



Arboreal vegetation structure and diversity in the gallery forest of the Xaltatempa river, Puebla, Mexico

Estructura y diversidad de la vegetación arbórea del bosque de galería del río Xaltatempa, Puebla, México

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ABSTRACT

Gallery forests are plant formations that develop parallel to rivers. They possess a great plant diversity; whose arboreal species are indicative of water quality. Here are described the variables of the arboreal plant life and their relationship with the water quality of the Xaltatempa river, Puebla, Mexico. To do this, six sampling units were established, each 1000 m², separated by 2 km, where all the trees and shrubs were measured and identified in order to generate information regarding: importance value index (IVI), forestry value index (FVI), Shannon-Weaver heterogeneity index (H'), and Sorenson's similarity index (SSI). Additionally, river water samples were taken to determine its main chemical characteristics. The results indicated a statistical difference between sites ($\alpha \leq 0.05$), where the most important species, given its dominance, density, and frequency, was *Platanus mexicana* (IVI=182.71); it was also the most important for its diameter, height, and cover (FVI=300.00). Specific richness (H'=0.54) was found in only six species: *Alnus acuminata*, *Ligustrum japonicum*, *Parathesis serrulata*, *Pinus patula*, *Platanus mexicana*, and *Quercus rugosa*. With regard to SSI, the paired combination of sites 4 (1586 m asl) and 5 (1536 m asl) matched the following species: *Alnus acuminata*, *Ligustrum japonicum*, and *Platanus mexicana* (SSI=1.00). The structure (fragmented) and diversity (very low) of the arboreal plant life of the gallery forest evidence the changes in its composition, without any negative effects on water quality for its exploitation.

KEYWORDS: importance value; forestry value; riparian vegetation; Shannon-Weaver; Sorenson's similarity.

RESUMEN

Los bosques de galería son formaciones vegetales que se desarrollan de forma paralela a los cauces de los ríos, poseen gran diversidad vegetal; siendo sus especies arbóreas importantes indicadoras de la calidad del agua; por ello, se describieron las variables de la vegetación arbórea y su relación con la calidad del agua del río Xaltatempa, Puebla, México. Se establecieron seis unidades de muestreo de 1000 m², distanciadas cada 2 km, en las que se midieron e identificaron todos los árboles y arbustos, para generar información acerca del: índice de valor de importancia (IVI), índice de valor forestal (IVF), índice de heterogeneidad de Shannon-Weaver (H') e índice de similitud de Sorenson (ÍSS); adicionalmente se tomaron muestras de agua del río, para determinar sus principales características químicas. Los resultados indicaron diferencia entre sitios ($\alpha \leq 0.05$), donde la especie más importante por su dominancia, densidad y frecuencia fue *Platanus mexicana* (IVI=182.71); de la misma forma lo fue por su diámetro, altura y cobertura (IVF=300.00). Mientras que la riqueza específica (H'=0.54), se concentró en: *Alnus acuminata*, *Ligustrum japonicum*, *Parathesis serrulata*, *Pinus patula*, *Platanus mexicana* y *Quercus rugosa*; en cuanto al ÍSS la combinación pareada de los sitios 4 (1586 m snm) y 5 (1536 m snm), hizo coincidir a las especies: *Alnus acuminata*, *Ligustrum japonicum* y *Platanus mexicana* (ÍSS=1.00). La estructura (fragmentada) y la diversidad (muy baja) de la vegetación arbórea del bosque de galería, hacen evidentes los cambios en su composición; sin tener efectos negativos en la calidad del agua para su aprovechamiento.

PALABRAS CLAVE: valor de importancia; valor forestal; vegetación ribereña, Shannon-Weaver; similitud de Sorenson.

INTRODUCTION

Gallery forests are plant formations characterized for their links to the banks of a river or equivalent hydrological entity (Santiago-Pérez, Ayón-Escobedo, Rosas-Espinoza, Rodríguez-Zaragoza, and Toledo-González, 2014). They are complex and fragile forest communities that fulfill a fundamental role in ecological, hydrological, and biodiversity terms, for the preservation of rivers (Meli *et al.*, 2017).

From the physiognomic and structural point of view, rarely can pure masses of a single species be formed, there generally being alternating species that, as mentioned by Sánchez (1986), can change in a little distance or be present in combinations of plant associations. In rivers, the distribution patterns of species are related with the microtopography and edaphic variables (Cortés-Castelán and Islebe, 2005); moreover, the changes in the riparian vegetation (distribution, composition, diversity, structure, and function) are related with the altitude gradient where it is located (Ward, Tockner, Arscott, and Claret, 2002; Acosta, Mondragón, and Alvarado, 2008).

In the riparian areas, the arboreal diversity has a well-defined vertical component, from the surface of the water up to the canopy, where distinctive plant strata are found (Granados-Sánchez, Hernández-García, and López-Ríos, 2006). Diversity can be evaluated from the number of arboreal species in a specific location (Meli *et al.*, 2017). The arboreal structure is an axis of environmental management, vitally important for the ecosystem balance of gallery forests (Romero, Cozano, Gangas, and Naulin, 2014).

The arboreal structure can also be defined by the type of species, number of individuals, spatial arrangement, and temporal ordering of its components. In this context, the spatial and dimensional disposition of the species stand out, as well as the structure of the ecosystem (community) (Aguirre, 2002). The vertical structure is the way in which the arboreal component is distributed on its vertical axis. The nature of the canopy changes, given that the forest is growing by patches all the time. According to this, three stages are recognized: clearing stage, reconstruction stage, and mature stage, or state of balance (Roman-Dañobeytia,

Levy-Tacher, Aronson, Rodrigues, and Castellanos-Albores, 2012; Meli, Martínez-Ramos, Rey-Benayas, and Carabias, 2014).

The vertical disposition of the arboreal vegetation of the gallery forest is primordial to maintain water quality, buffer the sedimentation processes of the riverbeds (Granados-Sánchez *et al.*, 2006), provide protection against soil erosion, and provide a habitat for aquatic and land organisms (Camacho, Trejo, and Bonfil, 2006). The horizontal structure refers to the way in which the components of the community are distributed along the ground. Said distribution is given by the topological arrangement of the trees (Roman-Dañobeytia *et al.*, 2012; Meli *et al.*, 2014).

The current state of the gallery forests requires detailed information on the structure and diversity of the arboreal vegetation in order to generate management strategies that guarantee the supply of environmental services for a growing human population (Méndez, Zermeño, and Ibarra, 2014; Meli *et al.*, 2017). However, the rivers and the plant communities that grow along their banks have been subjected to intense historical pressure due to varied human activities. This has led to their transformation since ancient times (Richardson *et al.*, 2007).

OBJECTIVES

The present paper has the objective of describing the structure and diversity of arboreal species of the gallery forest and their functionality as water quality indicators of the Xaltatempa river, Puebla.

MATERIALS AND METHODS

Study area

The Xaltatempa river is located in Puebla, Mexico (from $19^{\circ}43'00''$ to $19^{\circ}57'06''$ N, and $97^{\circ}38'42''$ to $97^{\circ}54'06''$ W, from 1680 m to 1451 m asl). It is in the zone of temperate climates of the Sierra Norte, and as one moves from south to north, the humidity rises (García, 2004). It lies within the Sierra Norte in Puebla, which is made up of hills, mountain groups, and valleys between the mountains. It is located in



the northern hydrographical zone of the state of Puebla, which is formed by the different partial watersheds of the rivers that empty into the Gulf of Mexico. The mean annual temperature is 13.9 °C, and the mean annual rainfall is 1260 mm (García, 2004). Most of the territory is covered by temperate and rain forests, where the following species stand out: *Abies religiosa*, *Alnus acuminata*, *Pinus ayacahuite*, *Pinus patula*, *Pinus teocote*, *Platanus mexicana*, *Quercus oleoides*, and *Quercus rugosa*.

Sampling sites

The criteria to select the sampling sites along the river were based on their location within the altitude range between 1680 m and 1451 m asl, to represent the conditions of the gallery forest. Six rectangular plots, 20 m × 50 m (1000 m²), were established along the river, taking into account 10 m width in each edge of the normal water flow. The plots were separated by 2 km, considering that the river has a mean length of 12 km. To define the coordinates of the plots, a global positioning system receptor (SOUTH S750-G2®) was used.

The following botanical identifications and measurements of the trees and shrubs were done in each site: height (with a Laser Nikon® telemeter / hypsometer), diameter (800 mm Haglof® green laser calipers), canopy (Stanley® measuring tape). Species identification was done based on specialized literature (Pennington and Sarukhán, 2005). Two water samples (250 ml) were analyzed in the laboratory (Colegio de Postgraduados [Colpos]) to determine: pH, electrical conductivity (EC, $\mu\text{S cm}^{-1}$), chlorine (Cl, $\text{mmol}_\text{c L}^{-1}$), sulfates (SO_4^{2-} , $\text{mmol}_\text{c L}^{-1}$), calcium (Ca^{2+} , $\text{mmol}_\text{c L}^{-1}$), and sodium (Na^+ , $\text{mmol}_\text{c L}^{-1}$).

Response variables

For the tree structure, the forestry value index (FVI) was applied in order to evaluate the bidimensional structure of the arboreal vegetation. It was calculated as follows (Corella *et al.*, 2001):

$$\text{FVI} = \text{Relative diameter} + \text{Relative height} + \text{Relative cover}$$

To classify the growth stages of the trees, the following diametric categories were considered: seedling stage (0 cm - 5 cm), thicket stage (6 cm - 12 cm), young timber stage (12 cm - 30 cm), high pole stage (31 cm - 50 cm), timber stage (> 50 cm).

For the tree diversity, the importance value index (IVI) served to hierarchically order the importance of each species in the sampling sites of riparian ecosystem, following Smith and Smith (2007):

$$\text{IVI} = \text{Relative density} + \text{Relative dominance} + \text{Relative frequency}$$

The Shannon-Weaver heterogeneity index (H') allowed us to learn the degree of uncertainty, in order to predict to which species a randomly chosen individual from each of the plots belongs; this is to say, the diversity in each sampling site is (Somarriba, 1999):

$$H' = - \sum_{i=1}^s P_i \ln(P_i)$$

where: s is the number of species and P_i is the proportion of individuals of species i .

The Sorensen's similarity index (SSI) was used to learn the floristic similarity between the sampling sites, based on the presence-absence ratio of the species. It takes on a value of 1 when there is maximum similarity and 0 when it is minimum (Chao, Chazdon, Colwell, and Shen, 2005):

$$\text{SSI} = \frac{2C}{A + B} (100)$$

where: A is the number of species in site 1, B is the number of species in site 2, and C is the number of species common in both sites.

Statistical analysis

One way analyses of variance (Anova) were used with mean comparison tests through the Tukey method ($\alpha \leq 0.05$). The tests were done independently for each species to find significant differences between the sampling sites. We worked with Excel and the multiple response surface

optimization model (Montgomery, 2006), using the Minitab® 17 software (Minitab, 2017).

RESULTS

Structure

In the gallery forest of the Xaltatempa river, 0.6 ha^{-1} were inventoried, resulting in a mean density of $820 \text{ trees ha}^{-1}$ of the following species: *Alnus acuminata* Kunth (ahile), *Platanus mexicana* Moric., (papalote), *Ligustrum lucidum* Ait., (Japanese privet), *Pinus patula* Schl. et Cham., (Mexican weeping pine), *Quercus rugosa* Née (neatleaf oak) and *Parathesis serrulata* Sw. (naranjillo).

With regard to the FVI, the species with the highest values in every site was *Platanus mexicana* (papalote), with a mean FVI of 244.92 for the six sampling sites (Table 1). Thus, the structural importance of the gallery forest of the Xaltatempa river, from the FVI, concentrates around two main species: *Platanus mexicana* (150.65 to 300) and *Alnus acuminata* (12.39 to 145.23). With regard to the dominant development stages, per species: *Alnus acuminata* (35.02% young timber stage), *Ligustrum japonicum* (51.13% young timber stage), *Parathesis serrulata* (56.25% thicket stage), *Pinus patula* (48.95% thicket stage), *Platanus mexicana* (29.36% timber stage), and *Quercus rugosa* (43.35% thicket stage) (Table 2).

Diversity

The most important tree species found in the forest vegetation of the gallery forest in the Xaltatempa river were: *Alnus acuminata* (ahile), *Ligustrum japonicum* (Japanese privet - aligustre del Japón), *Platanus mexicana* (álaro o papalote), *Quercus rugosa* (neatleaf oak - encino roble), *Pinus patula* (Mexican weeping pine - pino llorón), and lastly *Parathesis serrulata* (naranjillo). The last species had a very low density per hectare, is little known in the area, and is actually a shrub under 7 m tall with little or no forestry use.

Table 3 shows that the most outstanding species, based on its IVI, was *Platanus mexicana* (182.71) with far superior relative density, dominance, and frequency values. Meanwhile, *Parathesis serrulata* had the lowest value (7.82), which might be because it and *Ligustrum lucidum* are introduced, and have

been adapting to the riparian ecosystem of this temperate zone. In the case of *Ligustrum lucidum*, it has higher values than does *Pinus patula* (native species).

Site 6 has the highest diversity, with four species in the gallery forest (*Alnus acuminata*, *Platanus mexicana*, *Quercus rugosa*, and *Parathesis serrulata*), showing the highest H' with 0.73. This site was at the lowest part of the river, 1451 m asl. Meanwhile, site 3 was located in the middle part of the river at 1617 m asl, with the sole predominance of *Platanus mexicana*, obtaining the lowest H' with cero (Table 4).

With a low density (180 ind ha^{-1}) in site 6, we found mature trees in development, which suggests a late successional stage with little disturbance, even though there is evidence of mining in the area. Of these trees, 100% of the *Platanus mexicana* was in the timber stage while 33.33% of *Quercus rugosa* was in the thicket stage. Site 2 had the highest density with 1350 ind ha^{-1} , with mostly young trees.

In site 3 (located at 1617 m asl), there was only a homogeneous and coetaneous forest with *Platanus mexicana* in its timber stage. However, said species was found along the 12 km of the river, in different growth stages, with a five-level vertical stratification. This suggests that this species has adapted and evolved with the riparian ecosystem through time, and is not a species whose forestry benefits are important in the area, compared against *Pinus patula*, *Alnus acuminata*, and *Quercus rugosa*, which are native but with low population levels. Despite this, there is still an important timber reserve in the Xaltatempa river gallery forest, with an average $235.72 \text{ m}^2 \text{ ha}^{-1}$.

In the sampling sites, the paired combinations show that the combination of sites 4 and 5 had the highest value (1.00) (Table 5). The following value was 0.86, which corresponds to the combination of paired sites 1 and 2, where the coinciding species were: *Alnus acuminata*, *Pinus patula*, and *Platanus mexicana*. Paired sites 1 and 6 had the same value and the coinciding species were: *Alnus acuminata* and *Platanus mexicana*. Sites 5 and 6 also had the same value, and the coinciding species were: *Alnus acuminata* and *Platanus mexicana*. Meanwhile, the lowest index (0.40) was that of two paired combinations: sites 2 and 3 with *Platanus mexicana*, and sites 3 and 6 with the same species.



TABLE 1. Species with the highest forest value index (FVI), in the gallery forest of the Xaltatempa river, Puebla.

Site	Species	ReDi	ReHe	ReCo	FVI
1	<i>Alnus acuminata</i>	21.21	21.73	7.50	50.45
1	<i>Pinus patula</i>	4.43	03.70	0.33	8.46
1	<i>Platanus mexicana</i>	74.36	74.57	92.17	241.09
	TOTAL	100	100	100	300
2	<i>Alnus acuminata</i>	7.15	9.15	0.71	17.01
2	<i>Parathesis serrulata</i>	3.51	5.14	0.17	8.83
2	<i>Pinus patula</i>	5.28	4.12	0.39	9.78
2	<i>Platanus mexicana</i>	84.06	81.59	98.72	264.38
	TOTAL	100	100	100	300
3	<i>Platanus mexicana</i>	100.00	100.00	100.00	300.00
	TOTAL	100	100	100	300
4	<i>Alnus acuminata</i>	7.34	9.21	0.80	17.34
4	<i>Ligustrum japonicum</i>	11.54	21.46	1.97	34.97
4	<i>Platanus mexicana</i>	81.12	69.33	97.24	247.69
	TOTAL	100	100	100	300
5	<i>Alnus acuminata</i>	48.21	48.40	48.62	145.23
5	<i>Ligustrum japonicum</i>	2.29	1.72	0.11	4.12
5	<i>Platanus mexicana</i>	49.51	49.88	51.27	150.65
	TOTAL	100	100	100	300
6	<i>Alnus acuminata</i>	2.28	9.86	0.06	12.19
6	<i>Parathesis serrulata</i>	1.14	4.23	0.01	5.38
6	<i>Platanus mexicana</i>	92.96	72.77	99.77	265.50
6	<i>Quercus rugosa</i>	3.63	13.15	0.15	16.93
	TOTAL	100	100	100	300

ReDi = relative diameter, ReHe = relative height, ReCo = relative cover

TABLE 2. Development stages of the arboreal species found in the gallery forest of the Xaltatempa river, Puebla.

Species	SES (%)	TIS (%)	YTS (%)	HPS (%)	TMS (%)	TOTAL (%)
<i>Alnus acuminata</i>	5.00	19.82	35.02	26.15	14.01	100
<i>Ligustrum japonicum</i>	0	29.03	51.13	16.62	3.22	100
<i>Parathesis serrulata</i>	0	56.25	43.75	0	0	100
<i>Pinus patula</i>	0	48.95	22.52	28.53	0	100
<i>Platanus mexicana</i>	6.66	17.62	18.51	27.85	29.36	100
<i>Quercus rugosa</i>	0	43.35	25.64	31.01	0	100

SES = seedling stage, TIS = thicket stage, YTS = young timber stage, HPS = high pole stage, TMS = timber stage

TABLE 3. Species with the highest importance value index (IVI), in the gallery forest of the Xaltatempa river, Puebla.

Species	ReDo (%)	ReDe (%)	ReFr (%)	IVI (%)
<i>Alnus acuminata</i>	7.80	15.03	33.75	56.58
<i>Ligustrum lucidum</i>	1.04	6.70	5.40	13.14
<i>Parathesis serrulata</i>	0.40	2.02	5.40	7.82
<i>Pinus patula</i>	0.43	3.85	5.50	9.78
<i>Platanus mexicana</i>	62.39	71.72	48.60	182.71
<i>Quercus rugosa</i>	27.94	0.68	1.35	29.97
TOTAL	100	100	100	300

ReDo = relative dominance, ReDe = relative density, ReFr = relative frequency

TABLE 4. Shannon-Weaver index (H'), for the gallery forest in the Xaltatempa river, Puebla.

Site	Number of species	Density (ind ha^{-1})	Basal area ($m^2 ha^{-1}$)	H'
1	3	1300	143.64	0.59
2	4	1350	241.74	0.66
3	1	530	158.41	0.00
4	3	790	352.39	0.67
5	3	770	230.30	0.62
6	4	180	144.98	0.73
Mean	3	820	235.72	0.54
ED (σ)	1.61	255	71.48	0.04
CV (%)	12.00	18.83	21.71	20.11

TABLE 5. Paired combinations through the Sorensen's similarity index (SSI), for the gallery forest of the Xaltatempa river, Puebla.

Number	Combination	A	B	A + B	C	SSI
1	site 2 x site 6	4	4	8	3	0.75
2	site 2 x site 4	4	3	7	2	0.57
3	site 2 x site 5	4	3	7	2	0.57
4	site 2 x site 3	4	1	5	1	0.40
5	site 1 x site 2	3	4	7	3	0.86
6	site 1 x site 6	3	4	7	3	0.86
7	site 4 x site 6	3	4	7	2	0.57
8	site 5 x site 6	3	4	7	3	0.86
9	site 1 x site 4	3	3	6	2	0.67
10	site 1 x site 5	3	3	6	2	0.67
11	site 4 x site 5	3	3	6	3	1.00
12	site 1 x site 3	3	1	4	1	0.50
13	site 3 x site 6	1	4	5	1	0.40
14	site 3 x site 4	1	3	4	1	0.50
15	site 3 x site 5	1	3	4	1	0.50

A= number of species in first site; B= number of species in second site; C= shared species in the first and second sites.



Water quality

For the chemical results of the water samples of the Xaltatempa river, no important changes were observed in pH, as it remained neutral with a slight tendency to alkalinity (7.64 to 7.75), even though of the runoff with diverse carbonated materials and tributaries from springs (Table 6). With regard to electrical conductivity (EC), it increased towards the lower parts of the river, reaching up to $695.11 \mu\text{S cm}^{-1}$. Thus, the accumulation of chlorides, sulfates, carbonates, and sodium also had a slight increase in direct relationship with EC, which increased towards the lower part of the river (1451 m asl).

DISCUSSION

Structure

The gallery forest of the Xaltatempa river is ecologically dominated by only six species: *Alnus acuminata*, *Ligustrum japonicum*, *Platanus mexicana*, *Quercus rugosa*, *Pinus patula*, and *Parathesis serrulata*. Of these, *Platanus mexicana* was the only one to be found along the whole of the Xaltatempa river, where the soils are characteristic for being wet all year long. Along the 12 km of the river, there are trees in the five growth stages: seedling stage, thicket stage, young timber stage, high pole stage, and timber stage. This shows the spatial and dimensional disposition of the species, and generally, the structure of the ecosystem (Aguirre, 2002).

Platanus mexicana was also the species with the highest FVI (244.92), which is considered high compared against the study done by Zarco-Espinosa, Valdez-Hernández, Ángeles-Pérez, and Castillo-Acosta (2010), who obtained a

high FVI value (79.09) for the *Rinorea guatemalensis* species when studying the structure and arboreal vegetation diversity of the Agua Blanca state park in Tabasco. When comparing the FVI with the IVI in the present study, we find a predominance between *Platanus mexicana* and *Alnus acuminata*.

The aforementioned can be because this gallery forest has a very low diversity, mainly made up of young individuals, with very few trees that have reached maturity (Table 2); however, the riparian ecosystem is dynamic and in succession. In this sense, Treviño-Garza, Cavazos-Camacho, and Aguirre-Calderón (2001) reported strong human influence on this type of forests, where the distribution of this vegetation in favorable areas and its great productivity cause them to be used for wood.

Diversity

Despite diversity being very low along this river (only six species), *Platanus mexicana* adds a high importance value (182.71), compared with the results of other authors like Díaz-Pérez, Daza, and Sarmiento (2012) who, when studying the riparian forests of the Kakada river, Venezuela, identified up to 110 species, and reported an importance value of 163.7 for the ten most important ones. However, in the study by Treviño-Garza *et al.* (2001) on two rivers of the central south region of Nuevo Leon, Mexico, they registered 25 arboreal species, only four of which were considered dominant in each river, due to their importance value (*Taxodium mucronatum*, *Platanus occidentalis*, *Populus wislizenii*, and *Salix nigra*).

TABLE 6. Chemical composition of the water in six sampling sites along the gallery forest of the Xaltatempa river, Puebla.

Determination	Site 1 (1680 m)	Site 2 (1656 m)	Site 3 (1617 m)	Site 4 (1586 m)	Site 5 (1536 m)	Site 6 (1451 m)
pH	7.64	7.68	7.70	7.71	7.73	7.75
EC ($\mu\text{S cm}^{-1}$)	384.50	391.28	440.00	493.77	555.10	695.11
Cl ⁻ (mmol _c L ⁻¹)	0.29	0.29	0.31	0.31	0.33	0.33
SO ₄ ²⁻ (mmol _c L ⁻¹)	0.15	0.24	0.37	0.45	0.50	0.57
Ca ²⁺ (mmol _c L ⁻¹)	0.18	0.18	0.20	0.22	0.23	0.27
Na ⁺ (mmol _c L ⁻¹)	0.92	0.99	1.15	1.18	1.20	1.20

This indicates an important coincidence with regard to the present study for the *Platanus* genus. Therefore, the presence of this species in riparian zones can be predominant; although the IVI values obtained in Nuevo Leon: Cabezones river and Ramos river with 0.37 and 1.27, respectively, were low, compared with those obtained for *Platanus mexicana* (182.71) in the Xaltatempa river, Puebla.

In the studied area, this colonization behavior is shown mostly by *Platanus mexicana* which, like *Alnus acuminata* and *Pinus patula*, disperses its seeds in the wind. Sánchez (1986) mentioned that there is a constant succession caused by the effects of floods that act as control factor according to their return period, and considers that the species are subjected to a constant colonization process.

Like the report by Sánchez (1986) for the Pilon river, in this research there were pure or co-dominant patches of the *Platanus mexicana*, *Quercus rugosa*, *Pinus patula*, *Ligustrum japonicum*, and *Alnus acuminata* species; however, it is most common along gallery forests that there is not a clear dominance of any species. In the pure patches of the Xaltatempa river, young plants of the previously mentioned arboreal species are found in greater percentages (Table 2). Bock and Bock (1989) pointed out that some species in gallery forests often act as pioneers. This is the case of *Platanus wrightii*, which despite having a high seedling production, also has a high mortality percentage due to desiccation, together with the loss of renewal during the floods.

There are few works carried out in Mexico regarding gallery forests. Moreover, it is complicated to compare the results with other research works, given the differences in sampling methods. The mean value obtained (0.54) for the H' diversity was very low given the arboreal vegetation in the gallery forest of the Xaltatempa river if the index for tropical forests is taken as reference, as it oscillates between 3.85 and 5.85 (Knight, 1975). Moreover, $H' = 0.54$ is still low if compared with the study by Santiago-Pérez *et al.* (2014) who, in the gallery forest of the Sierra de Quila, Jalisco, obtained a Shannon diversity index of 1.8 to 2.6 with only six dominant species, like in the present study. Of these species, *Alnus acuminata* was common to both.

The low H' diversity in the present study could also be because the vegetation of the Xaltatempa river is discontinuous (due to the orographic and topographical position of Puebla in the Sierra Norte). In this regard, Camacho, Trejo, and Bonfil (2006), when studying the riparian vegetation of the Tembembe river basin, found that in the medium-high portion of the river (1110 m to 1700 m asl), the dominant species were: *Alnus acuminata*, *Trema micrantha*, and *Daphnopsis salicifolia*, with a mean H' of 1.69. This explains that large discontinuities also influence the diversity of species.

Díaz-Pérez *et al.* (2012) found in the riparian forest of the Kakada river, in the Caura river basin in Venezuela, 110 species represented by ferns, shrubs, trees, lianas, epiphytes, and weeds, whose highest H' value was 3.11 in seasonally flooded forests, in banks and dykes, with a mean density of 738 ind ha^{-1} and mean base area of $29.4 m^2 ha^{-1}$. These last results were lower than those of a temperate forest, like the one in the present research, with a mean density of 820 ind ha^{-1} and base area of $235.72 m^2 ha^{-1}$ (Table 4). Finally, in the study by Fernández-Méndez, Camargo-Martínez, and Sarmiento (2012) on the biodiversity of the underbrush in the gallery forest in the Llanos Orientales region in Colombia, they found a H' value of 0.42 with 53 species, arguing high beta-diversity for a lower value than that of the present study ($H' = 0.54$).

When applying the SSI in the gallery forest of the Xaltatempa river, the mean of the six sampling sites was 0.64, which indicates that *Alnus acuminata*, *Ligustrum japonicum*, *Platanus mexicana*, *Quercus rugosa*, *Pinus patula*, and *Parathesis serrulata*, were found in all the sites. It is because of this that the SSI depends on the total species in the studied ecosystem and the number of shared species (Chao *et al.*, 2005).

In the paired combinations, sites 4 (1586 m asl) and 5 (1536 m asl) had the highest SSI (1.00). To this regard, Treviño-Garza *et al.* (2001), found great similarity between arboreal populations dominated by *Platanus occidentalis*, *Populus wislizenii*, *Salix nigra*, and *Taxodium mucronatum*, located in the Cabezones and Ramos rivers, obtaining an SSI of 0.649. This means that it was a high index for 25



registered arboreal species, but only considering four dominant species. Meanwhile, in the present study, there were six species found and two dominant ones: *Platanus mexicana* and *Alnus acuminata*.

In the study by Fernández-Méndez *et al.* (2012) on biodiversity associated with forest plantations of *Pinus caribaea* and *Eucalyptus pellica*, they obtained high beta-diversity (84.1%). Nevertheless, the Sorensen's quantitative coefficients were low (0.16) for the paired combination of pine *versus* eucalyptus. This indicates that despite sharing a high species percentage, the abundances are distributed unequally, which makes them structurally different, presenting dissimilar communities according to the set of conditions and factors that regulate succession.

Meanwhile, Camacho *et al.* (2006) obtained a maximum Sorensen's similarity coefficient of 75% in sites with a density of 3200 ind ha⁻¹ to 3300 ind ha⁻¹ (greater than the present study with 820 ind ha⁻¹), although these were not the sites that shared the highest number of species (seven), when studying the riparian vegetation of the Tembembe river. This is similar to the findings in the present study, where the sites with the highest coincidences (combination 4 and 5) were not necessarily the ones that had the highest tree density, as the highest density in the present study was in site 2, with 1350 ind ha⁻¹ (Table 4), located in the higher portion of the river at 1656 m asl.

Water quality

The vegetation near the Xaltatempa river was mostly perennial-woody; although the herbaceous stratum was not measured and no floristic analysis of it was done, the herbaceous species were observed to have a very low predominance, since in the season of greatest rainfall (June to October), the river floods, inundating the lower parts of its banks. This fosters anaerobiosis, which impedes the development of weeds all year round. To this regard, Colonnello (1990) and Granados-Sánchez, Hernández-García, and López-Ríos (2006) mentioned that only the species adapted to conditions of little oxygen in the soil, tolerance to short flooding periods, and deep root systems can adapt and develop in the riparian environment. In the

present study, *Platanus mexicana* and *Alnus acuminata* were the best adapted species.

There are no previous studies related with the water quality in the river; however, in the six sampling sites, located from 1680 m to 1451 m asl, the water quality of the Xaltatempa river was not altered by any anthropocentric effect or lack of plant cover that would cause contamination. This suggests that the arboreal vegetation of the gallery forest continues fulfilling its soil stabilization function, decreasing threats of erosion and slides that might result in sediments in the water, endangering the habitat.

The EC increased slightly towards the lower parts of the river; however, the water samples indicated that the concentration of electrolytes was adequate for human and animal consumption as well as for farming and forests, as drinking water has an EC of 5-50 mS/m according to the water quality indexes (Torres, Cruz, and Patiño, 2009). Because of this, the accumulation of chlorides, sulfates, carbonates, and sodium also showed a slight increase directly associated with EC (Table 6) towards the lower parts of the river as a consequence of the runoff of diverse minerals along its 12 km length.

CONCLUSIONS

The arboreal structure of the gallery forest of the Xaltatempa river is vertically represented by five strata: seedling stage, thicket stage, young timber stage, high pole stage, and timber stage. Meanwhile, horizontally, it is a heterogeneous multietaneous forest, differing in the middle section of the river, with heterogeneous and coetaneous forests of *Platanus mexicana* in timber stage.

The arboreal diversity of the gallery forest of the Xaltatempa river shows low specific richness, with only six species: *Alnus acuminata*, *Ligustrum lucidum*, *Parathesis serrulata*, *Pinus patula*, *Platanus mexicana*, and *Quercus rugosa*. This makes it little diverse, especially in the middle section of the river, where dominance, density, and frequency are higher for *Platanus mexicana*.

The water quality of the Xaltatempa river, measured through diverse chemical parameters, showed a tendency to higher concentrations of chlorides, sulfates, carbonates,

and sodium towards the lower part of the river as consequence of the runoff of these minerals, without diminishing water quality for consumption.

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