Dynamic modeling of the transformation of wetlands and the supply of ecosystem services in the face of the urbanization process in the Kennedytown

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Abstracts

The objective of this research was to develop a dynamic model of the transformation of El Burro, La Vaca and El Techo wetlands, and the supply of ecosystem services by the processes of population growth and urban expansion in the Kennedytown. The modeling was carried out using the Vensim PLE ® program; as a result, it was observed that the population for the year 2050 will increase by 161.69% and urban expansion will reach 99.40% of hectares of permitted urban expansion. Additionally, by 2047, the percentage of reduction of the protection areas will be 98.2% and the ecosystem services will be reduced to a total of 0.28 by the year 2044. It was concluded that the environmental sustainability of wetlands is directly affected by the processes of population growth and urbanization and that modeling is a tool for the development of environmental management strategies.

Keywords: Wetlands , Ecosystem services, Urbanization, Dynamic Modeling.

1. Introduction

Wetlands are ecosystems whose fundamental component is water (Blanco 1999)and are considered the most productive and diverse ecological systems on the planet, since they offer a diversity of fundamental ecological functions for man, such as regulating hydrological regimes, erosion control, sediment and nutrient retention, microclimate stabilization, air quality regulation, among many more ecosystem services (Tabilo 1999; Abarca 2001; Cuellar and Perez 2023). Likewise, they provide the communities that live in the vicinity of these systems with other services, such as: recreation, tourism and the development of spiritual values, which makes them natural heritage within the city (Abarca 2001; Blanco 1999).

Despite the role that wetlands have played in the development of human societies that have inhabited the Bogotá Savannah for more than 2000 years, they have been subjected to different pressures that have triggered the progressive loss of their area of occupation and of compositional, structural (Matta 2021; Villa 2012)and functional (Caicedo 2016)biodiversity. These pressures, according to Andrade (2003)and Herrera (2024), can be of natural and anthropic origin, the latter being those that have generated the greatest impact on these systems, mainly due to local development models.

Anthropic pressures on wetlands are directly related to population growth, which has resulted in the expansion of urban boundaries and the consequent reduction in area and fragmentation of wetlands, the dumping of solid waste and wastewater into bodies of water, the extraction of flora and fauna, invasion by exotic and domestic species, and in some cases, the implementation of extensive agricultural and pastoral production systems (Cortes 2018; Mateus 2016). These pressures have been the common denominator in the degradation of Bogotá's wetlands, the impact of which has depended on the degree of intervention in the system and the comprehensive management plans for its protection (Corporación Autónoma Regional de Cundinamarca 2011; Castellanos 2001).

As an example of these transformations, we can mention the wetlands of Kennedy town, at the southwest of Bogotá. El Burro, La Vaca and Techo have been the wetlands with the greatest impacts in the last 70 years, where it is estimated that since 1940 to the present they have lost approximately 50%, 90% and 70% of their total area respectively (Pontificia Universidad Javeriana, Empresa de Acueducto y Alcantarillado de Bogotá, and Secretaría Distrital de Ambiente 2009a; 2009b; Universidad Nacional de Colombia 2008). In the past, these wetlands were part of the alluvial basin of the Bogotá River, the Fucha River and the extinct Tintal lagoon, and today they are widely intervened as a consequence of the accelerated urban growth that the town experienced after the second half of the 20th century, due to the early processes of industrial establishment that brought with it the settlement of working-class families; the old construction of the Techo airport and its consequent road and formal and informal residential expansion; and the reception of displaced population due to processes of violence and foreign migrants (Universidad Nacional de Colombia 2008; Alcaldía Mayor de Bogotá 2019b; 2014). Added to this is the collective ignorance of the environmental and cultural value of these ecosystems, which prevented timely intervention by the authorities to avoid their invasion and contamination (Mora and Bonilla 2009; Ballesteros and Castro 2017).

Kennedy wetlands, within the town, play an important role in the provision of Ecosystem Services (ES) to the communities that border these protected areas. Among the ES, which have greater relevance due to the geographic location of the town and the population qualities of Kennedy, we can mention, according to CAR (2011) and Cortés (2018), water regulation, which mitigates flooding scenarios in the Bogotá and Tunjuelo rivers, limits of the town; the conservation of fauna and flora, becoming strategic ecosystems in the migration processes and preservation of native and endemic species of the capital; carbon capture, coming from industrial settlements and the increase in the heavy-duty vehicle fleet; and the landscape and cultural value, which provides the town with educational, tourism, research and natural refuge scenarios within the large urban extension that Kennedy has.

However, the supply of these ecosystem services can be strongly affected by urbanization processes that directly affect the extension of wetlands, and endanger the environmental stability of the locality.(Caicedo 2016; Mora and Bonilla 2009). For this reason, through dynamic modeling and simulation processes, understood as tools that allow us to understand environmental systems in which any aspect of the world is conceived as the causal interaction of attributes that describe a system (Dhawan 2005), it is possible to describe, analyze and evaluate the transformation of these wetlands and their ecosystem services, due to the phenomena of population growth and urbanization with an estimated projection of 30 years.

Furthermore, the modeling intended to project the role of changes in the functioning of these systems, in order to generate contributions in the prediction of scenarios for the sustainable management of wetlands and the territory in which they are immersed, providing low levels of uncertainty, relative accuracy in the established predictions, and impacting the quality of life of the population; this based on the analysis of past changes that allow evaluating the rates of transformation of the wetland area and its repercussions on the supply of ecosystem services, taking into account their distribution and the correlated variables that affect the changes presented and estimated (Winz, Brierley, and Trowsdale 2009; Ibarra, Redondo, and Fajardo-Toro 2012).

The objective of the study was to project how the processes of transformation of the area and the supply of ecosystem services of El Burro, La Vaca and Techo wetlands have been due to the phenomena of population growth and urbanization in the town of Kennedy in the period between 2019 and 2050.

2. MATERIALS AND METHODS

2.1. Area of study

The Kennedytown, located in Bogotá, has an area of 3,859 hectares, made up of a flat terrain of alluvial deposits from the Bogotá River on the western side, the Fucha River on the northern side and the Tunjuelo River on the southern side, which favored the establishment of different wetlands within the area of jurisdiction (Alcaldía Mayor de Bogotá 2009). The main permanent water bodies generated by the hydrological dynamics of the town allowed the formation of different wetlands such as El Burro (HEB), La Vaca (HLV) and El Techo (HET), which presented a landscape and fauna connectivity and are located in the UPZ Calandaima, Corabastos and Castilla, respectively. However, given the urban and demographic dynamics, scenarios of reduction of the wetland area have been generated, causing fragmentation and reduction of ecosystem services.

In 1940, the Kennedy town showed low urban expansion associated with demographic processes, being a reference year to understand the reduction of wetlands, since, at the district level, no regulations for the protection of strategic ecosystems were used, which favored different reduction rates in subsequent years (Sánchez and Sierra 2017). The HEB, HLV and HET wetlands recorded an area of 55, 181.34 and 60 hectares respectively for that year (Pontificia Universidad Javeriana, Empresa de Acueducto y Alcantarillado de Bogotá, and Secretaría Distrital de Ambiente 2009b; 2009a; Universidad Nacional 2008).

In the years 1930 to 1940, the Kennedy town presented a low urban expansion associated with demographic processes, being a reference year to understand the reduction of wetlands, since, at the district level, regulations for the protection of strategic ecosystems were not used, which favored different rates of reduction in later years (Sánchez and Sierra 2017). Some constructions such as the Techo racetrack and years later the Américas'sAvenue, promoted urban development processes towards the west affecting large existing lakes and wetlands, such as the Tintal lagoon, which after the constructions generated several bodies of water known as the Tibanica, La Vaca, El Burro, Techo wetlands and TimizaLake (Personería de Bogotá 2003).

In 1940, the HEB, HLV and HET wetlands covered an area of 55, 181.34 and 60 hectares respectively (Pontificia Universidad Javeriana, Empresa de Acueducto y Alcantarillado de Bogotá, and Secretaría Distrital de Ambiente 2009b; 2009a; Universidad Nacional 2008). These hectares were reduced disproportionately at different rates, since territorial management and national and district interests did not generate conservation or regulation measures for strategic ecosystems such as wetlands, which left them exposed to urban growth and population densification (Alcaldía Mayor de Bogotá 2010). This situation was aggravated by the fact that administrative decisions were unaware of the ecosystem services related to wetlands, to the point that, by 1968, different parks were established on wetland bodies, such as Timiza Park (Sánchez and Sierra 2017; SDA 2016).

Currently, the total area of the Kennedy town has two representative classifications, corresponding to urban land with a value of 3,606 hectares and urban expansion land of 253 hectares, equivalent to 6.5% of the total area of the town (Alcaldía Mayor de Bogotá 2019b; 2019a), of this percentage, 12% corresponds to wetland areas, which do not have a protection instrument. Likewise, the town registered a population of 1,230,539 inhabitants for the year 2018, with a population density of 335 hab/ha for the year 2017 (Veeduría Distrital 2018).

3. METHODOLOGY

The dynamic modeling of the transformation of the Kennedy wetlands and their ecosystem services in relation to urbanization processes included values from studies conducted by the District Planning Secretariat (SDP), the Mayor's Office of Bogotá, the Bogotá Aqueduct and Sewer Company, the Bogotá Wetlands Foundation, the José Celestino Mutis Botanical Garden of Bogotá, the National University of Colombia, the Javeriana University, the National Administrative Department of Statistics (DANE), the District Institute for Risk Management and Climate Change (IDIGER), among others. These values allowed to define the variables involved in determining the environmental dynamics related to the transformation of wetlands in the next 30 years, such as: population growth, urbanization processes in the vicinity of wetland areas, reduction of the floodable area of these systems, and the supply of ecosystem goods and services (regulation and cultural).

The modeling of these scenarios was developed using the Vensim® PLE Plus program, a visual modeling software that allows conceptualizing, documenting, simulating, analyzing and optimizing simulation models in which the real process and random behavior were represented (Winz, Brierley, and Trowsdale 2009). Likewise, for the statistical analysis, the Monte Carlo multivariate sensitivity analysis was used, which allowed, through the collection of data, to establish the combinations of events that define the behavior of the system with precise estimates for its validation (Dhawan 2005).

3.1. Dynamic Model

The construction of the model related population growth and the extension of urbanization processes, with their influence on the transformation of the study wetlands area (Techo, El Burro and La Vaca) and the deterioration of ecosystem services (ES). Therefore, the following assumptions were built to help simplify and analyze the model:

a. As the population increases, urbanization processes in the area of influence of the wetlands increase.

b. An increase in urbanization processes triggers a reduction in the protected area of wetlands.

c. The reduction of the protected area of wetlands with a tendency towards urbanization processes changes and deteriorates the ecosystem services they offer.

d. District interventions in recovery processes could slow the reduction of the area of wetlands and the ecosystem services they provide.

3.2. Model Architecture

In order to determine the transformation of the wetland area and its correlation with population growth over the last 80 years, from 1940 to 2019, a base model was carried out, which allowed to visualize and estimate the change in this period of time. For this model, historical data from each of the wetlands was taken from DANE and its management plans (Table 1); with these, a base forester diagram was made, which will be projected to the three wetlands, which showed the transformation process for each one.

Subsequently, in order to predict how the transformation process of the wetland area (Techo, El Burro and La Vaca) will be and the deterioration of ecosystem services, projected from 2019 to 2050 in the wetlands, a base explanatory model was created (Figure 1) that covered the three protection areas within the locality. For the creation of this model, the following phases were taken into account: I) Search for information II) Design of a causal diagram that allows explaining the relationships of the main variables of the model, III) Identification of the variables and units of the model, IV) Design of the subsystems through small forester diagrams and their subsequent correlation, V) Assumptions of the model and mathematical supports, VI) Development of the model and VII) Validation of the model. The variables identified to structure the model for each wetland (Techo, La Vaca and El Burro), are presented in Table 2.

Table 1Data used for the simulation of wetland transformation from 1940 to 2019.

Element associated with the Model	**Data**			**Fountain**
	Year	Has [1].	TR [2]	
Surface of El Burro Wetland	1940	55	-	Sanchez & Sierra (2017)
	1952	49	0.5	
	1967	47	0.133	
	1976	48	-0.11	
	1981	27	4.2	
	2006	20	0.6	
	2015	19	0.1	
	2019	18.82	0.045	
La Vaca Wetland Surface	1940	181.34	-	Rodriguez-Tenorio & Rodriguez-Soto(2017)
	1977	92.17	2.41	
	1985	7.97	10.52	
	2004	7.33	0.33	
	2019	7.97	-0.33	
	1940	60	-	

Roof Wetland Area	1949	52	0.88	Rodriguez(2016)
	1956	23	4.14	
	2008	11.6	0.21	
	2019	11.6	0	

Note: Ha. [1] : Hectare; TR [2] : Area reduction rate.

Regarding the Ecosystem Services offered by these three wetlands, the CIC-Conservación Internacional Colombia/EAAB (2000), carried out an environmental assessment from two perspectives, the current environmental importance and the ecological potential of each wetland, considering three sets of categories with their respective parameters for the qualification of the set of wetlands of the District: (1) Physical, (2) Biotic and (3) Sociocultural, which correspond, in essence, to the types of environmental goods and services offered by these ecosystems.(Universidad Nacional de Colombia 2008).

In the physical categories, which correspond to the Regulatory Services that include the Parameters: A. Flood control; B. Sediment retention; C. Impact on the local microclimate; and D. Water purification; El Burro wetland had an average rating of 7 points, La Vaca and Techo wetlands had a low rating of 4 points.

Likewise, with respect to the Biotic categories, which also refer to regulation services, addressing the parameters: A. Protection of endemic or threatened species; B. Habitat supply for migratory aquatic birds; C. Habitat supply for migratory terrestrial birds; D. Flora species richness; E. Fauna species richness; F. Hydrobiological species richness; G. Habitat richness; H. Interrelation with other ecosystems; and I. Presence of species at high trophic levels; El Burro wetland obtained a medium supply rating with 12 points, La Vaca wetland a low rating with 5 points in total, and the Techo wetland a medium rating with 13 points.

Finally, with regard to the sociocultural category, which links the elements: A. Current recreational use; B. Use in research activities; C. Landscape value; and D. Use in environmental education activities; the three wetlands presented a low offer assessment with scores of 0 (La Vaca wetland), 4 (Burro wetland) and 5 (Techo wetland).

Figure 1Forester diagram *of* dynamic modeling .

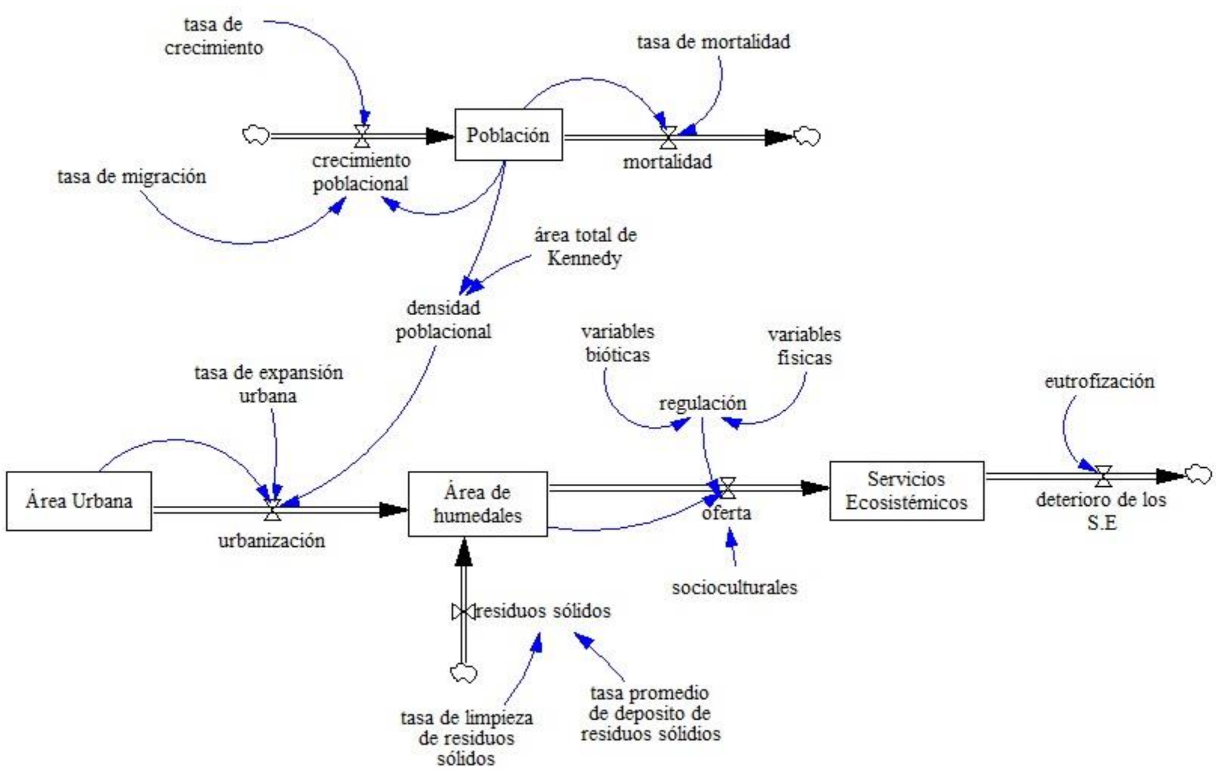

Table 2Elements and values associated with the model.

Elements associated with the Model	Data	Fountain
Population		
No. of Kennedy Inhabitants.	1,252,014 inhabitants.	(Mayor's Office of Bogotá, 2019a)
Net migrant rate per 1000 (Kennedy).	11.5 inhabitants/year.	(Mayor's Office of Bogotá, 2009, 2019b)
Net population growth rate per 1000 (Kennedy).	1.8 inhabitants/year.	(Mayor's Office of Bogotá, 2019b)
Net mortality rate per 1000 (Kennedy) .	3.33 inhabitants/year.	(SALUDATA, 2020)
Urbanization		
Total area of Kennedy	3606 Ha.	(Mayor's Office of Bogotá, 2019a)
Kennedy Urban Area	3859 Ha.	(Mayor's Office of Bogotá, 2019a)
Urban expansion rate	0.018 Dmnl.	(District Oversight, 2018)
Average rate of solid waste deposition within wetlands.	10% per year, which is equivalent to a deposit of 3,624 Ton/area.	((Duarte, Medina, and Santiago 2016)
Solid waste cleaning rate.	25% annually, which is equivalent to a cleaning of 0.906 Ton/area.	(Duarte et al., 2016)
Wetlands Area		
Total area of protection of wetlands (El Burro, La Vaca and El Techo)	238 Ha.	(Mayor's Office of Bogotá, 2019a)
Ecosystem Services		
Biotic Variables	33 Dmnl /ha	(National University 2008)
Physical variables	15 Dmnl /ha	(National University 2008)
Sociocultural variables	9 Dmnl /ha	(National University 2008)
Eutrophication coefficient	5 Dmnl /ha	(National University 2008)

4. RESULTS

4.1. Wetland area modelling (1940-2019)

Figure 2., shows in a comparative way the transformation processes of wetlands from 1940 to 2019, as a response to the dynamics of population growth and urban expansion that the Kennedy town has had. The behavior of the graphs shows that the transformation of the HEB area occurred gradually since the 1950s, where there was a reduction of 10.9% for 1952, 14.54% for 1967 and 50.91% for the year 1981, with respect to the initial area (55 Ha.), this last reduction being the one with the greatest impact on the wetland. Subsequently, there was a process of deceleration of the reduction of the area, reaching a total reduction of 65.78% for the year 2019 with respect to the initial area.

For its part, the HLV presents a more critical area decrease process compared to the other two wetlands, with values of 49.17% for the year 1977 and 95.06% for 1985 with respect to the initial area (181.34 Ha.), this led to the establishment of protection and delimitation standards for the wetland in 2015, so, in the modeling, it was possible to estimate that its recovery was 5% by 2019.

Finally, the HET showed a reduction of 13.33% for the year 1949 and 61.66% for the year 1956 with respect to the initial area. From 1990 to the present, this wetland showed the greatest reduction, falling to 11.6 hectares from 2005 to the present, equivalent to 80.66% with respect to the initial area with constant reduction rates of 21.92% per year.

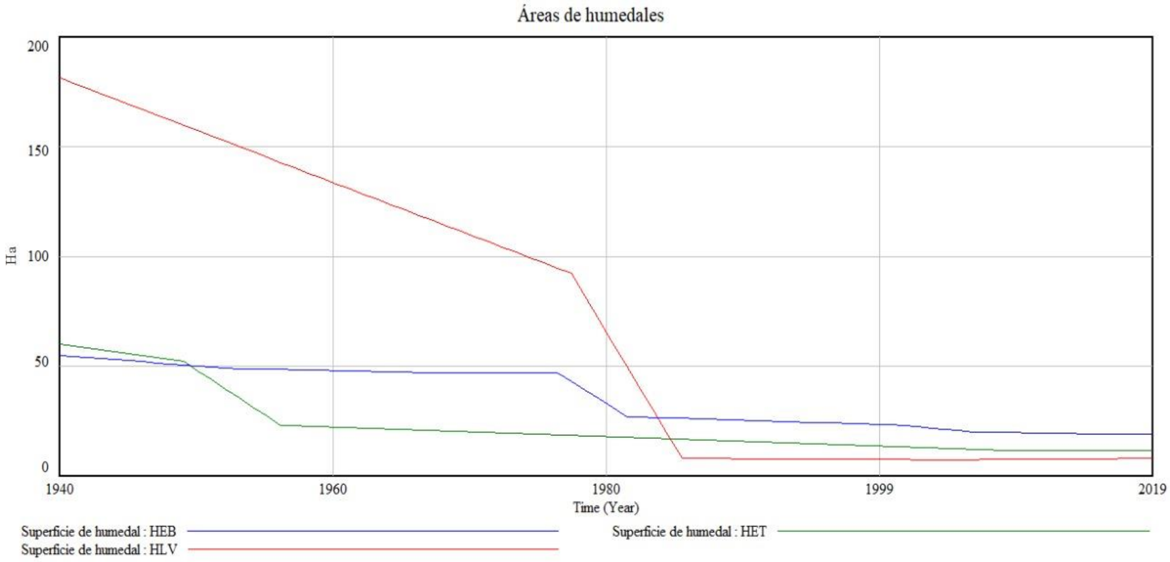

Figure 2Reduction of wetland area in the period 1940 to 2019.

4.2. Wetland area modelling and ecosystem services (2019-2050).

It was identified that the population within the Kennedy town in the period between 2019 and 2050 will present a significant exponential growth (figure 2a). It is projected that by the year 2050, the population will increase by 161.69%, going from 1,252,010 inhabitants to a total of 2,016,910 inhabitants according to the statistical data of the population census of the year 2019. This increase in the population in the model directly influences the urbanization rates projected for the town (figure 2b); where it is estimated that Kennedy will reach a total of 3836.18 ha urbanized by the year 2050, that is, 99.40% of the total hectares of urban expansion allowed for the town (3859 ha in total expansion).

The increase in the areas of urban expansion within the Kennedy town will directly affect the area of wetlands protection. It is estimated that when the urbanization area reaches a total of 3808.81 Ha., in the year 2047, the percentage of reduction in the areas of wetlands protection will be 98.2%, leaving an estimated total of 5.59 protected areas, which currently represent the total area of the HLV, whose intervention by urban planning processes is restricted.

In relation to ecosystem services, a chain reaction of different factors is evident that alters the supply of services due to external and internal phenomena of wetlands. External phenomena are understood as those generated by urbanization processes, which are related to demographic dynamics and the transformation of land use, and internal phenomena to the eutrophication process that the body of water suffers caused by discharges or local cycles.

For the year 2019, the initial year of the modeling, a value of 57 points of ecosystem services (regulation and sociocultural) generated by the three wetlands was recorded. The wetland that provides the least amount of ecosystem services due to its small area corresponds to the Vaca wetland, whose valuation is equivalent to 9 points out of 48 possible points, followed by El Burro and Techo wetlands with valuations of 24/49 points. The ecosystem services evaluated presented a rate of decrease with non-linear behavior, since the external factors that condition the supply such as the urbanized area and population presented ascending dynamics and the wetland area a descending dynamic, causing a loss of ecosystem services by the year 2044.

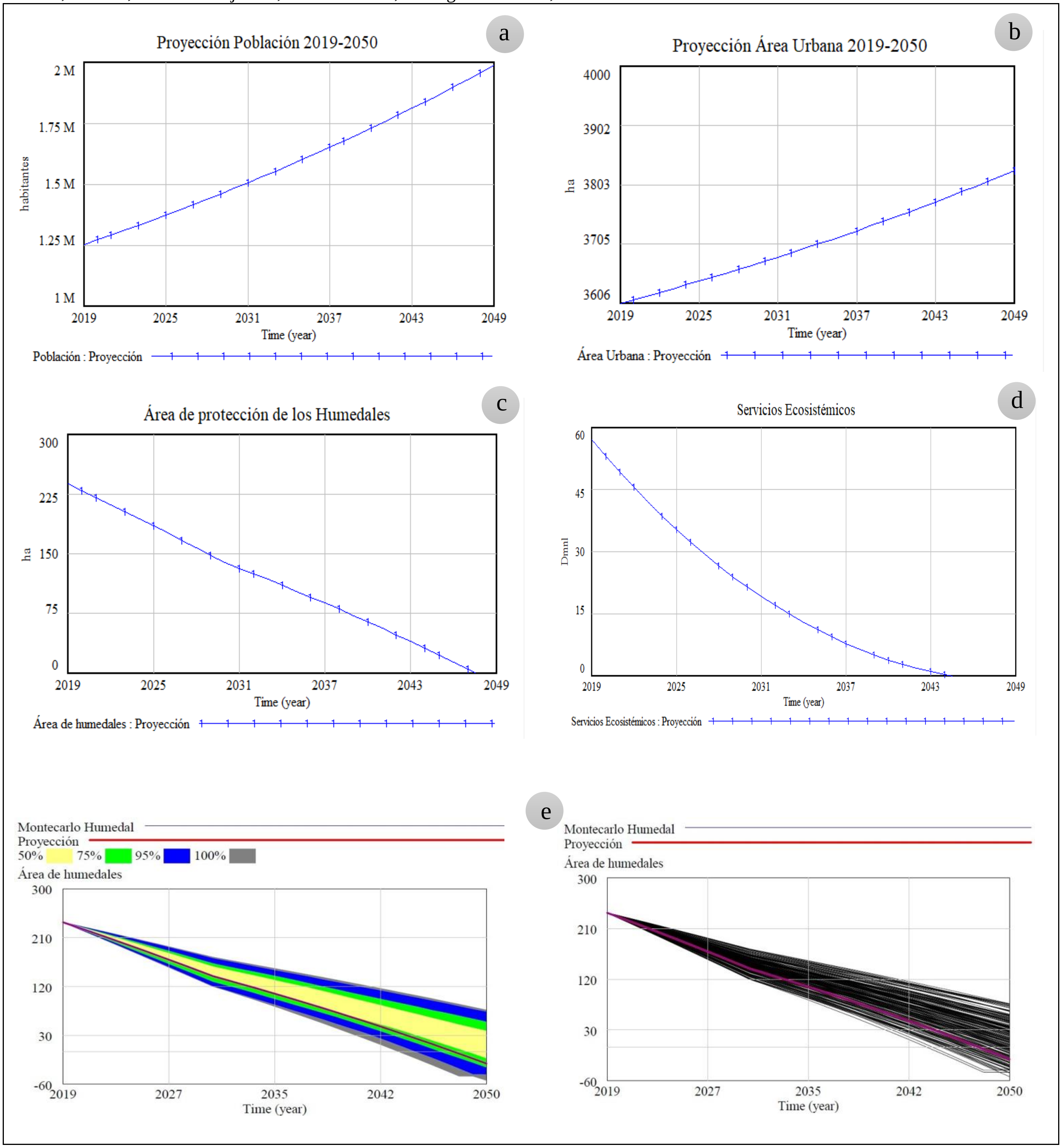

Figure 2a. Population projection from 2019 to 2050 based on mortality records, migration rate, and vegetation rate; Figure 2b. Projection of the urban area of Kennedy town for the period from 2019 to 2050 based on the urban expansion rate and population density; Figure 2c. Wetland area (set of the three study wetlands) projected according to the population and urban dynamics of the Kennedytown; Figure 2d. Ecosystem services generated by the three study wetlands according to the supply influenced by population and urban dynamics and reduction in wetland area; Figure 2e. Monte Carlo analysis and sensitivity analysis of the wetland area with probability concentrations according to data assigned to solid waste disposal variables, growth rate, and urban expansion.

4.3. Monte Carlo model

The sensitivity test for the model was performed based on the variables of population growth, urban expansion and solid waste disposal, since these model the dynamics of the transformation of wetlands and the loss of the ecosystem services they offer. The Monte Carlo graph (figure 2e) shows that the total mean of the modeling data is at a confidence level of 75%, indicating that the projection of the wetland area and the supply of ecosystem services will be exhausted around the year 2047 with a positive estimate until the year 2050. The most favorable scenarios (concentrated on the left side of the sensitivity figure) highlight that the wetland area may not be exhausted by the year 2050, since urban expansion would have a lower dynamic, which would favor the generation of ecosystem services. On the other hand, less favourable scenarios (with low probability according to the Monte Carlo model) could lead to a reduction of zero hectares by 2038-2039.

5. DISCUSSION

Wetland ecosystems within urban environments, as noted by Wang et al., (2008), constitute important ecological infrastructures, playing a decisive role in the form and growth patterns of cities and their sustainability. However, despite their importance, wetlands within metropolitan environments have succumbed to accelerated processes of population growth and the consequent urbanization (Lee et al. 2006; Li, Deng, and Huang 2010), leading them to be considered as the environments most threatened by anthropogenic developments, which generate drainage processes, desiccation, destruction of biota, sedimentation and pollution (Smith-Guerra and Romero-Aravena 2009). It can be stated that since the 19th century, urban development has been correlated with the destruction of wetlands, turning them into isolated ecosystems surrounded by environmental impacts.(Caicedo 2016; Mayorga 2016).

Bogotá D.C. city, has presented an acceleration in the processes of expansion of the urban fabric, which is influenced by migratory and demographic factors of the local population, which is concentrated in the north and west of the city, precisely in the localities of Suba, Kennedy, Bosa, Fontibón and Usme (Salgado and Rojas 2019), which caused drastic transformations of the landscape, an increase in the rate of resource consumption, loss of biodiversity, among others (Vitousek, 1997, Niemela et al., 2010, cited by Rojas et al., 2015)). This scenario generates a discontinuous structure (Inostroza 2017), and an unsustainable urban development in the medium and long term (Duque et al., 2019, cited by Salgado & Rojas, 2019), which generates pressure on fragile natural spaces such as wetlands (Muñiz and Galindo 2005; Rojas et al. 2015).

Based on the above, it can be stated that the transformations of the Kennedy Wetlands (HEB, HLV, HET), are directly correlated with the processes of population growth and urban development that began in the late 1940s and were consolidated during the 1980s (Mayorga, 2016). The above is consistent with the modeling carried out for these wetlands, shown in Figure 1, where in 1940, there was a total of 296 hectares of wetland area in the Kennedy town, which decreased rapidly during the 1950s and 1970s, which coincides with the densification of the population in the town.

The HET in the modeling showed an early process of area loss before the 1950s (figure 1) in contrast to the other wetlands; this can be explained according to Saldarriaga, (2006) as a failure in the management plans generated for the time, where urban instruments were included lacking regulations for land use and protection of flood zones. This made possible the construction of important urban infrastructures that fragmented the HET, such as the AméricasAvenida, the transfer of the Bavaria Brewery, the construction of the Techo Hippodrome, the Techo airport and the urban consolidation of the Carvajal neighborhood (Pontificia Universidad Javeriana, Empresa de Acueducto y Alcantarillado de Bogotá, and Secretaría Distrital de Ambiente 2009b; Mayorga

2016). Consequently, the HET as shown in the modeling, presented a drastic reduction, going from 60 ha., to a total of 23 ha., in 1953, with an approximate loss of 1.85 hectares per year.

Likewise, it can be observed in the modeling of the wetlands from 1940 to 2019, that the period with the greatest incidence in the HLV and HEB occurred between the years 70 and 80, with an estimated reduction in total area of 46% and an annual loss of 2.33 hectares. This drastic reduction of the wetlands according to Mayorga (2016), can be explained mainly by the consolidation project of Kennedy Town, which indiscriminately licensed the land of the wetlands for formal housing areas. Added to this is the arrival of communities displaced by the armed conflict and workers who illegally invaded the land of the wetlands (Bonilla 2011).

It should be noted that after the eighties, between the years 1990 and 2000, as shown in Figure 1, the process of loss of wetland area began to slow down, with an average annual loss of 0.5 hectares; loss that is attributed according to Saldarriaga (2006)and Bonilla (2011) to illegal settlements that generate contamination processes with the deposit of solid waste and debris.

Although the modeling of the wetland area until 2019 shows that the trend of loss just to urbanization processes tends to stabilize, due to the effect of different legal protection processes such as Decree 619 of 2000, which recognizes wetlands as "District Ecological Parks" (Bonilla, 2011), the trend in its transformation continues with loss rates of 0.18 annually, which could be explained, as mentioned by Rodríguez-Tenorio & Rodríguez-Soto (2017), to the legalization of informal properties and the granting of land for urban constructions.

Now, if we take into account that the population projections for the Kennedy town from 2019 to 2050 show exponential growth (Figure 2a), which is directly correlated with the expansion of urban land by 99% (Figure 2b), it can be stated, as shown in Figure 2c, that the processes of loss of wetland area will continue with low reduction rates, with a projection of existence until the year 2047.

The projected scenario for the HLV, HET and HEB responds to the lack of territorial planning instruments that control illegal urbanization processes on the effective area of the wetlands. In fact, the problem is aggravated by the evidence of the disposal of solid and liquid waste within the wetlands, whose variables influence the decrease of 2.71 ha/year, and lead to the generation of eutrophication processes with sudden increases in organic matter that affect dissolved oxygen, hydrological dynamics and landscape structure (Cortes 2018; Rubbo and Kiesecker 2005; Rojas et al. 2015). The analyzed wetlands presented a decrease rate of 8.66 ha/year under urban processes and solid waste disposal. At the time of generating cleaning processes and implementing treatment plants for solid waste disposed on the wetlands, the rate varies to 7.02 ha/year.

For this reason, the loss of ecosystem services is directly affected by urban, demographic and wetland area dynamics, which directly affects the supply and space for the development of regulating and sociocultural ecosystem services. The main impacts are evident in erosion, discharge capacity, morphology of the water body, sensitivity of the biota and recovery capacity of the wetland (Burton, Phillips, and Hawker 2004; Azous and Horner 2000). , describes that ecosystem services are directly affected by changes in the size of the patch area, and is aggravated if it presents waste disposal that leads eutrophication.

Thiscontextisevident in Kennedytown, sincethewetlands for the year 2019, according to the total area, presented a variety of services such as habitat supply for terrestrial and aquatic birds, richness of flora and fauna species, interrelation with other ecosystems, flood control, sediment retention, recreational use, research activity, among others, evaluated in a weighting of 59 points. This evaluation presents a non-linear decrease, reaching zero around the year 2043-2044, below the estimated year of total loss of the wetland area. This is justified since, if there is a low area in a wetland, it does not guarantee the diversity of services if it does not have the characteristics to support the different dynamics.

6. CONCLUSIONS

The environmental sustainability of the wetlands in Kennedy town is directly affected by population growth processes, where it is estimated that by 2050 the number of inhabitants will double, and the trend towards land transformation with a view to urbanization will reach a total of 3,836 ha.

Through dynamic modelling it was possible to demonstrate that by 2047, the total area of wetlands could be reduced if the current dynamics of urban expansion continue, reaching an average reduction of 98.2%, leaving an estimated total protection of 5.59 Ha.

Although the existence of wetland areas is projected for 2047 within the locality, the modeling of ecosystem services shows a rate of decline with non-linear behavior, which predicts that the supply of regulatory and sociocultural services by wetlands will be exhausted by 2044, since their supply depends not only on the amount of area, but also on associated processes such as pollution and eutrophication.

The dynamic simulation of the transformation of El Burro, La Vaca and El Techo wetlands area and their ecosystem services can be used as a tool for the development of environmental management strategies, generating legal, participatory and educational scenarios that promote the protection and restoration of these wetlands and their ecosystem services, in order to harmonize, from a sustainable perspective, the urbanization processes with the environmental dynamics of the context.

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8. **ANEXO.**Valores y fórmulas de la modelacióndinámica.

(01) Área de humedales= INTEG (-urbanización-residuossólidos+(oferta*0), 238)
Units: ha

(02) Área Urbana= INTEG (urbanización, 3606)
Units: ha [0,3859]
Área urbanizada. Kennedy no presenta área rural.

(03) área total de Kennedy=3859
Units: ha
El área total de Kennedy es de 3859 ha, sin posibilidad de aumentarya que no cuenta con área rural.

(04) crecimientopoblacional= (Población + tasa de migración) *tasa de crecimiento
Units: habitantes/año
Crecimientopoblacionalanual

(05) densidadpoblacional= Población/área total de Kennedy
Units: habitante/ha
Cantidad de población por hectárea.

(06) "deterioro de los S.E"= (100-eutrofización) /100
Units: Dmnl

(07) eutrofización=5
Units: Dmnl
Eutrófico (0); oligotrófico o mesotrófico (2.5); y hipertrófico (5)

(08) FINAL TIME = 2050
Units: year
Tiempo final de la simulación-

(09) INITIAL TIME = 2019
Units: year
Tiempoinicial de la simulación.

(10) mortalidad= Población*tasa de mortalidad
Units: habitantes/año
Cantidad de personas que fallecen por año

(11) oferta= Área de humedales/ (regulación + socioculturales)
Units: Dmnl

(12) Población= INTEG (crecimientopoblacional-mortalidad, 1.25201e+006)
Units: habitantes

(13) regulación= variables bióticas + variables físicas
Units: Dmnl/ha*humedal

(14) residuossólidos= IF THEN ELSE (tasapromedio de depósito de residuossólidos-tasa de limpieza de residuossólidos<=0, 0 , tasapromedio de depósito de residuossólidos-tasa de limpieza de residuossólidos)
Units: Dmnl

(15) SAVEPER = TIME STEP
Units: year [0,?]
La frecuencia con la que se almacena la salida.

(16) ServiciosEcosistémicos= INTEG (oferta*-"deterioro de los S.E", 9+24+24)
Units: Dmnl
Valores SE del humedal La Vaca, Techo y El Burro. Se tomacomo valor base elcálculo para elaño 2019 equivalente a 57 Dmnl

(17) socioculturales= 0+5+4
Units: Dmnl/ha*humedal
A. Usorecreativo actual; B. Usoenactividadesinvestigativas; C. Valor paisajístico; D Usoenactividades de educaciónambiental. (La Vaca + Techo + Burro)

(18) tasa de crecimiento= 0.0188
Units: habitantes/año
Tasa de crecimiento de 1,88% por cada mil habitantes

(19) tasa de expansiónurbana= 0.018
Units: Dmnl
Kennedy es una localidad que cuenta con una superficie total de 3.859 hectáreas de las cualesel 98.1 por cientocorresponden a suelourbano y el 1.8 por ciento restante constituyeelsuelo de expansiónurbana.

(20) tasa de limpieza de residuossólidos= 0.906+STEP (25.1, 2030)
Units: ton/año
El 0.906 equivale al 25% de tasa de producción de residuos, ya que cada 4 añosrealizanlimpieza de humedales. Asimismo, se estima una planta 25.1 toneladas/residuos*añolimpiada para elaño 2030

(21) tasa de migración= 0.0115
Units: habitantes/año
Tasa de migración de 11,5% por cada mil habitantes

(22) tasa de mortalidad= 0.0033
Units: habitantes/año
Tasa de mortalidad de 3.3% por mil habitantes

(23) tasapromedio de depósito de residuossólidos= 3.624
Units: ton/año
Tasa anual del 10% de basuradispuestaenhumedales Kennedy

(24) TIME STEP = 1
Units: year [0,?]
El paso de tiempo para la simulación.

(25) urbanización= IF THEN ELSE (Área Urbana>3851, 0, densidadpoblacional*tasa de expansiónurbana)
Units: ha [0,3859]
Cantidad de hectáreas que son urbanizadas por añoacorde a la tasa de expansiónurbana y densidadpoblacional. Cuando el valor supera las hectáreasmáximas, se regula a 0.

(26) variables bióticas= 5+15+13
Units: Dmnl/ha*humedal
A. Protección de especiesendémicas o amenazadas; B. Oferta de hábitat para avesmigratoriasacuáticas; C. Oferta de hábitat para avesmigratoriasterrestres; D. Riquezaespecies flora; E. Riquezaespecies fauna; F. Riquezaespecieshidrobiológicas; G. Riqueza de hábitats; H. Interrelación con otrosecosistemas; I. Presencia de especiesennivelestróficos altos. (La Vaca + Techo + El Burro).

(27) variables físicas= 4+4+7
Units: Dmnl/ha*humedal
A. Control de inundaciones; B. Retención de sedimentos; C. Incidenciaenelmicroclima local; D. Depuración de aguas. (La Vaca + Techo + El Burro).