LANDSCAPE STRUCTURE IN URBAN AND PERI URBAN AREAS IN THE METROPOLITAN REGION OF BUENOS AIRES (MRBA)

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Abstract

Urban and peri urban landscapes, as well as rural landscapes, exhibit diverse spatial patterns related to components or uses diversity (e.g: agricultural lots, forests, urban reserves, city settlements among others). Landscape ecology permits spatial understanding based on three particular characteristics: structure, functions and change. In this research, landscape indexes in urban and peri urban areas in the Metropolitan Region of Buenos Aires (MRBA) were identified. The associated research hypothesis states that: landscape characteristics will be differentially affected according to urbanization level (urban and peri urban). Landscape indexes (estimated and measured) were made for each municipality: heterogeneity; diversity, dominance; patch density. Also, the following levels were analysed: urban and peri urban; urbanization circular distribution (crowns): 1, 2, 3, 4 and urbanization radial distribution (subzones): North West and South. Landscape quantitative indexes were associated with uses: extensive agriculture: EA; intensive agriculture: IA; urban and peri-urban agriculture: UPA; green areas: GA; urban use: URB. EA and IA were affected according to urbanization level and crown ($p < 0.05$). UPA and GA presented significant differences between subzones and crowns: fourth crown and southern presented higher UPA percentages. In the southern subzone, urban and peri urban expansion occurred diminishing natural ecosystems and augmenting EA and IA uses. UPA presented a wide variation in the total number of patches between municipalities. The number and the average surface of the patches expressed as patches density presented differences between municipalities. Diversity index presented differences between municipalities, presenting values ranging between 0.18 and 1.09 in CABA and Berazategui, respectively. The results showed that dominance of EA and IA uses with greater surfaces may affect the occurrence of other natural uses in the landscape. Matrix characteristics showed a degree of fragmentation influenced by the differential heterogeneity between municipalities. Vegetated uses human uses (EA, EI, GA, UPA) can help decrease landscape fragmentation, increase diversity conservation and homogenization in MRBA and as seen in regions worldwide. MRBA characteristics come from the original ecosystem transformation, which generated a fragile landscape that requires human actions over time in order to keep urban ecosystem working. This research could be useful to evaluate landscape ecological processes within MRBA and mega cities worldwide.

Keywords landscape uses; landscape ecology; landscape indexes; urban vegetated uses

INTRODUCTION

Landscape structure in urban and peri-urban areas is related to territory social, economic and environmental elements occupation processes (Burel y Baudry, 2003; Dadashpoor et al., 2019). Landscape ecology studies territorial ecological heterogeneity. Landscape ecology allows urban and peri-urban spatial configuration understanding. Also, these studies may allow a sustainable management of urbanized areas and their surroundings. Landscape structure presents different properties and a greater diversity of shapes (Dadashpoor et al., 2019 Echeverria et al., 2012; Lausch, A. et al., 2015). Homogeneity and heterogeneity are the easiest ways to quantify the landscape structure. The most basic study to assess heterogeneity degrees is through land cover or uses. Land uses studies are ecologically relevant, since they directly affect landscape components such as: species distribution, species richness and functional groups numbers, among others. Landscape analysis involves the interpretation of structural, morphological and functional characteristics of the territory in order to include landscape ecology evaluation (Vila Subirós et al, 2006; Burel y Baudry, 2003; Lausch, A. et al., 2015).

Landscape ecology permits a territory structural analysis through a specific moment or evolution over time. In this sense, it can be summarised that landscape ecology is mainly based on three particular characteristics: structure, functions and landscape change (Forman, 1995; Vila Subirós et al, 2006 Burel y Baudry, 2003; Lausch, A. et al., 2015). Landscape morphological and structural components disposition affects matter and energy exchange, since each of the components has a specific function. Changes in landscape structure have their origin in ecosystems, natural and anthropic transformations. Anthropic activity affects landscape structure, especially in most human-interrupted landscapes and ecosystems (Naveh and Lieberman, 2001; Morello et al., 2003 y Forman, 1995; Mateucci, 2012). In several cases, society is configured as the dominant ecological variable in landscape construction. The latter is especially important in urban and peri-urban environments and therefore landscape anthropic interventions affect their functions and evolution over time.

Landscape structure and landscape ecology main components were defined and systematised years ago (Forman 1995) and currently several publications were dedicated to this subject (Vila Subirós et al, 2006; Farina, 2000; Lausch, A. et al., 2015). However, there are still fewer studies and publications, related to this subject, from Latin American countries (Burel and Baudry, 2003; Fan and Myint, 2014; Mateucci, 2012). Metropolitan Region of Buenos Aires (RMBA) urban and peri-urban landscape construction processes have generated, among other aspects, urbanized area expansion and vegetated spaces decrease. Also, in peri urban landscape, agricultural expansion still represents an important established change due to positive variations in economic agricultural indexes (Naveh y Lieberman, 2001; Morello et al., 2003; Mateucci, 2012). Human impact in the MRBA has changed structure and functional processes (e.g energy flows) that regulate the landscape. In this context, population increases replaced natural ecosystems with agricultural or urban uses and intensified landscape changes in the MRBA (Naveh y Lieberman, 2001; Morello et al., 2003).

Urban and peri-urban landscapes, as well as rural landscapes, exhibit diverse spatial patterns related to components or uses diversity (for example: agricultural lots, forests, urban reserves) (Vila Subirós et al, 2006; Laush et al, 2015; Dadashpoor et al., 2019). These patterns represent landscape structure and could be quantified with a diverse number of measurements and indexes. Different landscape index combinations are essential for an accurate landscape components analysis and understanding (Vila Subirós et al, 2006; Wagner and Fortin, 2005; Li and Wu, 2004; Laush et al, 2015; Dadashpoor et al., 2019). Landscape structure analysis in urban and peri-urban areas is especially relevant; because, in these areas, landscape changes occur rapidly and are mainly related to human activities. Also, landscape indexes analysis allows us to evaluate changes in uses and species diversity. Moreover, changes in landscape indexes affects ecosystem goods and services (ES) availability. ES associated with landscape indexes are relevant since they provide social and environmental benefits such as: fibers and food, pollination regulation, nutrients cycling and floods control, among other benefits (Kremen et al 2007; Civeira et al., 2020).

The data obtained in this study would be useful to analyse landscape ecological processes within MRBA and mega cities worldwide. Also, results could be used to assess conservation needs. Potential responses of urban and peri urban environment to rapid changes in landscape uses are necessary to recognize and understand, since they affect ecosystems resources and dynamics. Moreover, landscape changes by human activities are causing deterioration in the ES provided by urban and peri urban vegetated areas. In this research, landscape indexes in urban and peri-urban areas in the MRBA were identified. The associated research hypothesis states that: landscape characteristics will be differentially affected according to urbanisation level (urban and peri urban).

MATERIALS AND METHODS

LANDSCAPE INDEXES

Literature provides different landscape index methods (among others: Forman, 1995; Vila Subirós et al, 2006 Burel y Baudry, 2003; Lausch, A. et al., 2015). In this research, landscape indexes (estimated and measured) were calculated for each MRBA municipality. Also, for each municipality the following characteristics were analysed: urban and peri urban levels; urbanisation circular distribution (crowns): 1, 2, 3, 4 levels and urbanisation radial distribution (subzones): North West and South levels (more information in Civeira et al. 2020). Landscape indexes quantitative evaluation could be associated with ecosystems land uses richness in a given landscape (Mc Garigal, 1995; Botequilha et al., 2006, Vila Subirós et al, 2006 Fan, C., Myint, S., 2014 among others). Richness was evaluated as a proportion of land use types. Each use type was calculated as surface percentage at the municipality level (McGarigal and Marks, 1995; Vila Subirós et al, 2006; Civeira, 2016, 2020). Figure 1a and 1b show municipality's surface (km2) and landscape uses frequency in the MRBA. Relevant uses were: extensive agriculture (EA): which includes rainfed corn, wheat, sunflower and soybean crops and implanted pastures; intensive agriculture (IA) which includes horticulture, floriculture and farm; urban and peri-urban agriculture for self-consumption and eventual surplus sales (UPA); the green areas (GA); urban use (URB), road and river corridors (Cor) and other unspecified uses (Ot).

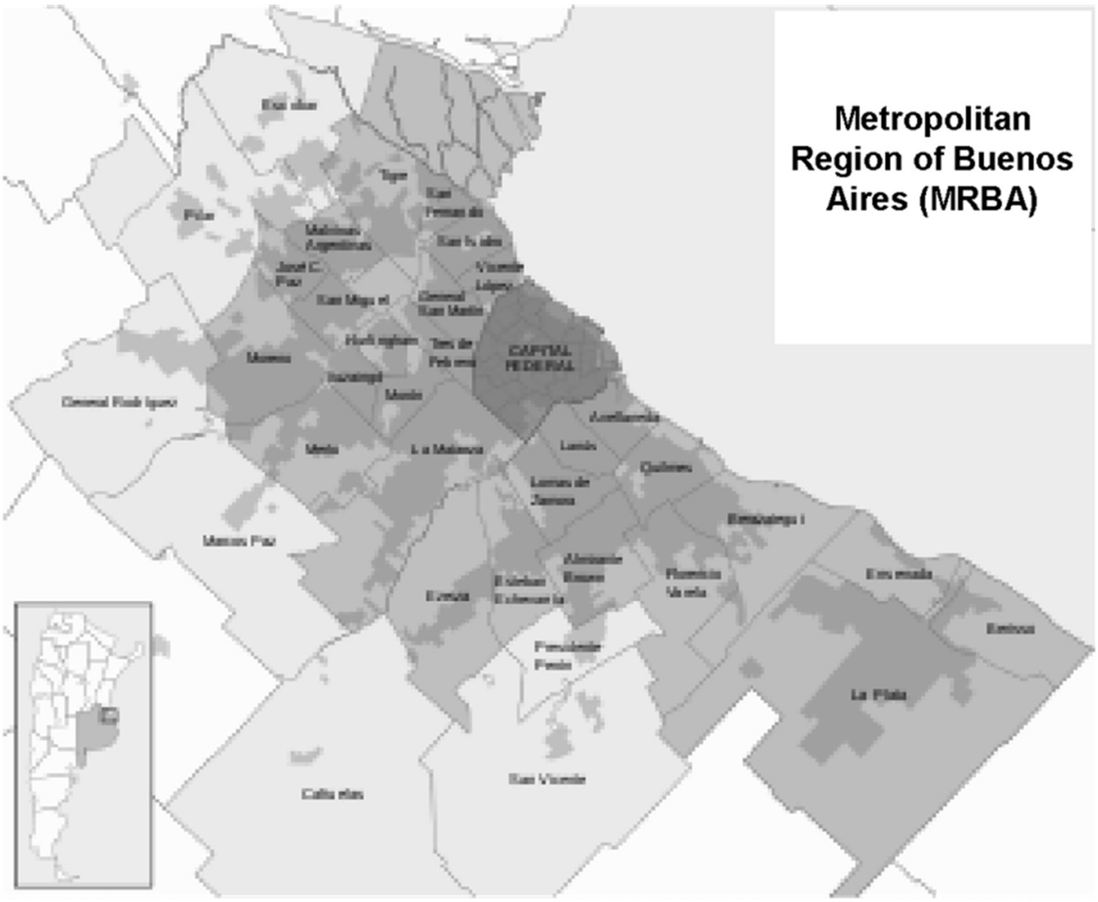


Figure 1a. Metropolitan Region of Buenos Aires (MRBA)

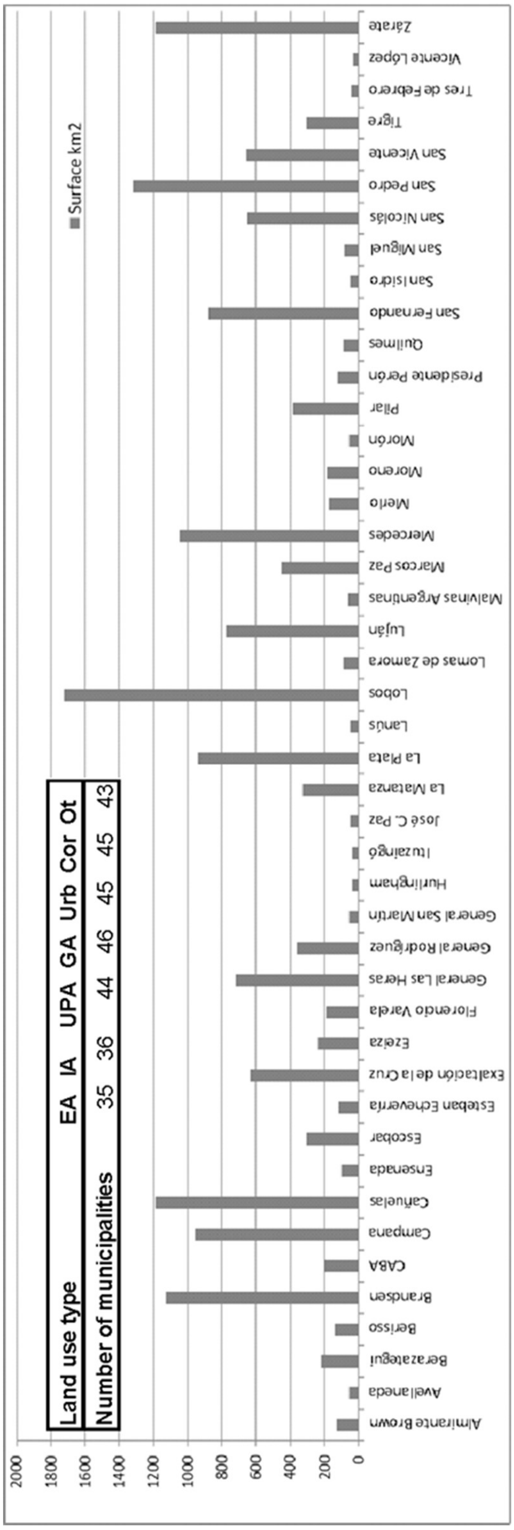


Figure 1b. Municipalities surface (km^2) and Frequency of landscape uses in the Metropolitan region of Buenos Aires MRBA. EA: extensive agriculture; IA: intensive agriculture; UPA: urban and peri urban agriculture; GA: Green areas; URB: urbanised; Cor: Corridors; Ot: other uses; MRBA: Metropolitan region of Buenos Aires)

Patches (or fragments) include morphological units which can be differentiated at the landscape level (McGarigal and Marks, 1995; Forman, 1995 Lausch, A. et al., 2015). In general, elements evaluation include: surface, shape, number and arrangement at landscape level. Also, differences between elements at landscape composition levels include patch variety and abundance evaluation. Landscape configuration includes patches spatial distribution within the landscape (McGarigal and Marks, 1995; Etter, 1991). Between patches exist corridors. These landscape uses act as connections between patches. Moreover, patches and corridors formed a complex medium named landscape matrix. These landscape structural and morphological elements were quantitative analysed. In some municipalities, when information was available, the presence of corridors and the landscape matrix were also evaluated. Landscape evaluation includes the interpretation of basic components. Basic components include mosaic concept, which is a part of other components set or landscape elements. The Mosaic concept is especially important in landscape evaluation, since three relevant elements can be distinguished at mosaic level: fragments or patches, corridors and matrix. The Mosaic concept, which includes that form landscape components (or elements), can be used on any scale (from tiny to global), showing the importance of this evaluation.
Patches density was evaluated measuring each use of patch numbers per unit area. Patches' average surface size was evaluated measuring the relationship between each used surface and its patch number. Dominance (D) was calculated as the relationship between total land use type and the patches number of a particular use in the MRBA (O'Neill et al. 1988 Lausch, A. et al., 2015). Heterogeneity (H) was assessed based on probabilities, such as landscape diversity. Heterogeneity obtained value represents the probability that two randomly selected elements in the landscape could be different. Therefore, the higher the H value, the greater the heterogeneity. Diversity was estimated through the diversity index of Shannon (SHDI), since it is a measure of landscape complexity and includes richness (number of uses, classes or categories) and patches use distribution equity.
Patches of each use type were evaluated at municipal level in the MRBA. As a result, patches number (total) were analyzed. Also, these data were used to calculate dominance index (D), which considered the amount of uses presented in the study area and the relative amount of each use at the municipality level. Also, all uses that presented percentages below 0% were eliminated. The following equation was used to calculate the dominance:

$$D = \frac{\ln(S) + \sum_i [p_i * \ln(p_i)]}{\ln(S)}$$

In this equation, S is the number of landscape uses; pi, is the proportion of the i*th* type of use. Possible scale values range from 0 to 1; those near 1 indicate a landscape dominated by one or several uses, while those near 0 indicate that the proportions of each use are practically equal (Wagner y Fortin, 2005; Li y Wu, 2004; Botequilha et al., 2006).
Shannon Diversity Index (SHDI), as a measure community ecology diversity was used in this study at landscape ecology scale by using the following equation:

$$\mathrm{SHDI} = -\sum_{i=1}^{m} (P_i \_ \ln P_i)$$

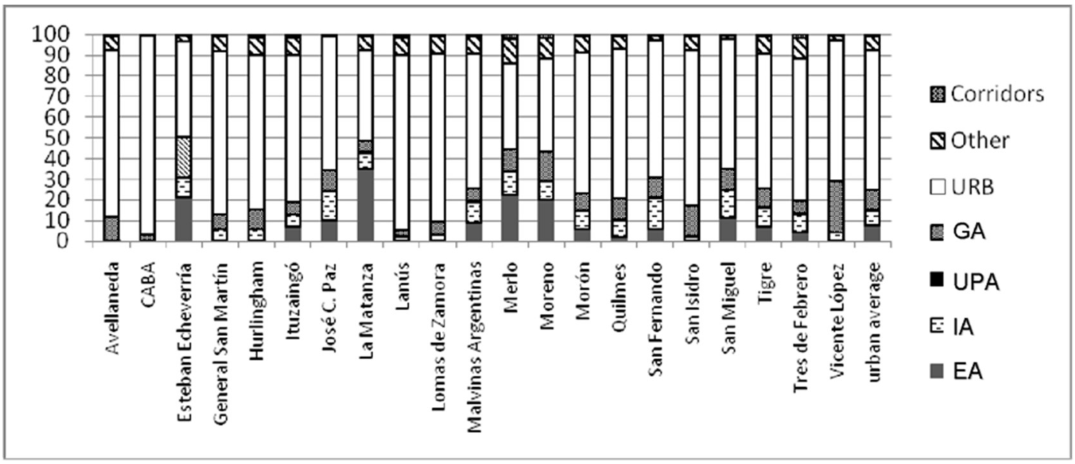
The equation items include a negative sum of each landscape fraction occupied by a patch use multiplied by its logarithm in base 2 or by the proportion of each landscape patch category (p) (among others: Wagner y Fortin, 2005; Li y Wu, 2004; Mc Garigal and Mark, 1995; Botequilha et al., 2006).
The landscape use heterogeneity index (H) was evaluated using coefficient variation index (Cv).Since, Cv was identified as the most useful way to analyse two different groups (or uses) dispersion. Cv was calculated using the following equation:

$$C_V = \frac{\sigma}{|\bar{x}|}$$

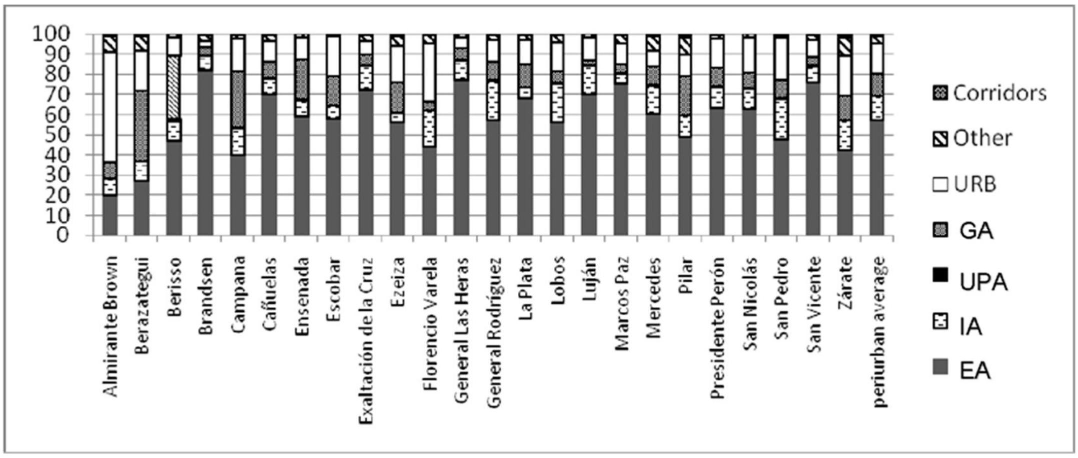
Cv equation expresses the standard deviation as a percentage of the arithmetic mean. This equation presents a better percentage interpretation than standard deviation variability. In order that Cv equation to reach positive values, all data must present positive values as well. The greater Cv value, the greater the heterogeneity between landscape uses (EA, EI, AUP, GA). Also, the lower Cv value, the greater homogeneity between evaluated landscape uses (Wagner y Fortin, 2005; Li y Wu, 2004; Botequilha et al., 2006).
Different data sources (censuses, data from official and private organisations, google earth and satellite images) following methodologies cited in literature (Wagner and Fortín, 2005; more details in Civeira, 2016, 2020) where used to obtain landscape indexes. As several land use data came from different sources, in some cases, an average of each use (hectares) was obtained. With these data, average use percentage in each municipality was calculated and comparisons between these units of analysis were made. In each municipality the percentage occupied by the productive area (EA, EI), the man built area (URB), the urban vegetated area (AUP, GA) and corridors area (Corr.) were analyzed (Priego-Santander, et al. 2004; more details in Civeira, 2016, 2020). To assess whether there were statistical differences in landscape indexes measured in municipalities and analyzed at the subzone, urbanization and crown level, the Kruskal-Wallis test was used (Kruskal and Allen Wallis, 1952). This test allows inferring whether urbanization level (urban and peri urban), crowns (1, 2, 3, 4) and sub zones (North West and South**)** presented different behaviours in relation to heterogeneity (H), uses proportion (Cv), diversity index (SDIH) and dominance (D) in each municipality from the MRBA. A 2018 version from Infostat program was used.

RESULTS

Results obtained showed differences between uses (surface and percentage) in the municipalities of the studied area (Figure 2). Municipalities with lower than 10% EA were: Avellaneda, Lomas de Zamora, San Isidro, CABA, Lanús, General San Martín, Hurlingham, Vicente López, Quilmes, Tres de Febrero, Morón, San Fernando, Ituzaingó, Tigre and Malvinas Argentinas (Figure 2 a). On the other hand, these municipalities presented the highest percentages in URB, reaching up to about 90% in the municipalities of Lanús and CABA. Municipalities with the highest percentages of EA (> 60%) were further away from CABA and were the following: Mercedes, San Nicolás, Presidente Perón, Cañuelas, Luján, La Plata, Exaltación de la Cruz, Marcos Paz, San Vicente, General Las Heras and Brandsen (Figure 2b). Also, these municipalities presented elevated URB use variations (between 4% and 17% for Brandsen and San Nicolás, respectively). IA showed a range between 0 and 20%, being Exaltación de la Cruz, Campana, José C. Paz, San Miguel, Mercedes, Luján, San Fernando, Zárate, Florencio Varela, Lobos, General Rodríguez and San Pedro those who presented percentages greater than 10%. All municipalities in the MRBA presented UPA use. Higher UPA percentages were observed at greater distances from CABA. Also, UPA was randomly distributed in the MRBA presenting the following order: Berisso> Quilmes> MarcosPaz> Lobos > Mercedes> SanPedro> Malvinas Argentinas> Tres de Febrero> San Nicolás> Tigre> President Perón> Ensenada. Following a similar trend as UPA, GA were also established in all municipalities and presented percentages ranging from 2 to 35%, without an observable trend in their spatial distribution. Municipalities with the highest GA percentages in descending order were: Berazategui> Berisso> Campana> Vicente López> Ensenada> Esteban Echeverría> Pilar> Ezeiza> San Isidro> Escobar> Moreno (Figure 2 a and 2 b).



A) Urban municipalities



B) peri urban municipalities. EA: extensive agriculture; IA: intensive agriculture; UPA: urban and peri urban agriculture; GA: Green areas; URB: urbanized; Corridors; Other: other uses.

Figure 2. Land uses proportion (% percentage) in each municipality from MRBA.

Urbanization level and crown affected EA and IA at each municipality ($p < 0.05$): peri urban level and crown 4 presented the highest percentages. Differently crown 1 and urban level presented the lower EA and IA percentage (Table 1). As observed, a closer proximity to CABA (higher urbanized area) demonstrated a lower EA and IA percentages and a higher URB percentage. This trend was also observed in Buenos Aires province and in other rural-urban areas in USA (Mateucci et al., 2006, Luck and Wu, 2002; Buzai and Mendoza, 2004; Mateucci, 2012).UPA and GA presented significant differences between subzones and crowns: South and crown 4 presented higher UPA percentages. Likewise, highest GA percentages were observed in North subzone and crown 4. In the literature, these results were related to dispersed housing constructions and larger areas with neocosystems and natural ecosystems fragments preservation, which diminished agricultural productions (EA and IA) (Civeira, 2016, 2020; Mateucci and Morello, 2009; Mateucci, 2012; Silva, 2003). On the other hand, in South subzone, urban and peri urban expansion diminished natural ecosystems and augmented EA and IA percentages. As expressed in literature, these agricultural products (EA and IA) were commercialized in urban and peri-urban areas with higher socioeconomic status (e.g., North subzone) (Mateucci et al., 2006; Morello et al., 2003; Mateucci, 2012). Urban level and crowns 1 and 2, presented the highest corridors (Corr) percentages, probably due to a greater presence of road networks (railways and routes) (Civeira, 2016; Naveh and Lieberman, 2001; McGarigal and Marks, 1995; Forman, 1995). In relation to corridors use, these were observed in all municipalities and presented significant differences between subzones, crowns and urbanization level. Higher percentages of corridors were observed in West subzone, urban level and crowns 1 and 2 (Table 1). The higher corridors percentages in West subzone were related to a higher proportion of river basins and road networks (railways, routes and highways) in this MRBA area (Mateucci, et al., 2006).

Levels	EA	IA	UPA	GA	URB	Cor	Ot
Subzone							
North	31,07	10,67	0,17	12,67	40,06	0,75	4,27
West	23,30	10,20	0,14	7,70	49,90	1,30	7,90
South	46,74	8,74	0,30	11,47	30,79	0,77	4,39
p	*0,1327*	*0.07*	***0,047***	***0,046***	*>0.99*	***0,01***	***0,01***
Crowns							
1	2,69	5,92	0,13	9,22	77,85	1,16	6,46
2	23,92	10,67	0,14	12,50	47,08	1,11	6,42
3	60,53	10,60	0,24	12,73	12,73	0,60	3,47
4	63,60	14,00	0,51	7,80	13,08	0,59	3,20
p	***<0,0001***	***<0,0001***	***0,0001***	***<0,0001***	*0,1745*	***0,023***	***0,024***
urbanization							
urban	8,38	7,79	0,19	10,43	67,71	1,19	6,38
peri urban	57,42	11,81	0,28	10,79	15,54	0,58	3,71
p	***0,0001***	***0,018***	*0,06*	*0,18*	***0,0001***	***0,016***	***0,0159***

Table 1. Land use type (% percentages) according to subzones (North, West, South), crowns (1,2,3,4) and urbanization levels (urban and peri urban) in the MRBA (Kruskal Wallis test). Bold numbers were statistically significant (p <0.05) EA: extensive agriculture; IA: intensive agriculture; UPA: urban and peri urban agriculture; GA: Green areas; URB: urbanized; Cor: Corridors; Ot: other uses.

Table 2 shows differences in each municipality between patch number, patches average surface size and patches total area in the MRBA. Evaluated uses were UPA; EA+IA, GA and URB. UPA presented a wide variation in patch numbers between municipalities, being lower in Mercedes and Brandsen (89 and 63, respectively) and higher in Moreno (4500), La Matanza (3000), Merlo (3000) and Florencio Varela (3000). Patches' average surface size showed differences between municipalities, presenting a wide range between 8 m^2 and 900 m^2 in Morón and Lobos, respectively. Also, EA+IA showed a great variation between municipalities in patches number: La Plata, Lobos and San Pedro (971, 338 and 330, respectively) presented the higher values; San Isidro, Vicente López, Lanús and CABA (0) presented the lower patches number values (<2). Patches average surface size also showed wide differences between municipalities, presenting a wide range between 0 ha and 33 hectares in CABA and Merlo, respectively.
GA patches number presented wide differences between municipalities: variation range was between 9 and 21000 in San Fernando and General Las Heras, respectively (Table 2). Also, GA patches average surface size presented a wide range of variation: the lowest was in Malvinas Argentinas (8 m^2) and the highest in San Fernando municipality (3.4 hectares). URB use exhibited the lowest patches number in Berisso, Ensenada and Presidente Perón (<1200) and the highest in CABA and La Matanza (> 10000), demonstrating a pronounced variability between municipalities. URB patches average surface size presented homogeneous difference between municipalities, presenting a variation range between: 10,493 m^2 and 16,850 m^2 in Avellaneda and Brandsen, respectively. This similar URB patches average surface size between municipalities was observed by Silva (2003) and related to a homogenization process occurring in the MRBA (Table 2).

A)

Municipalities	Patches average surface (hectares)				Patches number				Total surface (hectares)			
	UPA	EA+IA	GA	URB	UPA	EA+IA	GA	URB	UPA	EA+IA	GA	URB
Avellaneda	0.44	0.00	0.07	1.05	200	10	9019	4001	0.89	0.05	629.76	4198.40
CABA	0.60	0.00	0.21	1.63	419	0	3000	12000	2.51	0.00	630.23	19516.80
Esteban Echeverría	399.84	6.16	0.02	1.45	2	12	100384	3805	9.76	30.80	2345.54	5530.12
General San Martín	0.76	0.60	0.04	1.44	780	4	9481	3051	5.93	6.00	373.53	4404.25
Hurlingham	0.40	0.60	0.03	1.58	900	5	9342	1680	3.56	6.00	318.87	2657.25
Ituzaingó	26.90	1.29	0.02	1.68	1	3	9245	1622	0.39	12.90	221.79	2718.86
José C. Paz	0.34	0.48	0.01	1.64	800	50	48950	1984	2.69	24.00	501.60	3260.40
La Matanza	0.88	1.30	0.03	1.39	3000	70	70335	10400	26.30	42.83	1810.71	14485.68
Lanús	0.50	0.67	0.01	1.44	950	2	9580	2850	4.71	2.00	140.64	4109.75
Lomas de Zamora	0.04	0.75	0.04	1.44	2200	4	12802	4926	0.89	3.00	558.00	7071.30
Malvinas Argentinas	3.12	1.19	0.01	1.51	1010	16	42595	2725	31.55	19.00	378.54	4100.85
Merlo	0.20	33.50	0.04	1.31	3000	50	48234	5400	5.99	33.50	1904.43	7098.33
Moreno	0.07	0.15	0.03	1.35	4500	120	93416	6200	3.10	29.00	2605.82	8375.85
Morón	0.00	2.50	0.02	1.47	910	6	23106	2574	0.01	15.00	445.28	3784.88
Quilmes	12.56	1.43	0.04	1.26	620	7	25267	5216	77.85	10.00	905.75	6587.28
San Fernando	6.07	0.33	3.40	1.52	630	44	938	3801	38.22	20.96	8770.80	5788.00
San Isidro	0.44	2.00	0.13	1.33	589	1	5782	2902	2.57	2.00	771.60	3858.00
San Miguel	0.40	8.33	0.02	1.60	1100	3	47024	3250	4.45	25.00	823.53	5199.84
Tigre	6.76	0.19	0.43	1.59	1800	73	6324	8500	121.74	16.00	2739.15	7800.00
Tres de Febrero	5.38	1.63	0.03	1.51	320	8	8342	1956	17.22	13.00	258.24	2952.54
Vicente López	0.47	2.00	0.30	1.24	150	2	2834	1855	0.70	4.00	844.25	2296.36

B)

Municipalities	Patches average surface (hectares)				Patches number				Total surface (hectares)			
	UPA	EA+IA	GA	URB	UPA	EA+IA	GA	URB	UPA	EA+IA	GA	URB
Almirante Brown	0.16	1.67	0.04	1.37	2500	30	25434	5200	4.00	28.35	995.98	7113.15
Berazategui	3.54	0.41	0.35	1.54	990	88	22059	2873	35.00	36.50	7735.35	4420.20
Berisso	28.18	1.84	0.21	1.52	550	105	20040	833	155.00	56.90	4265.29	1265.83
Brandsen	230.16	0.38	0.23	1.68	63	234	19860	2142	145.00	89.00	4504.08	3603.26
Campana	1.09	0.46	1.19	1.65	220	116	22415	9233	2.39	53.30	26727.12	15272.64
Cañuelas	25.00	0.29	0.44	1.53	520	242	21487	7774	130.00	78.00	9520.88	11901.10
Ensenada	13.08	9.84	0.10	1.47	214	7	19893	746	28.00	68.85	1985.81	1099.23
Escobar	1.02	0.45	0.19	1.49	950	144	23363	4070	9.68	64.67	4342.11	6075.00
Exaltación de la Cruz	1.50	1.16	0.15	1.54	180	220	21458	2917	2.70	87.99	3113.14	4502.61
Ezeiza	0.48	6.07	0.19	1.60	2600	20	18756	2656	12.45	60.70	3552.15	4262.58
Florencio Varela	1.38	0.47	0.01	1.58	2900	132	51739	3490	40.00	61.90	759.60	5507.10
General Las Heras	40.84	0.61	0.02	1.63	380	125	210983	2212	155.20	89.00	4165.06	3600.50
General Rodríguez	10.18	0.96	0.05	1.47	980	83	66377	2694	99.80	79.52	3313.29	3961.54
La Plata	31.75	0.08	0.14	1.56	630	971	72480	7417	200.00	76.50	10353.22	11589.43
Lobos	919.65	0.22	0.41	1.67	150	338	21085	6100	1379.48	75.22	8621.75	4921.00
Luján	0.62	0.65	0.03	1.65	890	110	65089	5270	5.49	86.29	1942.83	8703.86
Marcos Paz	37.15	0.41	0.11	1.51	980	250	17709	3013	364.10	79.90	1911.50	4551.20
Mercedes	825.43	0.37	0.16	1.56	89	200	60545	5373	734.63	74.00	9445.23	8395.76
Pilar	1.07	0.57	0.11	1.56	930	104	65921	2770	9.95	59.60	7277.19	4328.01
Presidente Perón	5.28	3.68	0.02	1.56	800	30	70586	1159	42.26	73.50	1086.57	1810.95
San Nicolás	124.24	0.35	0.07	1.59	210	207	75085	6989	260.90	72.60	5218.08	11088.42
San Pedro	316.63	0.20	0.16	1.47	250	331	74292	7500	791.58	67.36	11873.70	6100.00
San Vicente	14.21	0.87	0.04	1.58	950	130	78723	3487	135.00	87.00	2887.59	5508.73
Zárate	17.83	0.36	2.02	1.60	200	160	7114	7852	35.67	57.00	14349.42	6410.00

Table 2 Land uses patches average surface size (hectares), patches number and patches total area (hectares). A) Urban municipalities and B) peri urban municipalities. EA: extensive agriculture; IA: intensive agriculture; UPA: urban and peri urban agriculture; GA: Green areas; URB: urbanized

Patches density and its variation coefficient were analysed and shown together in Figure 3. As previously stated, knowing average surface and patches density is relevant, since they directly affect landscape diversity and functions (Lausch, A. et al., 2015; Burel, F., Baudry, J., 2003). Patches density and its variation coefficient presented differences between municipalities, urban and peri urban level. Urban municipalities presented higher patches density than the peri-urban municipalities. Variation coefficient presented heterogeneity along municipalities, values ranged between 0.8 (Ezeiza) and 1.85 (Zarate). But, no significant differences between urban and peri urban municipalities were observed. Patches density values are showing vegetated patches (EA, IA, UPA, GA)surface reduction in peri urban level and URB patches average surface size increase in urban level (Table 2). Also, vegetated (EA, IA, UPA, GA) patches number presented a significant reduction in peri urban areas and URB patches number showed a consistent augmentation. The stated above, finally affected patches density in urban and peri urban areas as well.

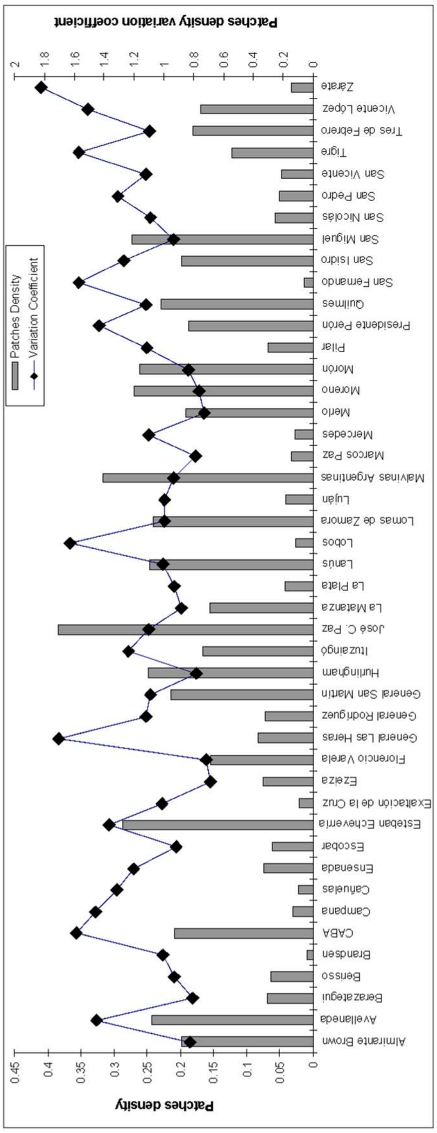


Figure 3. Patches density and variation coefficient in each MRBA municipalities

Figure 4 shows heterogeneity, dominance, richness and diversity indexes in MRBA municipalities. These landscape ecology indexes presented great variations between municipalities; demonstrating landscape uses differences in the studied area. Diversity showed differences between municipalities and values ranged between 0.18 and 1.09 in CABA and Berazategui, respectively. Municipalities which presented the highest values were: La Matanza, Escobar, San Miguel, Almirante Brown, Berisso, Merlo, Campana, Moreno, Esteban Echeverría, Berazategui. EA and IA presented greater surfaces and dominance values which may affect the occurrence of other natural landscape uses. Higher heterogeneity observed in several municipalities (for example: Lanús and Brandsen) may generate ecological complications and affected other indexes values and ecosystem processes. The latter occurs since landscape heterogeneity affects patches borders which influence, for example, species movement, matter and energy flows, among other ecosystems processes (Farina, 2000; Correa Ayram, 2005; Naveh and Lieberman, 2001; Botequilla et al.,2006). Moreover, results showed that heterogeneity and diversity were negatively related (R = 0.611; $p < 0.05$). Diversity increase may bring ecological problems such as landscape fragmentation and habitat reduction. So, elevated diversity and heterogeneity indexes are not always positive at landscape level (Figure 4) (Naveh and Lieberman, 2001).

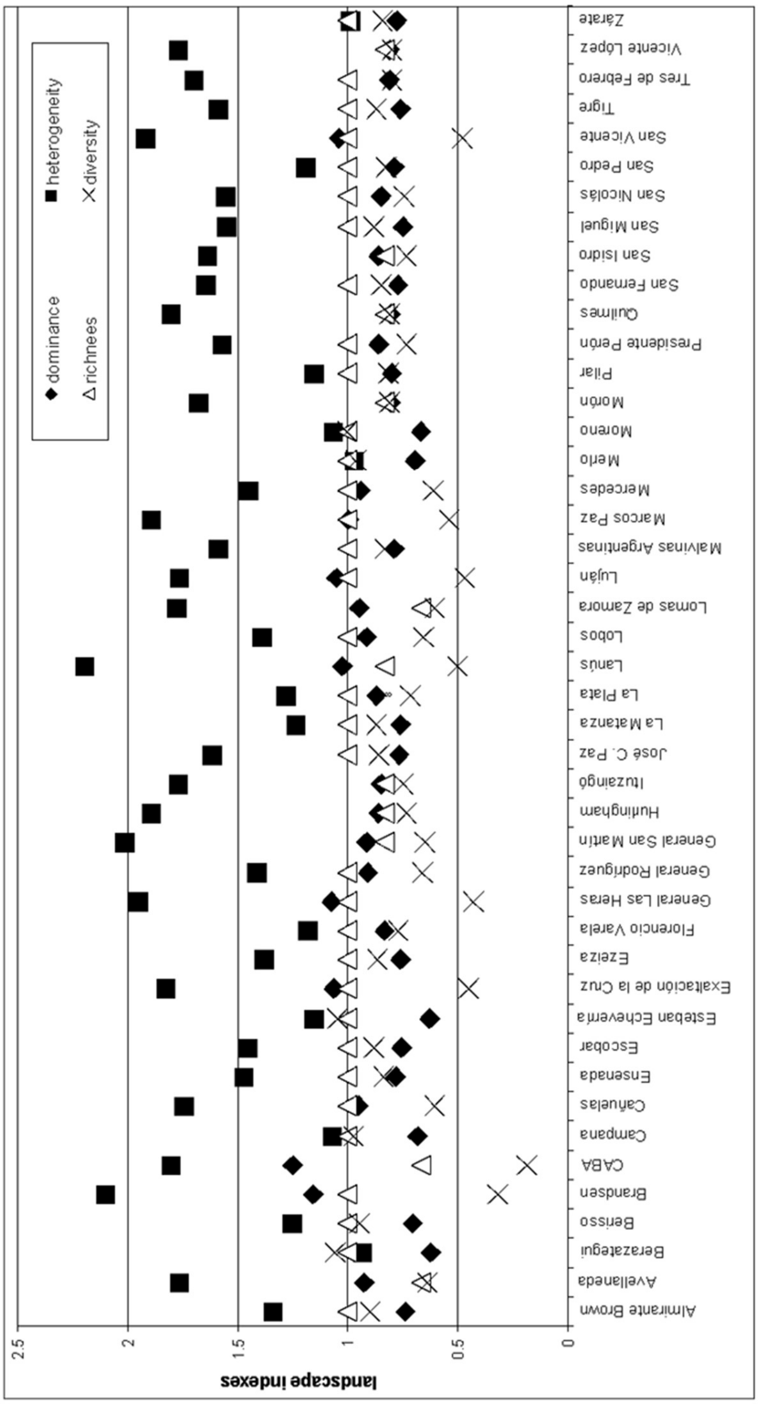


Figure 4. Landscape indexes: heterogeneity, dominance, richness and diversity in the MRBA evaluated municipalities.

Municipalities that presented higher diversity are mostly from crown 2 (Table 3). Higher diversity values expressed a more equitable distribution of patches at landscape level (McGarigal and Marks, 1995; Burel and Baudry, 2003; Lausch, A. et al., 2015). Richness index was significantly affected by crowns (Table 3). Lower richness was observed in crown 1 and higher values in the crown 2, 3 and 4. Urbanization level also affected richness: peri urban level presented higher richness values and urban lower richness values. Dominance and heterogeneity indexes were positively related ($R = 0.58$; $p < 0.05$). Therefore, municipalities with the highest heterogeneity values also presented the highest dominance rates: Lanús> Brandsen> General San Martín> General Las Heras> San Vicente> Hurlingham> Marcos Paz> Exaltation of the Cross> CABA. Heterogeneity and dominance indexes were not affected by the subzone, crowns and urbanization level (Figure 4; Table 3).

Levels	Heterogeneity	Dominance	Richness	Diversity
Subzone				
North	1,50	0,81	0,96	0,77
West	1,51	0,82	0,95	0,78
South	1,58	0,87	0,94	0,70
p	*>0,9999*	*>0,9999*	*0,0874*	*0,0915*
Crowns				
1	1,70	0,94	0,81	0,68
2	1,30	0,73	1	0,91
3	1,52	0,89	1	0,68
4	1,51	0,91	1	0,65
p	*0,06*	*0,07*	***<0,0001***	***0,0005***
urbanization				
urban	1,63	0,83	0,88	0,77
peri urban	1,47	0,87	0,99	0,71
p	*0,0816*	*0,3165*	***0,0001***	*0,3111*

Table 3. Influence of subzone (North, South, West), crowns (1, 2, 3, 4) and urbanization level (urban, peri urban) in landscape indexes: heterogeneity, dominance, richness and diversity (Kruskal Wallis heterogeneity test; Numbers in bold presented a significant level less than 0.05)

In the studied area, predominant landscape uses were different at municipality level and, as seen in literature, each predominant use acted as landscape matrix (Etter, 1991; Naveh and Lieberman, 2001) (Figure 5). According to Etter (1991) the matrix is a particular use that occupies a higher landscape surface and is the most interconnected. Also, landscape matrix is a result of patch division from larger surfaces into smaller fragments. The latter generates patches (or smaller fragments) of isolation in the landscape structure (Figure 5). Regarding patch connections (as can be seen in figure 5) the studied area presented medium to low corridors percentages (Figure 2; Table 1). Therefore, a large portion of the MRBA presented deficient landscape matrix connectivity (Figure 2; Table 2). In addition, there were landscape matrixes with greater URB and with greater agricultural (EA and IA) proportion. Also, there was a gradient between previous stated landscape matrixes types. These different landscape matrixes presented GA and UPA uses in varied percentages (Figure 5). In the MRBA, matrix characteristics varied depending on municipality and anthropic landscape uses with the highest and lower proportions (URB; EA and IA).

In general, the MRBA landscape matrix showed a fragmentation degree influenced by mostly differential heterogeneity between municipalities (Figure 4). In general, URB use in peri urban municipalities presented patches with higher average sizes (Table 2; Figure 3). As observed in literature, MRBA peri urban areas presented higher surfaces as a result of land division processes through the years (Mateucci et al., 2006; Mateucci, 2012; Laush et al, 2015; Echeverría et al., 2012; Dadashpoor et al., 2019). Over time, these peri urban areas incorporated URB uses, which expanded and penetrated a mostly rural landscape matrix (EA and IA) (Mateucci et al., 2006; Mateucci, 2012) (Figure 5). According to the latter, city borders expansion generated denser urban agglomerates, which finally were converted into a more consolidated URB use matrix inside peri urban areas (Figure 5) (Mateucci et al., 2006; Mateucci, 2012).

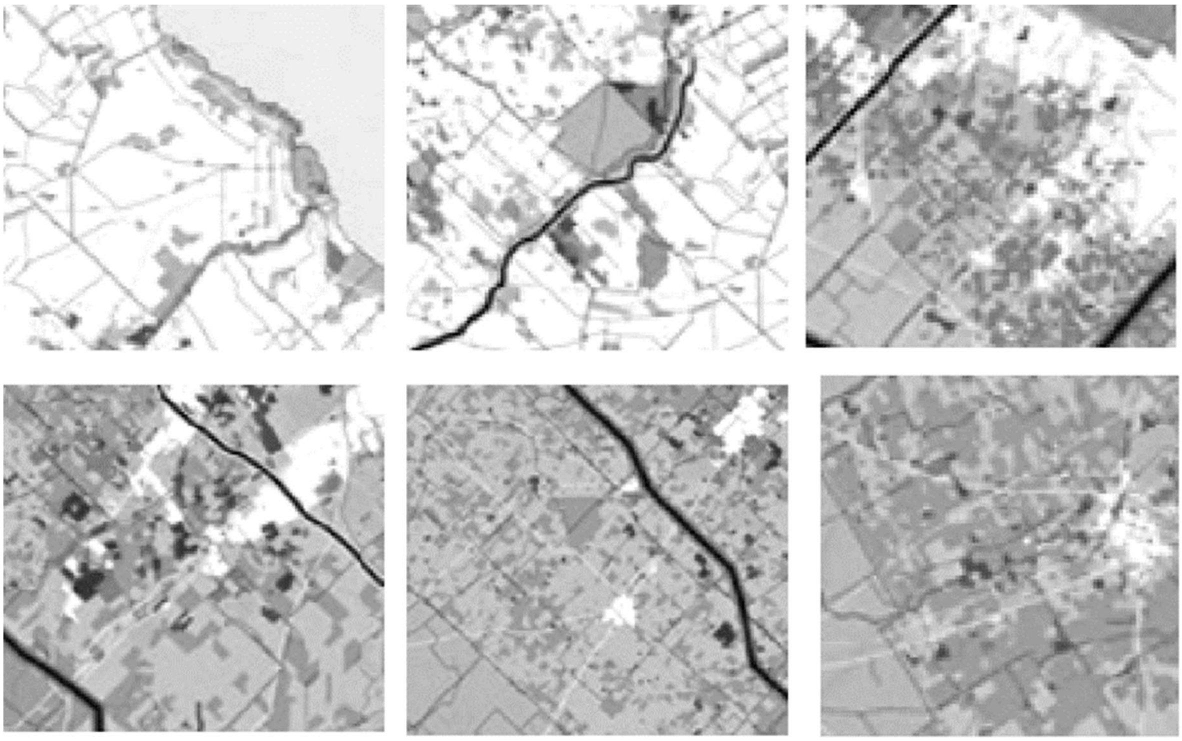


Figure 5. Landscape matrices observed in the RMBA. From left to right first row: Urban; urban with green spaces and urban agriculture; Urban with peri-urban agriculture in small plots. From left to right second row: peri-urban area: urbanizations in interstices of intensive and extensive agriculture with greater and lesser intensity of the urbanizations; peri-urban area with the highest percentage of intensive agriculture.

Urban settlements or higher aggregated urbanizations describe areas presenting artificial landscape uses as a result of anthropic activities (Correa Ayram, 2005; Mateucci, 2012; Lausch, A. et al., 2015 Dadashpoor et al., 2019). The results showed that peri urban landscape matrix presented dispersed higher surfaces that still conserved dispersed urban settlements of smaller sizes (Table 2; Figure 5) (Buzzai and Mendoza, 2004; Morello et al., 2003; Civeira et al., 2016; 2020). The latter is becoming increasingly widespread and URB use is increasing in areas where EA and IA were predominant in MRBA landscape matrix (Matteucci and Morello 2009; Mateucci, 2012). MRBA peri urban area is a very dynamic landscape so is quite difficult to establish clear limits. As observed in results and literature, expansion of new urbanizations ("barrios cerrados") and URB uses in peri urban municipalities are expanding MRBA borders. MRBA presents fragile limits, since, over the years, borders varied with the incorporation of new municipalities and landscape use changes (Civeira et al., 2016; 2020; Vidal-Koppmann, 2014; INTA, 2012) (Table2; Figure5).

DISCUSSION

EA use is still present in a considerable surface in the MRBA. In the last decades, crops introduction in the studied area included new technologies which led to traditional production models replacement, original ecosystems and IA uses reduce (Naveh and Lieberman, 2001; Mateucci et al 2006; Mateucci, 2012; Morello et al., 2003; INTA, 2012) (Table 2; Figure 1; Figure 2). Large crop areas, in the MRBA, are the result of various agro economic and model transformations over decades. These transformations were also reflected with agricultural production policies changes at country level. Also, biophysical and ecological factors can also explain EA use increase in the MRBA (Civeira, 2016; 2020); since higher EA and IA percentages were located in municipalities with higher proportions of soils with greater agriculture and livestock production aptitude (e.g more fertile soils) (Silva, 2003; Civeira, 2020; Morello, 2000; INTA, 2012 Table 1, Table3; Figure 2). Other factors that could explain the preponderance of EA over IA, in the studied area, were more related to producer's decision making strategies (Correa Ayram, 2005; Mateucci, 2012). For example, it has been observed that MRBA producers prefer extensive crops (EA) over intensive crops (IA), since EA requires fewer workers. So, probabilities that EA use are replaced by IA use may decreased in the studied area (Silva, 2003; Correa Ayram, 2005; INTA, 2012)

The results observed in this study, showed that agricultural uses (EA and IA) in the MRBA landscapes, unlike other uses (GA, UPA), presented more similarities with native ecosystems. Moreover, in peri urban matrix EA uses increased natural heterogeneity processes, since they present larger surface patches in the landscape (Table 2; Table 3; Figure 3; Figure 4; Figure 5). However, literature recorded that crops and pastures (EA) management practices increased symmetrical shapes, modified average patches surface and changed natural heterogeneity processes (Mateucci et al, 2006; Naveh and Lieberman, 2001; Correa Ayram, 2005; Mateucci et al, 2006; Fan, C., Myint, S., 2014; Naveh and Lieberman, 2001). Likewise, in Pampean Region crops and grasslands use (EA) generated homogenization processes in landscape patches surfaces. Greater landscape homogenization is related to agricultural uses with higher technification level, such as those in Pampas Region. In general, it was observed that higher technification levels tend to standardize and homogenize patches densities and surfaces (Forman, 1995; Morello et al, 2003; Naveh and Lieberman, 2001; Mateucci, 2012). However, this higher technification level in rural areas is not consistent with MRBA reality where a lesser technified agriculture is still conserved and recorded in agricultural Census (Naveh and Lieberman, 2001; INDEC, 2010).

Landscape structure previous researches were made in Buenos Aires rural areas and, as far as we are concerned, urban and peri urban areas were not evaluated until now. As observed by these researchers, rural areas presented both higher and lower diversity patches. The latter indicated that rural landscapes presented an elevated patches complexity and homogenization made by a higher anthropic intervention (Correa Ayram, 2005; Mateucci, et al., 2006; Morello, 2000; Civeira, 2016, 2020). So, unlike rural areas, MRBA urban areas could be subjected to biogeographic islands theory (Naveh and Liberman, 2001). This theory determines that: a continuous habitat diversity reduction generates ecosystem species loss. Consequently, such as habitat, landscape patch reduction affected urban uses diversity. Furthermore, the island theory concept could be used as an index to establish minimum patches area required to ensure urban ecosystems diversity (McGarigal and Marks, 1995; Forman, 1995; Vila Subirós et al, 2006, Reis et al., 2015).

Landscape uses diversity, evaluated by other researchers in Buenos Aires rural areas, presenting average values between 1.8 and 0.34 (Mateucci, 2006; Correa Ayram, 2005). Patch density data obtained in this research showed differences between municipalities and a greater range of values than those registered for rural areas in Pampas region (between 0.10 and 0.25), since MRBA included municipalities with different proportions of urban and agricultural uses (Silva, 2003; Mateucci, 2006; Mateucci, 2012; Correa Ayram, 2005; Civeira, 2016; 2020). Urbanized municipalities presented higher patch densities and dispersion values (0.02 and 0.38) than agricultural municipalities. URB and GA presented an elevated patches number; EA, IA and UPA presented medium to lower values. Furthermore, both agricultural uses (EA and IA) presented elevated patches size values (Table 2). The latter showed that patches (numbers and sizes) were affected by anthropic processes. Moreover, in many sectors of the MRBA, agricultural uses (EA and IA) are decreasing their patch number affecting landscape connections and corridors (Table 2; Figure 5). The latter was also observed in rural areas, where smaller patches number and larger sizes presented lower landscape interconnections, showing similar patterns with urban and peri urban areas (Lausch et al., 2015; Naveh and Liberman, 2001; Dadashpoor et al, 2019).

Patch number and density changes affected ecosystems diversity, dynamics and influenced landscape matrix (Table 2; Figure 5) (Eitter, 1991 Lausch et al., 2015; Dadashpoor et al, 2019). Also, these patch changes influenced environmental conditions inside patches, such as: wind effects, rainfall, frost frequencies and solar radiation, among others (Table 2; figure 5). So, radiation, rainfall, and temperature conditions variations can favour some species among others which are under environmental disadvantages, thus affecting ecosystem's biological components (Lausch et al., 2015; Naveh and Liberman, 2001; Dadashpoor et al, 2019).

In the MRBA, GA and corridor showed an essential role allowing interconnection between different patches or landscape fragments (Table 1; Figure 5). The latter increased landscape connectivity and reduced the so-called "distance effect" which generated a species number diminishing in the more isolated patches and augmented species ability to move between separated patches of a certain use type (or habitat) (Naveh and Lieberman, 2001; McGarigal and Marks, 1995; Vila Subirós et al, 2006). It was possible to identify that GA and river corridors in MRBA were associated with rivers and flood meanders and are currently fragmented in patches which still present remains original ecosystems grasslands, even the agricultural frontier increased in the area (Matteucci, 2012; Mateucci and Morello, 2009; Buzzai and Mendoza, 2004). In the studied area, GA and river corridors presented a lower density when compared to other landscape uses and were isolated in small water bodies and immersed within a larger matrix formed by grasslands, agricultural uses and to a lesser extent by urban uses (Table 3; Figure 4) (Buzzai and Mendoza, 2004; Correa Ayram, 2005).

Landscape fragmentation is promoted by an intense destruction of natural ecosystems and neo ecosystems. This fragmentation increased the distance between native habitat patches (Fan, C., Myint, S., 2014; Lausch, et al., 2015; Correa Ayram, 2005). In general, it has been observed that fragmentation affected positive processes such as matter and energy cycles in urban and rural landscapes. In the MRBA, vegetated uses (e.g EA, EI, GA, PUA) decreased landscape fragmentation and increased uses diversity. Also, diversity increased species habitats numbers and resources, improving landscape connectivity and fragmentation augmentation (Mc Garigal and Marks, 1995; Forman, 1995). In the MRBA, a decrease in vegetated patches number and density generated species number reduction (Figure 4) and in many cases a continuous disappearance of them were observed (Naveh y Lieberman, 2001; Correa Ayram, 2005).

When analysing landscape indexes, it is necessary to understand how results should be interpreted. Landscape indexes provide information on heterogeneity and homogeneity from a strictly quantitative view. So, it is impossible to formulate qualitative assessments of the derived results in a given landscape. Results obtained in this research showed that: a landscape may have higher diversity index values, but also a lower landscape quality index. The latter is due to a greater dominant patch's presence, greater use of diversity and higher degraded elements presence (Vila Subirós et al, 2006, Lausch et al., 2015; Echeverría et al., 2012). Our results, even presenting higher diversity uses, showed lower landscape spatial heterogeneity and higher similar uses distribution (or dominance) (Figure 4). The latter could be since, in the MRBA, landscape uses were distributed fairly equitably in relation to biophysical and socioeconomic factors. So, factors such as soil type, topography, routes communication proximity, urbanizations proximity and population level, among others, generated a great transformation in the MRBA landscape over time (Farina, 2000; Correa Ayram, 2005; Lausch et al., 2015; Echeverría et al., 2012).

MRBA uses diversity and patch distribution to generate higher heterogeneity levels associated with human activities. In general, it has been observed that both agricultural and urban uses (EA, IA and URB) standardize average patch sizes and densities (McGarigal and Marks, 1995; Forman, 1995) (Figure 4). MRBA vegetated human uses tend to homogenize landscape territory, according to human activities in colonised regions worldwide (Forman, 1995; Dadashpoor et al., 2019; Echeverria et al., 2012). Also, urban uses presented artificial patches sizes, numbers and densities associated with human activities (Table 2) such as: services accessibility, road network interconnection, infrastructure, among other citizen's requirements (Figure 5).

MRBA landscape presented a considerable anthropic intervention. In this scenario, landscape uses coverage's presented more symmetrical forms over time. Also, this landscape presented a greater dominance of human uses over the natural ones (Farina, 2000; Mateucci, 2006; Mateucci, 2012). MRBA current landscape structure manifested the heterogeneity created by man-landscape relationship. So, functional, morphological and structural changes are the result of urban-industrial and agricultural uses intensification. These uses are characterized by elevated fossil fuels consumption, native ecosystems replacement and lower ES contribution to population (Dadashpoor et al., 2019; Mateucci, 2012; Wagner and Fortin, 2005; Civeira et al., 2020). Moreover, anthropic uses presented heterogeneous technological levels and developed with an inefficient environmental landscape planning. This generated uncontrolled activities in an ecologically fragile area, such as urban and peri urban spaces, in coincidence with other metropolitan regions worldwide (Correa Ayram, 2005; Mateucci, 2012; Civeira, 2020; Dadashpoor et al., 2019).

CONCLUSIONS

Landscape structure allowed us to evaluate MRBA uses diversity and heterogeneity generated by society and environmental interaction. These relationships occured since, over time, various socioeconomic and ecological processes take place in megacities, such as the MRBA. Urban, agricultural and green spaces (URB, EA, IA, GA and UPA) were differentially distributed in each municipality through diverse landscape patches configuration. Landscape uses (URB, EA, IA, GA and UPA) heterogeneity and diversity emerges from anthropogenic activities disposition that take place in the territory. In addition, these geographic characteristics come from original ecosystem transformation. Both processes, human and natural, generated a fragile landscape that requires human actions in order to keep urban ecosystem functions over time. Municipalities with highest urban use proportions (URB) presented superior patches with lesser ecological value. Patches' average size was similar in municipalities with the lowest proportion of urban use. Municipalities with dominant agricultural use presented higher medium patches size which represented a greater ecological relevance. In peri urban areas, urban uses (URB) were immersed in an agricultural landscape matrix. Peri Urban agricultural uses (EA, IA) are quite relevant since they provide goods and services for the inhabitants in urban and peri urban areas. Those characteristics caused a significant landscape structure modification in MRBA surrounding areas. Urban landscape matrix presented higher green areas uses (GA) and lesser urban agriculture uses (UPA). Results obtained in this study showed that the MRBA landscape presented an important human intervention. This human intervention generated landscape uses homogenization and a higher reduction of the original ecosystem in urban and peri urban areas over time.

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