DOI : [http://doi.org/10.22438/jeb/38/6\(SI\)/04](http://doi.org/10.22438/jeb/38/6(SI)/04)

JEB™

ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Annual phytoplankton dynamics in La Antigua River, Mexico

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Key words

Diatoms
La Antigua River
Phytoplankton
Tropical rivers

Publication Info

Paper received : 20.07.2016
Revised received : 21.04.2017
Re-revised received : 19.05.2017
Accepted : 06.06.2017

Abstract

Aim: To contribute to the knowledge of rivers in Mexico, we studied the phytoplankton abundance and diversity over a year in La Antigua River, east Mexico.

Methodology: Monthly sampling was performed for one year (March 2013 to February 2014), at 5 stations. Physicochemical parameters and chlorophyll-a were analyzed. A diagram of Holston-Tukey was performed to identify the dominant, constant, temporary and rare species. Detrended Correspondence Analysis was applied to find possible links between species and environmental variables. Shannon-Wiener index was calculated.

Results: Mean water temperature was 26°C and depth was 1.7 m, dissolved oxygen was 8.9 mg l⁻¹, pH was 7.8, turbidity value was 10.6 NTU, conductivity was 488 µS cm⁻¹, SRP and nitrate were 2.6 µg l⁻¹ PO₄³⁻-P and 0.6 mg l⁻¹ NO₃-N, chlorophyll-a was 5 µg l⁻¹. About 200 taxa of microalgae were recorded. Diatoms were dominated. Chlorophyceae were rich in species. Cyanoprokaryota ranked third in species richness, Euglenophyceae, Dinophyceae, Cryptophyceae and Crysohyceae had a lower richness.

Interpretation: Stations 2 and 3 had the highest contamination by wastewater discharges of the population of La Antigua. Stations 4 and 5 were separated due to increases in salinity. These stations are the closest to the sea. Station 1 is likely to be cleaner and less salty.

Introduction

In Mexico, the study of riverine phycoflora has focused mainly on benthic algae, since these are more common in the presence of high currents. Studies on rivers date back to 1980s (Montejano *et al.*, 2000; Valadez *et al.*, 1996). The phycoflora in the central part of Mexico is constituted by a community indicative of clean waters. The most representative genera are *Cladophora*, *Spirogyra*, *Zygnema*, *Rhizoclonium*, *Oedogonium*, *Chara*, *Nitella*, *Vaucheria*, *Compsopogon*, *Hildenbrandia*, *Audouinella*, *Batrachospermum* (Carmona and Necchi 2001; Cartajena and Carmona, 2009), which serve as substrate to benthic diatoms and cyanoprokaryota (e.g. *Chamaesiphon*, *Phormidium*, *Blennothrix*, *Schizothrix*, *Homoeothrix*, *Komvophoron*, *Microcoleus*, *Leibleinia*, *Heteroleibleinia* and *Xenotholus*) (Montejano *et al.*, 2000; Montejano *et al.*, 2000). Central Mexican rivers (at high altitude), where the climate is colder, are characterized by a temperate climate phycoflora, such as the rivers of North America and Europe (Ramírez *et al.*, 2001, 2007).

Studies of phytoplankton in these environments are scarce. However, in large rivers, where flow velocity decreases, a true potamoplanktonic community constituted by phytoplankton and zooplankton is present, as reported in Moreno-Ruiz *et al.* (2008), where 298 species at Tehuantepec river (Mexico), were found, with a dominance of diatoms (42%), followed by Chlorophyceae and cyanoprokaryota (29% and 18%, respectively).

To contribute to knowledge of these water systems, we conducted an annual sampling effort in La Antigua, a shallow, wide river located in eastern Mexico. The diversity of aquatic organisms (flora and fauna) as well as physicochemical characteristics of water in this the basin have been little studied (CONABIO, 2000). This contribution describes temporal and spatial variations of main phytoplankton species that characterize this ecosystem and its relationship with the main environmental physicochemical variables.

Study area : La Antigua River arises on the eastern slope of the Sierra Madre Oriental (Fig. 1). It has a catchment area of 2,827 km² (0 to 3,000 m a.s.l.), with an average surface runoff of 2139 million m³ year⁻¹ and flows runs along for 139 km into the Gulf of Mexico. The river carries agrochemical pollution, domestic and industrial wastes and with deforestation at the top and bottom of the basin; in the middle of the basin there are cloud forests (CONAGUA, 2011).

The climate of the area is mainly warm (18-26°C), sub-humid with heavy and moderate rains from July to September and November to March, respectively (500 to 2500 mm) and a dry and hot season for the remaining months (Williams-Linera, 2007). La Antigua river basin is a High Biodiversity Area and Hydrological Priority (CONABIO, 2000).

Materials and Methods

Monthly sampling was performed for one year (March 2013 to February 2014), at 5 stations (19° 19' 15.9" to 19° 19' 55.7" N and 96° 19' 26.5 to 96° 19' 46.6" W). In this study, we analyzed: depth (sounding line), water temperature, conductivity (K25), dissolved oxygen (YSI 55), pH (Conductronic potentiometer), soluble reactive phosphorus (SRP), nitrates (YSI 9500 photometer), turbidity and chlorophyll-a (Turner 10-AU fluorometer). For phytoplankton analysis, 500 ml of sample was fixed with lugol and abundance count was done using an inverted light microscope (Carl Zeiss-D) with 10 ml sedimentation chambers following the Utermöhl method (APHA, 1995). The phytoplankton identification was done, as far as possible, to species level using standard literature (e.g. Krammer and Lange-Bertalot, 1986, 1991a,b; Comas, 1996; Komárek and Anagnostidis, 1999; Komárek, 2003; Komárek and Anagnostidis, 2005).

For diatoms identification, frustules were cleaned using acid digestion (Battarbee, 1986). Once free of organic material, the frustules were mounted in resin NAPHRAX for observation under a light microscope with phase contrast (Zeiss). Frustules were also mounted on aluminum cylinders for observation with scanning electron microscopy (JEOL-JSM6380LV). Abundance

Fig. 1 : Geographical location of the basin Antigua River, Veracruz, Mexico and sampling stations

was expressed as number of cells per milliliter (cell ml^{-1}). Biomass was calculated as biovolume ($\text{mm}^3 \text{m}^{-3}$) by approximation to the closest geometric forms (Sun and Liu, 2003) using average values of a minimum of 15 individual measurements for each identified species and multiplying by the species abundance (cell ml^{-1}).

A diagram of Holston-Tukey was performed to identify the dominant, constant, temporary and rare species. With the taxa identified at system (dominant, constant and temporary) Detrended Correspondence Analysis (DCA) was applied using Project R Program 3.1.3 to relate species with environmental variables. The same analysis was utilized to identify temporal dominance of algal groups and spatial heterogeneity between stations. Shannon-Wiener Diversity Index was derived using Primer Program 6.1.6.

Results and Discussion

Mean water temperature was $26 \pm 3^\circ\text{C}$; highest ($>28^\circ\text{C}$) corresponded to the dry period and decreased to 20°C in December. These values showed the tropical climate in the region. Mean depth value was $1.7 \pm 0.3 \text{ m}$, increasing $\sim 0.3 \text{ m}$ in wet months. Mean dissolved oxygen was $8.9 \pm 2.6 \text{ mg l}^{-1}$, with the highest value in the dry season (April, 19.1 mg l^{-1}), and the lowest during the rainy season (mean 8 mg l^{-1}) (Table 1). Turbulent water movement contributed to the relatively high values of dissolved oxygen but photosynthesis produced higher values.

Mean pH was 7.8 ± 0.4 , with maximum value in October and April and ~ 7.5 during the rainy period. Mean turbidity value was $10.6 \pm 7.2 \text{ NTU}$, with maximum value in rainfall (September, 22 NTU) and minimum in dry season (January to May, $\leq 5 \text{ NTU}$). Mean conductivity was $488 \pm 432 \mu\text{S cm}^{-1}$, presenting a strong gradient in the driest months (December to May) disappearing with the rains (Table 1).

Mean SRP and nitrate were $2.6 \pm 2.6 \mu\text{g l}^{-1} \text{PO}_4^{3-}\text{-P}$ and $0.6 \pm 0.5 \text{ mg l}^{-1} \text{NO}_3\text{-N}$. Highest values for both were recorded during the rainy season ($>3 \mu\text{g l}^{-1} \text{PO}_4^{3-}\text{-P}$ and $>0.6 \text{ mg l}^{-1} \text{NO}_3\text{-N}$) (Table 1).

Table 1 : Physico-chemical parameters (mean, standard deviation, range) determined in La Antigua River from March 2013 to February 2014

Variable	Unit	Mean $\pm$ SD	Range
Temperature	$^\circ\text{C}$	26 ± 3	(20.4–30.8)
Depth	m	1.7 ± 0.3	(1.16–2.50)
Oxygen	mg l^{-1}	8.9 ± 2.6	(5.6–19.1)
pH		7.8 ± 0.4	(6.8–9.2)
Turbidity	NTU	10.6 ± 7.2	(2.3–28.2)
Conductivity	$\mu\text{S cm}^{-1}$	488 ± 432	(130–1878)
SRP	$\mu\text{g l}^{-1}$	2.7 ± 2.6	(0.15–11.8)
Nitrates	mg l^{-1}	0.6 ± 0.5	(0.01–2.7)

Mean chlorophyll-a was $5 \mu\text{g l}^{-1}$; two pulses were recorded in October and February ($18.6 \mu\text{g l}^{-1}$, and $11.8 \mu\text{g l}^{-1}$, respectively) (Fig. 2).

The mean phytoplankton biovolume was $5386 \text{ mm}^3 \text{m}^{-3}$, with peaks in March, April and October (11545; 32866 and 9115 $\text{mm}^3 \text{m}^{-3}$, respectively). About 200 taxa of microalgae were

Fig. 2 : Variation of chlorophyll-a, N:P ratio; total phytoplankton biovolume; diatoms, Chlorophyceae and Cyanoprokaryota biovolume; diversity index and species richness, in La Antigua River, from March 2013 to February 2014

Fig. 3 : Holston-Tukey diagram: Constant, Dominant, Rare and Temporary species in La Antigua River

recorded; diatoms dominated (number of species and biovolume, 75 and $6354 \pm 9359 \text{ mm}^3 \text{ m}^{-3}$, respectively). Dominant species were central and araphids diatoms (Fig. 3).

Chlorophyceae had the highest species richness (68), but low biovolume $337 \pm 653 \text{ mm}^3 \text{ m}^{-3}$ and their maximum abundance was the dry period (April). Cyanoprokaryota ranked third in species richness (23). Euglenophyceae, Dinophyceae, Cryptophyceae and Chrysophyceae had a lower species richness and biovolume and were mainly present in warm and moderate rainy season (Fig. 4).

Euglenophyceae was associated with increased nitrates, Dinophyceae and diatoms with higher conductivity, Cyanoprokaryota was related to increase SRP. Chlorophyceae and Chrysophyceae were associated with temperature increase and Cryptophyceae maintained an intermediate position between months with high conductivity and increased nitrates (Fig. 4). With

respect to the diversity index values, it was > 3 bits from February to July, decreasing from August to October (< 3 bits) and increasing from November to January (3 bits) (Fig. 2). Sites 2 and 3 formed a group and sites 4 and 5 another group, site 1 remained as separate (Fig. 6). Weather conditions were reflected in fluctuations of environmental and biological parameters at seasons.

Hot-dry season : In this period (March and April), the depth of the channel was reduced due to low precipitation (30.1 mm; CONAGUA, 2011). A value of 5 NTU, equivalent to a transparency of about 60 cm (Kirk, 2011), allowed the passage of light to a depth ≥ 1.5 cm, which implies sufficient light in the water column for microalgal photosynthesis which in turn promoted high values of dissolved oxygen and pH, especially in April. SRP $> 1 \mu\text{g l}^{-1}$ was sufficient for the development of algae or macrophytes, however nitrates (0.5 mg l^{-1}) were low, producing a low ratio N:P (~ 0.1), which could limit the growth of these organisms, due to an imbalance in the relation of the Redfield ratio (Ekholm, 2008).

Fig. 4 : Temporal succession of algal groups throughout the study period

Fig. 5 : Distribution of dominant, temporary and constants species through the study period. Other details as in Fig. 3

Fig. 6 : Distribution of dominant, temporary and constants species through stations sampled. Other details as in Fig. 3

Low volume of freshwater allowed the entrance of a wedge of salt into the river channel, establishing a gradient: Stations 1 to 4 were classified as freshwater ($<1000 \mu\text{S cm}^{-1}$; Wetzel, 2001), while Station 5 exhibited brackish conditions ($1569 \mu\text{S cm}^{-1}$). Due to saline stress, teratological forms of *F. gouldii*, a freshwater species, were observed (Falasco *et al.*, 2009), and hence low species richness would be expected (Lampert and Sommer, 2007).

However, the greatest richness of phytoplankton species found can be explained by the diversity of contributions: planktonic halophytes and benthic polyhalobes (Gardes *et al.*, 2011; López *et al.*, 2010), such as *Thalassiosira weissflogii* (Grunow) G. Fryxell & Hasle; *Amphora holsatica* (Hustedt) sensu Krammer and Lange-Bertalot; *Tryblionella compressa* var. *elongata* (Grunow) L. Bert.; *Tryblionella compressa* var. *compressa* (J.W. Bailey) M. Poulin from sea. There was also a large biovolume of planktonic freshwater taxa: *Fragilaria gouldii* (Brébisson ex Grunow) L. Bert.; *Synedraula* (Nitzsch) Ehrenberg; *Cyclotella meneghiniana* Kützinger [diatoms]; *Pandorina morum* (O.F. Müller) Bory; *Eudorina* sp. [Volvocales]; *Tetraselmis cordiformis* (H.J. Carter) Stein [Chlamydomonadaceae]; *Desmodesmus quadricauda* (Turpin) Hegewald; *Pediastrum boryanum* (Turpin) Meneghini, [Chlorococcales]; *Oscillatoria princeps* Vaucher ex Gomont [cyanoprokaryota].

Volvocales, Chlamydomonadaceae, Chlorococcales, Euglenophyceae, Cryptophyceae and Dinophyceae are mixotrophic and can incorporate organic material to survive without photosynthesis. Therefore, these are considered as good indicators of organic pollution (Reynolds 1998), confirming the contamination reported in this system. *O. princeps* related to high SRP indicating concentration of contaminants by evaporation (Fig. 4).

Rainy season : In this season, conductivity decreased due to dilution with fresh water; values of depth, amount of sediment (which is reflected in turbidity), and nutrients (mainly nitrates) were increased. Phytoplankton growth decreased due to the lack of light by an increase in turbidity and higher velocity of water flow. This was observed in the drastic reduction of chlorophyll-a, biovolume and algal richness. The species present were benthic, such as *Navicula capitatoradiata* H. Germain and *Nitzschia palea* (Kützinger) W. Smith. In September, the month with heavy rains, Euglenophyceae and *O. princeps* indicated the presence of organic matter.

Cold - moderate rainy season: Favorable conditions for microalgae growth (mainly *F. gouldii* and *S. ulna*) were restored in October; low turbidity, increased nitrogen, and freshwater (mean K25 $380 \mu\text{S cm}^{-1}$) resulted in the highest chlorophyll-a values. In this respect, the pH and dissolved oxygen values were higher.

However, low species richness was observed. Salinity gradient was restored in November, and apparently this affected the growth of algae, since the biovolume decreased and abundance of *C. meneghiniana*, *N. capitatoradiata*, *N. palea*, *T. codiformis*, species tolerant to changes in the salinity, were observed. The presence of diatoms and Dinophyceae associated with high conductivity could provide evidence of the input of marine phytoplankton, since they are the dominant groups in the sea (Muciño-Marquez et al., 2011).

Rainfall in November, December and January (CONAGUA, 2011), accentuated by El Niño meteorological phenomenon, contributed nitrates to the environment, promoting more balanced conditions with respect to N:P ratio (Angulo and González, 2008), generating a small but sustained algal biovolume until February, when a pulse of biovolume and species richness was reached. The best quality of food represented by the increase in diatoms, and the highest diversity index confirmed the best conditions in this period.

The increase in phytoplankton after rainfall is a pattern described for other rivers, for example Sali River and Piedra Blanca River, in Argentina (Luque and Luján, 2003; Martínez de Marco and Tracanna, 2012), with a species richness similar to that recorded here (221 and 149 taxa, respectively).

Contribution of marine species to specific richness was also recorded at the mouth of Papaloapan River in Mexico (Moreno-Ruiz et al., 2008). The high species richness resembles other coastal systems such as the entrance to Sontecomapan lagoon in Mexico, which has high species richness (Muciño-Marquez et al., 2011).

Regarding zonation, station 1 was separated from stations 2 and 3 which constituted the area with the highest contamination by wastewater discharges of the population of La Antigua. Stations 4 and 5 were separated due to increases in salinity. These stations are the closest to the sea. Station 1 is likely to be cleaner and less salty. The predominance of diatoms in river systems is well documented (Luque and Luján 2003; Martínez de Marco and Tracanna, 2012) and focuses on the presence of structures such as raphe, which allow them to adhere to various types of substrates such as rocks, gravel, even vegetation. Range of the Shannon-Wiener index, which ranged from 1 to 3, would indicate water from clean to slightly polluted (Pérez-Munguía et al., 2007).

Acknowledgments

This work was done with the support of DGAPA/PAPIIT IN213413 Project and FES-I/PAPCA 26 Project. We thank Rafael Quintanar and César Flores for support in Scanning Electron Microscopy at the Department of Biotechnology and Prototypes, FES-Iztacala and special thanks by map elaboration to Biol.

Monica Chico-Avelino and Raymundo Montoya-Ayala, GIS Laboratory and Remote Perception, UNAM-FES-Iztacala-UBIPRO.

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