Soil organic carbon and particulate carbon in water in riparian systems under different land use
Carbono orgánico del suelo y carbono particulado en el agua en sistemas ribereños bajo diferentes usos del suelo

Eloísa A. Guerra-Hernández[1‡], Gerardo Cruz-Flores[2], and Jorge D. Etchevers-Barra[3]

[1] Doctorado en Geografía-UNAM. Calidad del Agua y Ecohidrología. [2] Laboratorio de Edafología y Nutrición Vegetal, UMIEZ. Facultad de Estudios Superiores Zaragoza, Universidad Nacional Autónoma de México. Batalla 5 de mayo esquina Fuerte de Loreto s/n. Col. Ejército de Oriente, Iztapalapa. 09230 CDMX, México.

‡ Corresponding author (eloisaaguerrah@gmail.com)

[3] Laboratorio de Fertilidad de Suelos. Colegio de Postgraduados, Campus Montecillo. Carretera México-Texcoco km 36.5, Montecillo. 56230 Texcoco, Estado de México, México.

SUMMARY

Overexploitation of hydric resources and lack knowledge of interactions between riparian vegetation, water and soil, generates loss of environmental services and ecological degradation in many mountainous riparian environments. In order to characterizing riparian-soils and non-riparian soils, soil organic carbon content and particulate carbon was evaluated as ecological degradation indicators and also degree of association between physical and chemical water properties with those of riparian soils. Twenty sites were selected in lotic systems between 1900-3900 m on slopes Western in Iztaccíhuatl-Popocatépetl National-Park and influence zone. Also variability soil organic carbon content was evaluated at 1 and 5 m from stream (riparian soils) and also at more than 5 m from river (non-riparian soils) in different types of land use. Results showed significant relationships between soil organic carbon, electrical conductivity, pH, total nitrogen and available phosphorus with water properties (temperature, pH, conductivity, nitrates, ammonia, total phosphorus, dissolved oxygen, biochemical oxygen demand and particulate organic carbon). An inverse relationship was observed between soil organic carbon content of with particulate organic carbon, nitrates and nitrites, conductivity and dissolved oxygen. No significant differences were found in riparian-soils organic carbon (1 and 5 m), but there were significant differences in non-riparian soils organic carbon. Both soil organic carbon and water organic carbon particulate contents showed significant differences with respect to land use. Organic carbon contents in preserved riparian soils were higher than 240 Mg SOC ha^{-1} but in riparian-soils of degraded sites almost fifty times smaller (5 Mg SOC ha^{-1}).

Index words: *natural protected area, mountainous lotic systems, temperate forests, riparian vascular plants, and riparian and no-riparian soils.*

RESUMEN

La sobreexplotación de recursos hídricos y desconocimiento de interacciones entre vegetación ribereña, agua y suelo, generan pérdidas en servicios ecosistémicos y degradación ecológica en ambientes ribereños de montaña. Además de caracterizar los suelos ribereños y no ribereños se evaluaron, contenidos de carbono orgánico del suelo (COS) y carbono orgánico particulado (COP) en agua, como indicadores de degradación ecológica y el grado de asociación entre propiedades físicas y químicas del agua con las de suelos ribereños. Se estudiaron veinte sitios en un intervalo altitudinal de 1900 a 3900 m en las laderas occidentales del Parque Nacional Iztaccíhuatl-Popocatépetl y zona de influencia. Se evaluó la variabilidad del contenido de carbono orgánico en suelos ribereños a distancias

Recommended citation:
Guerra-Hernández, E. A., Cruz-Flores, G., and Etchevers-Barra, J. D. (2021). Soil organic carbon and particulate carbon in water in riparian systems under different land use. *Terra Latinoamericana, 39*, 1-13. e1249. https://doi.org/10.28940/terra.v39i0.1249

Received: August 25, 2021. Accepted: December 12, 2021.
Article. Volume 39, December 2021.

de 1 y 5 m del cauce y a distancias mayores a 5 m del río para suelos no-ribereños en diferentes tipos de uso de suelo. Los resultados mostraron diferencias significativas entre carbono orgánico y conductividad eléctrica, pH, y nitrógeno total, así como el fósforo disponible en el suelo con algunas propiedades del agua (temperatura, pH, conductividad, nitratos, amoniaco, fósforo total, oxígeno disuelto, demanda bioquímica de oxígeno y COP). Se encontraron relaciones inversas entre el contenido de COS y el COP, nitratos y nitritos, conductividad y oxígeno disuelto en agua. Tanto el contenido de COP como el de COS mostraron diferencias significativas entre los diferentes usos del suelo. El COS en suelos ribereños a 1 y 5 m no presentaron diferencias significativas, pero las diferencias si fueron significativas entre suelos riparios y no riparios. Los contenidos de COS en suelos ribereños no deteriorados fueron superiores a 240 Mg COS ha^{-1}, y en suelos ribereños deteriorados fueron casi cincuenta veces menores (5 Mg COS ha^{-1}).

Palabras clave: *área natural protegida, bosque templado, plantas vasculares ribereñas, sistemas lóticos de montaña, suelos ribereños.*

INTRODUCTION

Many riparian ecosystems on the planet show severe degradation as result of human activities that eliminate vegetation, cause riparian soil erosion, and affect water quality and quantity (Waters, 1995), which has also been observed in other Areas. Natural Protected Areas (NPA), whose main function is the conservation of biodiversity and natural resources (CONANP, 2008), for this reason the preservation or restoration of riparian environments that preserve life in the ecosystem is essential.

Origin of streams in mountainous regions is attributed to melting of glaciers, orographic condensation of humid air masses and water retention in vegetation ecosystems receiving high precipitation (Legorreta, 2009).

Human activities in upper basin modify hydrographic network of riparian ecosystems, alter their ecological characteristics, cause floods, increase sediment transport, induce loss of biodiversity and decrease water and soil quality (NRC, 2002).

In Mexico, more than 60 national parks (NPs) offer scenic beauty and various ecosystem services depending on their type of vegetation and the quality of water and soil, in the latter the amount of organic carbon (SOC) is an indicator of productivity and its loss a threat of deterioration and threaten the conservation of biodiversity in the NPs (CONANP, 2008). Although Iztaccíhuatl-Popocatépetl National Park is part of a priority terrestrial region (PTR-107 Arriaga *et al*., 2000), there is no available information about forest soils characteristics and its organic carbon stocks.

Iztaccíhuatl-Popocatépetl National Park (IPNP), known for scenic beauty of two very important volcanoes in Mexico, is rich in ecosystems and endemic species (Challenger, 2003). Its forests supply oxygen and represent an important carbon sink in the vicinity of important urban centers such Mexico and Puebla cities. Recreational and scientific activities are continuously developed in this area due to its scenic beauty, its biological wealth and natural resources, as well as closely studying the processes and effects of the volcanic activity of Popocatépetl. The IPNP contains vegetation taxa that have resulted from speciation processes occurring during the hybridization of the Nearctic and Neotropical regions (Escalante, Rodríguez, and Morrone, 2005). Predominant vegetation types are those of high mountain pastures, pine and fir forests and agricultural crops, with a varied and abundant fauna (Villa and Cervantes, 2003). Dominant geological materials are andesite with pyroxene, microcrystalline vitric minerals and andesite-dacite of ancient volcanic emissions (Iztaccíhuatl) and andesite in Popocatépetl, with a young morphology (Macías, 2005). Conjugation of this material with climate, topography and vegetation has originated a soil mosaic dominating by associations of lithosols, regosols, and eutric andosols, among others (INEGI, 2009).

Riparian systems are essential for the health and sustainability of forests because they constitute a protective band of water quality due to their function of retention and filtration of sediments, nutrients and pesticides (Berka, Schreier, and Hall, 2001). Despite its high productivity, very little is known about the soil conditions in which riparian vegetation develops (Corbacho, Sánchez, and Costillo, 2003) and even less about association degree of the physical and chemical properties of soils have with the water properties in these riparian ecosystems (Pozo, González, Díez, Molinero, and Elósegui, 1997; Sepúlveda *et al*., 2009).

Research on the content of organic carbon in the soils of riparian ecosystems is important since carbon capture reduces atmospheric CO_2 and global warming is mitigated, it is an indicator of sustainability because its storage is the result of thousands of years of primary productivity; it positively influences the chemical and physical properties of the soil, favoring its conservation (Lal, 2004). Its loss due to different anthropic activities degrades the soil and endangers the conservation of biodiversity in the riparian systems of several national parks (Cruz and Etchevers, 2011).

In this research, an analysis was carried out of the relationship of the organic carbon of the riparian soil (SOC) with the particulate carbon and other physical and chemical properties of the water; compare the SOC of riparian soils with non-riparian soils, establish the degree of association of SOC with the total N and available P of the upper horizon of riparian soils and prepare a list of riparian vascular vegetation associated with the study sites at 3900 m (montane pastures and springs), between 3500 and 2400 m, intermediate forest areas (predominantly *Pinus* sp. and *Abies religiosa* (HBK) Schlecht. *et* Cham.) and zones of secondary vegetation and crops in forest vegetation limits (<2400 m), to conclude in riparian ecosystems adjacent to urban areas.

The SOC is expected to decrease as it descends altitude as an effect of soil degradation due to the change of vegetation and human activities that take place in the riparian zones, while the POC will have an inverse trend. On the other hand, the SOC of non-riparian soils may be higher because it is not subjected to continuous washing by the current of the river or stream, in addition, the amount of nitrogen and phosphorus in the soil will have a direct relationship with the SOC content. This research was carried out with the objective of estimating soil organic carbon content and water particulate carbon content as indicators of ecological degradation and also the degree of association of some physical and chemical properties of water with those of riparian soils under different land use.

MATERIALS AND METHODS

This research was carried out between February 2011 and February 2016 in permanent streams that form the Amecameca River and that originate west of the Iztaccíhuatl volcano to descend through the montane grass, coniferous forest and agricultural and livestock lands to reach areas urban areas in a descending altitudinal gradient from 3900 to 1900 m. Twenty sites were selected that corresponded to streams of riparian systems adjacent to montane grass, pine and fir forests, secondary vegetation, agricultural and urban areas.

In order to represent the greatest ecological variability of riparian and non-riparian environments, conserved and degraded by human activities, twenty sites were selected in the study area, making field trips and using topographic maps (1:50 000). At selected sites, altitude, geographic location, main exposure orientation and slope gradient were determined. INEGI's edaphological charts were reviewed to know the soil group of each site (INEGI, 2009), in addition to performing the aforementioned in situ and laboratory tests. To elaborate list of riparian vascular plants, botanic recollections were done in 25 × 1 m quadrants on both sides of river (50 m^2 total), recording microenvironmental conditions and main biological characteristics of species. The riparian plants were herborized for their determination with help of keys to plant taxonomy. The family, the genus or, where possible, the biological species were recorded. Taxonomic determination of specimens was made by comparing them with those deposited in collections of herbarium FES-ZA-UNAM, with those available on Internet and with those of Phanerogamic Flora of México Valley's (Rzedowski and Rzedowski, 2005).

At each study site, samples of riparian soils (RS) were taken on both sides of the stream, in the established quadrants. At 0 m, 12.5 m and 25 m along the quadrant, six soil samples were collected which were taken at distances of 1 and 5 m from the riverbank.

The samples were taken in a 0.3 × 0.3 m square and at a depth of 0 to -0.2 m with the help of a shovel, later they were placed in a bag, labeled, and stored in a cooler for transfer for laboratory treatment.

The difference between riparian soils and non-riparian forest soils was made with samples collected at random in nearby forests without direct influence of riparian environment, four to six edaphic samples were taken in quadrants of 50 × 20 m (distance 3), at depths of (0 to -0.2 m) and were processed in the same way as the riparian soil samples.

With the subsamples collected for each of distances (1 and 5 m) on both sides of river, composite samples were formed to determine percentages of moisture and porosity and the apparent and real densities (FAO, 2009). Subsequently, they were air-dried and sieved (2 mm mesh) to determine texture, pH in a 1: 2 ratios; in water and KCl (1N), electrical conductivity (1: 5 dilutions, at 25 °C); Total N (TN) including nitrates, available phosphorus (av-P; Bray-I), and soil organic matter percentage (SOM-Walkley and Black), % SOC was calculated based on the relation % SOM = % SOC × 1724 (SEMARNAT, 2002). The C/N rate from the soil was calculate with % SOC and TN percentage (Cruz and Etchevers, 2011).

The twenty study sites are shown in Figure 1. Twenty-five-meter transects, were marked in the streams and measured the hydrological variables as capacity (Q) and flow velocity (V) (Aparicio, 1994).

Water samples were taken to determine their physical and chemical characteristics with procedures APHA-AWWA-WPCF (1992) and Official Mexican Standards. In situ pH (NMX-AA-008-SCFI-2011)

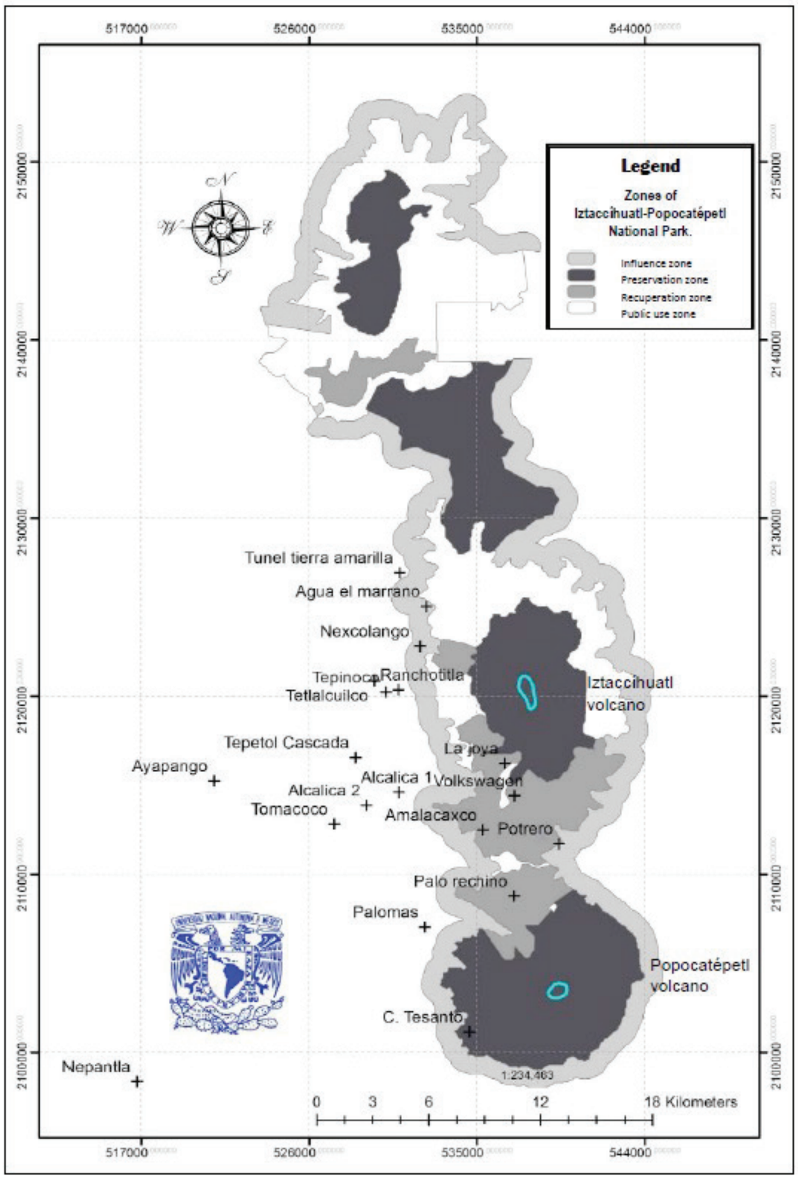

Figure 1. Map of sampling sites in Iztaccíhuatl-Popocatépetl National Park.

and electric conductivity (CE) (NMX-AA-093-SCFI-2000) were measured with a Combo-Hanna HI98129; dissolved oxygen (DO) with Winkler method (NMX-AA-012-SCFI-2001) and oximeter (YSI-55). In laboratory, were determined: BOD5 (NMX-AA-028-SCFI-2001); N-NO_3^- (phenoldisulfonic method), N-NH_4^+ (NMX-AA-099-SCFI-2006), total phosphorus and P-PO_4^{-3} (NMX-AA-029-SCFI-2001).

The particulate organic carbon content was obtained from the filtration of 250 to 500 mL of the composite water sample for each site, through GF-A glass fiber membranes (1.6 µm) and using acid digestion method of according to Strickland and Parsons (1992).

Statistical analysis. A Tukey test ($P \leq 0.05$) was used to differentiate the behavioral patterns between soil organic carbon percentage, with total nitrogen percentage, the C/N rate and available phosphorus (av-P) in riparian-soils and non-riparian soils (Pires, Imhoff, Giarola, and Tormena, 2001). Principal component analysis was performed to recognize the properties that explain the greater variability of riparian system and finally a canonical correlation analysis (CCA) as a tool to describe the relationship between soil organic carbon contents and other riparian-soils properties with the main water properties.

RESULTS AND DISCUSSION

Riparian vegetation observed on western exposure of the Iztaccíhuatl-Popocatépetl National Park in the studied gradient shows a list of 38 species, 34 genera and 22 families. In environments with an altitude above 3600 m where ecotones dominated by montane grassland and tall pines (*Pinus hartwegii*), we also observed some species of families: Fabaceae (Papilionaceae) as *Lupinus montanus* Kunt, and others of Poaceae families (*Muhlembergia* sp., *Muhlembergia macroura* (HBK), *Festuca* sp. Hitchc.) and family Cyperaceae (*Carex curviculmis* Reznicek). Individuals of family Adiantaceae were only found in low areas (> 2600 m) while the families Asteraceae and Marchantiaceae showed a cosmopolitan distribution from 1900 to 3850 m. Table 1 shows the species identified for each family.

Sánchez and López (2003) in their study, the vegetation of the northern Sierra Nevada and Cruz-Flores, Guerra, Valderrábano, and Campo (2020), in studies on soil quality indicators in temperate forests of the Volcanoes Biosphere Reserve, Mexico, recorded species of genera and families that coincide with those found in the riparian vegetation of this investigation; however, in both works, no distinction is made between riparian and non-riparian environments. The tree strata showed greater abundance and distribution of species in adjacent forests that develop at distances greater than 5 m from the river bed (trans-erosional forests) in areas with moderate to strong slope (10 to 35% slope) and from 1900 to 3500 m of altitude. The existence of *Pinus hartwegii* was only observed at altitudes above 3600 m and *Abies religiosa* from 2700 to 3500 m. Table 2 indicates the location, type of soil and the main tree species recorded in each locality.

The soil organic carbon (SOC) and total nitrogen (TN) percentages; and available phosphorus (Av-P) showed significant differences between riparian soils and non-riparian soils, however, pH and electrical conductivity did not show significant differences according to the Tukey Test, at a 95% confidence level.

The soils of preserved sites (deep and humid canyons) had highest organic carbon percentages, while those that presented a marked environmental deterioration, due to their easy access or the extractive or tourist activities to which they are subjected, registered the lowest SOC percentages. Similar results have been recently reported by Chavarin-Pineda *et al*. (2021), in research on soils quality of volcanic origin in Volcanoes Biosphere. Table 2 shows all the results of physical and chemical soil analyzes for each study site.

In hydrological results, flow and velocity current were lower in higher altitude sites, with clear water and a low concentration of dissolved and particulate nutrients and organic carbon.

The concentration of dissolved nutrients and suspended solids increased in the water as altitude decreased and anthropic activities increased. The average records of water and environment temperatures (9.3 and 12.9 °C) indicate that the localities are cold or temperate even in summer. The dissolved oxygen concentration was adequate for natural waters indicating that they had good and excellent quality, however there is a strong degradation of water quality that is more marked in sites with agricultural and urban use, in Ayapango site the system presented conditions anoxic substances associated with a high concentration of particulate organic carbon, and of nitrates, ammonium and total phosphorus, which makes the discharge of organic waste to lotic system evident (Guerra and Cruz, 2017).

Table 1. Riparian vegetation identified in adjacent strip (0 to 5 m) to the streams studied.

Family	Scientific name
Adiantaceae	*Adiantum andicola* Liebm. Mexic. Berng
Aspleniaceae	*Asplenium monanthes* L.
	Polystichum sp.
Asteraceae	*Cirsium ehrenbergii* Sch. BIP.
	Eupatorium glabratum H.B.K.
	Eupatorium pazcuarense H.B.K.
	Eupatorium rivale Greenm
	Eupatorium schaffneri Sch. Bip.
	Gnaphalium roseum H.B.K.
	Gnaphalium semiaplexicaule DC.
	Senecio angulifolius DC.
	Senecio barba-johannis DC.
	Senecio cinerarioides A.B.K.
	Senecio multidentalis Sch. Bip. Ex. Hemsl.
	Senecio orizabencis Sch. Bip. Ex. Hemsl.
	Senecio sp.
	Tagetes erecta L.
	Tagetes foetidisima DC.
	Tithonia tubiformis (Jacq) Cass.
Buddleiaceae	*Buddleia cordata* H.B.K.
Caryophyllaceae	*Stellaria cuspidata* Willd.
	Spergularia mexicana Hemsl.
Cyperaceae	*Carex curviculmis* Reznicek
Convoluvlaceae	*Dichondra sericea* Sw.
Dryopteridaceae	*Polystichum rachichlaena* Fée. Mém. foug
	Dryopteris cinnamonea (Cav.) C. Chr.
	Pleopeltis polylepis (Roem. Ex Kze.) T. Moore
Ericaceae	*Arbutus* sp.
Fabaceae	*Lupinus montanus* (Kunt)
Lamiaceae	*Stachys rotundifolia* Sexxé & Moc.
	Salvia elegans Vahl.
	Salvia polystachya Ort.
Malvacaceae	*Sida haenkeana* Presl.

Table 1 (continuation). Riparian vegetation identified in adjacent strip (0 to 5 m) to the streams studied.

Family	Scientific name
Marchantiaceae	*Marchantia* sp.
Onagraceae	*Fuchsia microphylla* H.B.K.
	Lopezia racemosa Cav.
Poaceae	*Muhlembergia* sp.
	Muhlembergia macroura H.B.K.
	Festuca sp.
Polipodiaceae	*Polypodium* sp.
Rosaceae	*Alchemilla pinnata* Ruíz& Pavón
	Potentilla sp.
Saliceaceae	*Salix paradoxa* H.B.K.
Saxifragaceae	*Heuchera orizabensis* Helms.
Scrophulariaceae	*Penstemon gentianoides* H.B.K.
Solanaceae	*Lycianthes moziniana* (Dunal) Bitter.
Thelypteridaceae	*Thelypteris* sp.

In general, low alkalinity values and low concentration of N-NO_3^-, N-NO_2^- and total phosphorus were observed, which are indicative of low water productivity, except in the sites Ayapango and Nepantla where the streams receive water discharges for domestic use, which coincides with that mentioned by Hernández *et al*. (2019) and Breton, Sanchez, Juárez, and Vera (2019). Table 3 shows that the water parameters had acceptable levels of natural water quality according to the limits established in NOM-001-SEMARNAT-1996 (SEMARNAT, 1997).

Regarding the soil, pH values showed to be more acidic at higher altitudes, which should be attributed to contributions of organic matter provided by pine forest an fir forest that favor soil acidity. In relation to riparian-soils properties, it was found that range of organic carbon contents was 5 to 300 Mg C ha^{-1} with averages between 62.5 and 63.6 Mg C ha^{-1} for the distances of 1 and 5 m from the stream. On the other hand, with a slightly higher difference of 15 Mg C ha^{-1}, in non-riparian soils, soil organic carbon content average was higher than 80 Mg C ha^{-1}, which should be attributed to the riverbed temporal variation of flow and speed of water in the stream drags and washes the edges of riparian soil and reduces the organic carbon content of system. Table 4 shows that although soil carbon contents average are similar in riparian-soils at distances of 1 and 5 m, the most frequent values (statistical fashion) in soils at a distance of 5 m from the beds rivers were 118 Mg C ha^{-1} of SOC and in the soils at a distance of 1 m the most frequent values were 35.9 Mg C ha^{-1}.

The organic carbon and TN content in both riparian and non-riparian soils increased with altitude, although carbon content in riparian-soils (63.5 Mg C ha^{-1}) was significantly lower ($P \leq 0.05$) than in non-riparian soils (80.3 Mg C ha^{-1}). Compared with other published works, the organic carbon contents shown in Tables 3 and 4 are important because of their similarity to Trans-Mexican volcanic belt soils (Balbontín, Cruz, Paz, and Etchevers, 2009). The C / N rate had wide ranges from 11 to 132 in soils whose distance to the stream is 1 m. The C / N rate decreases to values between 10 and 112 in soils distant up to 5 m from the riverbed, while, in non-riparian soils the C / N rate was observed between 5.0 and 62 (Table 4). The implications of these variations are related to high moisture content in soils close to stream water, which decreases the mineralization rates of nitrogen compounds but also greater carbon retention in these soils. (Table 4).

Table 2. Study sites, type and soil properties (0-0.2 m) and representative tree species.

Site Altitude	Cond-S	pH-S	SOC	TN	Av-P	Soil†	Representative Tree species
	dS m^{-1}		- - - %	- - -	mg kg^{-1}		
Volkswagen 3883 m	0.06	5.6	4.9	0.14	42.7	Umbric Andosol + Euthric Cambisol	*Pinus hartwegii*
La joya 3832	0.10	5.2	5.4	0.27	24.9	Euthric Regosol + Lithosol	*Pinus hartwegii*
Palo rechino 3642	5.39	3	3.2	21.22	94.5	Regosol + Lithosol	*Pinus hartwegii, Abies religiosa*
Amalacaxco 3651 m	0.07	5.1	6.9	0.29	23.8	Vitric andosol + Humic andosol + Molic andosol	*Pinus hartwegii*
Agua el Marrano 3522 m	0.06	4.9	7.9	0.29	89.8	Taptovítric-Regosol	*Pinus patula*
Nexcolango 3489 m	0.10	5.9	5.2	0.25	57.8	Humic andosol + Euthric cambisol	*Abies religiosa, Pinus pseudostrobus*
Potrero 3347 m	0.09	5.7	3.1	0.12	71.2	Vitric andosol + Humic andosol	*Abies religiosa, Pinus patula*
Tunel tierra amarilla 3311 m	0.06	4.5	7.2	0.34	116.2	Molic andosol + Humic andosol	*Pinus teocote, P. patula*
Ranchotitla 3280 m	0.30	5.1	4.5	0.58	0.22	Euthric cambisol Molic andosol	*Abies religiosa*
C. Tesanto 3116 m	0.06	6.2	2.2	0.10	30.2	Vitric andosol +Regosol	*Pinus hartwegii*
Tepinoco 3034 m	0.36	5.2	3.7	0.34	0.3	Euthric cambisol + Molic andosol	*Abies religiosa*
Palomas 2949 m	0.11	5.8	2.7	0.1	41.6	Humic andosol + Ochric andosol + Lithosols	*Abies religiosa, Cupressus lusitânica*
Alcalica 1 3200 m	0.16	5.8	6.9	0.24	114.2	Euthric cambisol + Ochric andosol	*Abies religiosa, Pinus pseudostrobus*
Tepetol Cascada 2780 m	0.08	5.9	4.4	0.16	185.7	Humic andosol + Ochric andosol + Lithosols	*Pinus montezumae, Abies religiosa*
Tetlalcuilco 3221 m	0.09	5.9	4.3	0.18	78.8	Euthric regosol + Lithosols + Humic andosol	*Abies religiosa*
Alcalica 2 3020 m	0.07	5.8	4.5	0.28	0.1	Ochric andosol Euthric regosol	*Abies religiosa, Pinus pseudostrobus*
Tomacoco 2573 m	0.16	6.2	4.2	0.27	92.6	Dystric fluvisol + Humic cambisol	*Pinus pseudostrobus*
Ayapango 2433 m	0.24	7.6	3.7	0.13	154.8	Humic andosol + Andic feozem	*Buddleia cordata. Alnus* sp.
Nepantla 1987 m	0.17	7.4	3.5	0.09	108.9	Haplic feozem + Humic fluvisol	*Alnus* sp., secundary vegetation
Axochiapa 2805 m	0.03	6.1	5.9	0.53	0.3	Euthric cambisol + Molic andosol	*Quercus ilex*

Cond-S = electric conductivity soil; pH-S = pH soil; SOC = soil organic carbon; TN = total nitrogen; Av-P = available phosphorus. Slope interval in studied sites was between 10 and 35% with an average of 20%. † https://www.inegi.org.mx/temas/edafologia/

Table 3. Selected water properties in each sampling site.

Sampling Sites	T	pH	Cond.	O.D.	POC	N-NO_3^-	N-NH_4^+	P-tot.	Flow
	°C		µs	- - - - - - - - - - - -	mg L^{-1}	- - - - - - - - - - - -			m^3 seg^{-1}
Volkswagen	8.7	6.1	38	5.9	-	0.06	0.05	0.20	0.01
La joya	11.3	6.6	79	5	500	0.08	0.05	0.46	0.02
Palo rechino	38.3	5.2	52	11.6	50	0.14	0.15	0.04	1.73
Amalacaxco	5.7	7.2	46	5.2	269	0.07	0.19	0.10	0.01
Agua el marrano	11.0	6.1	34	5.7	-	0.06	0.01	0.24	0.02
Nexcolango	7.0	5.9	141	5.9	-	0.04	0.10	0.53	0.13
Túnel tierra amarilla	11.1	5.9	51	4.6	212	0.15	0.04	0.17	0.01
Ranchotitla	9.6	7.2	67	11.9	132	0.04	0.02	0.16	0.01
Potrero	8.7	6.9	46	5.5	528	0.06	0.08	0.19	0.04
C. Tesanto	8.0	6.8	52	6	500	0.12	0.05	0.23	0.01
Tepinoco	8.3	7.8	67	10.3	88	0.12	0.05	0.19	0.01
Palomas	11.1	7.2	87	5.5	629	0.08	0.08	0.29	0.03
Alcalica 1	9.5	6.9	66	5.9	394	0.09	0.16	0.20	0.29
Tepetol Cascada	6.0	7.7	204	7.7	1067	0.07	0.14	0.24	0.12
Axochiapa	9.3	7.6	120	10.1	108	0.12	0.00	0.28	0.03
Tetlalcuilco	11.5	6.9	115	5.4	70	0.06	0.03	0.19	0.04
Alcalica 2	8.6	7.4	64	12.4	60	0.07	0.04	0.23	0.18
Tomacoco	11.0	6.8	68	9.9	173	0.08	0.06	0.17	0.05
Ayapango	15.0	7.1	727	0	1067	0.55	0.9	5.03	0.20
Nepantla	17.0	8.4	909	4.7	1038	0.42	0.68	6.36	0.25

Cond = electric conductivity; O.D. = dissolved oxygen; POC = particulate organic carbon; N-NO_3^- = nitrate; N-NH_4^- = ammonium; P-tot = phosphorus total.

Tukey's tests showed that in riparian-soils at 1 m distance from stream, values of C/N rate were significantly different ($P \leq 0.05$) from values observed in soils located 5 m away from the stream and from C/N values for non-riparian soils. Soils with a C/N rate of 11, 10 or 5 present an adequate rate of return of nutrients while, with C/N values of 132, 112 or 62, there is low mineralization of soil organic matter due to its low concentration of soil organic matter due to its low concentration of nitrogen (Devi and Yadava, 2006).

Regarding Available-P, although riparian-soils had higher available phosphorus content than non-riparian soils, no significant differences ($P \leq 0.05$) were found between riparian-soils at both distances (1 and 5 m) and with non-Riparian (Table 4).

Considering the integrity of water-edaphic system in riparian environments, and principal components analysis was carried out that included the water properties and soil together with flow rate, flow velocity and altitude of sites in order to identify which of properties have a greater influence on the behavior of riparian systems studied.

The principal component analysis showed that four components explain the system variability up to 75.22%: The first principal component is defined by variables that indicate trend towards system eutrophication and water electrical conductivity, nitrates and ammonia, COD, soil pH and land use. The second component is an indicator of oxygenation and oxidative processes of system with pH water, dissolved oxygen and BOD5 (Figure 2).

Table 4. Effect of riverbed distance on SOC content and on other riparian-soils properties.

Distance from the riverbed		SOC	TN	C/N	Available-P Bray-I
		- - - - - - Mg ha^{-1}	- - - - - -		mg kg^{-1}
1 m	Interval	5.9-242	0.2-9.6	11-133	0.6-56
	Mean	63.6 b	2.4 b	34.1 a	17.6 b
	Mode	35.9	1.2	34.1	13.1
5 m	Interval	5-241	0.4-6.7	10-112	0.2-48.4
	Mean	62.5 b	2.3 b	30.4 b	18.8 b
	Mode	119	2.2	13.3	37.5
>5 m	Interval	12.2-172	0.5-8.8	5-63	1.2-63
	Mean	80.3 a	3.6 a	26.4 b	25.2 a
	Mode	105	4.1	25.8	53.9

SOC = soil organic carbon; TN = total nitrogen; C/N = carbon-nitrogen ratio; Av-P = available phosphorus. Averages with different letters between columns were significantly different (Tukey, $P < 0.05$).

Third principal component, was defined by relation of carbon and nitrogen percentages in soils and fourth principal component, identifies the inverse relation between water electrical conductivity and the BOD5 (Figure 3). Research in riparian systems reported that parameters such as water pH, dissolved oxygen and BOD5, among others such as particulate organic carbon and water alkalinity, were indicated as robust variables to define water quality in streams of the Volcanoes Biosphere Reserve, Mexico (Guerra and Cruz, 2017).

After determining the principal components, a canonical correlation analysis was performed between five edaphic variables and the water variables. They also highlight five significant canonical correlations that show the importance of conductivity, COD and total phosphorus in the water and of conditions of system that also show the relationships of available phosphorus in the soil with its pH values.

The land use was first principal components, which was used to compare soil organic carbon and particulate organic carbon applying the Kruskal-Wallis test and the Mood's for medians comparison.

The carbon percentage in different land uses, showed significant differences (99% confidence, $P \leq 0.01$).

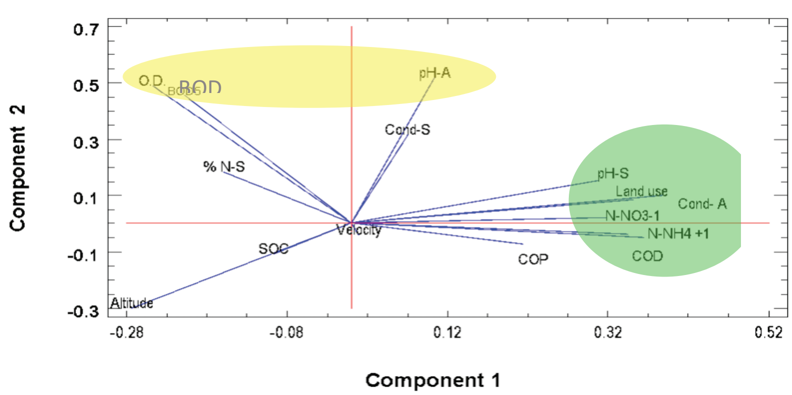

Figure 2. Principal components 1 and 2, extracted from all hydric and soil properties.

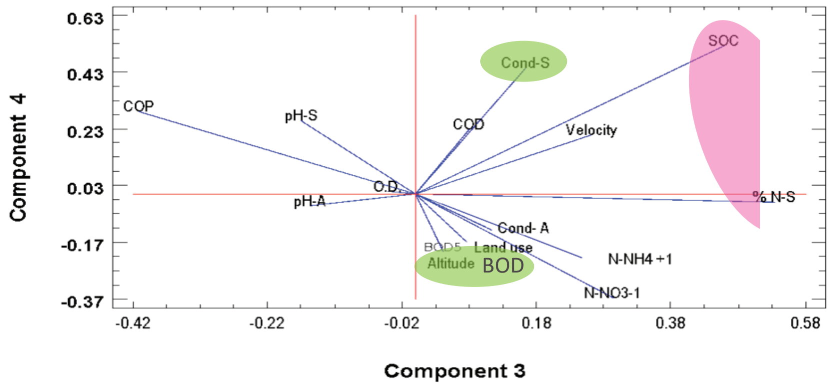

Figure 3. Principal component 3 and 4, extracted from all hydric and edaphic properties.

The higher carbon contents were recorder in forest respect to deteriorate zones. The carbon percentage of grassland is high, decreases in agricultural soils, and has its lowest content in urbanized areas.

The behavior of particulate organic carbon contents (POC) differs from soil organic carbon percentage. It was noted that the POC content increases significantly (99% confidence $P \leq 0.01$) in the urban area, decreases slightly in agricultural areas and has the lowest content in forest areas and in the area of forest-grassland.

CONCLUSIONS

The integrated analysis of behavior of the principal water and soil variables in mountainous riparian environments is novel and very useful to identify those that have the greatest interaction in the system and their ecological conditions.

Organic carbon contents of riparian soils increased with altitude and in sites with greater biodiversity in species and families (Asteraceae, Rosaceae and Caryophylaceae). Although there were no significant differences between the riparian soils located one and five m from the stream, there was a tendency to increase the soil carbon content at distances of 5 m. Significant differences were observed in soil organic carbon content between riparian soils and non-riparian soils.

Lowest soil organic carbon content (<5 Mg C ha^{-1} in riparian-soils was found in sites of easy access (ecotourism sites, road crossings or passage of vehicles), alongside water storage boxes, pastures for livestock, etc., while the highest levels (≥240 mg C ha^{-1} were observed in deep gullies with steep slopes and abundant vegetation.

Increases in N-NO_3^- and N-NH_4^+ in stream water were related to losses of soil organic carbon, total nitrogen and available phosphorus, which were the variables positively associated with water properties because the incorporation of soil organic matter into the water influences the concentrations of N-NH_4^+ and N-NO_3^-.

Among physical and chemical water properties that are positively associated with soil variables, statistical analysis showed that water electrical conductivity increases when it receives mineral salts provided by soil, due to turbulent currents and accelerated particle release which derives from riparian-soils erosion and land use change and inversely with the chemical oxygen demand and the biochemical oxygen demand of water.

Anthropogenic activities such as agriculture, livestock, recreation, or human settlements induces decreases in soil organic carbon contents that degrade the riparian ecosystem, decrease vegetation productivity, and increase compaction and soil erosion.

Results show that soil organic carbon is a good soil degradation indicator and soil quality indicator in riparian ecosystems. While particulate organic carbon in water, shows that the entrainment or incorporation of materials in the river that increase the amount of suspended solids occurs with greater intensity in deteriorated riparian environments and in soils of urbanized areas.

CONSENT TO PUBLICATION

Not applicable.

DATA AVAILABILITY

Data sets used or analyzed during the current study are property of the Research Line Soil-Water-Plant Relations in Watershed Management of Zaragoza Multidisciplinary Experimental Research Unit and are available from corresponding author upon reasonable request.

CONFLICT OF INTERESTS

Authors declare that they have no conflict of interest.

FINANCIAL SUPPORT

It had the financing and support of projects PAPIT-IN22840, DGAPA-UNAM; PAPIME-PE 215016, DGAPA-UNAM and support from Bachelor's Degree in Biology and Division of Postgraduate Studies and Research of the Faculty of Higher Studies Zaragoza, UNAM.

AUTHORS' CONTRIBUTION

Conceptualization: E.A.G.H. and G.C.F. Methodology: E.A.G.H. and G.C.F. Software: E.A.G.H. and G.C.F. Validation: E.A.G.H. and G.C.F. Research: E.A.G.H. and G.C.F. Methodology: E.G.F. and G.C.F. Writing, preparation of original draft: E.A.G.H. and G.C.F. Visualization: E.A.G.H. and G.C.F. Supervision: E.A.G.H., G.C.F. and J.E.B. Project administration: E.A.G.H. and G.C.F. Acquisition of funds: E.A.G.H. and G.C.F.

ACKNOWLEDGEMENTS

To PhD Geography Program, UNAM, for supporting the project implementation and Multidisciplinary Unit for Experimental Research, FES Zaragoza-UNAM for use of laboratories: 1) Edaphology and Plant Nutrition, 2) Water Quality and Eco-Hydrology. We thank to these laboratories staff for your extensive contribution in field phase and to students of the Social Service programs and Formative Research Laboratories of Bachelor´s Biology.

REFERENCES

Aparicio M., F. J. (1994). *Fundamentos de hidrología de superficie*. México, D. F: Limusa, Grupo Noriega Editores.

APHA-AWWA-WPCF (American Public Health Association-American Water Works Association-Water Pollution Control Federation). (1992). *Métodos normalizados para el análisis de aguas potables y residuales*. Madrid, España: Díaz de Santos.

Arriaga, L., Espinoza, J. M., Aguilar, C., Martínez, E., Gómez, L., & Loa, E. (2000). *Regiones terrestres prioritarias de México. Comisión Nacional para el Conocimiento y uso de la Biodiversidad, México*. Accessed January 31, 2016, from http://www.conabio.gob.mx/conocimiento/regionalizacion/doctos/terrestres.html

Balbontín, C., Cruz, C. O., Paz, F., & Etchevers, J. D. (2009). Soil carbon sequestration in different ecoregions of México. In R. Lal, & R. F. Follett. *Soil carbon sequestration and the greenhouse effect* (pp. 71-96). SSA Special Publication 57. Madison, WI, USA: ASA-CSSA-SSSA. https://doi.org/10.2136/sssaspecpub57.2ed.c5

Berka, C., Schreier, H., & Hall, K. (2001). Linking water quality with agricultural intensification in a rural watershed. *Water, Air, and Soil Pollution, 127*, 389-401. https://doi.org/10.1023/A:1005233005364

Breton-Deval, L., Sanchez-Flores, A., Juárez, K., & Vera-Estrella, R. (2019). Integrative study of microbial community dynamics and water quality along The Apatlaco River. *Environmental Pollution, 255*(part 1), 113158. https://doi.org/10.1016/j.envpol.2019.113158

Challenger, A. (2003). *Conceptos generales acerca de los ecosistemas templados de montaña de México su estado de conservación*. Accessed July 20, 2015, from http://www2.inecc.gob.mx/publicaciones2/libros/395/challenger.html

Chavarin-Pineda, Y., Reynoso, E. C., Torres, E., Cruz-Flores, G., Tenorio-Arvide, M. G., Linares-Fleites, G., & Valera-Pérez, M. A. (2021). Soil quality in volcanic soils in a forest biosphere reserve in Mexico. *Soil and Water Research, 16*, 217-227. https://doi.org/10.17221/108/2020-SWR

CONANP (Comisión Nacional de Áreas Naturales Protegidas). (2008). *Reglamento Interno del Consejo Nacional de Áreas Naturales Protegidas*. Accessed December 01, 2015, from https://www.gob.mx/conanp/documentos/reglamento-interno- del-consejo-nacional-de-areas-naturales-protegidas.

Corbacho, C., Sánchez, J. M., & Costillo, E. (2003). Patterns of structural complexity and human disturbance of riparian vegetation in agriculture landscapes of a Mediterranean area. *Agriculture Ecosystems & Environment, 95*(2-3), 495-507. https://doi.org/10.1016/S0167-8809(02)00218-9

Cruz-Flores, G., & Etchevers-Barra, J. D. (2011). Contenido de carbono orgánico de suelos someros en pinares y abetales de áreas protegidas de México. *Agrociencia, 45*(8), 849-862.

Cruz-Flores, G., Guerra-Hernández, E. A., Valderrábano-Gómez, J. M., & Campo-Alves, J. (2020). Indicadores de calidad de suelos en bosques templados de la Reserva de la Biosfera los Volcanes, México. *Terra Latinoamericana, 38*(4), 781-793. https://doi.org/10.28940/terra.v38i4.421

Devi, N. B., & Yadava, P. S. (2006). Seasonal dynamics in soil microbial biomass C, N and P in a mixed-oak forest ecosystem of Manipur, North-east India. *Applied Soil Ecology, 31*(3), 220-222. https://doi.org/10.1016/j.apsoil.2005.05.005

Escalante, T., Rodríguez, G., & Morrone, J. J. (2005). Las provincias biogeográficas del componente mexicano de montaña desde la perspectiva de los mamíferos continentales. *Revista Mexicana de Biodiversidad, 76*(2), 199-205.

FAO (Organización de las Naciones Unidas para la Agricultura y la Alimentación). (2009). *Guía para la descripción de perfiles de suelo*. Rome, Italy: FAO.

Guerra-Hernández, E. A., & Cruz-Flores, G. (2017). Uso de suelo y calidad del agua. Caso de estudio: Reserva de la biosfera Los Volcanes. *Revista Latinoamericana el Ambiente y las Ciencias, 8*(18), 41-67.

Hernández-Ramírez, A. G., Martínez-Tavera., E., Rodríguez-Espinosa, P. F., Mendoza-Pérez, J. A., Tabla-Hernández, J., Escobedo-Urías, D. C., ... & Sujitha, S. B. (2019). Detection, provenance and associated environmental risks of water quality pollutants during anomaly events in River Atoyac, Central Mexico: A real-time monitoring approach. *Science of the Total Environment, 669*, 1019-1032. https://doi.org/10.1016/j.scitotenv.2019.03.138

INEGI (Instituto Nacional de Estadística y Geografía). (2009). *Edafología. Principales suelos en México*. Accessed September 15, 2021, from https://www.inegi.org.mx/temas/edafologia/

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma, 123*(1-2), 1-22. https://doi.org/10.1016/j.geoderma.2004.01.032

Legorreta, J. (2009). Ríos, lagos y manantiales del Valle de México. México, D. F.: SEDEMA-UAM.

Macías, J. L. (2005). Geología e historia eruptiva de algunos de los grandes volcanes activos de México. *Boletín de la Sociedad Geológica Mexicana, 57*(3), 379-424.

NMX-AA-093-SCFI-2000. (2000). Análisis de agua - determinación de la conductividad electrolítica - método de prueba. (Cancela a la NMX-AA-093-1984). Secretaría de Economía. *Diario Oficial de la Federación*. D. F.: SEGOB.

NMX-AA-012-SCFI-2001. (2001). Análisis de agua - determinación de oxígeno disuelto en aguas naturales, residuales y residuales tratadas - método de prueba (Cancela a la NMX-AA-012-1980). Secretaría de Economía. *Diario Oficial de la Federación*. D. F.: SEGOB.

NMX-AA-028-SCFI-2001. (2001). Análisis de agua - determinación de la demanda bioquímica de oxígeno en aguas naturales, residuales (DBO_5) y residuales tratadas - método de prueba (Cancela a la NMX-AA-028-1981). Secretaría de Economía. *Diario Oficial de la Federación*. D. F.: SEGOB.

NMX-AA-029-SCFI-2001. (2001). Análisis de aguas - determinación de fósforo total en aguas naturales, residuales y residuales tratadas - método de prueba (Cancela a la NMX-AA-029-1981). *Diario Oficial de la Federación*. D. F.: SEGOB.

NMX-AA-099-SCFI-2006. (2006). Análisis de agua – medición de nitrógeno de nitritos en aguas naturales, residuales, residuales tratadas y marinas – método de prueba (Cancela a la NMX-AA-099-1987). *Diario Oficial de la Federación*. D. F.: SEGOB.

NMX-AA-008-SCFI-2011. (2011). Análisis de agua - determinación del ph - método de prueba- (Cancela a la NMX-AA-008-SCFI-2000). Secretaría de Economía. *Diario Oficial de la Federación*. D. F.: SEGOB.

NRC (National Research Council). (2002). Riparian areas: functions and strategies for management. Washington, D.C., USA: National Academies Press.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). (1997). Norma Oficial Mexicana NOM-001-SEMARNAT-1996. Que establece los límites máximos permisibles de contaminantes en las descargas de aguas residuales en aguas y bienes nacionales. *Diario Oficial de la Federación*. D. F.: SEGOB.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). (2002). Norma Oficial Mexicana NOM-021-SEMARNAT-2000 antes NOM-021-RECNAT-2000. Que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudio, muestreo y análisis. *Diario Oficial de la Federación*. D. F.: SEGOB.

Pires da Silva, A., Imhoff, S., Giarola, N. F. B., & Tormena, C. A. (2001). Análisis multivariado y univariado en la discriminación de sistemas de uso de suelos del Centro de Santa Fe. *Edafología, 8*, 21-34.

Pozo, J., González, E., Díez, J. R., Molinero, J., & Elósegui, A. (1997). Inputs of particulate organic matter to streams with different riparian vegetation. *Journal of the North American Benthological Society, 16*(3), 602-611. https://doi.org/10.2307/1468147

Rzedowski, G. C. de, & Rzedowski, J. (2005). *Flora fanerogámica del Valle de México* (2nd. ed.). Pátzcuaro, Michoacán, México: Instituto de Ecología, A.C. y Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Sánchez-González, A., & López-Mata, L. (2003). Clasificación y ordenación de la vegetación del norte de la Sierra Nevada, a lo largo de un gradiente altitudinal. *Anales del Instituto de Biología (Serie Botánica), 74*(1), 43-71.

Sepúlveda-Lozada, A., Geissen, V., Ochoa-Gaona, S., Jarquín-Sánchez, A., Hernández de la Cruz, S., Capetillo, E., & Zamora-Cornelio, L. F. (2009). Influencia de tres tipos de vegetación ribereña en el control de la erosión fluvial en Pantanos de Centla, México. *Revista de Biología Tropical, 57*(4), 1153-1163. https://doi.org/10.15517/RBT.V57I4.5453

Strickland, J. D. H., & Parsons, T. R. (1972). *A practical handbook of seawater analysis* (2nd. ed.). Ottawa, Canada: The Alger Press.

Villa R., B., & Cervantes, F .A. (2003). *Los mamíferos de México*. México, D. F.: Grupo Editorial Iberoamérica.

Waters, T. F. (1995). *Sediments in streams. Sources, biological effects, and control*. Monograph 7. Bethesda, MD, USA: American Fisheries Society.