Diversity of Herbivorous Communities in Blueberry Crops of Different Regions of Argentina

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ABSTRACT   When a crop is introduced into a new region the herbivorous insect communities are structured from the regional pool of species, and the spatio–temporal heterogeneity of the landscape and the spatial arrangement of habitat elements are essential for species diversity. The blueberry, *Vaccinium corymbosum* L., is a crop native to the northern hemisphere and was introduced in Argentina in the 1990s. We have analyzed the richness and diversity of insect herbivore communities in several blueberry crops located in different agricultural landscapes of Buenos Aires and Entre Ríos, in Argentina. In total, the number of families recorded throughout the study period was 31. The richness and the diversity showed significant differences among phenological stages and years, although the sites had an effect on the richness, in Buenos Aires. Aphidae was the most abundant family in all sites, followed by different families depending on the surrounding crops and their more common herbivores. The highest values of cumulative alpha diversity were in crops located in more changing landscapes. There were high values of temporal beta diversity everywhere. Spatial beta diversity was higher in Buenos Aires than in Entre Ríos, probably because the crops of the latter are located in similar landscapes. Gamma diversity was 29 families for communities of Buenos Aires and it was 15 families in Entre Ríos. The herbivorous communities in blueberry crops of Argentina are shaped by ectophagous generalist (South American and cosmopolitan) from the regional pool of species, characteristic of the landscape where the crops were introduced.

KEY WORDS   *Vaccinium corymbosum*, landscape, herbivorous, family diversity, family richness

When a crop is introduced into a new region the herbivorous insect communities are structured from the regional composition of species. Although at a regional scale biogeographic processes are the main determinants of the numerical structure of communities, at a local scale the ecological processes predominate (Strong et al. 1984, Gaston 2000b, Lewinsohn et al. 2005, Schowalter 2006). Both the richness and diversity of insects in a crop introduced reflect the communities' response to this new environment. Spatial variations at local, landscape, and regional scale, as temporary, let us understand the mechanisms through which communities are structured (Schluter and Ricklefs 1993, Whittaker et al. 2001).

To understand the importance of historical processes at a regional level, and ecological processes at a local level, studies of various components of species richness have been proposed: alpha diversity (α), the number of species within a habitat; beta diversity (β), which measures the change between the species in two communities in different places or landscapes; and gamma diversity (γ) or regional diversity, which refers to the number of species of all the communities

in the region (Whittaker et al. 2001, Koleff et al. 2003, Halffter and Moreno 2005, Schowalter 2006).

Spatio–temporal heterogeneity of the landscape and the spatial arrangement of habitat elements are essential for species diversity (Burel 1992). The survival and population abundance of arthropods in a crop depend on the suitability of the habitats and the characteristics of the surrounding landscape (Jeanneret et al. 2003).

The blueberry, *Vaccinium corymbosum* L. (Ericaceae), native of the northern hemisphere, was introduced in Argentina in the 1990s as a productive alternative destined mainly for export. Its introduction signifies a change in environmental conditions, primarily in terms of food resources for the communities of herbivores present in the ecosystem. The herbivorous insects that will adapt more quickly to the use of the blueberry crop in Argentina will be the native or established in the region, and most of them will be polyphagous (Strong et al. 1984) and ectophagous (Kennedy and Southwood 1984).

Moreover, the diversity of the local community can be explained by regional species composition (Gaston 2000b, Lewinsohn et al. 2005), so it is important to study considering different spatial scales (local, landscape, region). Several studies have found evidence of a linear increase of the local to regional diversity,

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suggesting that local communities are examples of regional pool of species (Gaston 2000b).

The analysis of insect herbivore communities in blueberry crops of Argentina, as a wide-scale comparative study, can contribute to the knowledge of the structure of herbivore assemblage on this particular plant, as well as the processes or factors that determine their local and regional variation.

In this system, the local alpha diversity will increase over time as a process of colonization from the regional pool of species. Also it will depend on the amount and combination of resources that the blueberry offers and the time that they are available. The presence of rare species, tourist's species, or both belonging to this pool of species will also increase alpha diversity. However, dominant herbivorous insect families in each community will be linked to the communities surrounding crops. In turn, the blueberry crop found in different agricultural landscapes will have higher spatial beta diversity than those crops located in similar landscapes.

We analyze the richness and diversity of insect herbivore communities in several blueberry crops located in different agricultural landscapes in Argentina. Also we compare the structure of these communities with those structures of Chile, where the crop was also introduced, and those of the United States, where it is a traditional crop.

Materials and Methods

Study Area. The study was conducted from June 2006 to December 2008 in six blueberry crops situated in Buenos Aires and Entre Ríos provinces, two important productive areas of Argentina. Four sites were selected in Buenos Aires: Gobernador Castro (33° 38′9.7″ S, 59° 51′6.4″ W); San Pedro (33° 42′6.9″ S, 59° 51′8.9″ W); Chascomús (35° 40′42.7″ S, 57° 56′55.8″ W); and Colonia Urquiza (34° 57′2.7″ S, 58° 04′55.9″ W); and two sites were selected in Entre Ríos: Concordia A (31° 19′29.09″ S, 58° 01′16.64″ W); and Concordia B (31° 19′29.09″ S, 58° 01′32.93″ W) (Fig. 1). In Buenos Aires the two first sites were typically citrus and stone fruit production areas, and in recent years the area devoted to extensive field crops, especially soybeans, has increased. The blueberry crop of Gobernador Castro was surrounded by citrus, soybeans, and small vegetable orchards, and the one located in San Pedro was surrounded by soybeans. The Chascomús blueberry crop area was typically of extensive crops while the Colonia Urquiza crop was in a horticultural and floricultural area under greenhouse and open field. In Entre Ríos the two crops selected were located in a citrus area, the site Concordia A was limited by other blueberry crops, and the site Concordia B was surrounded by citrus and other berries such as raspberries, blackberries, and boysenberries (*Rubus* spp.) (Fig. 2).

Relation of Sites to the Agricultural Landscape. An analysis of ordination "Detrended Correspondence Analysis" (DCA) (Hill and Gauche 1980) was done from a matrix of presence and absence of crops adjacent to the blueberry crop at each site. The model showed a differentiation of the sites in relation to crops that characterize the landscape at each site (the two first axes explained 60.9% of the variation). Concordia A and Concordia B were associated with berries and citrus, Gobernador Castro and San Pedro with citrus and extensive crops, Colonia Urquiza was closely associated with horticultural crops, and Chascomús to extensive crops (Fig. 3).

Sampling. A stratified random sampling design was used in the aerial part of the plant. Twenty sample units were taken in three plots in each crop. The sample unit consisted of three leaves, three buds, three flowers, and three fruit, depending on the phenological stage of the plant. Monthly samples were taken in the province of Buenos Aires and were grouped by crop phenological stage (Table 1). In Entre Ríos each phenological stage of the crop was sampled (Table 2).

Indices and Statistical Analysis. Analysis of herbivorous insect richness and diversity were done at family level (Gaston 1998, 2000a; Cagnolo et al. 2002; Giraldo Mendoza and Arellano Cruz 2002), because in some cases it was not possible to determine genus and species.

The richness was estimated with the index S, as the total number of families in the community and the diversity index used was Shannon (H') (Peet 1975, Begon et al. 2006). The relative abundance of each family of herbivores for each phenological stage, for the entire study period, was calculated with all data for each site.

A generalized linear model with Poisson distribution and log link function (Lindsey 1997) was used to examine the relationship between richness, sites, phenological stages, and years of study in each province. Data of 2006 were not considered in this analysis because the first two phenological stages were not sampled. The statistical significance of each variable was tested in turn in the model (forward stepwise procedure). The effects were tested by the Wald statistic with a significance level of 0.05.

Variations in the Shannon–Wiener diversity index were compared by one way repeated-measured analysis of variance. Previously, Mauchly's Sphericity test was used to test the assumption of circularity. When this assumption could not be met the adjustment of the F-statistic degrees of freedom was performed by the Greenhouse–Geisser method (Scheiner and Gurevitch 2001).

The local alpha diversity was calculated by phenological stage and per site. The average alpha diversity was estimated as the average local diversity of all phenological stages for each site each year. Average alpha diversity throughout the study period and cumulative alpha diversity per year and throughout the three year of study for each site were also calculated. The cumulative alpha diversity versus time for each site was plotted. To know the beta diversity among communities of herbivores in blueberry crops of different sites indices of similarity and dissimilarity and species replacement index of Whittaker (1972) were used. The qualitative similarity indices used were the

Fig. 1. Map of Argentina with the sites selected for the sampling (marked with black point). The circles show the principal areas devoted to the blueberry crop.

Jaccard and Sørensen similarity coefficient (Begon et al. 2006).

The replacement index was calculated as follows:

$$\beta = \frac{S}{\alpha} - 1$$

where S is the number of species recorded in a sample set (gamma diversity) and $\bar{\alpha}$ = average number of species in each sample (average alpha).

The stability of the communities was analyzed by temporal beta diversity (Halffter and Moreno 2005). Temporal beta diversity was calculated as the number of exclusive families in relation to the total richness of families between two consecutive samples within each crop (Moreno and Halffter 2001). This value varies between 0, when two consecutive samples are identical and one when they are completely different. The mean temporal beta diversity for the entire period of study was calculated for each site. It was related to the ratio of average alpha diversity (alpha diversity average/cumulative alpha diversity) using linear regression, after arcsine transformation of the variables. When the average alpha diversity represents a large proportion of cumulative alpha, the species composition is more stable over time than in the habitats where average
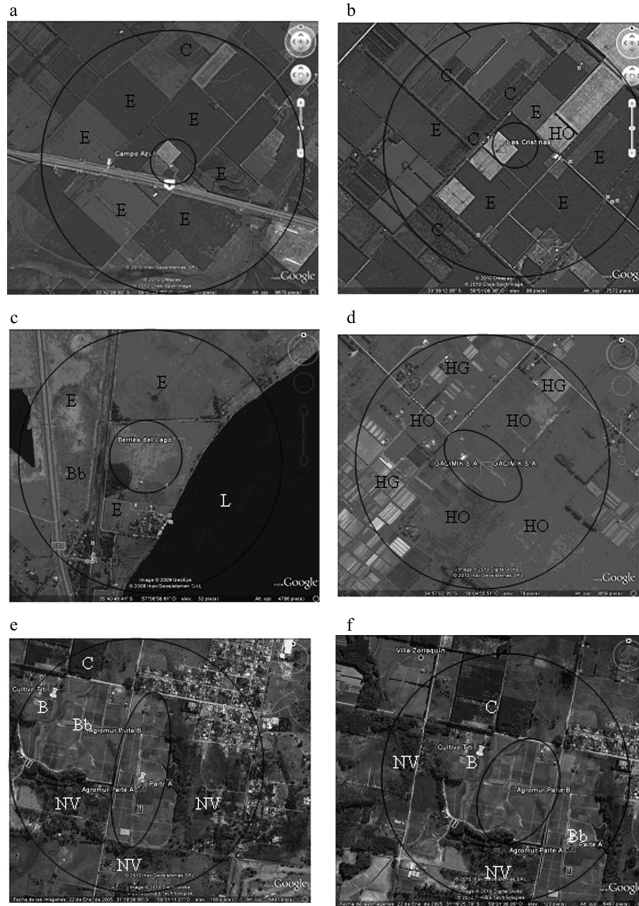
Fig. 2. Satelital photographs of selected blueberry crops sampled for herbivorous richness, diversity and relative abundance, and surrounding crops in Buenos Aires: a) San Pedro, b) Gobernador Castro, c) Chascomús, d) Colonia Urquiza, and in Entre Ríos: e) Concordia A, f) Concordia B. Small circle indicates the site and the bigger circle depicts 1.5 km radii around the blueberry crop and shows how crops are situated within different agricultural landscapes. C: citrics; E: extensive crops; HO: horticultural crops at open field; HG: horticultural crops at greenhouses; B: berries; Bb: blueberry; NV: natural vegetation; L: lagoon.

alpha diversity is considerably lower than the cumulative (Moreno and Halffter 2001).

The gamma diversity was calculated for each province, as follows:

$$\gamma = \bar{\alpha} \times \beta \times n$$

where $\bar{\alpha}$ is the average α diversity of n localities, β is the inverse of the average number of localities occupied by a family and n is the total number of localities (Schluter and Ricklefs 1993).
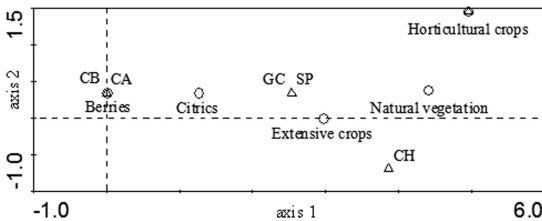

Fig. 3. Detrended Correspondence Analysis (DCA) to associate sites and agricultural landscapes. The first axis explained 56.9% of the variability while the second axis explained 3.7%. CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro, CA: Concordia A, CB: Concordia B. The circles show sites and triangles the kind of crop surrounding sites.

Table 1. Phenological stages of the blueberry crop in Buenos Aires and months that each stage involves

	Phenological stage	Month
V2	Summer budding	Jan-Feb-Mar
V3	Dormancy and the presence of senescent leaves	April-May
V1/R1	Budding starts, spring budding and flower bud formation	June-July
V1/R2	Spring budding and flowering starts	Aug-Sept
R3	Open flower, fruit formation, unripened fruit	Oct
R4	Ripe fruit	Nov-Dec

Table 2. Phenological stages of the blueberry crop in Entre Ríos and months that each stage involves

	Phenological stage	Month
V2	Summer budding	Dec-Jan-Feb
V3	Dormancy and the presence of senescent leaves	Mar-April-May-June
V1/R2-R3	Spring budding, open flower, and unripened fruit	July-Aug-Sept
R4	Rip fruit	Oct-Nov

Results

In total, the number of families recorded in all sites throughout the study period was 31. The 51.6% belonged to the Hemiptera order, the 19.3% to Lepidoptera, the 16.5% to Coleoptera, the 6.6% to Orthoptera, and the Thysanoptera and Hymenoptera orders were represented just by 3.2% each. In the Hemiptera order, 37.5% of the families belonged to Auchenorrhyncha, while Sternorrhyncha and Heteroptera represented 31.25% of the total each. Table 3 shows orders, families, and species registered.

In Buenos Aires, sites, phenological stages and years had a significant effect on variation of the richness of families (Table 4), which was higher in 2007 primarily in phenological stages of V2, V3, and R4. In Gobernador Castro the richness was higher than the other sites and less variable among phenological stages (Fig. 4).

In Entre Ríos, no differences were found in families' richness between sites, years, and phenological stages (Table 5).

The analysis of the diversity of families in Buenos Aires sites showed significant differences between phenological stages, and the interaction was significant too, while only 9% of significance was registered between sites (Table 6). It is noted that diversity has a similar pattern everywhere, except in Gobernador Castro in 2007, where diversity remained high during all phenological states. In general, V1/R1, V1/R2, and R3 showed lower values of diversity, while higher values were recorded in V2, V3, and R4 (Fig. 5).

In Entre Ríos, the diversity did not differ either between sites or among the phenological stages. The interaction was not significant (Table 7; Fig. 6).

In blueberry crops of Buenos Aires, Aphidae was the most abundant family in all sites, followed by Aleyrodidae, Coccidae and Thripidae in Colonia Urquiza, Tortricidae and Thripidae in Chascomús, Coccidae and Margarodidae in Gobernador Castro (Table 8). As it can be seen in San Pedro and Chascomús the other families present have very low relative abundances (Tabla 8), resulting in low values of diversity and high dominance. In contrast, in Gobernador Castro and Colonia Urquiza most of families were well represented and with similar relative abundances (Table 8), therefore diversity was higher and dominance was low. In Entre Ríos, Aphidae and Thripidae recorded the highest relative abundances, but other families as Margarodidae, Coccidae and Tortricidae have been well represented (Table 9).

Table 3. List of species found in blueberry crops in Buenos Aires and Entre Rios sites

Order	Family	Genus - species
Coleoptera	Curculionidae	*Naupactus xanthographus* (Germar)
		N. cervinus (Boheman)
	Chrysomelidae	*Colaspis varia* Lefebure
		Diabrotica speciosa (Germar)
		Disonychodes exclamationis (Boheman)
Hemiptera		
Sternorrhyncha	Aphidae	*Aphis spiraecola* Patch
		A. gossypii Glover
		Macrosiphum euphorbiae (Thomas)
	Coccidae	*Ceroplastes* sp.
		Coccus sp.
	Margarodidae	*Icerya purchasi* Maskell
	Pseudococcidae	*Planococcus* sp.
Auchenorrhyncha	Cicadellidae	*Paviloma victima* (Germar)
		Reticana lineada (Burmeister)
		Sonesimia grossa (Signoret)
Heteroptera	Coreidae	*Leptoglossus impressicollis* Berg
	Largidae	*Largus rufipennis* Laporte
	Lygaeidae	*Lygaeus alboornatus* Blanchard
		Nysius simulans Stål
		Oncopeltus fasciatus (Dallas)
	Pentatomidae	*Dichelops furcatus* (F.)
		Edessa sp.
		Nezara viridula (L.)
		Piezodorus guildinii (Westwood)
Lepidoptera	Megalopygidae	*Megalopyge amita* Schauss
	Psychidae	*Oiketicus* sp.
	Tortricidae	*Argyrotaenia sphaleropa* (Meyrick)
		Clarkeulia sp.
		Platynota sp.
Thysanoptera	Thripidae	*Caliothrips phaseoli* (Hood)
		Frankiniella gemina Bagnall
		F. shultzei (Trybom)
		F. occidentalis
		F. rodeos Moulton
		Frankliniella sp.
		Thrips Australis (Bagnall)
		T. tabaci Lindeman
		Thrips sp.
Diptera	Tephritidae	*Ceratitis capitata* (Wiedermann)

Alpha, Beta, and Gamma Diversity. Colonia Urquiza and Chascomús in Buenos Aires, and Concordia A in Entre Ríos, had the highest cumulative alpha diversity over the entire study period (Table 10).

The cumulative alpha diversity versus time for each site showed a different pattern for Buenos Aires and Entre Ríos. In the first one, it became asymptotic in late 2007 and early 2008 (Fig. 7), whereas at sites of Entre Ríos the cumulative alpha diversity was increasing throughout the period (Fig. 8).

The highest values of the mean temporal beta diversity were recorded for the province of Entre Ríos, 60% in Concordia A and 50% in Concordia B. In the province of Buenos Aires the highest values were found in the community of Colonia Urquiza (49.3), followed by Chascomús (40.6), Gobernador Castro (39.8), and San Pedro (37.4).

Table 4. Summary of the stepwise procedure used to build a multiple regression model for family richness in Buenos Aires blueberry crops

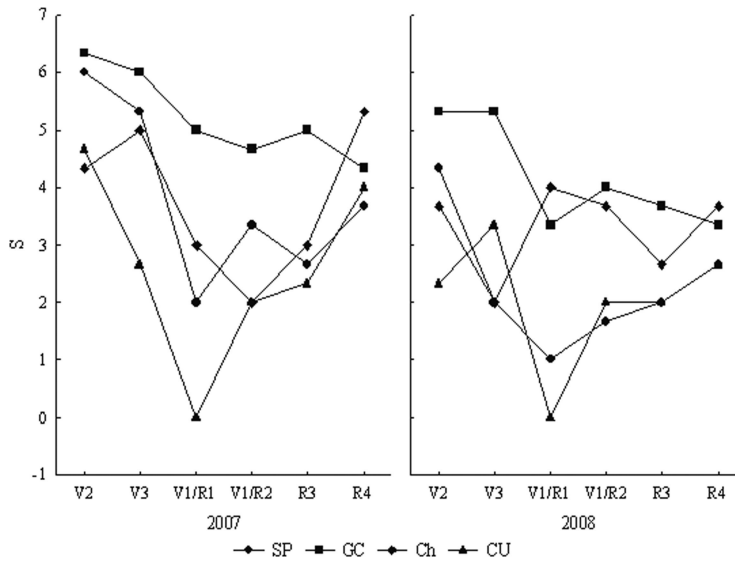| Model	Wald stat.	df	Wald P
+ sites	30.41	3	<0.0001
+ sites + phen. stages	24.87	5	<0.001
+ sites + phen. stages + years	8.83	1	0.003

Fig. 4. Richness of herbivorous families per phenological stage in each site of Buenos Aires during 2007 and 2008. V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R1: Budding starts, spring budding and flower bud formation, V1/R2: Spring budding and flowering starts, R3: Open flower, fruit formation, unripened fruit, R4: Ripe fruit. CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro.

The simple linear regression between temporal beta diversity and the proportion of average alpha diversity (average alpha diversity/cumulative alpha diversity) showed a negative but not significant slope ($P = 0.28$) (Fig. 9).

The qualitative similarity indices (Jaccard and Sørensen) (Table 11) calculated to compare the similarity between the communities of herbivores of the different sites in each province showed levels above 50% of similarity. The highest similarities were found between the herbivorous communities of Gobernador Castro and San Pedro in Buenos Aires. The two sites of Concordia also showed a high percentage of similarity.

The analysis of beta diversity (β), as a measure of the replacement of species in an area (beta diversity in space) was higher in Buenos Aires than in Entre Ríos (Table 12).

Gamma diversity (γ) for communities of Buenos Aires was 29 families, equal to cumulative alpha diversity taking into account all sites in the province, whereas in Entre Ríos it was 15 families, equal to the cumulative alpha diversity for the province: Buenos Aires province, $\gamma = 17 \times 0.43^{-1} \times 4 = 29$ and Entre Ríos province, $\gamma = 13 \times 0.58^{-1} \times 2 = 15$.

Discussion

According to the literature on herbivorous insects in blueberry crops in the United States (Millholland and Meyer 1984, Elsner and Whalon 1985, Eck et al. 1990, Gough 1994, Meyer and Cline 1997, Capinera 2004, Schilder et al. 2004) and Chile (Casals 1994, Hetz et al. 2004, Larraín Sanhueza et al. 2007), the number of families recorded in this study is somewhat lower. Some species of the United States are oligophagous or monophagous [*Acalitus vaccinii* (Keifer), *Pyrrhalta vaccinii* Fall, *Dysmicoccus vaccinii* Miller & Polavarapu, *Gracilaria vacciniella* Ely, *Acrobasis vaccinii* Riley, *Frankliniella vaccinii* Morgan, *Catinathrips vaccinophilus* (Hood)], whereas in Argentina, as in Chile, none of the species identified so far are specialists. Some specimens could not even be identified to genus and species, however, by their very low relative abundance, they are unlikely to be monophagous species (Basset 1999) and could be rare or tourist generalist species of the regional pool. The blueberry is a crop of long-standing in the United States, so historical and evolutive processes can explain geographical differentiation of local assemblages (Lewinsohn et al. 2005). Herbivorous assemblages could decrease from the plant's center of origin, toward others geographical areas where the plant was introduced, mostly through

Table 5. Summary of the stepwise procedure used to build a multiple regression model for family richness in Entre Ríos blueberry crops

Model	Wald stat.	df	Wald P
+ sites	1.11	1	0.29
+ sites + years	0.55	1	0.46
+ sites + years + phen. stages	0.88	2	0.64

Table 6. Result of repeated-measured ANOVA of the analysis of diversity of families in Buenos Aires sites

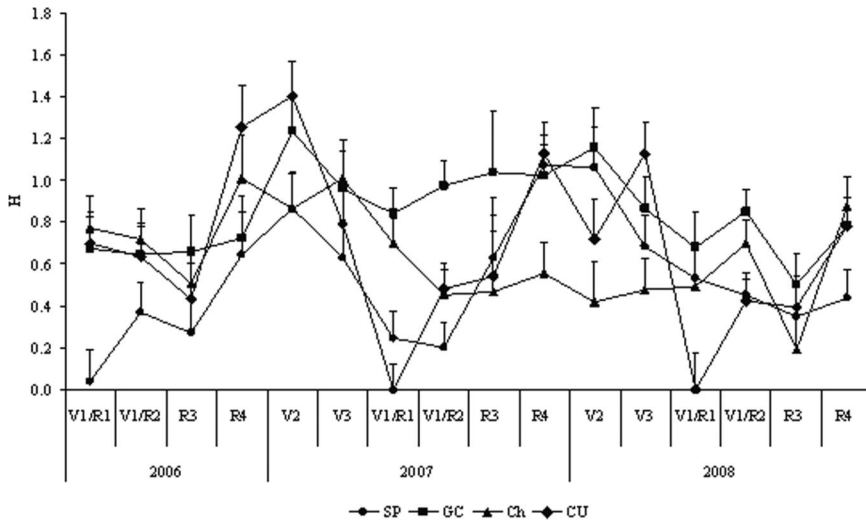| Factors	d.f. effect	d.f. error	F	P
Sites	3	8	3,10	0,09
Phenological stages	15	120	7,48	<0,00
Interaction	45	120	2,27	<0,00

Fig. 5. Diversity of herbivorous families per phenological stage in each site in Buenos Aires from 2006 to 2008. V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R1: Budding starts, spring budding and flower bud formation, V1/R2: Spring budding and flowering starts, R3: Open flower, fruit formation, unripened fruit, R4: Ripe fruit. CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro. Bars indicate standard errors.

loss of specialists. Thus, in the new region we will be more likely to find small assemblages consisting largely of polyphages (Sobhian and Zwölfer 1985, Brändle and Rieger 1999). Our results confirm the hypothesis that the majority of insects colonizing introduced plants are generalists that feed on a wide range of hosts, often unrelated to the introduced plant, and are mainly folivorous or sucking (Strong et al. 1984, Kogan 1998). The regional species pool is a variable assortment of specialists and generalists that have different probabilities of pertaining to local communities, according to conditions such as host abundance and predictability (Lewinsohn et al. 2005).

Many of the species recorded in the United States and Chile have not been found in the crops of Argentina, although they are widely distributed species. This may be because the majority of arthropods colonizing introduced plants belong to the native flora where the plant was introduced (Strong et al. 1984) and they can be native or cosmopolitan. In this case, some species have only South American distribution (e.g., *Naupactus xanthographus* (Germar), *N. cervinus* (Bohemian), and *Diabrotica speciosa* (Germar)) and others are cosmopolitan (e.g., *Ahis gossypii* (Glover), *Macrosiphum euphobiae* (Thomas), and *Icerya purchasi* (Haskell).

The processes that occur at inter-regional or continental spatial scales where situations, such as replacing taxa, can be explained by temporal and geographical environmental factors. The general hypotheses that explain the spatial patterns of richness and diversity are commonly referred to as historical factors, such as dispersal and speciation rates, factors related to the area, such as environmental heterogeneity and sampling effects, disturbs, and biological or ecological interactions, such as competition and predation (Whittaker et al. 2001, Lewinsohn et al. 2005).

The richness of herbivorous insects in blueberry crops of Buenos Aires varied mainly according to the site and the phenological stage. In Gobernador Castro it was higher, probably because of the diverse agricultural landscape in which the crop is, consisting of orange [*Citrus* × *sinensis* (L.) Osbeck] crops, field crops (mainly soybean [*Glycine max* (L.) Merr.]), and small horticultural crops. The phenological stages of V2, V3, and R4 had greater richness. The stage V2 combines leaves and buds as resources, and occurs in
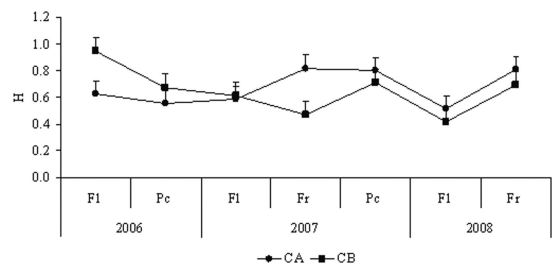

Fig. 6. Diversity of herbivorous families per phenological stage in each site in Entre Ríos from 2006 to 2008. V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R2-R3: Spring budding, open flower and unripened fruit, R4: Rip fruit. CA: Concordia A, CB: Concordia B. Bars indicate standard errors.

Table 7. Result of repeated-measured ANOVA of the analysis of the diversity of families in Entre Ríos sites

Factors	d.f. effect	d.f. error	F	P
Sites	1	4	0,18	0,70
Phenological stages	6	24	1,46	0,23
Interaction	6	24	1,25	0,31

Table 8. Relative abundance of herbivorous families in each site of Buenos Aires, in the different phenological stages

Sites	Colonia Urquiza							Chascomús							Gobernador Castro							San Pedro						
Phenol. stages	V2	V3	V1/R1	V1/R2	R3	R4	T	V2	V3	V1/R1	V1/R2	R3	R4	T	V2	V3	V1/R1	V1/R2	R3	R4	T	V2	V3	V1/R1	V1/R2	R3	R4	T
Acrididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	0.2	1.3	0.2
Aleyrodidae	2.6	40.9	17.6	2.7	-	3.9	6.7	89.7	77.6	5.1	61.2	95.7	83.6	85.9	2.7	2.8	0.2	-	0.9	0.6	1.2	1.9	-	-	0.2	1.7	-	0.2
Aphidae	51.3	18.2	47.1	73.0	93.1	52.2	61.2	-	-	-	-	-	-	-	24.1	18.8	67.0	42.9	84.3	60.0	48.0	71.6	86.1	98.2	84.8	93.8	64.5	90.0
Cercopidae	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chrysomelidae	6.1	-	-	-	-	3.4	2.3	0.9	0.1	-	-	0.7	6.3	2.1	0.4	0.1	0.3	-	2.6	4.6	0.7	2.7	0.3	-	-	-	14.2	0.6
Cicadellidae	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
Coccidae	5.2	21.2	-	-	1.9	17.4	9.2	0.1	11.4	2.6	0.6	0.4	6.3	3.9	35.7	30.8	8.9	5.5	0.2	27.1	17.3	6.9	3.0	-	0.3	-	11.6	1.4
Coreidae	0.9	-	-	-	-	1.0	0.5	0.1	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crambidae	0.9	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Curculionidae	-	1.5	-	-	-	-	0.2	-	-	2.6	0.6	0.1	0.2	0.1	-	0.1	0.2	-	-	-	0.1	0.8	0.2	-	-	-	-	0.1
Delphacidae	-	-	-	-	-	0.5	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Formicidae	-	1.5	-	-	-	-	0.2	1.4	-	5.1	1.2	-	0.1	0.5	8.5	0.5	-	2.2	3.7	0.9	1.6	2.3	1.3	0.2	0.1	0.2	0.6	0.5
Largidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	0.1	0.1	-	-	-	-	-	-
Fulgoromorpha	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Geometridae	0.9	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heteroptera	4.3	-	-	-	0.6	0.5	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lygaeidae	-	-	-	-	-	-	-	2.6	-	2.6	0.6	-	0.1	-	-	-	0.1	-	0.2	1.2	0.1	-	-	0.2	-	-	-	0.7
Margarodidae	1.7	1.5	-	-	-	-	0.3	18.4	-	-	-	-	-	-	18.4	37.8	17.4	4.1	2.6	0.9	19.2	2.3	1.2	-	1.2	-	-	-
Megalopygidae	-	-	-	-	-	-	-	-	-	-	3.5	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melyridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-
Meloidea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-
Membracidae	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.1	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-
Noctuidae	-	-	-	-	-	-	-	-	-	5.1	1.2	0.1	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pentatomidae	3.5	-	-	-	0.6	1.9	1.4	0.3	0.1	-	-	0.1	-	0.1	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-
Pseudococcidae	0.9	-	-	-	-	-	0.2	0.6	0.3	-	-	-	-	0.2	2.7	6.7	2.9	0.5	0.7	1.2	3.5	-	0.1	-	-	-	-	-
Psychidae	1.7	3.0	-	1.4	0.6	0.5	1.1	0.1	0.1	5.1	1.2	-	-	0.1	0.4	0.1	-	0.9	0.7	0.3	0.5	0.4	0.4	-	0.3	-	-	-
Tettigonidae	0.9	-	-	-	-	-	0.2	0.2	-	-	-	0.1	0.3	0.1	0.4	-	-	-	-	-	-	0.4	-	-	-	-	-	-
Thripidae	7.0	3.0	29.4	21.6	0.6	15.9	10.1	-	2.9	20.5	27.6	1.8	0.8	2.4	0.2	0.1	1.6	43.8	1.7	0.6	6.1	2.3	0.8	0.3	12.6	3.3	3.2	3.7
Tortricidae	12.2	9.1	5.9	1.4	1.9	2.4	4.7	6.5	6.4	51.3	2.4	1.1	2.2	4.1	3.1	2.1	1.2	0.2	2.2	2.2	1.6	8.0	6.4	0.9	0.5	0.7	3.9	2.3

V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R1: Budding starts, spring budding and flower bud formation, V1/R2: Spring budding and flowering starts, R3: Open flower, fruit formation, unripened fruit, R4: Ripe fruit.

Table 9.   Relative abundance of herbivorous families in each site of Entre Ríos, in the different phenological stages

Sites	Concordia A					Concordia B				
Phenol. stages	V2	V3	V1/R2-R3	R4	T	V2	V3	V1/R2-R3	R4	T
Acrididae	1.1	-	-	0.7	0.2	-	-	-	-	-
Aphidae	50.8	95.5	51.0	61.6	55.9	11.1	-	78.1	96.9	77.2
Cercopidae	0.6	-	-	-	0.1	1.9	-	-	-	0.1
Cicadellidae	0.6	-	-	2.2	0.3	-	-	-	-	-
Cicadidae	-	0.9	-	0.7	0.2	-	-	-	-	-
Coccidae	3.9	-	0.8	0.7	1.2	22.2	-	5.1	-	5.2
Coleoptera morfo 1	-	-	0.2	0.7	0.2	5.6	-	0.6	-	0.8
Formicidae	-	-	0.3	0.7	0.3	-	-	0.4	0.8	0.5
Fulgoromorpha	-	-	-	2.2	0.2	1.9	-	-	-	0.1
Margarodidae	14.4	-	-	1.4	2.2	-	-	-	0.4	0.1
Melyridae	-	-	-	0.7	0.1	-	-	-	-	-
Pentatomidae	0.6	-	-	0.7	0.2	3.7	-	-	-	0.3
Psychidae	0.6	-	-	-	0.1	-	-	-	0.4	0.1
Thripidae	27.1	3.6	47.4	27.5	38.7	42.6	-	15.8	1.2	14.5
Tortricidae	0.6	-	0.2	-	0.2	11.1	-	-	0.4	1.0

V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R2-R3: Spring budding, open flower and unripened fruit, R4: Rip fruit.

summer season when most insects find the optimal conditions for their development. The same applies to R4, which also offers fruit. The stage V3 provides only leaves, but it is the stage when the crop begins the period of dormancy, which spans several months and involves a larger number of samples. However, in V2, V3, and R4 a higher number of families rare or tourists (represented by a single individual), such as Lygaeidae (*Lygaeus alboornatus* Blanchard), Pentatomidae [*Nezara viridula* (L.)], Coreidae (*Leptoglossus impressicollis* Berg), Curculionidae [*N. xanthographus* (Germar)], Cicadellidae [*Pawiloma victima* (Germar)], and *Reticana lineata* (Burmeister), Fulgoromorpha, Crambidae, and Noctuidae were found. The low richness recorded in V1 and R1 could be explained because it comprises the winter months, where the low temperatures can be limiting for many insects.

The diversity varied largely between phenological stages. Blueberry crops surrounded by changing landscapes (horticulture, extensive seasonal) would receive seasonal contributions of some families. This occurrence would cause greater dominance and therefore less diversity in specific phenological stages. In Colonia Urquiza, although the Aphidae family was the most abundant, Thripidae and Aleyrodidae families had high relative abundances and are common in horticultural and flower crops that characterize this area (Polack 2005, López and Andorno 2009, Strassera 2009). Likewise, in Chascomús the Aphidae family had the highest relative abundance in most of the pheno-

logical stages. However, in the stage of V1 and R1, there was a significant increase in the Tortricidae family, whose main hosts are stone fruit, pome, and vine (Betancourt and Scatoni 1995). While these tortricid hosts are not part of the agricultural landscape of the area, tortricids are polyphagous species (citrus, pepper, jasmine (*Oleaceae*), privet, rose, kapok, in addition to the above) that may be present in the natural vegetation and have found in blueberries a good quality resource. In San Pedro, Aphidae family was dominant in all phenological stages. Although this crop is in a citrus area, the remoteness of these crops is the reason why scales, frequent in these fruit trees, may not yet reach important abundances. In this crop, however, the family Chrysomelidae, in relation to crops of the other sites, reaches higher relative abundances, especially in R4. This family, represented by *Colaspis* spp., is frequently found in soybean crops (Molina 1992) surrounding the blueberry on this site for R4.

The similarity of diversity among phenological stages observed in Gobernador Castro and Concordia sites could be because of the stability of the surrounding landscape, as both are composed of perennial crops (citrus, blueberries, raspberries, and boysenberries). These crops would provide a constant pool of species over time that will determine slight fluctuations of dominance. In Gobernador Castro (Buenos Aires), the dominance of Aphidae family is restricted to certain phenological stages, and generally associated with other families with similar abundances to

Table 10.   Values of average alpha diversity ($\bar{\alpha}$) and cumulative alpha diversity (α cum.) per year in herbivorous communities of blueberry crops in Buenos Aires (CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro) and Entre Ríos (CA: Concordia A, CB: Concordia B)

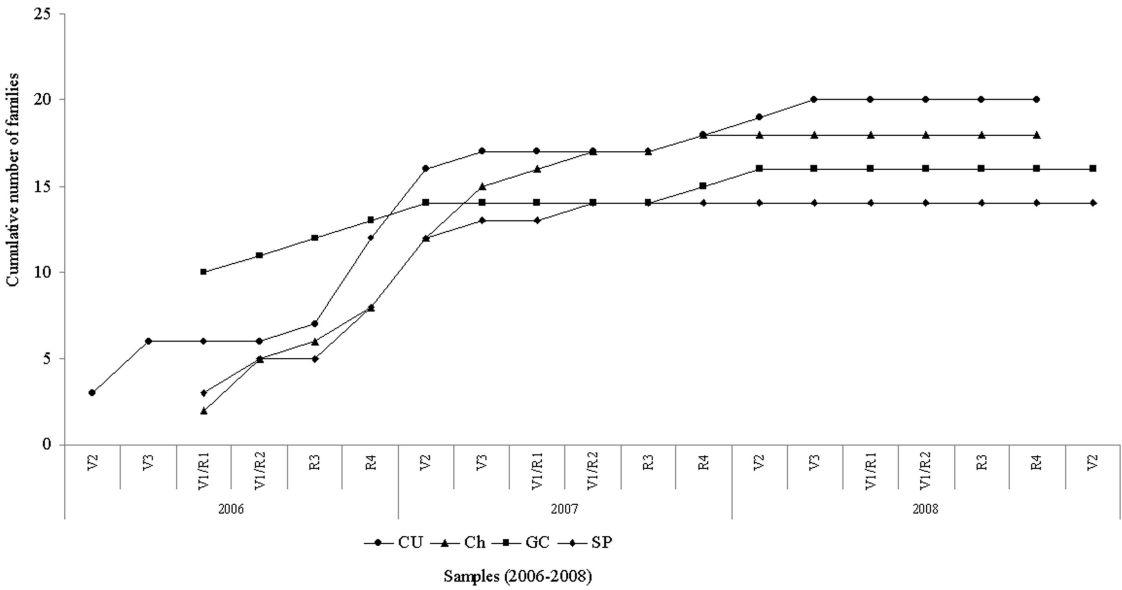|	CU		Ch		GC		SP		CA		CB	
	$\bar{\alpha}$	α cum.	$\bar{\alpha}$	α cum.	$\bar{\alpha}$	α cum.	$\bar{\alpha}$	α cum.	$\bar{\alpha}$	α cum.	$\bar{\alpha}$	α cum.
2006	4.50	13	4.25	8	6.80	15	5.00	12	4.60	12	3.00	4
2007	5.67	15	6.50	16	7.67	14	7.00	12	4.60	9	4.30	8
2008	4.40	11	5.80	11	5.00	9	2.67	7	4.50	7	2.50	4
Total	4.86	20	5.52	18	6.49	16	4.89	14	4.59	15	3.30	11

Fig. 7. Cumulative alpha diversity of herbivorous families from 2006 to 2008 in blueberry crops in Buenos Aires. V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R1: Budding starts, spring budding and flower bud formation, V1/R2: Spring budding and flowering starts, R3: Open flower, fruit formation, unripened fruit, R4: Ripe fruit. CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro.

generate a relatively high diversity. On this site, the scales become extremely important, mainly from the Coccidae and Margarodidae families, which are common and important pests of citrus (Granara de Willink 1995). In Entre Ríos, Thripidae and Aphidae families were well represented in almost all phenological stages in Concordia A. In Concordia B Aphidae family was dominant in V1/R2-R3 and R4, while in V2 the families Thripidae, Coccidae, and Aphidae had similar relative abundance.

In all crops a marked increase in the relative abundance of the family Thripidae at phenological stages of V1/R1 and V1/R2 can be seen, which results in less diversity. This is because these stages involve the initial flowering and flowering itself and of course the

crop provides an important resource of good quality for this family at all sites.

The relationship between the families of herbivores more abundant in blueberry crops and the species listed as pests in neighboring plants (SINAVIMO-SENASA 2010) confirm the insect colonization of blueberry from the surrounding landscape.

In Buenos Aires, cumulative alpha diversity was higher in blueberries surrounded by changing landscapes with annual or temporary crops, where resources for herbivores are limited to a period. However in blueberries surrounded by crops, soybean monoculture in San Pedro, and citrus and stone fruit in Gobernador Castro, low values of cumulative alpha were observed. In Entre Ríos, where the landscape is
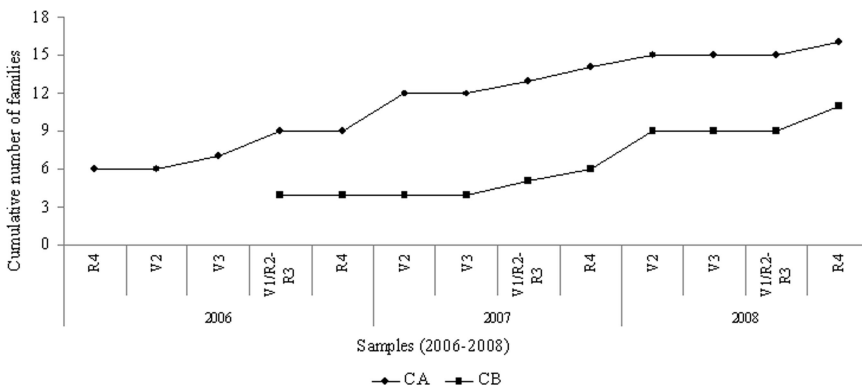

Fig. 8. Cumulative alpha diversity of herbivorous families from 2006 to 2008 in blueberry crops in Entre Ríos. V2: Summer budding, V3: Dormancy and the presence of senescent leaves, V1/R2-R3: Spring budding, open flower and unripened fruit, R4: Rip fruit. CA: Concordia A, CB: Concordia B.
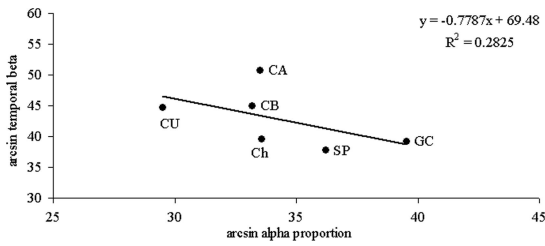
Fig. 9. Simple linear regression between temporal beta diversity and the proportion of average alpha diversity. CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro.

similar at both sites, the difference of this index could be that in Concordia B sampling began a phenological cycle later.

The cumulative alpha diversity of each site was higher than local alpha diversity in each phenological stage. This would reflect the presence of rare or tourist's species that belong to the regional pool of species that use the crop or are in the crop on a transitional basis (Novotný and Basset 2000, Schowalter 2006).

Temporal beta diversity values indicate that there was an important replacement of families in time during the study period in all sites. This may be because of the variety of resources offered by the blueberry to herbivores through the different phenological stages. The spatial and temporal heterogeneity of the landscape which provided the species that integrate the community explain the higher values of temporal beta diversity in Colonia Urquiza, Chascomús, Concordia A, and Concordia B. In theory, these communities could be expected to change easily affected by stochastic processes, while those with low temporal beta diversity tend to persist with little change unless there are variations in the physical environment (Moreno 2000, Moreno and Halffter 2001).

As shown by the values of qualitative similarity index, the communities of Gobernador Castro and San Pedro, as well as Concordia A and Concordia B, which are in the same area and share features of the landscape and weather conditions, were most similar. These results are consistent with those found through analysis of beta diversity as a measure of species turn-

Table 11.   Similarity indices for herbivorous communities of Buenos Aires (CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro) and Entre Ríos (CA: Concordia A, CB: Concordia B)

Sites	Shared Families	Qualitative coefficient	
		Jaccard	Sørensen
CU-Ch	13	0.52	0.68
CU-GC	13	0.56	0.72
CU-SP	12	0.54	0.71
Ch-GC	13	0.55	0.71
Ch-SP	10	0.50	0.63
GC-SP	11	0.58	0.73
CA-CB	11	0.73	0.85

Table 12.   Spatial beta diversity (β) for herbivorous communities of blueberry crops of Buenos Aires (CU: Colonia Urquiza, Ch: Chascomús, GC: Gobernador Castro, SP: San Pedro) and Entre Ríos (CA: Concordia A, CB: Concordia B)

	CU-Ch	CU-GC	CU-SP	Ch-GC	Ch-SP	GC-SP	CA-CB
β	0.31	0.30	0.24	0.30	0.38	0.27	0.15

over among sites and confirmed the strong relationship between the blueberry communities of herbivores at each site and the landscape.

The gamma diversity of Buenos Aires was higher than the cumulative alpha diversity at each site, while in Entre Ríos they were both similar. The landscapes of Buenos Aires, more heterogeneous spatially and temporally, may offer different families that cause greater gamma diversity.

Sites with high gamma diversity would have a high species turnover in space rather than a high local diversity (Cornell and Lawton 1992, Lawton 1999, Koleff and Gaston 2002, Rodríguez et al. 2003). In Buenos Aires, the cumulative alpha diversity increased over time and became asymptotic when it approached the value of gamma, and gamma diversity was higher than the highest value of alpha, so that beta diversity would be primarily responsible for the gamma value (Halffter and Moreno 2005). In Entre Ríos, however, the same pattern was not found, and the highest alpha diversity found comprised the most of gamma diversity, which would be strongly influenced by the alpha diversity of the richer community. In this case, spatial beta diversity would have a minimal contribution. Again, the landscape characteristics explain the differences found between sites.

Herbivore communities in blueberry crops recently introduced in Argentina are formed by ectophagous generalist from the regional pool of species, characteristic of the landscape in which these crops are established. This study provides evidence about the patterns of arthropod colonization to new habitats and it could represent a relatively short process, possibly to analyze (Schowalter 2006).

Acknowledgments

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