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Butterfly communities of urban forest fragments in Campinas, São Paulo, Brazil: Structure, instability, environmental correlates, and conservation

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Abstract

A comparative study of butterfly communities in 15 urban/suburban remnants of tropical semideciduous forest in Campinas (São Paulo state, SE Brazil; 24°S, 47°W), with areas from 1.0 to 252 ha and widely varying histories and environments, shows that the most significant factors, besides area and sampling time, distinguishing the sites and influencing their diversity (80–702 species) and composition are connectivity, permanent water, vegetation, flowers, and human impact (negative, including pollution). The diversified Nymphalidae butterflies (38–213 species) and especially two fermented-bait-attracted groups (Satyrinae, 2–30 species, and Biblidini, 9–44 species), are among the more useful indicators of the quality and diversity of the environments in these fragments. Effective conservation of butterfly communities in tropical cities may be achieved by maintenance of arboreal green corridors along streets and watercourses between moderately large (>10 ha) humid areas, not near to the most built-up or polluted city centre(s), and the inclusion within these areas of ponds or streams, diversified native forest, and open vegetation including abundant nectar-rich flowers.

Introduction

In the humid tropics, the substitution of highly diversified natural forest vegetation by an intensive-agriculture landscape typically leads to the elimination of most resident organisms, including soil microbes and fauna, saprophytes, herbivores, parasites, and predators (Ehrlich 1980; Paoletti *et al.* 1992; Whitmore & Sayer 1992; Laurance & Bierregaard 1997). The application of fertilizers, herbicides, insecticides, and other 'protective' chemical agents terminates the remaining native animal populations and soil biota, leaving a 'monoculture' highly subject to invasions by resistant pests, fungi, and pathogens that attack the primary cultivated species (Garcia 1991). The return of such systems to complex communities of tropical plants and animals may take a very long time or be entirely impossible (Brown 1997). Thus, few opportunities for conservation of native invertebrates and plants persist in such poisoned 'anthropic' or economic landscapes.

Tropical urban and suburban landscapes, on the other hand, often include a mosaic of vegetation types (flower gardens, hedgerows, copses, and springs) interconnected by many different kinds of green corridors (tree-lined railroads and streets, small rivers, grass lawns) with larger exurban reserves and forest remnants (Ruszczyk 1986a–e; 1987; Hobbs 1988; Ruszczyk & Araujo 1992; Rodrigues *et al.* 1993; Fortunato & Ruszczyk 1997; McIntyre 2000: 830; Alkutkar *et al.* 2001; Pickett *et al.* 2001). Urban parks and gardens often include diverse woody vegetation, partly introduced but also native, with food resources, original or secondary forest patches, and large trees that serve as nourishment, shelter, and substrate to a wide variety of animals. Here, the invertebrate fauna can be surprisingly rich, especially when general spray application of biocides is absent (Owen 1971; Rodrigues *et al.* 1993; McIntyre 2000; Kunte 2000–2001).

The ideal management of these urban vegetation patches should follow a set of guidelines to maintain the richness of invertebrate species in urban landscapes. Using butterflies as models, the following questions may be proposed to help define these guidelines:

1. How many species are able to colonize, interact, and persist in gardens, parks, and reserves of different sizes and vegetation within complex urban landscapes in the humid tropics?
2. Are these species usually 'erratic', moving through the urban matrix, or are they mostly residents that reproduce in the parks?
3. Which environmental or landscape factors most influence (positively or negatively) the different parts of the invertebrate community present in tropical urban 'green areas'?

Answers to these questions can help to know which indicators, thresholds, and management policies are most useful for conservation in urban tropical forest fragments. These data are very important to urban planning agencies, especially in the humid tropics where natural diversity is impressively high (Raven 1988), and probably quantitatively related to human health and quality of life in dense urban centres. This paper will describe well-known insects (diurnal Lepidoptera) in urban and suburban reserves of various types and sizes in southeastern Brazil, seeking patterns in the maintenance, reduction, and/or transformation of the originally diverse butterfly communities in these areas, and possible directives for their future monitoring, management, and conservation.

Study areas and methods: Butterfly lists and environmental factors

Butterfly communities were repeatedly censused in urban and green-belt parks and reserves in the region of Campinas, São Paulo (22°40′–23°S, 46°50′–47°10′W, 600–750 m above sea level, with a seasonal dry/humid climate) over the past three decades, in connection with population studies and community analyses, seeking to identify suitable indicator groups for conservation evaluation and priorities (Brown 1991; 1992; 1997; Morais & Brown 1992; Rodrigues *et al.* 1993; Tyler *et al.* 1994; Brown *et al.* 1995; Vanini *et al.* 1999; Brown & Freitas 2000). Fifteen various-sized sites in the region were chosen for analysis in the present study (Figure 1, Table 1, Appendix); of these, only three small urban parks (FV, GR and AR; see codes in Appendix) had not been visited or censused regularly in previous years. These received special attention in repeated visits during 2002. The base map for Figure 1 (upper) was obtained from the Atlas of the BIOTA-FAPESP web site (http://www.biota.org.br/) and updated, and the aerial regional photo (base for Figure 1, lower) was taken by Mario Belloni Jr. and used with permission.

Non-destructive, opportunistic, visual butterfly censuses (Brown 1972; Brown & Freitas 2000; Freitas *et al.* 2002) were made with binoculars and standard check-lists, and included daily notes on weather, vegetation and its phenology, interactions with other animals including observers, host-plant inspections, and other observations of resource use. Specimens occasionally captured for secure identification or reared from juveniles were preserved in the collection of the Natural History Museum of the State University of Campinas (ZUEC/UNICAMP), Campinas, São Paulo.

Censuses were repeated in smaller parks and reserves until new visits produced very few or no additional species (usually after 15–20 h, with lists of 80–120 species; this total number is often recorded in less than one hour on flower-patches or along edges of larger green-belt forest blocks). A separate list for a small recently-planted butterfly garden (JB, Table 1 and Figure 1, lower) beside a marsh and a residential area on the east edge of the largest unit (Santa Genebra, SG) was also included, to study the relative effects of vegetation, resources, location and human presence on the fauna. An 'outgroup' list (JP, leftmost in Table 1; 679 species) was added from the Serra do Japi, a mountainous area 40 km SSE of Campinas with a extensively studied butterfly fauna (Brown 1992, Brown & Freitas 2000); this forested area of over 10,000 ha includes a broader altitude range (700–1300 m), hilltops and rushing streams, and a dryer N face.

The total lists represent about 5000 h of butterfly counts by the authors, varying among the fragments and sites due to different sampling periods and intensities. The complete species *versus* sites matrix in EXCEL may be consulted and downloaded at Francini *et al.* (2000) (http://genesis.unisantos.com.br/biotasp/).

For the purpose of comparison, reduced lists [14–28 h; rightmost 10 rows in Table 1A, with suffixes R, 1, 2, or C, indicating *R*educed (for RY only), or (for SG, RC, and XL) single 'weekly' 14-h lists in April or May of 200*1* or 200*2*, or these last two *C*ombined] were used for the four most extensively studied areas in Campinas, to avoid bias due to different sampling efforts (Table 1B).

Faunal similarities among areas were obtained with the Sørensen index $s = 2c/(a + b)$, most effective when the total lists were not greatly different in size (following Brown & Freitas 2000). Comparative grouping of butterfly lists for sites, including reduced/combined versions as above, by species composition (Table 1A) used simple Euclidian distances and Ward's similarity, forming small-sized clusters and minimizing the sum-of-squares (variance) of these. These analyses were performed with the Statistica software (StatSoft 1995)

Relevant site-specific environmental information was modified in part from that in Brown & Freitas (2000: 942–3), with more emphasis on local microclimate, soils and vegetation, degree of urbanization and modification, and intensity of human disturbance (Table 1B, legend). The calculation of connectivity, based on size, height, density, linkage, width, and humidity of vegetated areas in the matrix around a fragment, follows (with a few modifications) Brown & Freitas (2000: 936–7). More detailed environmental and vegetation information, and historical data on the Campinas reserves, came from Dionete Santin (1999 and personal communication).

Sites were analysed and compared by principal components analysis (PCA) of their relevant environmental factors (Table 1B, see also Brown & Freitas 2000), using PC-ORD (McCune & Mefford 1997). Interactive analysis among these factors and the proportions of butterfly groups for each site (using the Combined 28-h lists for the larger sites) was performed by Redundancy Analysis (RDA, required by the small gradient, only 0.397 for the first axis) within the CANOCO environment (Ter Braak & Smilauer 1999). Two taxonomic/ecological groups of Nymphalidae in which few or no species were present on some lists (Danainae-Libytheinae and Acraeinae), and Lycaenidae and Hesperiidae (lists far from complete in many reserves) were not included in the latter analysis.

Results

Patterns in the urban butterfly faunas of Campinas forest fragments

The combined list of butterflies for the Campinas municipality is 773 species, with the lists for well-studied individual areas varying almost nine-fold (Table 1). Reduced lists (less than 40 h over-all effort in the four most studied areas) vary from 80 to 344 species (still a 4.3-fold difference in richness). Santa Genebra, the largest, most completely sampled and richest site in the Campinas region (702 species) has a list very similar (0.80) to that of the other large area (567 species in Ribeirão Cachoeira), unchanged in Combined reduced lists (see Table 1). Both are also quite similar to the equally sampled Serra do Japi (679 species; Sørensen index with SG 0.75 over-all, with the larger species in Nymphalidae + Pieridae + Papilionidae (NPP) 0.86, small erratic Lycaenidae 0.65, and small wide-ranging Hesperiidae 0.70; similarity with RC 0.71). Sørensen similarities among the smaller Campinas reserves vary from 0.32 to 0.33 (AL or IT, lacking water and flowers, with the flowered marshes XL, RY, or JB) to 0.79 (the marshes with each other).

Clustering of the reserves by Ward's algorithm (based on Euclidian distances) shows that the total lists of the three large and well-sampled areas (JP, SG, and RC) are close to each other, and the seven small urban parks also fall together, separate from the greenbelt reserves and the partial lists (Figure 2, upper). This picture remains virtually unchanged when using lists of Papilionoidea, NPP, or just the bait-attracted Nymphalidae (not illustrated), but is greatly modified for the extensively sampled, humidity-loving Ithomiinae (Figure 2, lower), where reserve size and position seem to be much less important than the physical environment (see below).

Faunal instability in well-sampled urban reserves

The lists for each reserve varied appreciably with the decade, year, month, and day that which they were made. For example, the large Santa Genebra municipal forest reserve (252 ha) is quite level and homogeneous (semideciduous forest with some swampy headwaters) and increasingly influenced by suburban expansion on its eastern edge (Figure 1); it has been very thoroughly studied since 1973 (see Morellato & Leitão-Filho 1995, Brown & Freitas 2000), with over 700 species of butterflies recorded by mid-2002 (Table 1A). Lists made in the 1970s include several dozen species not seen more recently, including a few associated with the large native bamboos that flowered regionally and then died back in the mid-1980s. Standard daily (4–11 h) and weekly (14 h) lists of butterfly species observed in SG vary from lows near 150 (in October to February, during the spring–summer rainy season, and also in June–July, very cold) to peaks well over 300, usually in the

Table 1. Richness of butterfly groups and environmental factors in 15 sites (JB = part of SG) in Campinas, SP, Brazil and in a natural site (JP) 40 km south.[a]

	JP	SG	err	RC	XL	RY	JB	CS	MJ	GB	US	TQ	JQ	FV	AL	IT	GR	AR	SG1	RC1	XL1	SG2	RC2	XL2	SGC	RCC	XLC	RYR
A. Butterfly species																												
Nymphalidae	208	213	61	169	121	127	105	101	109	91	117	56	67	54	44	38	54	52	109	94	83	90	97	90	121	110	103	80
Ithomiinae	32	28	7	22	20	19	9	21	26	17	23	12	22	19	11	11	13	16	14	16	15	13	16	17	17	19	20	12
Danainae + Libytheinae	5	6	1	5	5	5	5	4	6	3	4	0	3	0	0	0	0	0	4	3	3	2	2	3	4	3	4	3
Heliconiini	13	12	2	9	8	12	10	9	10	7	11	6	6	4	6	5	7	6	8	8	8	9	9	7	9	9	8	8
Acraeini	13	12	1	7	9	8	8	3	4	6	4	1	2	0	2	1	1	0	10	2	4	1	3	5	10	3	5	5
Nymphalinae	18	18	3	16	15	16	16	13	13	12	13	9	8	5	6	2	11	9	14	12	12	12	13	12	15	13	14	13
Morphinae	6	5	3	2	1	3	1	1	2	2	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Brassolinae	14	13	7	11	4	7	2	3	7	2	4	4	3	3	1	1	1	3	3	1	1	1	2	1	3	3	1	3
Satyrinae	30	30	10	28	13	9	7	5	7	7	14	6	3	3	2	2	3	4	11	11	9	8	11	10	11	14	12	5
Biblidinae	37	44	14	33	26	25	26	24	21	20	21	11	12	11	9	9	10	9	25	24	19	24	22	20	27	24	22	14
ALCC	25	28	10	21	11	16	14	11	8	7	15	2	3	5	2	3	2	2	9	9	4	11	9	5	14	12	7	9
Charaxinae	15	17	3	15	9	7	7	7	5	8	6	5	4	4	4	4	5	2	10	7	7	8	9	9	10	9	9	7
Bait-attracted groups	177	185	37	151	82	86	67	60	66	57	80	38	33	32	22	22	27	29	74	66	52	63	68	58	81	81	66	48
3 indicator groups (Ith-Sat-Bib)	99	102	31	83	59	53	42	50	54	44	58	29	37	33	23	22	26	29	50	51	43	45	49	47	55	57	54	31
Pieridae	36	28	3	26	19	20	24	19	21	20	22	15	11	9	15	16	12	11	19	18	17	17	15	13	19	19	17	15
Papilionidae	19	17	4	14	13	13	15	12	16	13	13	5	7	3	5	5	2	4	10	9	9	9	3	7	10	10	10	8
Mimetic groups, Nym-Pie-Pap	86	73	31	58	71	74	77	72	80	67	72	38	52	34	42	37	42	38	64	55	57	53	47	52	69	58	64	55
Lycaenidae	163	133	54	113	65	71	51	18	35	20	48	11	6	11	2	4	12	11	40	26	14	21	35	17	43	47	23	32
Theclinae	111	91	40	75	43	49	34	10	22	16	32	6	3	7	0	3	7	5	25	19	10	14	25	8	28	32	13	19
Riodininae	52	42	14	38	22	22	17	8	13	4	16	5	3	4	2	1	5	6	15	7	4	7	10	9	15	15	10	13
Papilionoidea	426	391	122	322	218	231	195	150	181	144	200	87	91	77	66	63	81	78	178	147	123	137	150	127	193	186	153	135
Hesperioidea	253	311	93	245	165	159	173	64	76	87	76	31	29	26	14	18	25	25	138	62	77	100	64	104	151	90	123	81
Hesperiinae + Heteropterinae	123	156	50	120	77	61	79	29	41	38	28	14	8	8	7	7	9	13	62	30	32	41	26	45	69	41	55	25
Pyrrhopyginae + Pyrginae I–II	130	155	43	125	88	98	94	35	35	49	48	17	21	18	7	11	16	12	76	32	45	59	38	59	82	49	68	56

	JP	SG	err	RC	XL	RY	JB	CS	MJ	GB	US	TQ	JQ	FV	AL	IT	GR	AR	SG1	RC1	XL1	SG2	RC2	XL2	SGC	RCC	XLC	RYR
Total species	679	702	215	567	383	390	368	214	257	231	276	118	120	103	80	81	106	103	316	209	200	237	214	231	344	276	276	216
Threatened or rare species[b]	15	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	—	—	—	—	—	—	—	—	—	—
Erratic or absent species (SG)[c]	127	215	—	136	28	35	1	3	4	3	1	2	1	0	1	1	0	0	—	—	—	—	—	—	—	—	—	—
Unique species (Campinas sites)	—	102	88	48	1	0	0	0	2	1	3	0	1	1	0	0	0	0	—	—	—	—	—	—	—	—	—	—
B. Environmental factors																												
Total area (ha)[d]	10,000	252	207	5	1	2	12	20	23	100	10	10	3.3	2.1	1.4	10	2.6											
Total sampling time[e]	4	4	3	2	3	3	2	2	2	1	1	1	1	2	2	1	1											
Topography[f]	4	2	3	2	1	1	2	1	2	4	1	3	3	1	1	3	3											
Principal soil types[g]	2	4	2	1	4	4	4	4	4	2	1	3	3	4	4	3	3											
Permanent water[h]	3	2	3	3	3	4	2	3	3	3	2	3	1	0	0	2	3											
Vegetation[i]	5	3	4	2	1	1	3	2	3	4	2	3	3	3	3	3	2											
Bamboo patches[j]	1	1	2	1	2	0	1	1	2	1	0	0	1	0	0	2	1											
Vines and lianas[k]	2	3	2	2	2	2	2	1	3	1	1	1	1	1	1	2	1											
Forest cover (1–4)[l]	4	4	4	3	2	1	4	2	4	2	3	4	4	4	3	2	2											
Flowers (edges/interior)[k]	4	4	2	3	4	4	2	3	1	3	1	1	1	1	1	3	3											
Human impact[m]	3	4	1	4	5	4	3	4	2	2	5	5	5	5	5	5	5											
Pollution (0–3)[n]	1	2	1	2	2	2	3	2	2	1	3	3	2	3	2	2	2											
Connectivity (0–10)[o]	8	6	6	4	5	9	4	6	6	7	3	1	1	1	1	2	2											

[a]The two-letter abbreviations for sites (see also Figure 1) are explained in the Appendix.

[b]Number of threatened or rare species on Brazilian national or state lists, plus a few others that indicate special habitat (see Brown & Freitas (2000) for references).

[c]Erratic or absent species (SG) indicates the number of species on the list for the site that have been recorded on 8 (3%) or fewer of the daily lists for Santa Genebra to X/2002, plus species never recorded in Santa Genebra but present in the site.

[d]In the analyses, the total areas are transformed to their logarithms, base 10 (1 ha = 0, 10,000 ha = 4).

[e]Total sampling time coded as 1 = <40 h, 2 = 40–200 h, 3 = 200–1000 h, and 4 = >1000 h of field census of butterfly species.

[f]Topography (dominant surface relief) coded as 1 = level, 2 = gently rolling, 3 = hilly, 4 = mountainous, averaging over the area.

[g]Soil types coded as 1 = sandy, 2 = shallow or coarse, 3 = fertile latosols and loams, using a detailed soils map of the region (CETEC 2000).

[h]Permanent water coded as sum of standing water including lakes and swamps (0–2) plus running water (0–2).

[i]Vegetation (predominant) coded as 1 = meadow, marsh, low scrub, 2 = swamp forest, 3 = open forest, 4 = semideciduous forest, 5 = dense forest, averaging types.

[j]Bamboo patches coded as 0 = absent, 1 = present, 2 = dominant.

[k]Vines and lianas, and flowers, coded as 1 = few, 2 = common, 3 = abundant, plus 1 if there is year-round blooming in the flowers.

[l]Forest cover in area coded as 1 < 40%, 2 = 40–59%, 3 = 60–79%, 4 = 80–100%.

[m]Human impact coded as the visitation level (1–3), plus degree of environmental alteration as 0 = occasional hunting or plant gathering, 1 = extensive hunting and removal of plants and trees in recent past, and 2 = continual removal of plants and animals today.

[n]Total pollution coded as the sum of traffic intensity around or within the area (1–3), water pollution (1–3), and light pollution (1–3), minus 2.

[o]Connectivity between vegetation patches evaluated as in Brown & Freitas (2000, Table 2), as the sum of four factors in the connecting landscape matrix, each one averaged over at least the first km in all directions: A (humidity), 0 = dry earth, 1 = variably dry and humid, 2 = always humid with high water table, 3 = swamp or gallery with much exposed water; B (height and density), 0 = denuded urban sprawl or open fields, grasslands, or agriculture, 1 = scrub or low bushy vegetation, 2 = open or disturbed forest, 3 = dense continuous forest; C (linkage between forest patches), 0 = scattered and unlinked small forest patches, 1 = mosaic with many linked or larger forest fragments, 2 = all fragments effectively interconnected; and D (width of forest corridors between patches), 0 = none present, 1 = narrow strips 1–5 m wide, 2 = broad corridors 5–30 m wide, 3 = essentially continuous forest. These criteria and categories are adapted to landscapes that contain tropical butterflies associated with small watercourses, forest interiors and/or shaded edges.

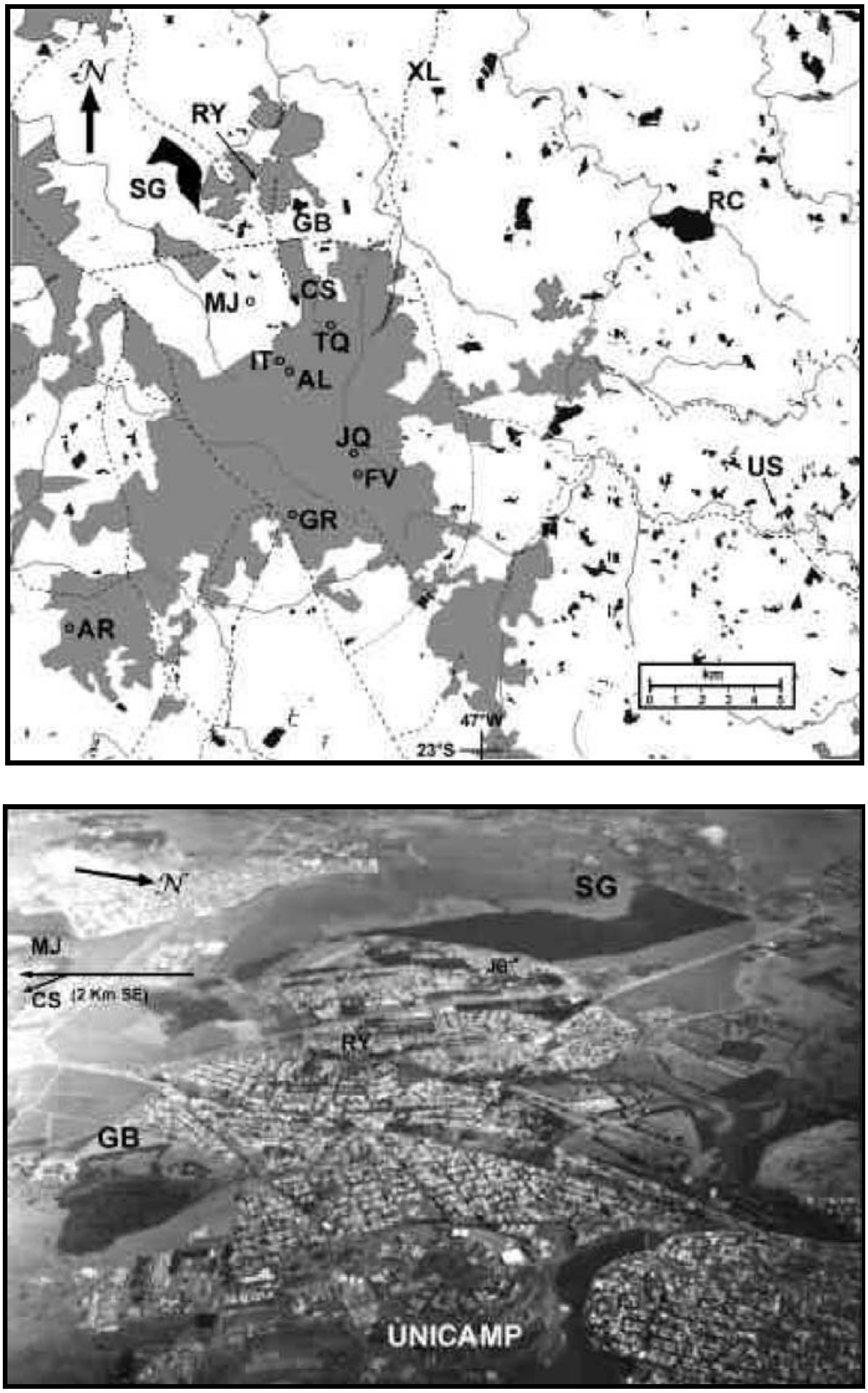

Figure 1. (Upper) Map of the region of Campinas, São Paulo. Shaded areas are urbanized; remnant woodlots are in black; continuous irregular lines = rivers, dashed lines = highways. Sampled reserves (15) are indicated by two-letter codes as in Table 1 and Appendix. (Lower) Aerial view of the north-western sector of the same area (base photograph by Mario Belloni Jr.), showing urbanization patterns of the region, the State University campus (bottom), the smallest reserve (RY, about 1 ha), the green-belt reserves GB (23 ha) and SG (252 ha), and the location of the butterfly garden (JB) on the urbanized eastern edge of SG.

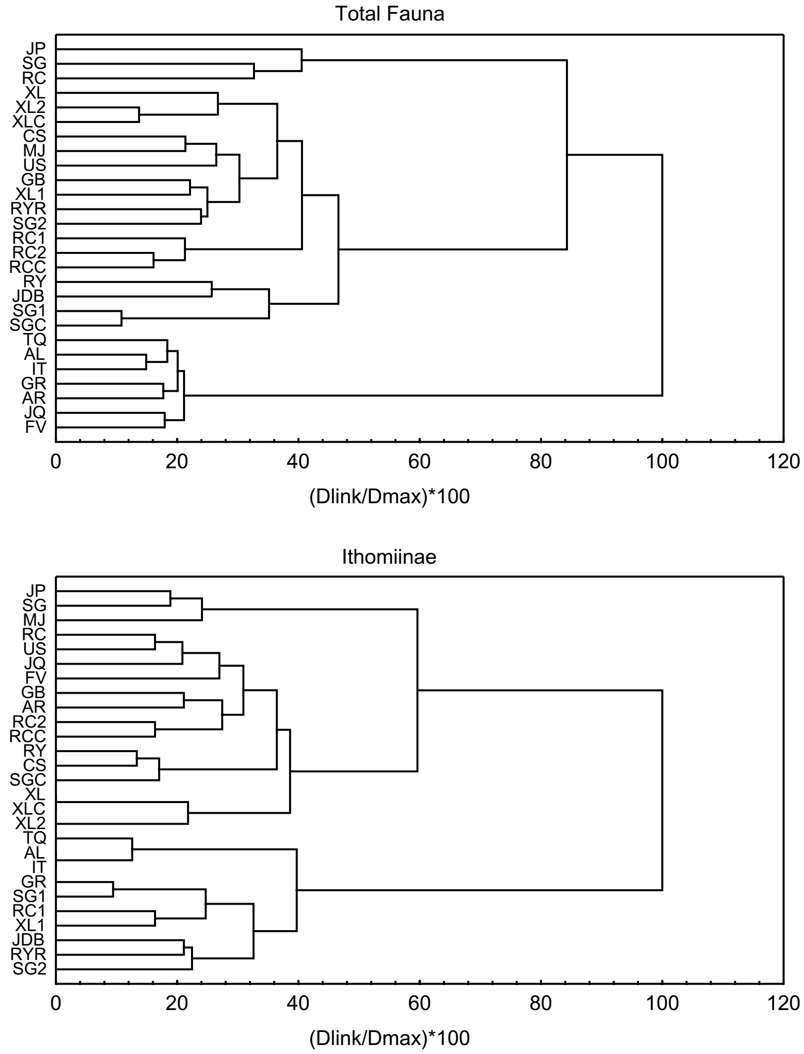

Figure 2. Similarities among the butterfly faunas recorded in the 15 reserves, the sub-area (JB), and the external site (JP), showing the relations among the entire butterfly faunas (upper) and only the Ithomiinae (lower). Ten ‘reduced’ lists, using 14 h in 2001; the same in 2002 (suffixes 1 and 2); and the sum of these two (suffix C) for the largest lists (SG, RC, and XL, plus an equivalent reduction of RY to RYR), were used to compare with the small lists of urban parks, and are also included in the dendrograms. For the total lists (upper), note the separate cluster of the seven urban parks (80–120 species), that of the two large green-belt reserves with the ‘outgroup’ Japi (>500 species), and that of the smaller fragments with the reduced lists (200–390 species) that often form well-defined pairs and triads, contrasting with the very different (lower) and apparently very locally determined clustering of the nearly completely sampled, shade- and humidity-dependent but migratory Ithomiinae (9–32 species).

major wildflower season in April, but also with occasional peaks in dryer winter months (August). The relative abundances of species are very different between the ‘high’ and ‘low’ seasons, evident in all butterfly families. A surprisingly large part of the species (215, about 30%) is composed of erratically appearing individuals, recorded on fewer than 3% of the 281 sampling days over seven years (Table 1). Some of these are seasonal migrants; a few may maintain stable populations in other fragments in the region (Brown & Freitas 2000: 937–939), while others are common only in areas distant more than 100 km north or south of Campinas.

Indeed, marked differences in the total fauna occur where the semideciduous forest gives way to a Cerrado landscape (tropical savannah, 500–1000 m altitude), 100 km N of Campinas, or south of São Paulo city where dense rain forests clothe the steep inner and seaward faces of the Serra do Mar (see dendrograms in Brown & Freitas 2000, Figure 2). In both of these biomes, several hundred species not recorded in Campinas occur, giving similarities of 0.5 or lower. In each region, the fauna has a typical composition that seems to respond differently to area, disturbance, and various micro-environmental factors (Table 1B), in part also due to varying common or dominant butterfly species and the presence of distinct plant resources.

It seems probable, nevertheless, that individual butterflies regularly transfer among these regions and areas, since humid green connectivity is nearly continuous (Table 1B; see Brown & Freitas 2000). Many years of data indicate that some butterflies leave their 'home' areas in peak periods of population growth in late summer or late winter, stopping at resource patches (flowers, fruits, denser vegetation) en route, often following watercourses and tree-lined streets in the highly fragmented landscape (Figure 1, Table 1B). In Campinas, a few long-distance recaptures of swallowtails have been recorded (see Brown *et al.* 1981; 1995: 418; Tyler *et al.* 1994: 58), and 'erratic' species were often first recorded in Santa Genebra shortly after their observation in large populations in nearby areas. Many of the 215 'erratic' species in Santa Genebra maintain large stable populations in these adjacent regions (see Brown 1992).

The environmental situation, conservation potential, and variation of the butterfly fauna in the Santa Genebra reserve can be highlighted by comparison with that of the similarly large (206 ha) preserved area only 16 km to the east (Ribeirão Cachoeira = RC, upper right in Figure 1, upper). This reserve, in a countryside/ suburban landscape 5 km distant from denser urban areas, is topographically varied with many rocks and a rushing stream flowing through all its length to join, at its western tip, the gallery forests of the large Atibaia River. It still harbours four species of native primates (only two survive in Santa Genebra) and large predators. The 567 butterfly species recorded there include 76 (13%) that are among the 215 'erratic' species in Santa Genebra, and a further 60 species never recorded in the latter reserve (total 136, 24%). Many of these are associated with montane (such as Japi) or Cerrado faunas (see also details in Brown & Freitas 2000: Table 4). Although the similarity between SG and RC for the entire faunas is 0.80, it falls to only 0.66–0.71 in non-combined reduced lists, especially emphasizing the differences in the commonest species (Table 1).

Although both of these large reserves protect typical diverse butterfly communities, 'listed' species officially regarded as rare or threatened are almost absent in them, even though quite frequent in the large continuous area of the Serra do Japi (Table 1A, third from bottom line). These sparse populations probably do not survive in small areas, and may use far-flung wandering or colonization to persist in the landscape. Even in the large Santa Genebra reserve, the 30% of the species that are erratic probably rarely if ever reproduce.

A few of these erratic species (including one pierid and 17 skippers) became much more visible when a large butterfly garden (JB) was planted beside the urbanized east marsh of the Santa Genebra reserve (Figure 1, lower). These hardly affected the over-all classification of the fauna, however, especially since their larval resources are rare or pre-occupied by close relatives in Santa Genebra. Thus, local communities often include species rarely seen and probably not resident nor breeding at the present time, even though still able at times to arrive and attempt colonization, because of the large connectivity in the landscape in the green belt (Table 1B).

A quite small (5 ha), very marshy reserve with abundant flowers, halfway between Santa Genebra and Ribeirão Cachoeira, beside a suburban housing project with many gardens (Xangri-Lá, Figure 1, upper), gave 383 species recorded after only 49 h sampling (April–May, 2000-2002) with just as many lycaenids (65) as Santa Genebra showed after 200 h sampling. Going to the extreme, a 1-ha humid, partly forested swamp with many flowers (RY) near to Santa Genebra gave 71 species of Lycaenidae in casual observations during April flowering periods (*Mikania*, *Eupatorium,* and *Vernonia* species, all Asteraceae highly attractive to passing butterflies, almost none of which have food plants in the swamp), and 159 species of skippers (Hesperiidae). Probably less than 20% of the species recorded in these two small wetlands are breeding residents; species replacement (turnover) is very large between months and years, but the humidity and the flowers continue to attract scarce and previously unrecorded species.

Environmental influences on the structure of local butterfly communities

Besides showing marked differences in the structure, composition, and variation of their butterfly faunas (Table 1A, Figure 2), the forest patches in Campinas are heterogeneous in their size, vegetation, soils, topography, humidity, disturbance, and butterfly resources (flowers, fruits, and host plants) (see Table 1B, and details in the Appendix).

Table 2. Correlation values (r) between environmental factors and species richness of butterflies in 15 urban sites in Campinas region. All significant values ($P < 0.05$) are included (bold underline $p \leq 0.001$; bold $p \leq 0.005$; regular underline $p \leq 0.01$; regular $p \leq 0.05$).

Butterfly groups	Total area	Permanent water	Bamboo patches	Vines & lianas	Flowers	Human impact	Pollution	Connectivity
Total species	**0.72**	0.57		0.61	0.55	**−0.67**		**0.91**
Papilionidae	0.55	0.53				**−0.69**		**0.84**
Pieridae	0.60					**−0.74**		**0.85**
Hesperiidae	0.60			**0.72**	0.52	−0.52		**0.80**
Hesperiinae	0.64			**0.69**		−0.52		**0.78**
Pyrginae I, II	0.55	0.52		**0.73**	0.52			**0.79**
Nymphalidae	**0.76**	0.62			0.53	**−0.73**		**0.90**
Lycaenidae	**0.74**	0.56	0.53		0.61	**−0.69**	**−0.72**	**0.91**
Theclinae	**0.78**	0.54	0.54		0.53	**−0.74**	**−0.75**	**0.92**
Riodininae	0.64	0.58			**0.73**	−0.54	−0.62	**0.85**
Ithomiinae		0.56						
Danainae	0.55	0.62				−0.57		**0.80**
Heliconiini	0.66	0.57			0.67	−0.64		**0.87**
Acraeini	0.61			**0.76**				**0.73**
Nymphalinae	0.54	**0.75**	0.60	0.63	**0.70**	−0.54		**0.83**
Morphinae		**0.76**	0.59					0.67
Brassolinae								
Satyrinae	**0.76**	0.55				**−0.75**	−0.66	**0.82**
Biblidinae	**0.76**			0.61		**−0.74**		**0.83**
ALCC	**0.71**					**−0.72**	−0.55	**0.85**
Charaxinae	0.60			**0.82**		−0.61		**0.72**
Bait-attracted	**0.71**	0.57				**−0.78**	−0.54	**0.92**
Mimetic	0.60	0.56				−0.63		**0.83**
3 indicators	**0.78**	0.59				**−0.76**		**0.82**
Papilionoidea	**0.77**	0.60			0.54	**−0.75**	−0.54	**0.94**

Highly significant collinearity ($p < 0.01$) was seen in a few of these environmental factors (Table 1B) across the 15 areas, such as connectivity with human impact, and forest cover with flowers (both negative). These factors were not eliminated in the analysis, since they are not obligatorily related nor conflicting; rather, any possible redundancy was tested in the multivariate analyses.

A cross-correlation matrix (Table 2) among the 11 environmental factors in Table 1B and the richness of various groups of butterflies in Table 1A (using *R*educed or *C*ombined lists to eliminate dominance by sampling time) showed an especially strong correlation of connectivity with all groups except Ithomiinae and Brassolinae (both are dawn-and-dusk, high-humidity wanderers) (Table 2), highly significant positive effects of area, permanent water and abundance of vines and wildflowers with some groups, and significant negative influence of anthropic impacts on almost all groups of butterflies (pollution mostly on the Lycaenidae).

Principal components analysis of the environmental factors of all the Campinas sites (Table 1B) showed that 73.7% of their variance could be attributed to the predominant factors in the first three axes (Table 3A). Especially important were area, connectivity and (negative) human influences on Axis 1, vegetation-related factors on Axis 2, and substrate-related factors and lianas on Axis 3 (Table 3B). The sites were arranged suggestively along the first two axes (Figure 3), with appreciable tendency for grouping of the smaller urban areas.

Multivariate (canonical, CCA/RDA) analysis of the environmental factors influencing the proportions of the various butterfly groups, using *R*educed or *C*ombined lists (<30 h) for the more intensively sampled areas, revealed (Table 3C) a predominant influence of connectivity and permanent water on the structure of the local butterfly fauna. These factors were also among the most important in the simpler analyses (correlation and PCA). The graph of the RDA analysis shows their influence on the Papilionidae, Pieridae, and eight larger taxonomic subdivisions of the Nymphalidae (Figure 4). The relative vectors of the factors and butterfly groups, as well as the resulting positions of the various sites, help to identify which elements had the most influence on the others in the three-fold canonical ordination (sites, factors, and proportions of groups on the site lists). All these analyses confirm the sensitivity of

Table 3. (a) Variance extracted from the first 10 axes of PCA analysis; (b) participation of 13 environmental variables in the three axes of PCA analysis (principal loadings in bold) and (c) statistics of the principal vectors obtained in the RDA between environmental factors and proportions of butterfly groups in the total fauna of each site.

	Eigenvalue	% of variance	Cum. % of variance
(a) PCA axis			
1	4.626	38.553	38.553
2	2.491	20.758	59.311
3	1.729	14.409	73.720
4	0.974	8.119	81.840
5	0.740	6.167	88.007
6	0.559	4.658	92.664
7	0.459	3.826	96.490
8	0.167	1.396	97.886
9	0.114	0.954	98.839
10	0.087	0.726	99.565
	Axis 1	Axis 2	Axis 3
(b) PCA factors			
Total area	**0.3622**	−0.2509	0.0330
Topography	0.2383	−0.2094	−0.4244
Principal soil types	−0.0850	0.0519	**0.5273**
Permanent water	0.3185	0.2328	−0.1415
Vegetation	0.1678	**−0.5395**	−0.1031
Bamboo patches	0.3422	0.1931	0.1698
Vines and lianas	0.2639	0.0247	**0.5252**
Forest cover	−0.0496	**−0.4891**	0.3573
Flowers	0.2411	**0.4399**	0.0190
Human impact	**−0.3813**	0.2505	−0.0709
Pollution	**−0.3522**	−0.0383	0.2184
Connectivity	**0.3981**	0.1023	0.1576
	F	*P*	%
(c) RDA factors			
Connectivity	5.80	<0.001	30.9
Permanent water	3.94	0.005	17.1
Sampling time (n.s.)	1.99	0.087	8.0
Vines and lianas (n.s.)	1.94	0.110	7.2

the butterfly community (smaller groups and the entire fauna) to a limited set of local environmental factors (Tables 1B, 2 and 3); for more details on these in the smaller urban parks, see the Appendix.

Discussion

In the extreme northeastern Brazilian Atlantic Forests, two previous butterfly lists for urban parks in state capitals [Maceió, Alagoas (Cardoso 1949) and João Pessoa, Paraíba (Kesselring & Ebert 1982)] were included in the analyses of Brown & Freitas (2000). Both indicated great species depletion within these hot coastal cities. Similarly large effects could be seen in two large 'green areas' near the centre of the megalopolis São Paulo (Accacio 1997, also included in Brown & Freitas 2000), that grouped with less-rich sites in extreme southern Brazil, and like the two northeastern urban sites showed very low connectivity. The present study, which is in part an expansion of the research reported by Rodrigues *et al.* (1993) for three of the 15 areas used (AL, IT and CS), leads to results and recommendations closely corresponding to these previous studies (and also to Ruszczyk 1986a–e; 1987; Hobbs 1988; Ruszczyk & Araújo 1992; Fortunato & Ruszczyk 1997; Santin 1999; Vanini *et al.* 1999; Pickett *et al*. 2001) especially in relation to details of the internal environment of small, isolated tropical urban parks and the importance of the connective landscape matrix.

These results help to answer the three questions raised in the Introduction (above). While almost all groups of butterflies can survive in the urban matrix, many species are poorly represented or absent in smaller or more homogeneous parks (especially the larger Papilionidae, Brassolinae, and Morphinae, but also the stenotopic Charaxinae, Biblidinae, Satyrinae, Acraeinae, Danainae, and Pierinae, and the small

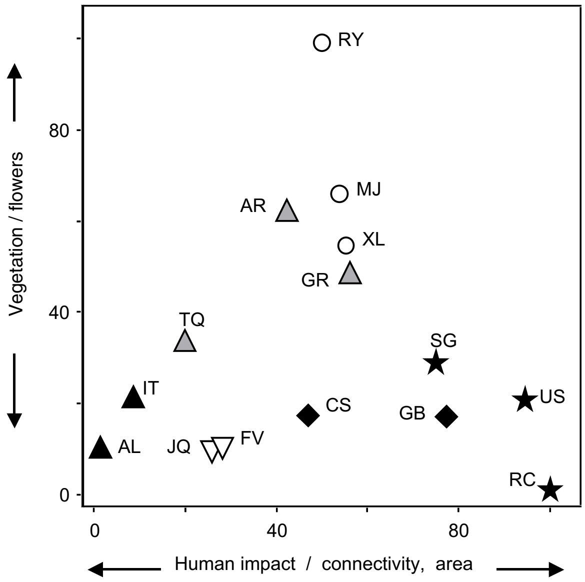

Figure 3. Biplot of the results of a principal components analysis of environmental factors in the 15 Campinas reserves (not including JB), showing positions of the sites along the first two composite axes (see Table 3A and B). Preponderant factors and their sign (left = −, right = +) are indicated on each axis; their influence can be easily seen in the respective lines of Table 1B.

Lycaenidae and Hesperiidae). All these groups require space, heterogeneous vegetation, and other special resources (like ant mutualists) in order to persist in city parks (Fortunato & Ruszczyk 1997). Some are only seasonally present, immigrating from exurban forests where large broods occur sporadically (as suggested for Staten Island and New York City by Shapiro & Shapiro 1973). The best survivors are the Nymphalinae, Heliconiinae, and Ithomiinae, the last group only persisting if good humid 'pockets' can be formed in forested, well-watered parks. The communities in all the reserves seem to be highly permeable and unstable; this can often be seen within a single week or month. Whether this variation can be reduced in smaller areas through enrichment of native resources (avoiding exotic plants, see Shapiro 2000) and increased shelter, remains to be investigated by adequate experiments (for a parallel example in an Asian tropical city, see Kunte *et al.* 1999; Kunte 2000–2001; Alkuktar *et al.* 2001).

Of the many environmental factors that favour the maintenance of diverse tropical butterfly communities in small urban parks, connectivity in the matrix is clearly the most important (Tables 2 and 3; Figures 3 and 4). As a landscape component, it is under control by urban planners, who have many ways to increase it (with arboured streets and watercourses, other green corridors, and pollution control). This gives a straightforward, if often very politicised road to more effective conservation in cities. Other important factors (like open areas, flowers, host plants, and human impact) are under direct control of local park managers and personnel, who can greatly increase the attractiveness to birds and butterflies of a small green area, by proper mixtures of various types of vegetation, resources, and landscape mini-mosaics, always protecting water-springs, older and larger trees, and steep areas.

With relation to the guidelines published by Ruszczyk (1986a), Rodrigues *et al.* (1993), Fortunato & Ruszczyk (1997), especially concerning the community of fruit feeding (bait-attracted) species found in shady forest habitats, this work confirms their relative scarcity in smaller reserves. As Ruszczyk mentions, their ecology in urban habitats needs more study, but the abundance of species and individuals in this group could be increased by maintaining high humidity and planting larval host-plants and trees that also furnish fruits to adults. In two later papers, Ruszczyk (1987), Ruszczyk & Araujo (1992) elegantly demonstrated the coherent urban gradient of Porto Alegre (Rio Grande do Sul, in temperate/Mediterranean climate) and its effects on many butterfly species; very few inhabit the urban centre, in spite of large 'green areas.' In this work in Campinas, we found very few butterflies near the urban centre, but the gradient was not as clear as in Porto Alegre, due to large open fallow lands in certain sectors of Campinas (Figure 1, upper). It is also important to note that in those papers, Ruszczyk recorded butterflies in the urban matrix, while in the present paper butterflies were censused in the 'island' parks. The paper by Fortunato & Ruszczyk (1997) analyses patterns for parks in a somewhat smaller and much younger city (Uberlândia, MG), within an open 'Cerrado' matrix with few aspects in common with Campinas, but with noteworthy similarity of the occurrence of 'erratic' species.

A recent paper by McIntyre (2000) calls for increased attention to quantitative mechanisms determining the distribution and abundance of urban arthropods, and presents six hypotheses to be investigated. Only two are partly supported by our data (negative effects of pollution; immigration from adjacent indigenous habitat giving high diversity of vagile species in peripheral sites). Another three (higher occupation of scarce habitats and host-plants, more early successional species and predators in younger parks, increase of species diversity with park age) may apply better in strongly seasonal temperate environments. The sixth hypothesis in that paper (increase of exotic

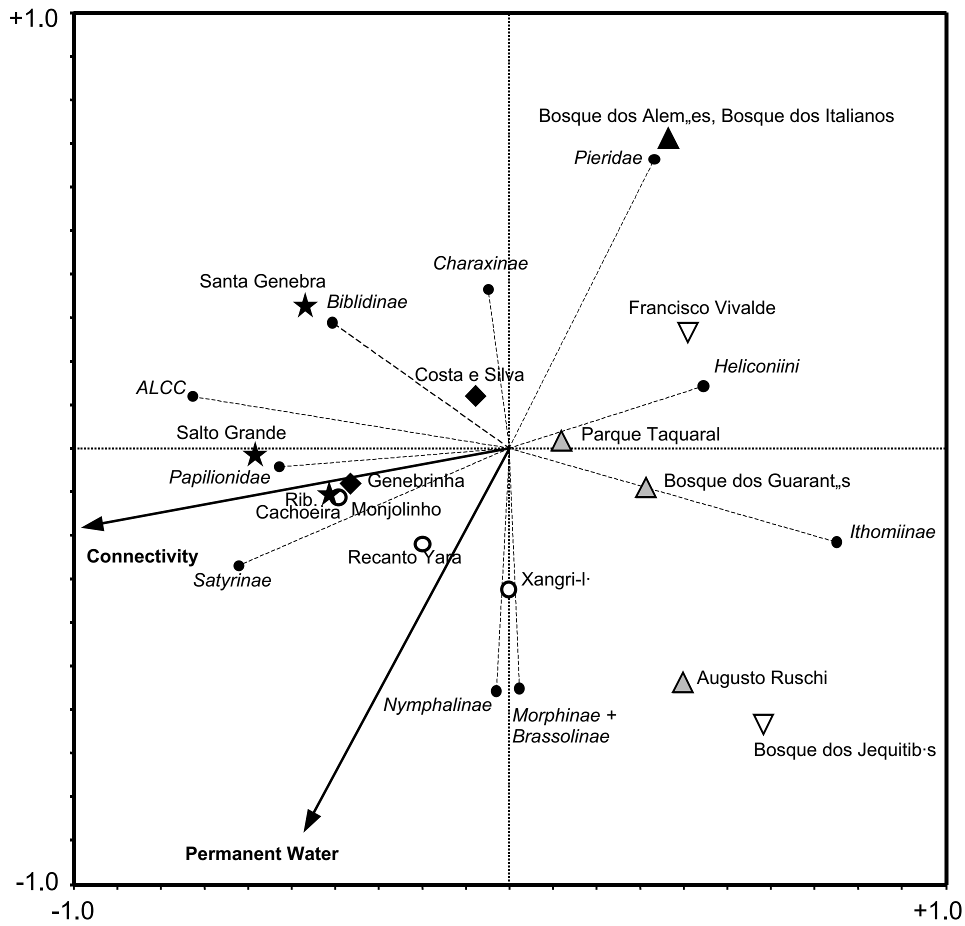

Figure 4. Canonical (Redundancy) correspondence analysis (Triplot graph), from interaction of the environmental factors in the fifteen reserves with the proportions of 10 groups on the species lists (Papilionidae, Pieridae, and eight subgroups of Nymphalidae, see Table 1; the four largest lists used as their respective Combined or Reduced lists for 2001–2002, each totalling 28 h of census over two to four days). Note that all seven isolated city parks occupy the right quadrants, with dryer ones at the top. Easily sampled butterfly groups of wet forest, swamps or grottos also appear to the lower right, while scarcer species of grassy marshes concentrate to the lower left, along with the corresponding sites (XL, RY, and MJ) (See Table 3).

species with park age) is not (yet?) relevant to our work. The final question raised in that paper, about socio-economic influences, can eventually have a positive answer in tropical forest areas, due to edge effects giving an increase of habitat diversity, food plants, and insects after low-level disturbance in these systems (see Brown 1996 for more details, examples, and discussion of this polemical subject).

Conclusions and recommendations

Besides simple area and sampling effort, the most important factors determining the structure of the butterfly faunas in the small forest reserves around and within the urban matrix of Campinas are connectivity, permanent water, and vegetation (including bamboo, vine and flower abundance), all with positive effects on species richness. The negative impact of human use and pollution is strong in the correlation matrix and in the first PCA axis (independent of butterfly communities). Pieridae and Charaxinae (strong flyers), Heliconiinae and Ithomiinae (common models for mimicry) seem to show smaller effects of these factors (Table 2, Figure 4).

Among all these environmental factors, the most important, relatively easy to address in city planning and management programs, is connectivity with its various components (broad space planning, tree-lined avenues, abundant nectar-rich flowers, and watercourses). Within the parks, maintenance of sunny clearings and especially flower gardens will make the butterflies more active and visible to visitors. In the early stages of park planning and location (still possible in some regions), the inclusion of varied topography and vegetation, and complete water heads with small streams and their associated native vegetation (as in AR and JQ), can greatly help in the maintenance of complex and species-rich natural butterfly communities.

Tropical butterflies seem to be amenable to sharing their space with human populations, especially when their natural resources are enriched and pollution is controlled. Certainly, they can help humans (and especially children) understand complexity, beauty, and the importance of the environment in supplying resources and maintaining an agreeable life-style for many kinds of animals, including our own species.

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Appendix: Further details and information on the forest fragments analysed

CODES USED FOR THE 16 AREAS (and one sub-area), in the same order as in Table 1, are: JP = Serra do Japi, Jundiaí, SG = Santa Genebra Forest Reserve, RC = Ribeirão Cachoeira forest in the Condomínio Colinas do Atibaia, Souzas District, XL = Woodlot and marsh beside the Condomínio Xangri-lá, RY = Woodlots and marshes in the Recanto Yara, JB = Butterfly garden on the eastern border of Santa Genebra Forest Reserve, CS = Costa e Silva woodlot in the Santa Elisa Experimental Farm, MJ = Monjolinho Arboretum in Santa Elisa, GB = Santa Genebrinha woodlot, US = Forests and hilltops in the region of the Salto Grande mini-hydroeletric plant (usina), Joaquim Egídio District, TQ = Lake Taquaral Park, JQ = Jequitibás Woodland Park, FV = Francisco Vivalde Park, AL = Alemães Park, IT = Italianos Park, GR = Guarantãs Park, AR = Augusto Ruschi Park.

Descriptions and comparisons among seven small public parks and nearby reserves

The two urban forest fragments studied by Rodrigues *et al.* (1993; AL and IT) include entirely-fenced city blocks inside a very completely built-up housing matrix (mostly single- or two-story residences with a few shops). Both include rather unstable, moist dark 'pockets' of Ithomiinae; the larger Alemães (AL, 2.1 ha) has many large native trees and a dense understory, while the smaller Italianos (IT, 1.4 ha) was more open and sunlit in the early study, with various flowered bushes used by butterflies (it is less open but more trampled, and has very few flowers at present). Neither park has much topographical variation nor permanent water, and recreational facilities (like swings and slides) are small and shaded. The lists in both are the smallest of all the reserves (80–81 species, in spite of extensive sampling), and equally poor in almost all groups, even after repeated recent visits to complete their lists; they have a similarity (Sørensen) of 0.67 at present.

A slightly larger park on the city's periphery (Figure 1), Augusto Ruschi (AR, 2.6 ha, a large part bearing a moderately trampled recomposed forest 16 years old) has a distinct 'flavour' due its open sunlit areas, many springs, a running stream and small lakes; it shows an appreciably richer fauna than the above two parks (Table 1A). In a little-polluted region with high landscape connectivity, it has some noteworthy species and proportions of butterflies.

The Francisco Vivalde woodlot (3.3 ha) is a deep U-shaped water-head with a unique fauna in which many common species in Campinas are absent (Table 1). The precipitous terrain prevents trampling, and the low light and high humidity of the grotto favour a small fauna of unusual deep-forest species within the relatively level Campinas landscape (similarity with Alemães 0.57, with Italianos 0.53). It is most similar (but still only 0.66) with the nearby Bosque dos Jequitibás (named for the enormous tree *Cariniana estrellensis*, Lecythidaceae), a 2-ha native forest remnant in a 10-ha park, that for the past 80 years has been the site of the municipal zoological park, also in a steep watershed with abundant running water (just downstream from Francisco Vivalde) and very intense human use; the latter, and the shade of the many very large trees, may contribute to the small and somewhat exceptional fauna of JQ (second most similar with AR, 0.65, highest for this park also). The two neighbouring forests FV and JQ are the richest in native trees (160 and 144 species, respectively) of all the areas included in this paper (and in all the region of Campinas as well; Santin 1999).

Another 10-ha area, the Bosque dos Guarantãs (named for the valued native hardwood and papilionid host plant, Rutaceae: *Esenbeckia leiocarpa*) is also cut by a steep-sided stream, whose banks are unfortunately deforested but support many flowers. The forested 30% of this park has a humid native undergrowth and a rich tree community (76 species; Santin 1999), with many unusual species but few Ithomiinae (most similar with Augusto Ruschi, 0.64, and Taquaral, 0.63).

In the 65-ha Taquaral park (over half of which is covered by lakes), the 10-ha recently recomposed arboretum sector censused (with native and introduced trees) shows a relatively poor fauna with very few rarer species. The flowered understory suffers from heavy trampling by people and capybaras; the unwary visitor is more likely to catch ticks or be confronted, than to record uncommon butterfly species, but the total list is the second largest for the seven city parks, with good balance (most similar with nearby Alemães, 0.68).

The 12-ha Costa e Silva forest, part of the experimental farm of the Agronomical Institute of Campinas, is bordered on two sides by dense urban development (many of whose residents use it as a dump or rendezvous) and on a third side by a stream and divided highway. It has a rich fauna almost twice as large as, and very distinct from those in the public parks (similarities 0.50–0.64) and very similar (0.77) to that in the superhumid and rich old arboretum (MJ) in the same large green area. This suggests the influence of connectivity and reduced visitation on the faunal richness and composition.

The Recanto Yara site, a flowered marsh just west of the Barão Geraldo suburban centre (Figure 1), has two small woodlots (each about 0.3 ha) and ten human families including the first author and also a well-known ornithologist (Edwin Willis). An apparent parody of the species-area equation, it has over 100 nesting songbird species and almost four times as many butterflies recorded (390) as the largest of the above public parks, including 35 species regarded as erratic in the 250-ha Santa Genebra forest, with which it has high similarity (0.71, increased to 0.80 after correction for the sampling disparity in the total lists), emphasizing their proximity and connectivity (Figure 1). Obviously, few of these butterflies are resident; many are just flower-visitors or migratory transients, but these include three species of *Morpho* and all 13 local swallowtails. In this case, the proportion of 'erratic' species is very high (>80%) and the large list is due to two factors: abundant flowers and high connectivity, including along a watercourse to the nearby Santa Genebra forest (Figure 1, Table 1).

The small butterfly garden and marsh (JB), part of the larger Santa Genebra reserve, gives a special resource concentration leading to a very dense and diverse butterfly community, biased towards skippers (Hesperiidae), swallowtails (Papilionidae), other sun-lovers (Pieridae, Nymphalinae), and mud-puddlers, including some Riodininae and Biblidinae: *Dynamine* and *Eunica*. Especially after major flower enrichment (adding Rubiaceae and Verbenaceae to the already abundant Asteraceae), and daily censuses starting in 2000, it showed a continuously growing and often surprising list of rare Hesperiidae; but it is not formally separable from the rest of SG, where most food-plants grow and shade-lovers like Ithomiinae spend most of the day.

References

Accacio, G. (1997) Borboletas em parques urbanos: Estudos na cidade de São Paulo. Master's Dissertation: Departamento de Zoologia, Instituto de Biociências da Universidade de São Paulo, iii + 136 pp.

Alkutkar, A., Athalye, P., Adhikari, S., Ranade, A., Patwardhan, M., Kunte, K. and Patwardhan, A. (2001) Diversity of trees and butterflies in forest fragments around Pune city. In *Tropical ecosystems: Structure, diversity and human welfare* (K.N. Ganeshaiah, R. Uma Shaankar and K.S. Bawa, eds), pp. 685–8. New Delhi: Oxford-IBH.

Brown Jr., K.S. (1972) Maximizing daily butterfly counts. *J. Lepid. Soc*. **26**, 183–96.

Brown Jr., K.S. (1991) Conservation of Neotropical environments: Insects as indicators. In *The conservation of insects and their habitats* (N.M. Collins and J.A. Thomas, eds), pp. 349–404. London: Academic Press/Royal Entomological Society.

Brown Jr., K.S. (1992) Borboletas da Serra do Japi: Diversidade, habitats, recursos alimentares e variação temporal. In *Historia natural da Serra do Japi: Ecologia e preservação de uma área florestal no sudeste do Brasil* (L.P.C. Morellato, ed), pp. 142–86. Campinas, SP: Editora da Unicamp.

Brown Jr., K.S. (1997) Diversity, disturbance, and sustainable use of Neotropical forests: Insects as indicators for conservation monitoring. *J. Insect. Conserv.* **1**, 25–42.

Brown Jr., K.S., Damman, A.J. and Feeny, P. (1981) Troidine swallow tails (Lepidoptera: Papilionidae) in Southeastern Brazil: natural history and foodplant relationships. *J. Res. Lepid* **19**, 199–226.

Brown Jr., K.S. and Freitas, A.V.L. (2000) Atlantic Forest butterflies: Indicators for landscape conservation. *Biotropica* **32**(4b), 934–56.

Brown Jr., K.S., Klitzke, C.F., Berlingeri, C. and Rubbo dos Santos, P.E. (1995) Neotropical swallowtails: Chemistry of food plant relationships, population ecology, and biosystematics. In *Swallowtail butterflies: Their ecology and evolutionary biology* (J.M. Scriber, Y. Tsubaki and R.C. Lederhouse, eds), pp. 405–45. Gainesville, Florida: Scientific Publishers.

Cardoso, A. 1949. Lepidópteros de Alagoas. *Rev. Entomol.* **20**, 427–36.

CETEC. 2000. Situação dos Recursos Hídricos das Bacias Hidrográficas dos Rios Piracicaba, Capivari e Jundiaí. Relatório Técnico Final. Centro Tecnológico da Fundação Paulista de Tecnologia e Educação /Comitê das Bacias do Piracicaba, Capivari e Jundiaí, 2000 (http://www.comitepcj.sp.gov.br/).

Ehrlich, P.R. (1980) The strategy of conservation, 1980–2000. In *Conservation biology – an evolutionary-ecological perspective* (M.E. Soulé and B.M. Wilcox, eds), pp. 329–344. Sunderland, MA: Sinauer Associates.

Fortunato, L. and Ruszczyk, A. (1997) Comunidades de Lepidopteros frugívoras em áreas verdes urbanas e extraurbanas de Uberlândia, MG. *Revta. Bras. Biol.* **57**, 79–87.

Francini, R.B., Freitas, A.V.L. and Brown Jr., K.S. (2000) Lepidoptera do Estado de São Paulo: diversidade, distribuição, recursos, e uso na análise e monitoramento ambiental (http://genesis.unisantos.com.br/biotasp/)

Freitas, A.V.L., Francini, R.B. and Brown Jr., K.S. (2002) Insetos como indicadores ambientais. In *Manual Brasileiro em Biologia da Conservação* (L. Cullen, R. Rudran and C. Valladares-Pádua, eds), in press. Washington, D.C.: Smithsonian Institution Press.

Garcia, M.A. (1991) Arthropods in a tropical corn field: Effects of weeds and insecticides on community composition. In *Plant–animal interactions: Evolutionary ecology in tropical and temperate regions* (P.W. Price, T.M. Lewinsohn, G.W. Fernándes and W.W. Benson, eds), pp. 619–34. New York: John Wiley.

Hobbs, E.R. (1988) Species richness in urban forest patches and implications for urban landscape diversity. *Landscape Ecol.* **1**, 141–52.

Kesselring, J. and Ebert, H. (1982) Relação das borboletas encontradas na 'Mata do Buraquinho,' João Pessoa, Estado do Paraíba, Brasil. *Revta. Nordestina Biol.* **2**, 105–18.

Kunte, K. (2000–2001) Butterfly diversity of Pune city along the human impact gradient. *J. Ecol. Soc.* **13/14**, 40–5.

Kunte, K., Joglekar, A., Utkarsch, G. and Padmanabhan, P. (1999) Patterns of butterfly, bird, and tree diversity in the Western Ghats. *Curr. Sci. (India)* **77**, 577–86.

Laurance, W. and Bierregaard, R.O., eds (1997) *Tropical forest remnants*. Chicago, Ill: University of Chicago Press, xv + 616 pp.

McCune, B. and Mefford, M.J. (1997) *Multivariate analysis of ecological data*, Version 3.11. Gleneden Beach, OR, USA: MJM Software.

McIntyre, N. (2000) Ecology of urban arthropods: A review and a call to action. *Ann. Entomol. Soc. Am.* **93**, 825–35.

Morais, A.B.B. and Brown Jr., K.S. (1992) Larval foodplant and other effects on Troidini guild composition (Papilionidae) in southeastern Brazil. *J. Res. Lepid.* **30**, 19–37.

Morellato, P.C. and Leitão Filho, H.F., orgs. (1995) *Ecologia e preservação de uma floresta tropical urbana – Reserva de Santa Genebra.* Campinas, SP, Brazil: Editora da UNICAMP.

Owen, D.F. (1971) *Tropical butterflies: The ecology and behavior of butterflies in the tropics with special reference to African species*. Oxford: Clarendon Press.

Paoletti, M.G., Pimentel, D., Stinner, B.R. and Stinner, D. (1992) Agroecosystem biodiversity: Matching production and conservation biology. *Agri., Ecosyst. Environ.* **40**, 3–23.

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.L. and Constanza, R. (2001) Urban ecological systems: Linking terrestrial ecological, physical, and socio-economic components of metropolitan areas. *Annu. Rev. Ecol. Syst.* **32**, 127–57.

Raven, P.H. (1988) Our diminishing tropical forests. In *Biodiversity* (E.O. Wilson, ed), pp. 119–22. Washington, DC: National Academy Press.

Rodrigues, J.J.S., Brown Jr., K.S. and Ruszczyk, A. (1993) Resources and conservation of Neotropical butterflies in urban forest fragments. *Biol. Conserv.* **64**, 3–9.

Ruszczyk, A. (1986a) Hábitos alimentares de borboletas adultas e sua adaptabilidade ao ambiente urbano. *Rev. Brasil. Biol*. **46**, 419–27.

Ruszczyk, A. (1986b) Organização das comunidades de borboletas (Lepidoptera) nas principais avenidas de Porto Alegre, Rio Grande do Sul. *Revta. Brasil. Entomol*. **30**, 265–9.

Ruszczyk, A. (1986c) Mortality of *Papilio scamander scamander* (Lepidoptera: Papilionidae) pupae in four districts of Porto Alegre (S. Brazil) and the causes of superabundance of some butterflies in urban areas. *Revta. Brasil. Biol.* **46**, 567–79.

Ruszczyk, A. (1986d) Ecologia urbana de borboletas, I. O gradiente de urbanização e a fauna de Porto Alegre, RS. *Revta. Brasil. Biol.* **46**, 675–88.

Ruszczyk, A. (1986e) Ecologia urbana de borboletas, II. Papilionidae, Pieridae e Nymphalidae em Porto Alegre, RS. *Revta. Brasil. Biol.* **46**, 689–706.

Ruszczyk, A. (1987) Distribution and abundance of butterflies in the urbanization zones of Porto Alegre, Brazil. *J. Res. Lepid.* **25**, 157–78.

Ruszczyk, A. and Araujo, A.M. (1992) Gradients in butterfly species diversity in an urban area in Brazil. *J. Lepid. Soc.* **46**, 255–64.

Santin, D.A. (1999) A vegetação remanescente do município de Campinas (SP). Mapeamento, caracterização fisionômica e florística visando a conservação. Doctoral Thesis: UNICAMP, Campinas, SP, Brazil: xviii + 199 pp., 4 anexos (Map; 163 pp.; 3 pp. + 178 sites × 478 species matrix; 70 pp.). UNICAMP Press, thesis number 38966-7.

Shapiro, A. (2000) The California urban butterfly fauna is dependent on alien plants. *Divers. Distr.* **8**, 31–40.

Shapiro, A.M. and Shapiro, A.R. (1973) The ecological associations of the butterflies of Staten Island. *J. Res. Lepid.* **12**, 65–128.

Statsoft Inc. (1995) *Statistica for windows* [Computer Progam Manual], Tulsa, OK, USA.

Ter Braak, C.J.F. and Smilauer, D. (1999) *Canoco for windows*, version 4.02, The Netherlands: Centre for Biometry. Wageningen.

Tyler, H., Brown Jr., K.S. and Wilson, K.H. (1994) *Swallowtail butterflies of the Americas: A study in biological dynamics, ecological diversity, biosystematics, and conservation*. Gainesville, FL: Scientific Publishers.

Vanini, F., Bonato, V. and Freitas, A.V.L. (1999) Polyphenism and population biology of *Eurema elathea* (Pieridae) in a disturbed environment in tropical Brazil. *J. Lepid. Soc*. **53**, 159–68.

Whitmore, T.C. and Sayer, J.A. (1992) *Tropical deforestation and species extinction*. London: Chapman & Hall.