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# Land use and vegetation change (1970-2005) in Eslava river basin, Distrito Federal, Mexico.

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## ABSTRACT

Eslava River basin is part of Mexico City Conservation Soil, located in the south-west of the State. It is an area, which is involved in carbon sequestration and in local aquifer recharge. Also is an employment sources through ecotourism and agricultural activities. However, as part of the dynamic growth of the City there have been changes in land cover, a phenomenon that threatens the ecosystem services it provides to society. Understanding the temporal space land use and vegetation (LUaV) changes is fundamental to establish the proper management of the area. In this context, this paper proposed to assess these changes in the basin during a 35 years period (1970-2005). This study was processing in a GIS by crossing maps and analyzing the change matrix where different transition values (gains and losses, net and absolute change, persistence, rates and direction of change) were obtain among the five classes considered. The results show a value of persistent of LUaV classes in the watershed of 77.5 % (43 % in anthropogenic classes and 93 % in natural ones), with negative annual rates of change for Scrub-oak (-100 %) and Temporary agriculture (-1.68 %) and positive for Urban areas (5.96 %), Induced grasslands (2.92 %) and Forest (0.03 %). The most important change directions were temporary agriculture and Scrub-oak to urban areas and forest to temporary agriculture and induced grassland. The ability of water infiltration into the soil and carbon storage in aboveground biomass of vegetation has diminished by the conversion of LUaV produced during the time period considered.

**Key words**
Mexico City, Land use and vegetation transition, Urban growth, Forest, Ecosystem services.

## INTRODUCTION

Mexico City is considered a major metropolis on the planet, along with Tokyo and Sao Paulo, which is not without a number of environmental problems characteristic of cities, generated by population agglomeration and consumption of natural resources that are damaged, weakening the habitability of a suitable space for urban residents (Perló 1999 cited by Escobar and Jimenez 2009). The main Mexico City environmental problems are air pollution, accumulation of household waste, the scarcity and deterioration of green areas for recreation of citizens, local aquifer depletion and the drastic loss of natural cover (forest) in conservation areas (≈ 8591 ha for the period 1997-2005), among others (INEGI 2005; PAOT and CentroGeo 2010).

These problems in the medium term will be highlight in Mexico City, a phenomenon as is often thought, is cause by the increase in the number of inhabitants. However, population growth in next decades will be insignificant since it is estimated to be less than 400,000 inhabitants, growing from 8.85 million in 2010 (INEGI 2013) to 9.25 million by 2025 according to a programmatic scenario (GDF 2003). The impacts on key natural areas will be essentially generated by the patterns of internal mobility of the population, due to the trend in decreasing the density of the central political delegations (Fig. 1) and densification in delegations located towards the periphery (Suarez and Delgado 2007). These projections are based on negative (-1.47) and positive (0.3 to 2.4) rates of population growth of the central and peripheral delegations, respectively (Schteingart 2006), political delegations (peripheral) in which is the largest forest areas that still retain communities and carried out agricultural activities yet (GDF 2012).

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Much of these areas have been enacted as "Suelo de Conservación del Distrito Federal" (SCDF), mainly those located to the southeast, south and southwest of the capital, since an important part involved in the generation of ecosystem services.

Particularly, Eslava river basin located principally in the SCDF, is considered a medium ecological fragility (5.6) area (property of the system to withstand an activity) due to the fragility of the vegetation. The total erosion degree presents and aquifer vulnerability; is also a priority area with high and very high importance, since it was one of the two flowing rivers that are still preserved in the Capital. It has medium levels of water infiltration (23.4 mm day$^{-1}$), average carbon storage in aboveground biomass of 69.65 tons ha$^{-1}$ and a high aptitude for ecotourism for its attractive landscapes and ecosystems (GDF 2012). Similarly, Eslava river offer a habitat to 165 species of flora (Roldán-Aragon et al. 2011) and 178 species of reptiles, amphibians, mammals and birds (Peña and Lira 2008).

A process that has affected the area is urban growth, with the consequent conversion of natural plant communities to other land cover. Examples are the cases published by Schteingart (2006) who observed for 1971-1997 period in areas that are partially contained in the Rio Eslava (Ajusco area and the suburbs of San Nicolás Totolapan) a decrease between 9.5% and 15% of the surface in natural communities and an increase between 20% and 25% of the urban area and induced grassland.

The conservation of biotic communities in this area is critical to the local population, as a source of income with the forest (ecoturism) and development of agricultural activities and, for the inhabitants of Mexico City, be essential to the maintenance of urban life and the dynamics of ecosystem services.

In this context, and as part of the "Master Plan for Integrated Management and Sustainable Use of Eslava river basin 2007-2008" (Eibenschutz 2008), was carried out this work, with the objective of estimating the values of transition (gains and losses, net and absolute change, persistence, rates and direction of change) of land use and vegetation in the Eslava river basin. Understanding the forces and dynamics that lead is vital to understand, model and predict environmental change at local and regional level, and to establish actions and proper management of the area (Meyer and Turner II 1994).

## *Study area*

Eslava river basin is located in the southwest of Mexico City, between 19 º 15 '10 "and 19 º 17' 30" north latitude and 99 º 15 '18 "and 99 º 16' 40" west longitude. Occupies 2402 ha, of which 85% are located in the Magdalena Contreras political delegation and the rest in the Tlalpan delegation policy. Of the total area of the basin about 98% (2217.06 ha) is located in the SCDF (Fig. 1).

Physiographically belongs to the Sierra of the Ajusco characterized by an undulating topography and volcanic materials. In the lower parts of the basin between 2600 and 2900 MASL are some small valleys with agricultural activities, and 2900-3700 MASL is the mountainous area, forming a series of glens with southwesterly – northeast direction. The climate is temperate sub humid and summer rains, presents a precipitation gradient ranging from 700 mm annually in the lower area to 1174 mm in the highlands. The reported average annual temperature is 11.4 º C, with a highest (13.5 ° C) occurs in May and minimum (9.1 ° C) in January (GDF 2004).

The soils of the area are of volcanic origin, developed from igneous rocks as andesites, dacites and tuffs. This lithological composition and age of the materials along with other factors have developed a low soil cohesiveness, adhesiveness, and high organic matter content, characteristics that make them susceptible to erosion. Andosol soil and Leptosol Phaeozem is reported (Vela et al. 2008).

The vegetation consists of coniferous, broadleaved and mixed forest such as *Abies religiosa* forest, *Pinus hartwegii* forest, *Pinus teocote* - *P. montezumae* forest, *Quercus rugosa* - *Q. laurina* and *Pinus* spp. - *Quercus* spp. forest. These communities occupy approximately 70% of the basin; the rest is occupying by induced grasslands, agricultural and urban areas. The main impacts on vegetation are from the advance of the urban area in the lower parts and to a lesser extent, by logging, fire and grazing in the middle and upper zones (Roldán-Aragon et al. 2011).

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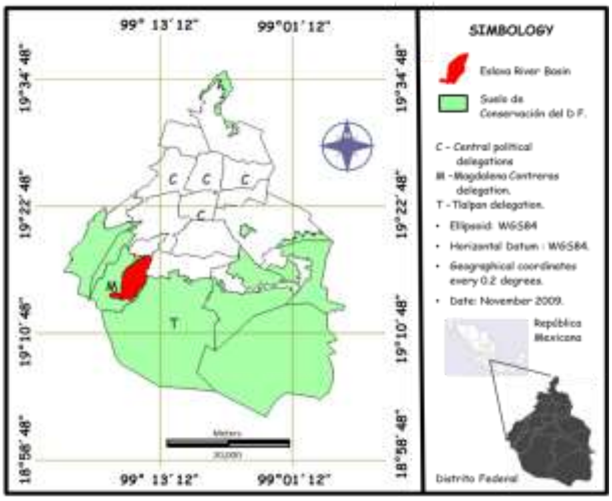


**Fig. 1**. Locating Eslava river basin in Distrito Federal.

## MATERIAL AND METHODS

To meet the stated objective a general five classes legend of land use and vegetation (Table 1) was used. The number of used classes is due to differences in the scale and legend of the information sources available. To elaborate map of 1970 took into account the mapping of land use and vegetation published by INEGI (1970a and 1970b) at 1:50,000 scale, which formed the basis for the visual interpretation of black and white aerial photographs (scale 1:40,000 ) of the same year, thus allowing to define in greater detail the five classes considered (Table 1). The 2005 map was obtain from Eslava river basin vegetation and land use map produced by Roldán-Aragon *et al.* (2011), which was generate based on the visual interpretation (Chuvieco 2005) of color compositions of a multispectral image Quick-Bird 2005. Given the characteristics of spatial resolution of both sources of information, and so to reconcile the information from time 1 ($T_1$ = 1970) and time 2 ($T_2$ = 2005), it was necessary to apply a process of generalization to both planes, by incorporating small to larger neighboring homogeneous regions according to the threshold of ≤ 2500 $m^2$ (Eastman 2012).

For the analysis of land use and vegetation changes, a matrix of cross-tabulation was generate from crossing the planes $T_1$ and $T_2$, a process that was developed in IDRISI Selva software (Eastman 2012). On this table was obtained: a) the area occupied by each class to $T_1$ (sum of the cells in each row) and $T_2$ (sum of the cells in each column); b) the persistence of each class, represented by the diagonal of the table, which corresponds to the surface of each class that had no change; c) Gain (G), which is the difference of the total area of $T_2$ (2005) interest class less persistence; d) Loss (P), which corresponds to the difference of the total area of $T_1$ (1970) interest class less persistence; e) Net Change (NC), represented by the difference between the total surface of $T_2$ and total surface of $T_1$, given in absolute values for the class of interest ($CN = | T_2 - T_1 |$) and; f) Total Change (CT), which is the sum of the gains and losses of the class in question (Lopez and Plata, 2009; Eastman, 2012). The annual rate for each class was estimated based on the following formula (FAO, 1996):

$$t = \left(1 - \frac{S_{1-}S_2}{S_1}\right)^{1/n} - 1$$

Where:

t = annual change rate;
S1 = surface coverage at time 1;
S2 = surface coverage at time 2;
n = number of years between two dates.

Finally, to establish the relationship between the slope of the terrain, distance to locations, persistent, change areas and the effect on ecosystem services (infiltration aptitude and stored carbon in biomass), we used the digital drawings from Geographic Atlas of the SCDF (GDF, 2012), which were cartographically standardized and processed in the IDRISI Selva software v.17 (Eastman, 2012).

Table 1. Land use and vegetation (LUaV) legend used in this work and their correspondence with 1970 map ($T_1$) and 2005 map ($T_2$).

| LUaV | LUaV (INEGI, 1970). | LUaV (Roldán-Aragón *et al.*, 2011) |
|---|---|---|
| Urban area. | Urban area. | Urban area. |
| Seasonal agriculture | Permanent seasonal agriculture<br>Annual seasonal agriculture.<br>Annual seasonal agriculture - Induced grassland. | Seasonal agriculture |
| Induced grassland. | Induced grassland. | Induced grassland. |
| Shrubland- oak | Unarmed shrubland with natural oak forest. Secondary unarmed shrubland with natural oak and pine forest | *Senecio praecox* – *Quercus* spp. shrubland. |
| Forest. | Oyamel natural forest. Oyamel – Pinus natural forest. Oak natural forest. | *Abies religiosa* forest. *Pinus hartwegii* forest. *Pinus teocote* – *P. montezumae* forest. *Quercus rugosa* – *Q. laurina* forest. *Pinus* spp. – *Quercus* spp. forest. |

## RESULTS AND DISCUSSION

Eslava river basin is immersed in the dynamics of growth and change of the Metropolitan Area of Mexico City (MAMC), constituted by the Distrito Federal and some municipalities of the state of Mexico. Although whole the population growth rates have declined, the surface occupancy continuously increase, showing the fastest growth in southeast municipalities (Chalco, Valle de Chalco, Chalco Solidaridad and Ixtapaluca), at north (Cuautitlan and Ecatepec) and expelling people from the central delegations to peripheral delegations, occupying mainly places at south of the Capital (López and Plata, 2009; Schteingart 2006). In this context, Eslava river basin dynamics shown changes in their 22.5% total surface in land use and vegetation (540.7 has in 35 years period), mainly in the southern and middle part of the Basin and 1861.3 has (77.5 %) have been in the class (persistent areas) to which they belonged at the beginning of the considered period (1970-2005) (Fig. 2). Velazquez *et al*. (2002) at the national level for a period of 24 years (1976-2000) obtained a persistence of 80.6%. Lopez and Plata (2009) for the MAMC which considering 10 years (1990-2000), estimate a persistence of 92.4% and Pineda et al. (2008), at state of Mexico from 1993 to 2002 93.3% value. The numbers that compared with those obtained for the Basin show that the landscape has presented changes more pronounced in the classes of land use and vegetation present in the year 1970.

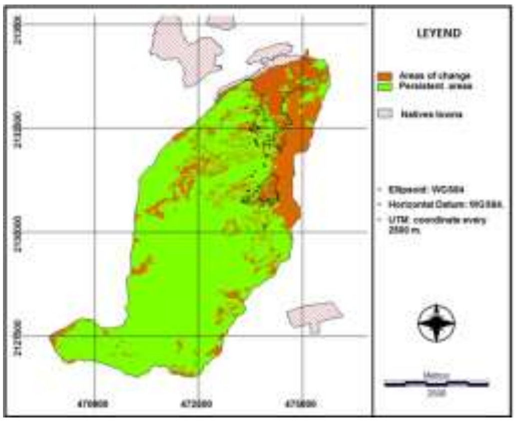


Fig. 2. Areas of change and persistent areas in Eslava river basin (1970-2005 period).

Table 2. Transition values for Eslava river basin between 1970 and 2005.

| LUaV | Superficies 1970 (has) | Superficies 2005 (has) | Exchange rate (%/year) | Persistence 1970 has (%) | Gains (has) | Losses (has) | Net change (has) | Total change (has) |
|---|---|---|---|---|---|---|---|---|
| Seasonal agriculture | 501.2 | 277.1 | -1.68 | 227.5(45.3) | 49.6 | 273.7 | -224.1 | 323.3 |
| Induced grassland. | 25.5 | 69.7 | 2.92 | 3.2(12.5) | 66.5 | 22.3 | 44.2 | 88.8 |
| Forest | 1694.1 | 1713.5 | 0.03 | 1586.6(93.6) | 126.9 | 107.4 | 19.5 | 234.3 |
| Urban area | 45.1 | 341.7 | 5.96 | 44.0(97.5) | 297.7 | 1.2 | 296.5 | 298.9 |
| Shrubland- oak | 136.2 | 0.0 | -100.00 | 0.0(0.0) | 0.0 | 136.2 | -136.2 | 136.2 |

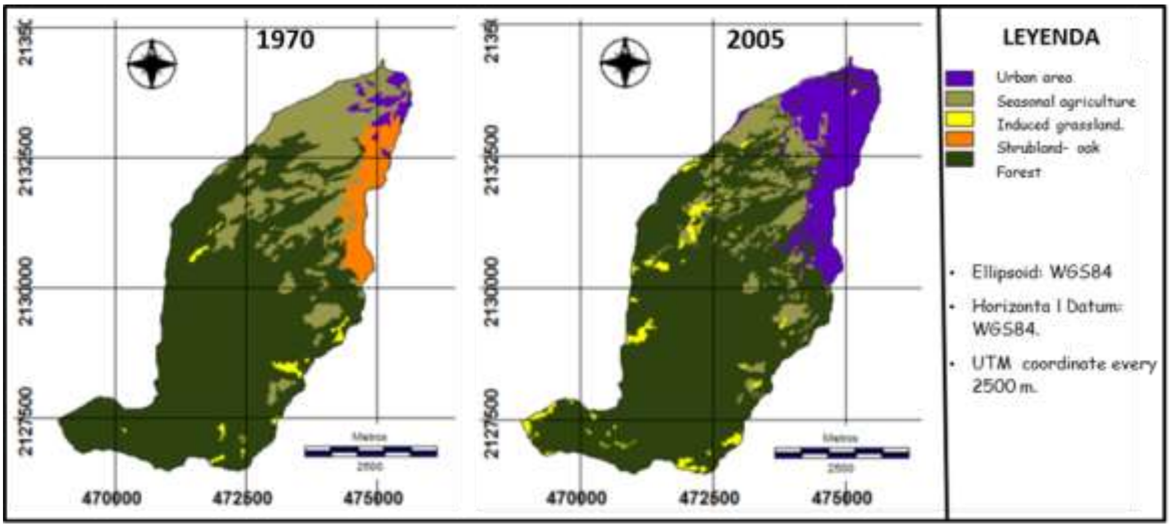
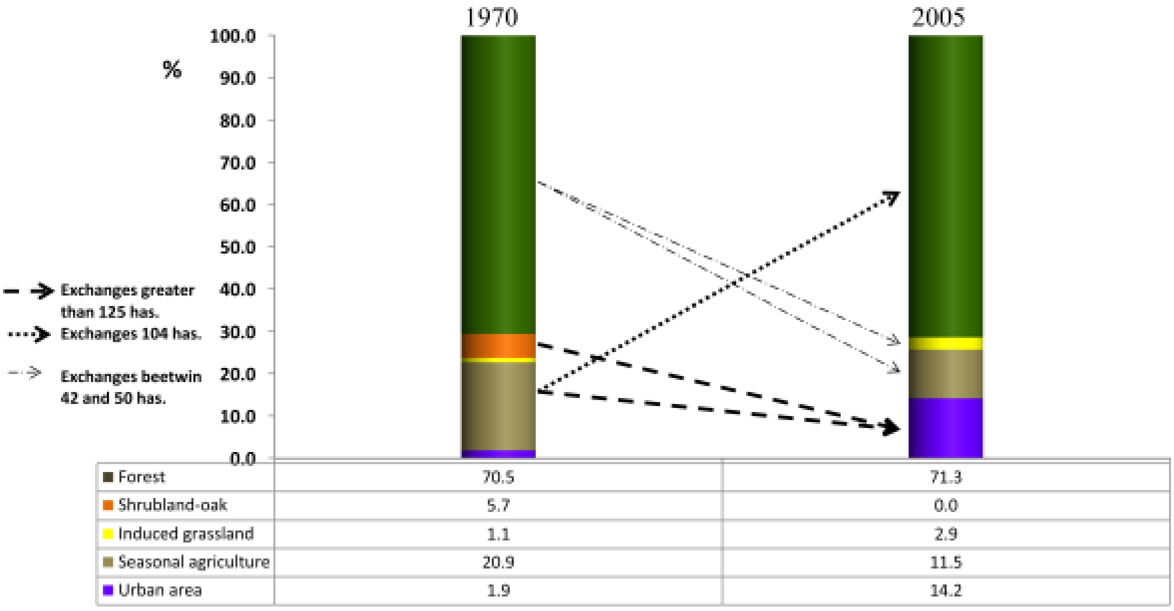


**Fig. 3**. Eslava river basin land use and vegetation for 1970 and 2005.

On the other hand, considering the persistence of anthropogenic (urban area, seasonal agriculture and induced grassland) and "natural" coverages (Shrubland-oak) separately, there are estimates of 48% and 93% respectively, values generally indicate that major changes in the landscape have been the result of relative exchanges (gains and losses) between anthropogenic coverage mainly and, secondly with the "natural" classes. In the latter sense, the persistence of the "natural" coverages obtained for Eslava river basin was higher than estimated by Velázquez et al. (2002) for Mexico (82.6%) between 1976 and 2000 and for MAMC (87%) calculated by Lopez and Plata (2009) for the 1990-2000 period. Suarez and Delgado (2007) mentioned that change probability due territory urbanization depends on physical variables such as terrain slope and distance to nearest town, among other socioeconomic variables aggregated at delegation policy and municipality level, pattern that is consistent with the coverage change of Eslava river basin, since the areas of change and persistent present statistically significant differences in the slope of the terrain ($Z=-809.4$, $\rho<0.05$) and distance to locations ($Z=-1065$, $\rho<0.05$), with higher average values for the inclination and locations distance for persistent areas (Fig. 2).

Based on the analysis of each LUaV, the urban area was the class that presented the highest annual rate (5.96 %), from 45.1 hectares occupied in 1970 (1.8% of the total area of the basin) to 341.7 hectares in 2005 (14.2% of the total basin area), with a total change of 298.9 hectares (Table 2 and Fig 3).

The rate calculated for Eslava river basin for Urban area is then higher than that estimated with data cited by Lopez and Plata (2009) for the Distrito Federal (1.2% $yr^{-1}$) between 1970 and



| | 1970 | 2005 |
|---|---|---|
| ■ Forest | 70.5 | 71.3 |
| ■ Shrubland-oak | 5.7 | 0.0 |
| ■ Induced grassland | 1.1 | 2.9 |
| ■ Seasonal agriculture | 20.9 | 11.5 |
| ■ Urban area | 1.9 | 14.2 |

Fig. 4. Occupied area (%) and major exchanges of land use and vegetation between 1970 and 2005 in Eslava river basin.

2000, as well as, the value of 3.3 % year$^{-1}$ obtained for the Distrito Federal Southern from 1973 to 2000 (Sorani 2003), however, is much lower than that estimated with Schteingart (2006) and Romero (2008) data for the ejido de San Nicolás Totolapan which had a value rate of 12.8% year$^{-1}$ for the period 1971 to 2005.

Among anthropogenic coverages, Induced Grassland class was the one that showed the second largest positive growth rate after Urban Area, with a value of 2.9% yr$^{-1}$. By 1970 occupied just over 25 hectares and increased to 69.7 by 2005, however, showed a persistence of only 12.5% and a total change of 88 hectares, considered one of the classes more dynamic exchange (Table 2 and Fig. 3). For Mexico between 1976 and 2000, Velázquez et al. (2002) estimate the rate of change in Induced Grasslands of 1.72% year$^{-1}$ and in Distrito Federal 1.19% yr$^{-1}$ between 1996 and 2000 (INEGI 2005). Schteingart (2006) obtained for the period 1971 to 1997 in the suburbs of Ajusco and San Nicolas Totolapan an increase of 2 to 3 percentage points in Induced Grasslands, which is close to the 1.8% increase observed on the surface of this class in Eslava river basin.

presented an annual negative rate of -1.68% and a net change of -224 hectares, from 502 hectares in 1970 to 277 hectares in 2005. The persistence obtained for the class was 45% and the overall rate was 323 hecatres, which ranks as the class that showed the largest area of exchange between all classes considered, both anthropogenic and "natural" (Table 2 and Fig. 3). Using data from López and Plata (2009) a negative rate of -0.19%/year for seasonal agriculture in the metropolitan area is obtained in a 10 year period (1990-2000) and for D.F. a positive rate of only 0.083% yr-1 between 1996 and 2000. On a local scale, Schteingart (2006) confirms the loss of 5% of the agricultural areas in the Ajusco for the period 1971-1997, however, also reported the increase of agricultural areas to the ejido de San Nicolás Totolapan by 3.8 % of the area for the period mentioned and Romero (2008) for a longer time period (1971-2005) increased agricultural area (5.1%) in this ejido.

The class with the greatest loss during the period considered was Shrubland-oak, which showed a loss rate of -100% /year, indicating the disappearance of the 136.2 hectares occupied in 1970 (Table 2 and Fig. 3). The downward trend in the area of Shrubland-oak equally consistent with the data reported by Schteingart (2006) for the Ajusco, which went from 14% occupied by this class in 1971 to 8% in 1997. For the southern area of the Distrito Federal using data published by Sorani (2003), the loss of scrub (badlands) from 1973 to 2000, showed an annual loss of -2.36% /year. The differences in rates are mainly due to the limit distribution of this plant community is located in the area, thus producing the complete disappearance of cover (Fig. 3).

Finally, the analysis of Table 2 shows that the class that occupied the largest area in both 1970 (1694.1 ha) and 2005 (1713.5 ha) was Forest, with a slight increase in the number of hectares by the end of period, resulting in a positive annual rate of 0.03% and a persistence of 93.6%, which corresponds to an area of 1586.6 hectares, equivalent to 66% of the total area of the Basin. If one takes into account the net change (19.5 ha) between 1970 and 2005 think of the quasi-invariance of Forest class, however, if the absolute values of Gains and Losses are added, show that spatially has been a total change of 234.3 hectares, placing this class in third place in his dynamic exchange compared to other classes in the Basin. Of this total change, 126 hectares correspond to Gains during the period considered, which implies the presence, at least in these areas corresponding to 5% of the surface of the basin, of different successional stages in the forest community.

For temperate forests at the national level between 1976 and 2000, Velázquez et al. (2002) estimated a rate of change of -0.25% year$^{-1}$, in contrast to regional level data for ZMCM, Lopez and Plata (2009) who consider forests of pine, oak and fir have a positive rate of 0.051%/year between 1990 and 2000, however, with data for forests in Mexico City (INEGI 2005) annual losses of -0.98% for a period of 6 years (1994-2000) and Sorani (2008) for Distrito Federal south zone was obtained an annual loss of -1.13% between 1973 and 2000. The trend at national and regional level is to the loss of forest cover, also locally, as Romero (2008) estimated a loss of 420 hectares of forest between 1971 and 2005 to ejido de San Nicolas Totolapan going from 1830.3 has to 1713.5, calculating with this rate of -0.8%/year.

Among the dynamic exchange of LUaV, whether win or lose surface, five exchanges are greater than 40 hectares. The most significant losses was in Seasonal Agriculture class, since 152 hectares passing to Urban Area and 104 hectares to Forest, totaling 256 hectares. Second order of importance is the Shrubland-oak having a direction of change to the Urban Area of 129.7 hectares and, in third place Forest, who loses 91 hectares of which 49 change to Induced Grasslands and 42 hectares to Seasonal Agriculture (Fig. 4). The class in 2005 received the largest surface is the Urban Area (297.7 hecatres), with the difference that the Shrubland-oak gives the entire surface (129.7 hectares) to this class, Seasonal Agriculture contributes 153 hectares and Forest 15.2 hectares. The direction of change patterns for coverages near urban areas commonly show a conversion of agricultural areas and forest communities to urban areas, as has been exposed by Sorani (2003) and Lopez and Plata (2009). Similarly, the direction of change is documented for different areas of the City in the agricultural areas that were urbanized during the second half of the twentieth century.

Regarding the involvement of ecosystem services produced by the increase in Urban Area, there is the loss of ability of water infiltration in 129.7 hectares (Shrubland-oak surface loss), which corresponds to potential decline of 3035 m$^3$ day$^{-1}$ for the area (based on an average value for the infiltration in Eslava river basin of 2.34 mm day$^{-1}$ = 2.34 L m$^2$ day$^{-1}$) (GDF 2012), what would stop "supply" to 15,485 people daily under a comfort provision of 196 L day$^{-1}$ (Izazola, s/year). Moreover, in terms of carbon storage in aboveground biomass of vegetation are lost 297.7 hectares which become Urban Area, implying a decrease of 4% (6039 ha$^{-1}$ Tc) of Carbon stored in the Basin (GDF 2012; Santiago et al. s/year).

## CONCLUSIONS

The results obtained in this work show exchanges between LUaV classes for Eslava river basin (1970-2005). It is concluded that just under a quarter of the area has been changed, showing an increase in Urban Areas and Induced Gasslands at the expense of classes as the

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Shrubland-oak, Seasonal Agriculture and Forest. However, the dominant cover (Forest) is preserved in the basin, which shows a high value of persistence.

In particular, the directions of change are presented as two separate vectors, one change from natural classes to anthropogenic classes (Forest to Seasonal Agriculture and Induced Grasslands), and another, between anthropogenic classes (Seasonal Agriculture to Urban Area), latter showing the largest magnitude vector.

The physical variables for which a relationship with LUaV changes observed are land slope and distance to towns, however, it is necessary to further socio-economic variables to understand better how the dynamics of change in the area. The basin has lost some of the ability to provide ecosystem services, especially those derived from natural communities as carbon sequestration by vegetation and the suitability of water infiltration into the soil in different recharge areas.

Urban growth as part of the dynamics of the metropolitan area is the main force for change in Eslava river basin and to the SCDF, so it is necessary to support agricultural production due to its dynamic exchange, so that conversion to urban area stops and ecotourism activities already undertaken by residents of the area and payment programs for environmental services are a way to add value to the land and discourage conversions to other land uses.

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