
47. Ayuntamiento Municipal SCLC, Comisión Nacional del Agua (CONAGUA) (2010) Plan de gestión integral de la cuenca del Valle de Jovel, Chiapas. 86 p.
48. Instituto Nacional de Estadistica Geografia e Informatica (INEGI) (2012) http://mapserver.inegi.gob.mx/geografia/espanol/datosgeogra/basicos/estados/chis_geo.cfm <2013 January>
49. Comite Estatal de Información Estadistica y Geográfica de Chiapas (CEIEG) (2012) http://www.ceieg.chiapas.gob.mx/home/?page_id=9571&maccion=9571 <2013 January>
50. Trens M (1957) Bosquejo histórico de San Cristóbal Las Casas. México: Patronato Fray Bartolomé de las Casas. 274 p.
51. Aubry A (2008) San Cristóbal de las Casas. Su historia urbana, demográfica y monumental 1528-1990. México: Fray Bartolomé de Las Casas. 235 pp.
52. Vásquez L (2010) La agricultura urbana como elemento promotor de la sustentabilidad urbana. Situación actual y potencial en San Cristóbal de las Casas, Chiapas. Tesis de Maestría. El Colegio de la Frontera Sur. 164 p.
53. Triplehorn CA, Johnson NF (2005) Borror and DeLong´s introduction to the study of insects. Australia:Thompson, Brooks/Cole. 879 p.
54. ESRI 2006. ArcGis 9.2 and extensions; Environmental Systems Research Institute Inc. (ESRI). Redlands, CA, USA. http://www. esri.com.
55. Elkan C (2011) Nearest neighbor classification. http://cseweb.ucsd.edu/~elkan/250B/nearestn.pdf <June 2013>

56. Ferrier S, Guisan A (2006) Spatial modelling of biodiversity at the community level. J. Appl. Ecol. 43:393–404.
57. Golicher DJ, Cayuela L, Alkemade J, Rob M, González-Espinosa M, Ramírez-Marcial N (2008) Applying climatically associated species pools to the modelling of compositional change in tropical montane forests. Global Ecology and Biogeography 17: 262- 273.
58. Oksanen J (2011) Multivariate Analyisis of Ecological Communities in R: Vegan Tutorial. URL. http://cran.r-project.org. < 2013-January >.
59. R Development Core Team (2012) R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria, ISBN 3-900051-07-0, URL http://www.R-project.org
60. Forgy EW (1965) Cluster analysis of multivariate data: efficiency vs. interpretability of classification. Biometrics 21: 768-769.
61. Hartigan JA, Wong MA (1979) A K-means clustering algorithm. Applied Statistics 28: 100-108.
62. Clarke KR (1993) Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18:117-143
63. Legendre P, Legendre L (2012) Numerical Ecology. Third edition, Elsevier, Netherlands. 250 p.
64. Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Wagner H (2012) Vegan: Community Ecology data tables. Ecology, 84, 11, 3078–3089
65. Package. R package version 2.0-5. http://CRAN.R-project.org/package=vegan
66. Dray S, Chessel D, Thioulouse J (2003) Co-inertia analysis and the linking of the ecological
67. Dray S, Dufour AB (2007) The ade4 package implementing the duality diagram for ecologist. J. Stat. Softw. 22:1-20.
68. Shrewsburry PM, Leather SR (2012) Using biodiversity for pest suppression in urban landscape. In: Gurr GM, Wratten SD, Snyder WE, editors. Biodiversity and insect pests, key issues for sustainable management. West sussex: John Wiley and Sons Ltd. pp 273-308.

69. Roschewitz I, Hücker M, Tscharntke T, Thies C (2005) The influence of landscape context and farming practices on parasitism of cereal aphids. Agriculture, Ecosystems & Environment, 108: 218–227. doi:10.1016/j.agee.2005.02.005
70. Riley JR, Reynolds DR, Mukhopadhyay S, Ghosh MR, Sarkar TK (1995) Long-distance migration of aphids and other small insects in northeast India. Eur. J. Entomol. 92: 639–653.
71. Hodek I, Iperti G, Hodkova M (1993) Long-distance flights in Coccinellidae (Coleoptera). European Journal of Entomology 90: 403–414.
72. Brodeur J, Boivin G. (2004) Functional ecology of immature parasitoids. Annual review of entomology, 49: 27–49. doi:10.1146/annurev.ento.49.061703.153618
73. Blackman RL, Eastop VF (2007) Taxonomic issues. In: van Emden HF, Harrington R, editors. Aphids as Crop Pests. London: CAB International. pp. 1-30
74. Helden AJ, Leather SR (2004) Biodiversity on urban round- abouts – Hemiptera, management and the species area relationship. Basic and Applied Ecology 5: 3
75. Lin BB, Fuller RA (2013) Sharing or sparing ? How should we grow the world ' s cities ? doi:10.1111/1365-2664.12118
76. Vilca K, Vergara C (2011) Los áfidos (Hemiptera: Aphididae) en el callejón de Huaylas – Ancash, Perú. Ecología aplicada, 10: 93- 98.

Tables

Table 1. Descriptive data for sampling sites. Groups are those identified by DCA. Diversity data are Shannon indices based upon the narrowest taxomic level identified for each category of organisms.

Site	Group	Vegetation diversity	Aphid diversity	Natural enemy diversity	Vegetation layers*			Garden type**	Location ***		
					T	S	H		HC	AC	P
Lucy	1	3.25	2.31	1.17	X		X	B			X
Rocío	1				X		X	B			X
Bety	1				X	X	X	B	X		
Virginia	1				X	X	X	P		X	
Miguel	1				X	X	X	B	X		
Antonio	1				X	X	X	P		X	
Gaby	2	3.13	2.35	1.27	X	X	X	B			X
Miriam	2				X	X	X	B	X		
Casa_árbol	2				X	X	X	B	X		
Lily	2				X	X	X	B	X	X	
Liz	2				X	X	X	B	X	X	
Parador	2				X	X	X	P		X	
Pierre	2				X	X	X	B	X		
Albarrada	3	3.15	2.09	1.29	X	X	X	P			X
Helda	3				X	X	X	B			X
Martin	3				X	X	X	P		X	X
Casa_pan	4	2.64	2.08	0.92		X	X	R	X		
Cris	4					X	X	P	X		
Cuper	4					X	X	R		X	

*Vegetation layers: T: tree., S: shrub, H: herbaceous. ** Garden types: B: backyard garden, P: patio surrounded by buildings and pavement, R: rooftop garden. ***Location: HC: Historic city center; AC: Outside the historic center but within or near the beltway; P: Recently developed periurban areas outside the beltway. Sites with two designations are in transitional areas.

Table 2. Plants significantly associated with aphids and natural enemies

Species*	Abbreviation	Growth form	Aphid host**	Relationship identified by CIA	
				Aphids	Natural Enemies
Agave sp.	Aga_sp	succulent	host	x	
Amaranthus sp.	Ama_sp	herbaceous	host		x
Arecaceae sp.	Are_sp	palm	host	x	
Beaucarnea recurvata	Bea_rec	tree	host	x	
Capsicum pubescens	Cap_pub	shrub	host		x
Chlorophytum comosum	Chl_com	herbaceous	host	x	
Citrus limon	Cit_lim	tree	host		x
Cyperus papyrus	Cyp_pap	herbaceous	host		x
Dysphania ambrosioides	Dys_amb	shrub		x	
Eriobotrya japonica	Eri_jap	tree	host	x	x
Foeniculum vulgare	Foe_vul	shrub	host		x
Hibiscus sp.	Hib_sp	shrub	host		x
Lactuca sativa	Lac_sat	herbaceous	host	x	x
Malus sp.	Mal_sp	tree	host		x
Origanum vulgare	Ori_vul	shrub			x
Pachystachys lutea	Pac_lut	shrub			x
Papaver sp.	Pap_sp	herbaceous	host	x	x
Phaseolus sp.	Pha_sp	herbaceous	host	x	
Physalis philadelphica	Phy_phi	shrub			x
Pinus sp.	Pin_sp	tree	host	x	
Raphanus sativus	Rap_sat	herbaceous	host		x
Rosmarinus officinalis	Ros_off	shrub			x
Rubus ulmifolius	Rub_ulm	shrub		x	
Ruta graveolens	Rut_gra	shrub	host	x	
Sambucus nigra	Sam_nig	tree			x
Sinapis alba	Sin_alb	herbaceous	host		x
Solanum tuberosum	Sol_tub	herbaceous	host	x	
Taraxacum officinale	Tar_off	herbaceous	host	x	
Taxodium huegelii	Tax_hue	tree		x	x
Xanthosoma sagittifolium	Xan_sag	herbaceous	host	x	

*Plant scientific names were cross checked with www.theplantlist.org, maintained by the Royal Botanical Garden and the Missouri Botanical Garden.

**Host plants are those identified in Anderson P., Voegtlin, D., Villalobos, W., Rivera, C. available in: http://www.biologiatropical.ucr.ac.cr/attachments/suppls/sup51-2%20Afidos/Plantas%20hospederas.pdf and Vilca and Vergara 2011 [76].

Table 3. Mean abundance of insects collected for each group of sites identified by DCA.

	ONE	TWO	THREE	FOUR
Aphids				
Aphis	23	72	110	224
Brevicoryne	21	64	137	202
Dysaphis	6	35	25	60
Geopemphigus	4	24	150	20
Hyperomyzus	12	53	41	77
Macrosiphum	1	3	4	5
Metopolophium	1	1	1	1
Microparsus	3	3	26	13
Myzus	3	23	8	53
Nasonovia	5	29	14	10
Rhopalosiphum	7	10	9	44
Tetraneura	4	52	110	10
Uroleucon	4	13	7	41
Utamphorophora	5	19	16	16
Wahigreniella	2	7	6	14
Parasitoid Wasp				
Braconidae	51	37	46	10
Chalcidoidae	102	100	103	34
Ichneumonidae	23	28	30	5
Predators				
Coccinelidae	6	22	5	0
Syrphidae	7	5	23	1

Table 4. AIC*mod* for models with best fit at each scale of spatial analysis. Only cover classes identified by the models are reported. Sign indicates positive (+), negative (-), or mixed (M) relationships with insect taxa as detailed in Table 4.

Scale in radii	**Natural Enemies**	**Aphid**	**Natural Enemies**			**Aphids**		
	AIC*mod*		**effect**	**cover type**	**Alpha value**	**effect**	**Cover type**	**Alpha value**
10 m	24.45	56.96	M	Open areas	p<0.01	M	Infrastructure	p<0.15
			+	Herbaceous vegetation	p<0.16			
20 m	24.1	57.28	M	Open areas	p<0.025	M	Herbaceous vegetation	p<0.19
			M	Herbaceous vegetation	p<0.055			
40 m	27.26	56.71	+	Woody vegetation	p<0.18	M	Herbaceous vegetation	p<0.0.85
80 m	25.88	***	+	Woody vegetation	p<0.035		***	
160 m	***	53.21		***		+	Herbaceous vegetation	p<0.01
						M	Open areas	p<0.01
						+	Water bodies	p<0.27
320 m	***	52.64		***		+	Herbaceous vegetation	p<0.01
						+	Water bodies	p<0.03
640 m	25.29	56.1	M	Open areas	p<0.14	M	Infrastrcuture	p<0.03
			+	Water bodies	p<0.19			
1250 m	27.11	54.05	M	Water bodies	p<0.14	+	Woody vegetation	p<0.010
						+	Open areas	p<0.25
						+	Herbaceous vegetation	p<0.010
						+	Water bodies	p<0.005

*** No significant

Table 5. Part 1. Associations between land cover and insect abundance by scale of analysis (circles of the indicated radii around sampling sites). Named taxa are those with significant associations with land cover as identified by CCA. CCA was performed for each group of insects (aphids and/or natural enemies) for combinations of scale and cover class previously identified as significant by AIC (Table 3).

Scale (m)	**Cover class**									
	Infrastructure		**Woody vegetation**		**Herbaceous vegetation**		**Open areas**		**Water bodies**	
	Natural enemies	**Aphids**	**Natural enemies**	**Aphids**	**Natural enemies**	**Aphids**	**Natural enemies**	**Aphids**	**Natural enemies**	**Aphids**
10		Aphis sp (+)			Syrphidae (+)		Braconidae (+)			
		Myzus sp (+)					Ichneumonidae (+)			
		Metopolopium sp (+)					Coccinelidae (-)			
		Microparsus sp (-)								
		Geopemfigus sp (-)								
		Tetraneura sp (-)								
20					Syrphidae (+)	Geopemfigus sp (+)	Braconidae (+)			
					Coccinelidae (-)	Tetraneura sp (+)	Ichneumonidae (+)			
						Microparsus sp (-)	Coccinelidae (-)			
						Macrosifum sp (-)				
						Myzus sp (-)				
40			Syrphidae (+)			Geopemfigus sp (+)				
			Coccinelidae (+)			Tetraneura sp (+)				
						Macrosifum sp (-)				
						Microparsus sp (-)				
						Myzus sp (-)				
						Nasonovia sp (-)				
80			Syrphidae (+)							

Table 5. Part 2.

Scale (m)	Cover class									
	Infrastructure		Woody vegetation		Herbaceous vegetation		Open areas		Water bodies	
	Natural enemies	Aphids	Natural enemies	Aphids	Natural enemies	Aphids	Natural enemies	Aphids	Natural enemies	Aphids
160						Geopemfigus sp (+)		Macrosifum sp (+)		Geopemfigus sp (+)
								Microparsus sp (+)		Tetraneura sp (+)
								Tetraneura sp (-)		
								Myzus sp (-)		
320						Geopemfigus sp (+)				Myzus sp (+)
						Microparsus sp (+)				Uroleucon sp (+)
										Brevicoryne sp (+)
640		Myzus sp (+)					Ichneumonidae (+)		Ichneumonidae (+)	
		Metopolopium sp (+)					Chalcididae (+)		Braconidae (+)	
		Dysaphis sp (+)					Syrphidae (-)		Coccinelidae (+)	
		Macrosifum sp (+)								
		Geopemfigus sp (-)								
		Tetraneura sp (-)								
1250				Myzus sp (+)		Wahlgreniella sp (+)		Aphis sp (+)	Braconidae (+)	
				Uroleucon sp (+)		Brevicoryne sp (+)		Metopolopium sp (+)	Syrphidae (-)	
				Wahlgreniella sp (+)		Microparsus sp (+)		Rhopalosiphum (+)		
				Macrosifum sp (+)						

Figures

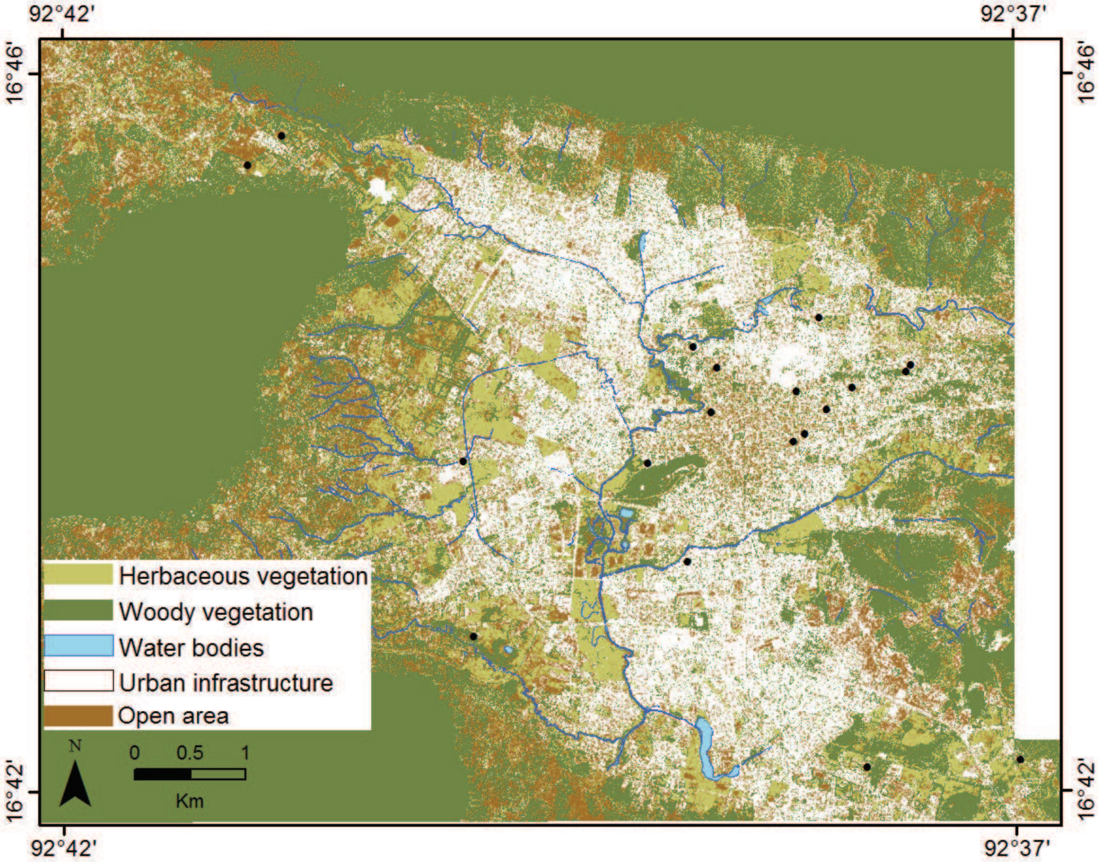

Figure 1. Land cover classification for San Cristóbal de Las Casas, Chiapas. Black dots indicate garden study sites.

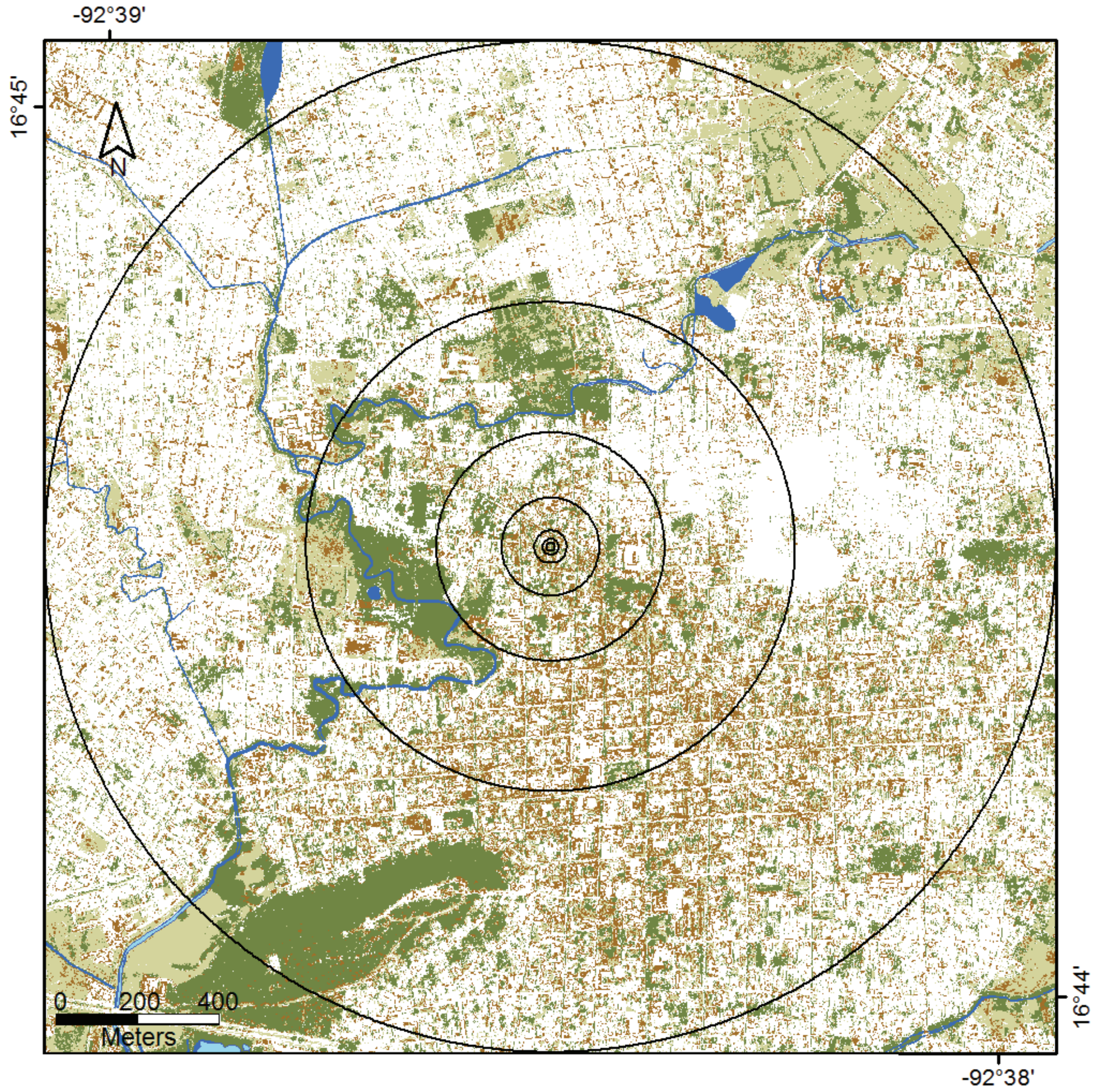

Figure 2. Example of circular landscape sectors (10, 20, 40, 80, 160, 320, 640, and 1250 m radii) for land cover analysis around a sampling site.

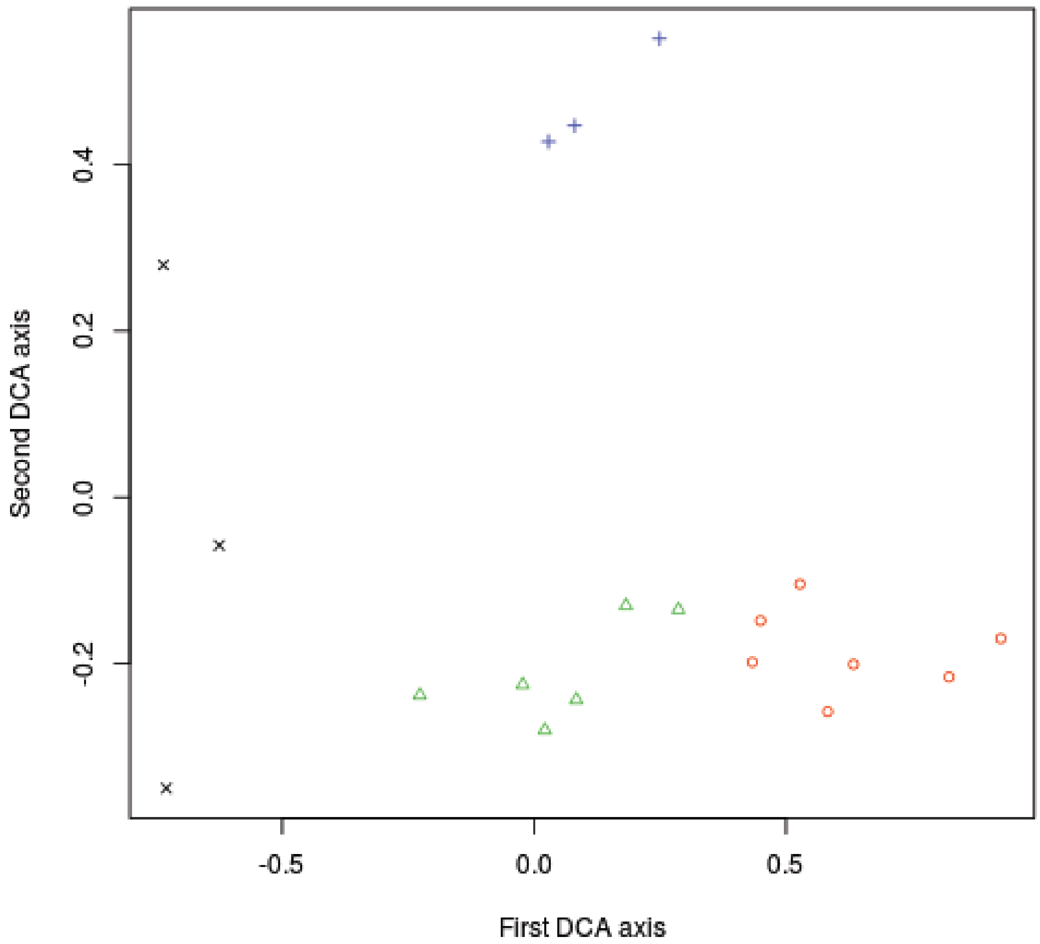

Figure 3. Detrended correspondence analysis of insect communities with site groupings: group 1(o) consisting of seven sites spread across the city; group 2 **(Δ)**, with six sites spread across the city; group 3 (+) with three periurban sites; and group 4 (x) with two roof garden and one garden in a cement patio.

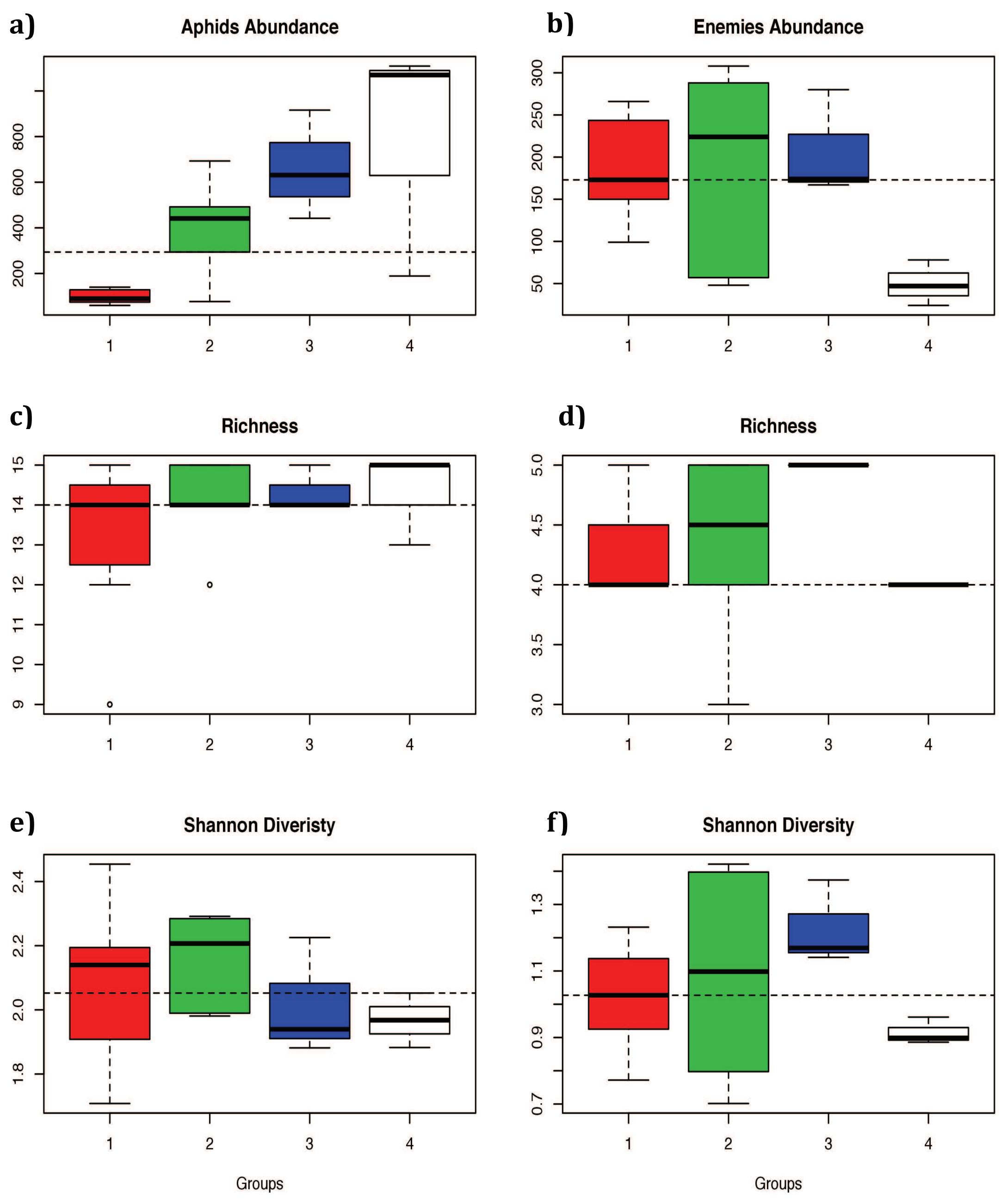

Figure 4. Box plots of abundance, observed richness of taxa (at the narrowest level identified for each group), and Shannon diversity indices for aphids and their natural enemies. Dark lines inside each box are median values, while the top and bottom of the boxes show third and first quartiles respectively; the inter-quartile range (IQR). Whiskers designate maximum and minimum values, or, where the difference between the minimum value and the first quartile or the maximum value and the third quartile exceeds 1.5*IQR, then the whisker extends to the smallest or largest value within 1.5*IQR. Data outside these limits are indicated by points.

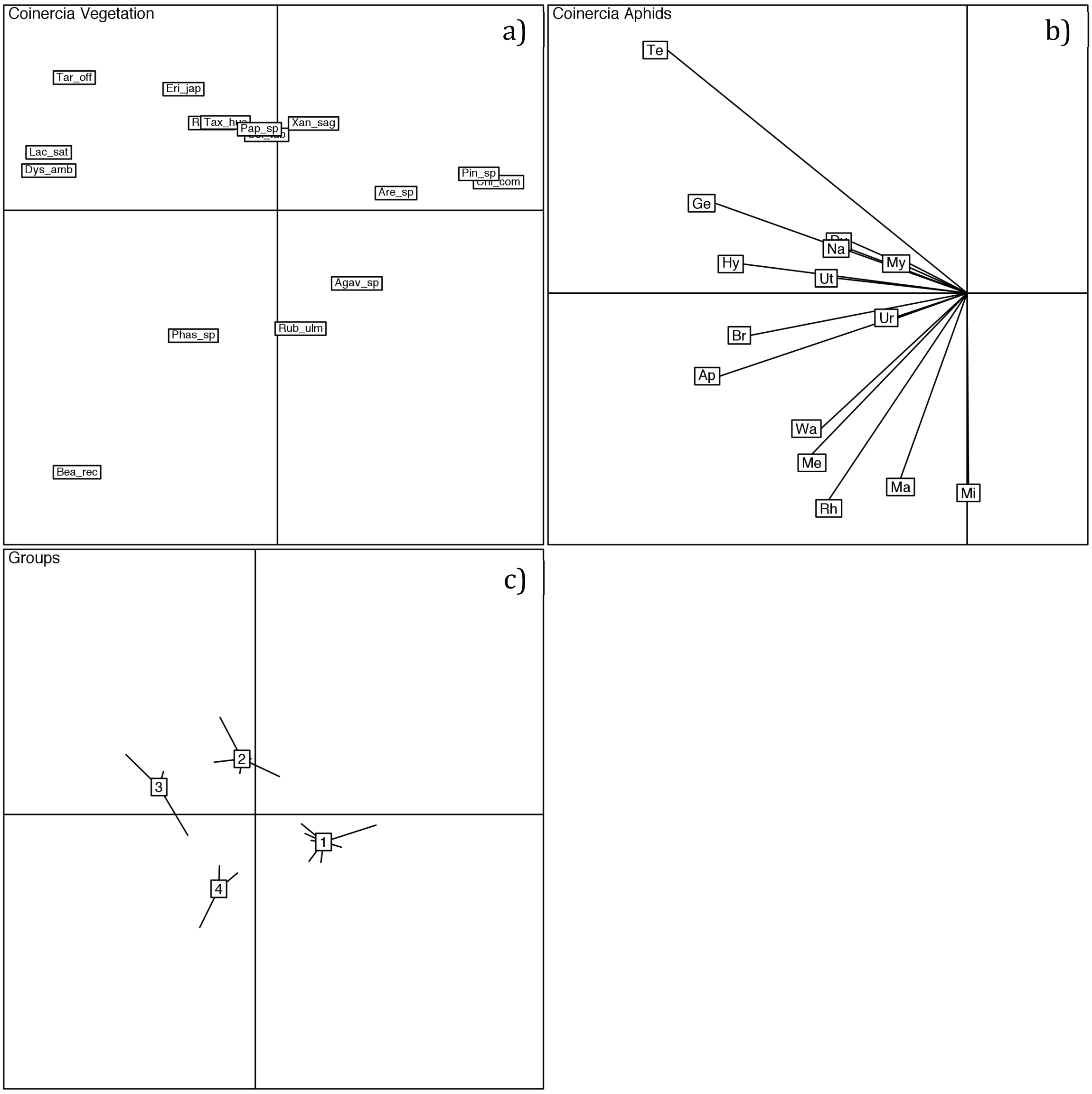

Figure 5. Conertia Analisis for vegetation (a), aphid (b) and site groups (c). Visual analysis of the coinertia plots suggests association between site group ONE and the plants Arecaceae sp., *Pinus* sp., and *Chrlophytum comosum* but no association with aphids. Site groups TWO and THREE was associated with the aphids *Tetraneura sp., Geopemphigus sp., Utamphorophora sp., Hyperomyzus sp., Nasonovia sp*., and *Uroleucon*, and the plants *Taxodium huegelii, Eriobotrya japónica, Papaver* sp., *Ruta graveolens, Dysphania ambrosioides, Xanthosoma sagittifolium,* and *Solanum tuberosum.* Abbreviations for plant taxa are listed in Table 2 and those for insects in Appendix 2.

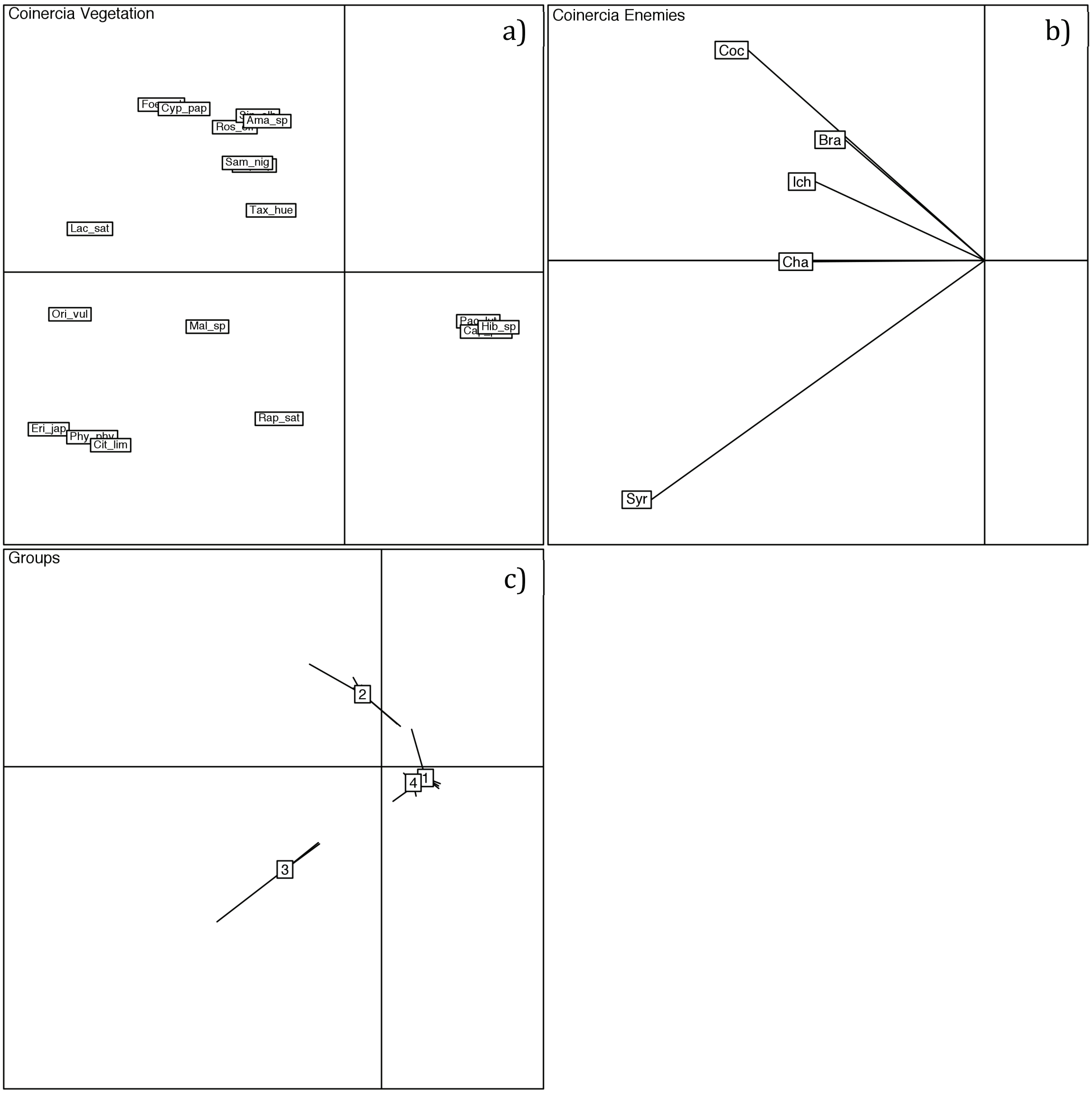

Figure 6. Coinertia análisis for vegetation (a), natural enemies (b) and site groups (c). Visual analysis of the coinertia plots suggests association between site groups ONE and FOUR and shrubs (*Hibiscus sp, Pachystachys lutea, Capsicum pubescens*) but no association with naturale enemies. Site group TWO was associates with natural enemies (Braconidae, Ichneumonidae y Coccinellidae), and the plants (*Taxodium huegelii, Foeniculum vulgare, Papaver sp., Cyperus papyrus, Rosmarinus officinalis, Prunus persica, Sinapis alba, Sambucus nigra, Lactuca sativa*). Site group THREE, Syrphidae was associated with tres and shrubs (*Eriobotrya japonica, Malus sp., Physalis philadelphica, Citrus limon, Raphanus sativus, Origanum vulgare*). Abbreviations for plant taxa are listed in Table 2 and those for insects in Appendix 2.

Supporting information

Appendix 1. Plants identified in garden sites. Abundance is the total number of individuals found across all 19 sites.

Plants	Abrevviature	Abundance
Agapanthus africanus	*Aga_afr*	9
Agave sp.	*Agav_sp*	48
Allium cepa	*All_cep*	124
Allium sativum	*All_sat*	7
Alnus sp.	*Aln_sp*	1
Aloe vera	*Alo_ver*	42
Amaranthus hybridus	*Ama_hyb*	183
Amaranthus sp.	*Ama_sp*	12
Apium graveolens	*Api_gra*	9
Arecaceae	*Are_sp*	18
Artemisia absinthium	*Art_abs*	16
Artemisia ludoviciana	*Art_lud*	16
Arundo sp.	*Aru_sp*	1
Beaucarnea recurvata	*Bea_rec*	3
Beta vulgaris var. Cicla	*Bet_vul*	166
Bougainvillea glabra	*Bou_gla*	8
Brassica oleracea var. Italica	*Bra_ole*	18
Brassica oleracea var. Viridis	*Bra_ole_v*	137
Brugmansia arborea	*Bru_arb*	10
Cactaceae sp.	*Cact_sp*	6
Calendula officinalis	*Cal_off*	19
Canna indica	*Can_ind*	91
Capsicum pubescens	*Cap_pub*	2
Capsicum sp.	*Caps_sp*	3
Chamaemelum nobile	*Cha_nob*	18
Chlorophytum comosum	*Chl_com*	11
Cichorium intybus	*Cic_inty*	66
Citrus limon	*Cit_lim*	13
Citrus sinensis	*Cit_sin*	1
Cnidoscolus chayamansa	*Cni_cha*	5
Coffea arabica	*Cof_ara*	6
Coriandrum sativum	*Cor_sat*	59
Crasulaceae	*Cras_sp*	4
Crataegus pubescens	*Crat_pub*	3
Crataegus sp	*Cra_sp*	7
Cucurbita ficifolia	*Cuc_fic*	11
Cucurbita sp.	*Cuc_sp*	9

Cupressus sp.	*Cup_sp*	9
Cydonia oblonga	*Cyd_obl*	5
Cymbopogon citratus	*Cym_cit*	11
Cyperus papyrus	*Cyp_pap*	8
Daucus carota	*Dau_car*	45
Dianthus caryophyllus	*Dia_car*	4
Dysphania ambrosioides	*Dys_amb*	40
Eichhornia sp	*Eich_sp*	7
Equisetum arvense	*Equ_arv*	2
Eriobotrya japonica	*Eri_jap*	7
Eruca sativa	*Eru_sat*	61
Erythrina americana Miller	*Ery_ame*	17
Ficus carica	*Fic_car*	15
Foeniculum vulgare	*Foe_vul*	28
Fragaria vesca	*Frag_ves*	44
Geranium sp.	*Ger_sp*	7
Hibiscus sp.	*Hib_sp*	7
Hylocereus sp.	*Hyl_sp*	2
Impatiens walleriana	*Imp_wal*	1
Jacaranda mimosifolia	*Jac_mim*	2
Jasminum sp.	*Jas_sp*	1
Lactuca sativa	*Lac_sat*	558
Leucaena leucocephala	*Leu_leu*	2
Ligustrum vulgare	*Lig_vul*	22
Lilium sp.	*Lil_spp*	116
Magnolia sp.	*Magn_sp*	5
Malus sp.	*Mal_sp*	21
Mangifera	*Man_sp*	4
Menta sativa	*Men_sat*	25
Monstera deliciosa	*Mon_del*	4
Musaceae	*Mus_sp*	1
Nicotiana tabacum	*Nic_tab*	6
Ocimum basilicum	*Oci_bas*	2
Oenothera rosea	*Oen_ros*	117
Opuntia sp.	*Opun_sp*	112
Oreopanax sp.	*Oreo_sp*	2
Origanum vulgare	*Ori_vul*	17
Pachystachys lutea	*Pac_lut*	2
Papaver sp.	*Pap_sp*	10
Passiflora edulis	*Pas_edu*	3
Passiflora sp.	*Pas_sp*	3
Persea americana	*Per_amer*	32
Petroselinum crispum	*Petr_cri*	19

Phaseolus sp.	*Phas_sp*	10
Phaseolus vulgaris	*Pha_vul*	8
Phyllostachys aurea	*Phy_aur*	11
Physalis philadelphica	*Phy_phy*	35
Pinus sp.	*Pin_sp*	8
Piper auritum	*Pip_aur*	31
Podocarpus matudae Lundell	*Pod_mat*	45
Portulaca oleracea	*Por_ole*	16
Prunus cerasifera	*Pru_cer*	2
Prunus domistica	*Pru_dom*	2
Prunus persica	*Pru_per*	8
Prunus virginiana	*Pru_vir*	14
Psidium sp.	*Psid_sp*	1
Pteridophyta	*Pte_sp*	4
Punica granatum	*Pun_gra*	1
Pyrus malus	*Pyr_mal*	39
Raphanus sativus	*Rap_sat*	277
Rheum rhabarbarum	*Rhe_rha*	108
Rosa sp.	*Ros_sp*	73
Rosmarinus officinalis	*Ros_off*	13
Rubus idaeus	*Rub_ida*	7
Rubus ulmifolius	*Rub_ulm*	10
Rumex sp.	*Rum_sp*	60
Ruta graveolens	*Rut_gra*	13
Salvia hispanica	*Sal_hisp*	12
Sambucus nigra	*Sam_nig*	5
Sechium edule	*Sec_edu*	8
Senecio sp.	*Sen_sp*	1
Sinapis alba	*Sin_alb*	100
Solanum lycopersicum	*Sol_lyc*	4
Solanum tuberosum	*Sol_tub*	101
Tagetes erecta	*Tag_ere*	6
Taraxacum officinale	*Tar_off*	74
Taxodium huegelii	*Tax_hue*	9
Vicia faba	*Vic_fab*	10
Xanthosoma sagittifolium	*Xan_sag*	18
Zantedeschia aethiopica	*Zan_aet*	6
Zea mays	*Zea_may*	132

Appendix 2.

Insects	**Abbreviature**	**Abundance**
Aphids		
Aphis	Ap	1595
Brevicoryne	Br	1542
Hyperomyzus	Hy	751
Myzus	My	339
Wahigreniella	Wa	115
Geopemphigus	Ge	680
Dysaphis	Dy	507
Uroleucon	Ur	248
Nasonovia	Na	281
Rhopalosiphum	Rh	266
Utamphorophora	Ut	246
Macrosiphum	Ma	55
Tetraneura	Te	696
Metopolophium	Me	15
Microparsus	Mi	155
Parasitoids wasp		
Chalcidoidae	Cha	1727
Braconidae	Bra	747
Ichneumonidae	Ich	432
Predators		
Syrphidae	Syr	145
Coccinelidae	Coc	193

CONCLUSIÓN

En la ciudad de San Cristóbal de Las Casas prevalecen áreas de vegetación que favorecen la abundancia de la comunidad de insectos. Su contexto histórico y condiciones fisiográficas han permitido la existencia de áreas de vegetación herbácea y leñosa indispensables para el desplazamiento de diferentes grupos de insectos.

Al estudiar el sistema trófico áfidos-enemigos naturales en huertos urbanos y periurbanos, se sugiere que la abundancia de áfidos y enemigos naturales en los huertos es dependiente de la composición de plantas cultivadas así como de la composición del paisaje circundante a las parcelas, entre otros factores. Huertos embebidos en la mancha urbana y carentes de estratos arbóreo y arbustivo presentaron mayor abundancia de áfidos y menor de enemigos naturales. En estos sitios, la regulación de potenciales plagas puede ser inadecuada.

En una perspectiva de paisaje, la cobertura de vegetación leñosa próxima a los huertos urbanos promueve la presencia de enemigos naturales –depredadores, principalmente- , y en consecuencia, aquellas casas ubicadas en el centro de la ciudad que carecen del espacio necesario para tener arboles, pueden ser favorecidas por la cercanía a otras o a parques y jardines públicos con vegetación leñosa.

Con el auge mundial por la agricultura urbana, este trabajo contribuye a la literatura sobre aspectos ecológicos, sugiriendo que la regulación de potenciales plagas en estas áreas será favorecida por la diversificación de plantas cultivadas, siempre y cuando se ubiquen en un paisaje con diversas coberturas de vegetación. Para el caso de los huertos urbanos de San Cristóbal de Las Casas, es recomendable continuar con un manejo diversificado de plantas dentro de los huertos. Mientras que a nivel de la zona urbana , la conservación de áreas verdes con diversidad estructural de vegetación puede promover condiciones para el establecimiento de enemigos naturales.

LITERATURA CITADA EN CAPITULO DE INTRODUCCION

Altieri, M.A., Letourneau, D.K. (1982). "Vegetation management and biological control in agroecosystems". Crop Protection, 1, pp. 405-430.

Altieri, M.A. (1999). "The ecological role of biodiversity in agroecosystems". Agriculture, Ecosystems & Environment, 74, pp. 19–31.

Altieri, M.A., Nicholls, C.I. (1999). "Biodiversity, ecosystem function and insect pest management in agricultural systems". En: W.W. Collins y C.O. Qualset (eds), Biodiversity in Agroecosystems.

Atauri, J., de Lucio, J. (2001). "The role of landscape structure in species richness distribution of birds, amphibians, reptiles and lepidopterans in Mediterranean landscapes". Landscape Ecology, 16, pp. 147–159.

Bailey, C.G. (1976). "Temperature effects on nondiapause development in Mamestra configurata (Lepidoptera: Noctuidae)". Canadian Entomologist, 108, pp. 1339–1344.

Banaszak, J., Cierzniak, T. (2002). "Environmental islands of agricultural landscape as refuges of polinating insects – preliminary evaluation". En: J. Banaszak, ed. Environmental Islands. Biodiversity and a Preliminary Typology. Bydgoszcz: Bydgoszcz University Press, pp. 105-125.

Banks, J. E. (1998). "The scale of landscape fragmentation affects herbivore response to vegetation heterogeneity". Oecologia, 117, pp. 239–246.

Barttlet, B. (1958). "Laboratory studies on selective aphicides favoring natural enemies of the spotted alfalfa aphid". J. Econ. Entomol., 51, pp. 374-378.

Bianchi, F. J. J., Booij, C. J. H., Tscharntke, T. (2006). "Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control". Proceedings. Biological sciences / The Royal Society, 273, pp.1715–27.

Bowne, D. R., Peles, J. D., Barrett, G. W. (1998). "Effects of landscape spatial structure on movement patterns of the hispid cotton rat (Sigmodon hispidus)". Landscape Ecology.

Cappuccino, N., Houle, M. J., Stein, J. (1999). "The influence of understory nectar resources on parasitism of the spruce budworm Choristoneura fumiferana in the field". , pp.1994–1997.

Cermelli, M. (1989). "Aphids that affect potato in Venezuela". Fonaiap Divulga, 7, pp. 33-35

Cermelli, M. (2005). "Los áfidos de importancia agrícola en Venezuela y algunas observaciones sobre ellos (Homoptera; Aphididae)". Agronomía Tropical, 20, pp. 15-61.

Coll, M. (1998). “Parasitoid activity and plant species composition in intercropped systems”. En Pickett, C. H., Bugg, R. L. (eds.) Enhancing Biological Control. Berkeley, CA: University of California Press, pp. 85–120.

Corbett, A., Rosenheim, J.A. (1996). “Impact of natural enemy overwintering refuge and its interaction with the surrounding landscape”. Ecological Entomology, 21, pp. 155-164.

Cousons, S.A., Ericksson, O. (2002). “The influence of management history and habitat on plant species richness in a rural hemiboreal landscape”. Landscape Ecology, 17, pp. 517-529.

Croft, B. A. (1989). “Arthropod biological control agents and pesticides”. Wiley, New York, p.723.

Cronin, J.T. (2004). “Host–parasitoid extinction and recolonization in a fragmented prairie landscape”. Oecologia, 139, 503–514.

Czechowski, W. (1982). “Occurrence of carabids (Coleoptera: Carabidae) in the urban greenery of Warsaw according to the land utilization and cultivation”. Mem. Zool., 39, pp. 103 -108.

Davies, R. G., Barbosa, O., Fuller, R. a., Tratalos, J., Burke, N., Lewis, D., Warren, P. H., et al. (2008). “City-wide relationships between green spaces, urban land use and topography”. Urban Ecosystems, 11, pp. 269–287.

Deelstra, T., Girardet, H. (2000). “Urban agriculture and sustainable cities”. En: N. Bakker, M. Dubelling, S. Gundel, V. Sabel-Koschella, A. Zeeuw, (eds.) Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda. Feldafing: Food and Agriculture Development Centre.

Díaz, S., D. Tilman, J. Fargione, F.S. Chapin III, R. Dirzo et al. (2005). “Biodiversity regulation of ecosystem services”. En: R. Hassan, R. Scholes y N. Ash (eds.), Ecosystems and hu- man well-being: Current state and trends, Vol. 1. Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment. Island Press, Washington, D.C. pp. 297-329.

Dyer, L. E., Landis, D. A. (1996). “Effects of habitat, temperature, and sugar availability on longevity of Eriborus terebrans (Hymenoptera: Ichneumonidae)”. Environ. Entomol., 25, pp. 1192–1201.

Ehrlich, P.R., Murphy, D.D., Singer, M.C., Sherwood, C.B., White, R.R., Brown, I.L., (1980). “Extinction, reduction, stability and increase: the response of checkerspot butterfly (Euphydryas) populations to the California drought”. Oecologia, 46, pp. 101–105.

Fetridge, E. D., Ascher J. S., Langellotto, G. A. (2008). “The bee fauna of residential gardens in a suburb of New York City (Hymenoptera: Apoidea)”. Annals of the Entomological Society of America, 101, pp. 1067–1077.

Forman, R. T. (1995). “Land mosaics: the ecology of landscape and regions”. Cambridge, University Press.

Gibb, H. Hochuli, D.F. (2002). “Habitat fragmentation in an urban environment: large and small fragments support different arthropod assemblages”. Biological Conservation, 106, pp. 91–100.

Gliessman, S. R. (2002). “Agroecología, procesos ecológicos en agricultura sostenible”. Turrialba: LIOCAT.

Grau, H. R., Hernández, M. E., Gutierrez, J., Gasparri, N. I., Casavecchia, M. C., Flores-ivaldi, E. E., Paolini, L. (2008). “A Peri-Urban Neotropical Forest Transition and its Consequences for Environmental Services”. , 13. pp.

Gurr, G. M., Wratten, S. D., Barbosa, P. (2000). “Success in conservation biological control of arthropods”. En: G. Gurr and S. D. Wratten (eds.) Biological Control: Measures of Success. Dordrecht, the Netherlands: Kluwer Academic Publishers, pp. 105–132.

Hailemichael, Y., Smith Jr, J. W. (1994). “Development and longevity of Xanthopimpla stemmator (Hymenoptera: Ichneumonidae) at constant temperaturas”. Ann. Entomol. Soc. Am., 87, pp. 874–878.

Heimpel, G. E., Jervis, M. A. (2005). “Does floral nectar improve biological control by parasitoids ?”

Holman, J. (1974). “Los áfidos de Cuba”. La Habana: Instituto Cubano del Libro.

Horn, D. J. (1981). “Effect of weedy backgrounds on colonization of collards by green peach aphid, Myzus persicae, and its major predators”. Environ. Entomol. 10, pp. 285-289.

Hunter, M. D. (2002). “Landscape structure, habitat fragmentation, and the ecology of insects”. Agricultural and Forest Entomology, 4, pp. 159–166.

Jmhasly, P., Nentwig, W. (1995). “Habitat management in winter wheat and evaluation of subsequent spider predation on insect pests”. Acta Oecologica, 16, pp. 389–403.

Kapos, V., (1989). “Effects of forest fragmentation on the water status of forest patches in the Brazilian Amazon”. Journal of Tropical Ecology, 5, pp. 173–185.

Kindlmann, P., Jarošík, V., Dixon, A. (2007). “Population dynamics”. En: H.F. van Emden y R. Harrington, (ed.) Aphids as crop pest. Londres: CAB Internacional, pp. 311-329.

Kruess, A. (2003). “Effects of landscape structure and habitat type on a plant-herbivore-parasitoid community”. Ecography, 26, pp. 283–290.

Kruess A., Tscharntke T. (2000). “Species richness and parasitism in a fragmented landscape: experiments and field studies with insects on Vicia sepium”. Oecologia, 122, pp. 129–137.

Kruess, A., Tscharntke, T. (1994). “Habitat fragmentation, species loss, and biological control”. Science, 264, pp. 1581-1584.

Landis, D. A., Wratten S. D., Gurr, G. M. (2000). “Habitat maagment to conserve natural enemies of arthropods pests in agriculture”. Annu. Rev. Entomol., 45, pp. 175-201.

Leather, S. R. (1993). “Overwintering in six arable aphid pests: a review with particular relevance to pest management”. J. Appl. Entomol., 116, pp. 217–233.

Letourneau, D. K., Armbrecht, I., Rivera, B. S., Lerma, J. M., Carmona, E. J., Daza, M. C., Escobar, S., et al. (2011). “Does plant diversity benefit agroecosystems? A synthetic review”. Ecological applications : a publication of the Ecological Society of America, 21, pp. 9–21.

Lugo, A. E. (2010). “Let’s Not Forget the Biodiversity of the Cities”. , 42, pp. 576–577.

Maier, C. T. (1981). “Parasitoids emerging from puparia of Rhagoletis pomonella (Diptera, tephritidae) infesting hawthorn and apple in Connecticut USA”. Can. Entomol., 113, pp. 867–870.

Matienzo, Y., Veitía, M. M., Alayón, G. (2011). “Composición y riqueza de insectos y arañas asociados a plantas florecidas en sistemas agrícolas urbanos”. Fitosanidad, 15, pp. 25-29.

McGarr R. L., (1942). “Relation of fertilizers to the development of the cotton aphid”. Journal Economic Entomology, 35, pp. 482–483.

Olmos, J. L. (2012) El blog del professor Josebio. <Accesado por última vez: 25 de octubre de 2012> http://profesorjosebio.blogspot.mx/2010/04/practica-con-pulgones.html

Perrin, R. M. (1975). “The role of the perennial stinging nettle Urtica dioica as a reservoir of beneficial natural enemies”. Ann. Appl. Biol., 81, pp. 289–297.

Pettit, F. L., Loader, C. A., Schon, M. K. (1994). “Reduction of nitrogen concentration in the hydroponic solution on population growth rate of the aphids (Homoptera: Aphididae) Aphis gossypii on cucumber and Myzus persicae on pepper”. Environmental Entomology, 23, pp. 930–936.

Pickett, S. T., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E., Kaushal, S. S., Victoria Marshall, Brian P. McGrath, C.H. Nilon, R.V. Pouyat, Katalin Szlavecz, Austin Troyl, Paige Warren (2011). “Urban ecological systems: scientific foundations and a decade of progress”. Journal of environmental management, 92, pp. 331–62.

Pinkus, M.A. (2006). “Diversidad y estructura poblacional de arañas en un paisaje fragmentado en San Fernando, Chiapas”. Tesis Doctoral. San Cristóbal de las Casas. El Colegio de la Frontera Sur.

Poveda, K., Martínez, E., Kersch-Becker, M. F., Bonilla, M. A., Tscharntke, T. (2012). “Landscape simplification and altitude affect biodiversity, herbivory and Andean potato yield”. Journal of Applied Ecology, 49, pp. 513–522.

Powell, G., Tosh, C.R., Hardie, J. (2006). “Host plant selection by aphids: behavioral, evolutionary, and applied perspectives”. Annu. Rev. Entomol. 51, pp. 309–330.

Premat, A. (2005). “Moving Between the Plan and the Ground: Shifting Perspectives on Urban Agriculture in Havana, Cuba”. En: J.A. Mougeot, ed. s/a. Agropolis: The Social, Political, and Environmental Dimensions of Urban Agriculture. Earthscan/IDRC. Capítulo 6.

Puszkar, L., Puszkar, T., Michalska, Z. (2002). “Midfield woodlots as reservoirs of grophages”. En: J. Banaszak, ed. Environmental islands. Biodiversity and a preliminary typology. Bydgoszcz: Bydgoszcz University Press, pp. 293-305.

Ragsdale, D.W., Landis, D.A., Brodeur, J., Heimpel, G.E., Desneux, N. (2011). “Ecology and management of the soybean aphid in North America”. Annu. Rev. Entomol. 56, pp. 375–399.

Rahim, A., Hashmi, A. A., Khan, N. A. (1991). “Effects of temperature and relative humidity on longevity and development of Ooencyrtus papilionis Ashmead (Hymenoptera: Eulophidae) a parasite of the sugarcane pest Pyrilla perpusilla Walker (Homoptera: Cicadellidae). Environ. Entomol., 20, pp. 774–775.

Rand, T.A., Tylianakis, J.M. & Tscharntke, T. (2006). “Spillover edge effects: the dispersal of agriculturally subsidized insect natural enemies into adjacent natural hábitats”. Ecology Letters, 9, pp. 603–614.

Richards, O.W., Davies. R.G. (1984). “Tratado de Entomología”. 10 a Edición. Barcelona: Ediciones Omega.

Rieux, R., Simon, S. & Defrance, H. (1999). “Role of hedgerows and ground cover management on arthropod populations in pear orchards”. Agric. Ecosyst. Environ., 73, pp. 119–127.

Schmitz, G. (1996). “Urban ruderal sites as secondary habitats for phytophagous insects”. Verh. Ges. Okol. 26, pp. 581- 585.

Smith RM, Gaston KJ, Warren PH, Thompson K (2006a). "Urban domestic gardens (VI): environmental correlates of invertebrate species richness". Biodiversity and Conservation, 15, pp. 2415–2438.

Smith RM, Gaston KJ, Warren PH, Thompson K (2006b). "Urban domestic gardens (VIII): environmental correlates of invertebrate abundance". Biodiversity and Conservation, 15, pp. 2515–2545.

Steffan-Dewenter, I., Münzenberg, U., Tscharntke, T. (2001). "Pollination, seed set and seed predation on a landscape scale". Proceedings of the Royal Society London, 268, pp. 1685–1690.

Stern, V.M., Van Den Bosh, R. (1959). "The integration of chemical and biological control of the spotted alfalfa aphid. Part II. Field experiments on the effects of insecticides". Hilgardia, 29. pp. 103-130.

Thapa, R. B., Murayama, Y. (2008). "Spatial structure of land use dynamics in Kathmandu valley. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information". Sciences. 37. Parte B8. Beijing.

Thevathasan, N.V., Gordon, A.M. (2004). "Ecology of tree intercropping systems in the North températe region: Experiences from southern Notorio, Canada". Agroforestry Systems, 61, pp. 257-268.

Thies, C., Roschewitz, I., Tscharntke, T. (2005) The landscape context of cereal aphid-parasitoid interactions. Proceedings of the Royal Society B, 272, 203–210.

Thies, C., Tscharntke, T. (1999). "Landscape structure and biological control in agroecosystems". Science, 285, pp. 893 - 895.

Tischendorf L, Bender DJ, Fahrig L. (2003). "Evaluation of patch isolation metrics in mosaic landscapes for specialist vs. generalist dispersers". Landscape Ecology, 18, pp. 41–50.

Tischendorf, L., Fahrig, L. (2000). "On the usage and measurement of landscape connectivity". Oikos, 90, pp. 7-19.

Tscharntke, T., Bommarco, R., Clough, Y., Crist, T. O., Kleijn, D., Rand, T. A., Tylianakis, J. M., et al. (2007). "Conservation biological control and enemy diversity on a landscape scale". , 43, pp. 294–309.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., Thies, C. (2005). "Landscape perspectives on agricultural intensification and biodiversity: ecosystem service management". Ecology Letters, 8, pp. 857–874.

Tscharntke, T., Steffan-Dewenter, I., Kruess, A., Thies, C. (2002). "Characteristics of insect populations on habitat fragments: A mini review". Oikos, pp. 229-239.

Tylianakis, J.M., Didham R.K., Wratten S.D. (2004). "Improved fitness of aphid parasitoids receiving resource subsidies". Ecology, 85, pp. 658–666.

van Emden, H. F. (1965). "The role of uncultivated land in the biology of crop pests and beneficial insects". Sci. Hort., 17, pp.121 –136.

van Rensburg, B., Chown, S., Van Jaarsveld, A., McGeoch, M. (2000). "Spatial variation and biogeography of sand forest avian assemblages in South Africa". Journal of Biogeography, 27, pp. 1385–1401.

Vásquez, L. (2010). "La agricultura urbana como elemento promotor de la sustentabilidad urbana. Situación actual y potencial en San Cristóbal de las Casas, Chiapas". Tesis de Maestría. Tijuana. El Colegio de la Frontera Norte y CICESE.

Vergara R.R., Galeano. O.P. (1994). “Interacciones poblacionales entre áfidos y sus enemigos naturales en algodonero, en dos zonas del Tolima”. Rev. Col. Ent., 20, pp. 15-22.

Völkl, W., Mackauer, M., Pell, J.K., Brodeur, J. (2007). “Predators, parasitoids and pathogens”. En: H.F. van Emden y R. Harrington, ed. Aphids as crop pest. Londres: CAB Internacional, pp. 187-233.

Wackers, F.L. (2004). “Assessing the suitability of flowering herbs as parasitoid food sources: flower attractiveness and nectar accessibility”. Biological Control, 29, pp. 307–314.

Waring, G. L., Cobb, N. S. (1992). “The impact of plant stress on herbivore population dynamics”. En: E. Bernays (ed.), Insect Plant Interactions, Vol IV. Boca Raton, Florida, USA, pp. 167–226.

Wood, S., S. Ehui, J. Alder, S. Benin, K.G. Cassman et al. (2005). “Food”. En: R. Hassan, R. Scholes y N. Ash (eds.), Ecosystems and human well-being: Current state and trends, Vol. 1, Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment. Island Press, Washington, D.C., pp. 209-242.

Wratten, S., Berndt, L., Gurr, G., Tylianakis, J., Fernando, P., Didham, R. (2003). “Additing floral diversity to enhance parasitoid fitness and efficacy”. 1er International Symposium on Biological Control of Arthropods, pp. 211-214.

Zabel J. Tscharntke T. (1998). “Does frag- mentation of Urtica habitats affect phytophagous and predatory insects differentially?”. Oecologia, 116, pp. 419–425.