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Spatial and temporal changes in the phytoplankton community in a cascaded reservoir system: San Juan River, Mexico

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Abstract: Alteration of natural flows with dams for water harvesting has caused changes in water quality and habitat of biological communities. In Mexico there are more than 4000 reservoirs, which in some cases are located in the same river system, resulting in a cascading effect from the release of water up to downstream reservoirs, decreasing the system connectivity which depends on hydraulic management. The phytoplankton community was characterized to determine the temporal and spatial variations in a cascade system. In places where connectivity is maintained, diatom species were presented, while in reservoirs had a clear dominance of chlorophytes and cyanophytes related to nutrient enrichment and wastewater discharges. A total of 112 species were identified, 38% were Chlorophyceae, 35% Bacillariophyceae, 13% Cyanophyceae and 13% Euglenophyceae. Microcystis aeruginosa and Anabaena variabilis (cianophytes) were abundant in reservoirs. Phytoplankton succession indicated the presence of species with characteristics strategists C in autumn and winter, replaced by R strategists species in spring. The canonical correlation analysis between environmental variables and species presence was related to concentrations of sulfates, total suspended solids, nitrates and phosphates.

Keywords: Pollution, Succession, Phytoplankton

1. Introduction

Fresh water ecosystems are one of the main sources of water for human needs. They are used as a water supply, for irrigation and electric energy and as receptors of wastewater. Water management in basins has led to a deterioration in lotic systems and their biotic and abiotic components [1]–[4].

Due to the urgent need to supply water, food and energy to population, the number of man-made reservoirs has increased dramatically over recent years. Pollution problems driven for mismanagement of their hydrographic basins are present in both natural and man-made lakes. [5]–[8]. Four thousand storage dams have been built in Mexico for the purposes mentioned above [8]. When many reservoirs are located in the same basin in a fluvial system, a cascade effect is produced by water release upstream from the reservoirs, thereby interrupting the continuity of the system and altering the longitudinal and lateral connectivity of aquatic ecosystem. [9]–[11] Changes in a river's natural regime result in geomorphological and biological effects that modify river functioning both downstream and upstream from a flood control structure. This leads to changes in fluvial systems and habitats from lotic (river) to lentic (lake) [3]. As a consequence, habitat quality deteriorates, affecting biotic structure. Changes occur in a river as a result of manipulating its flow which leads to modifications in its physical, chemical and habitat attributes, thereby producing changes in the structure of biotic communities. These changes contribute to the ecosystem's loss of biotic integrity [12], [13]; this loss is an important aspect because it reflects accumulated effects of a wide variety of stress factors.

Every fluvial system is closely related to the geology and basin management, as well as its morphology and flow patterns. Therefore, different habitats (biotopes) and their communities (biocenosis) are complex systems. Biological communities adapt to their environments changing characteristics of their habitats from headwaters to the mouth of river. Their growth patterns and survival techniques evolve in order to handle changes in flow, droughts, solids loads (erosion) nutrients, and contamination [14] in [15].

Phytoplankton communities are composed of algae, whose populations are maintained by the ongoing supply of nutrients from tributaries, as well as by allochthonous and recycled organic matter that enters in the reservoir. Phytoplankton's growth rate increases when the retention time of water in the reservoir is longer. Meanwhile, algal death increases as a result of sediment loads, predation by zooplankton and flushing events. Under short retention times, phytoplankton community is not able to compensate losses from death because of the lack of continuous conditions needed for community growth. [16], [17].

Phytoplankton community is one of the aquatic communities most recommended for establishing the trophic state of a lake or reservoir and as indicator of water quality and habitats suitability. Because of their short life cycles, phytoplankton quickly respond to environmental changes and play a strategic role in the aquatic system's food chain [18], [19]. Different algae species have different growth rates and nutrient and sediment requirements which, in addition to water quality, determine the presence and dominance of certain phytoplankton groups in reservoirs and downstream from dams [20].

According to Reynolds (in [21]) and [22], phytoplankton communities are structured according to the availability of nutrients and light. Those predominant in environments that have nutrients availability are called C-strategists, which are small opportunistic organisms that grow and reproduce rapidly and have a high surface/volume ratio. When nutrients are limited, organisms that are tolerant to stress, called S–strategists, become predominant. And in environments with frequent changes in water quality, generally due to turbulence, R-strategists are dominant.

Phytoplankton can also be classified by functional criteria, according to [20] Phytoplanktonic succession depends on biological factors such as competition, predation and parasitism. Physical and chemical factors, including water temperature, light intensity, conductivity, oxygen, pH, and nutrients can influence such succession. Knowledge on these aspects, along with changes caused by precipitation and wastewater discharges, are factors that regulate communities' dynamics, since changes in periodicity of ecological processes decrease species richness and, consequently, succession [23]–[25]

Therefore, the present study provides new information about the composition and dynamics of the phytoplankton community in a cascaded reservoir system by analyzing the spatial and temporal distribution of nutrients concentrations. This study also identifies functional groups according to Reynolds' theory.

2. Study Area

The San Juan River sub-basin is located between 19° 50' and 20° 45' north latitude and 99° 30' and 100° 15' west longitude. It begins at the Mexico State, where it is known as the Zarco stream, and after 23 km it reaches Queretaro State, at 2,100 masl (meters above sea level), where its name changes to the San Juan River, at 1,943 masl.

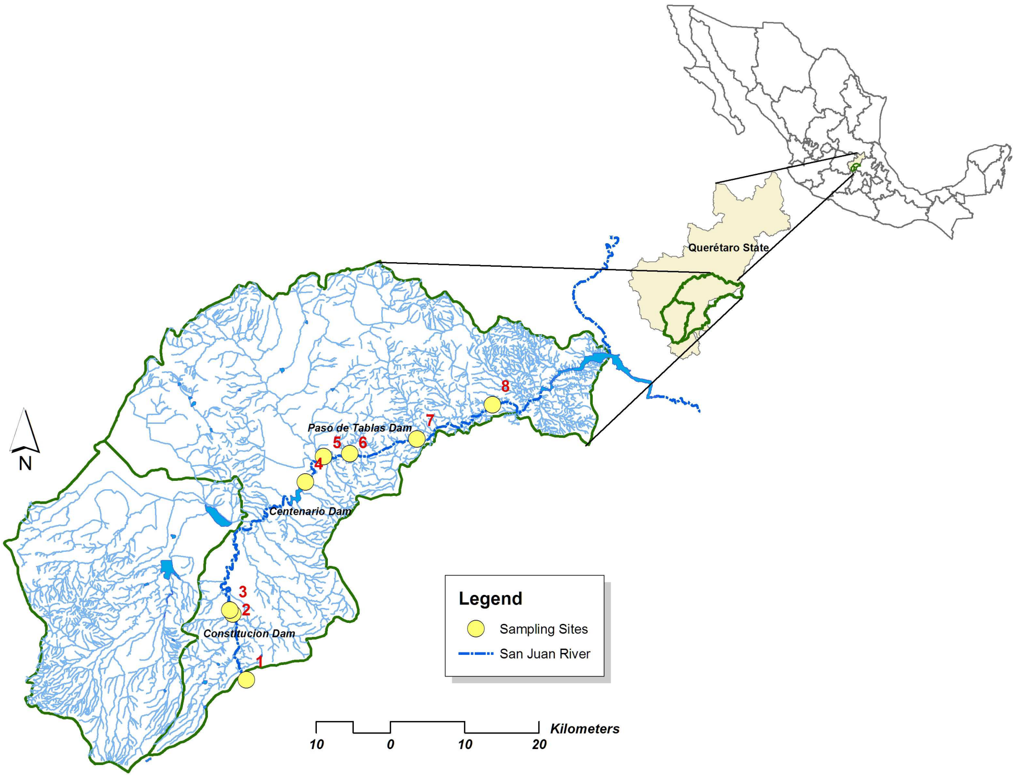

Figure 1. Location of Sampling Sites in the San Juan River, Qro.

The San Juan River sub-basin is 5 427 km^2. A total of 86km of the river's main channel was included in the study zone, whit 8 sampling sites, beginning at site 1 in San Sebastian (code 1SS, km 0) and ending at site 8 in Taxhido (code 8TAX, km 86). The sites with lotic characteristics were 1SS, 3BCON, 5BM, 7LR and 8TAX and those with lentic systems, or reservoirs, were 2CON, 4CEN and 6PT (Table 1 and Figure 1). According to the Köppen classification, adapted by [26], the climate is BS1 kw (w), dry and its subtype is semi-dry and semi-hot, with summer rains and a percentage of winter rainfall between 5 and 10.2 of total annual rainfall. Particularly in the municipalities of Ezequiel Montes, Cadereyta, Tequisquiapan and San Juan del Río, annual mean precipitation varies between 450 and 630 mm [27]. In addition, B group dry climate is where xerophytes plants prosper and evaporation exceeds precipitation [26].

Table 1. *Sampling Sites Location in the San Juan River Cascaded Reservoir System, Qro.*

Sites	Code	Site Name	System	Altitude (masl)	North Longitude	West Latitude
1	1SS	San Sebastian	Lotic	2086	20°15' 41.1"	99°56' 32.9"
2	2CON	1857 Constitucion Dam	Lentic	1943	20°21' 46.3"	99°59' 59.3"
3	3BCON	Downstream 1857 Constitucion Dam	Lotic	1930	20°21' 50.6"	99°59' 58.1"
4	4CEN	Centenario Dam	Lentic	1902	20°30' 46.1"	99°53' 57.5"
5	5BM	Magdalena Neighborhood	Lotic	1885	20°32' 25.8"	99°52' 11.6"
6	6PT	Paso de Tablas Dam	Lentic	1869	20°32' 23.2"	99°50' 53.7"
7	7LR	Las Rosas	Lotic	1745	20°33' 44.0"	99°45' 16.6"
8	8TAX	Taxhido	Lotic	1568	20°36' 15.5"	99°39' 19.3"

3. Methods

After a prospective visit of the study area, sampling sites were located taking into account the input contributions of both industrial and municipal wastewater. Water uses in the surrounding basin, such as agricultural irrigation, flood control and power generation of dams were also considered along the path of the San Juan River in Queretaro State, Central Mexico. Sites were geo-referenced with Garmin GPS 45 XL. The qualitative sampling of phytoplankton community was obtained filtering 10 liters of water through a mesh with a grid size of 20 micrometers. Filtered water was preserved in a 4% formaldehyde solution. Taxonomical identification of collected species was performed in laboratory with an optical microscope, and was based on codes defined by [28]–[31]. Water samples were taken bimonthly from each site between October 2004 and June 2006 to determine physiochemical parameters. The water quality parameters analyzed in situ included dissolved oxygen in mgL-1 (DO), temperature in ºC (T), conductivity in µScm-1 (CND) and potential hydrogen (pH). These readings were performed with an YSI model 85 multi-parametric measuring device for the first three parameters and a Hanna potentiometer for pH. At the same time water samples were collected and analyzed with spectrophotometry using Hach DRL 2010 equipment to quantify turbidity (FTU = formazine turbidity unit) (TU), total suspended solids (TSS), nitrites (NO_2), sulfates (SU) and total phosphates (P) (the latter parameters were measure in mgL-1). The sampling strategy took into account relevant techniques [32], [33] such as separating a small portion (sample) from the total study universe in such a way it represents characteristics water mass quality from which sample was taken, and transferring water from each point in the system to laboratory without causing changes on any of its properties.

To determine species richness, spatial-temporal variations in species composition at the sampling sites were analyzed.

A cluster analysis was performed with qualitative data for the presence-absence of species to determine similarities of the phytoplanktonic community among the sites. A canonical correspondence analysis (CCA) was also performed to determine relationships between water quality and the biotic community. The MVSP version 3.13 statistical package was used for these analyses.

From all the identified species, indicators of system's contamination were determined according to its environmental quality characteristics and the functional groups as proposed by Reynolds were also established.

4. Results

4.1. Composition of the Phytoplankton Community

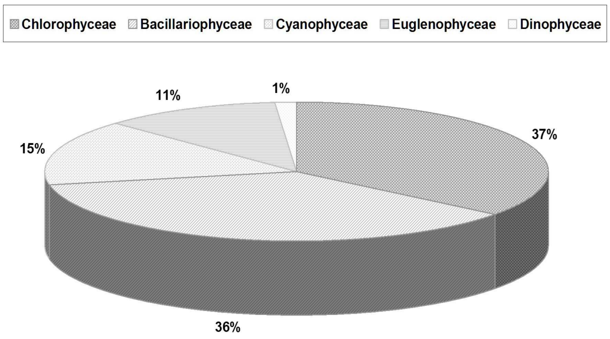

Figure 2. *Species Richness of Phytoplankton Groups.*

The phytoplankton community in the San Juan River is composed by 5 classes, as shown in Figure 2. A total of 112 species were identified, of which 42 (38%) were Chlorophyceae (green algae), 39 (35%) were Bacillariophyceae (diatoms), 15 (13%) were Cyanophyceae (cyanobacteria), 14 (13%) were Euglenophycea (euglenoids) and only 2 species (2%) were Dinophyceae.

The spatial distribution of groups can be seen in Figure 3. Bacillariophyceae behavior was cyclical, increasing from site 1SS (9 species) to 3BCON (23 species), decreasing at 4CEN

(12 species) and 5BM (6 species), and then increasing from 6PT (14 species) to 8TAX (31 species). The highest species richness was found at site 8. The Chlorophyceae followed an inverse behavior, with the greatest species richness occurring at site 1SS (25 species).

Fifty-one and 49% of the species found in sites 3BCON and 8TAX were diatoms, respectively; Navicula cuspidata was the most representative taxon at the first site and Amphipora ornata at the second. Cyanophyceae accounted for 29% and 27% of the species at sites 5BM and 6PT, respectively, and Microcystis aeruginosa was the most representative species. At site 1SS, Chlorophyceae accounted for 48% of the species, and Schroederia setigera was most representative.

Differences were found in the quantity of species over the sampling cycle. Chlorophyceae and Cyanophyceae reached their peak in October 2004, corresponding to the fall season, and progressively decreased during the beginning of the dry season. Bacillariophyceae peaked in the spring of 2005 and decreased toward the end of the sampling period. Figure 4 shows that the peaks in species richness occurring towards the end of fall and in the spring corresponded to Chlorophyceae and Bacillariophyceae, respectively.

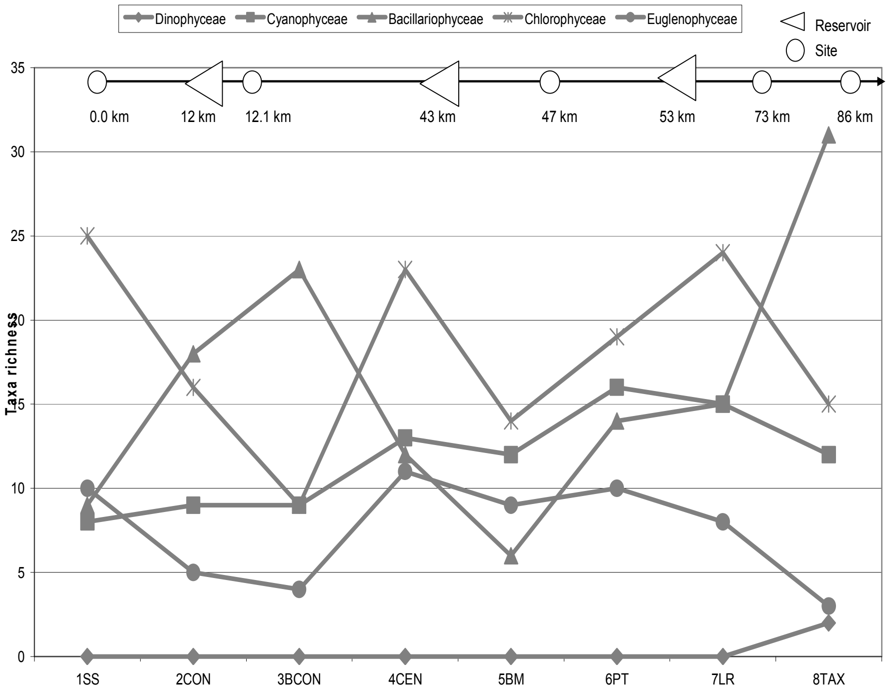

Figure 3. *Spatial Variations and Relative Abundance of Phytoplankton Groups*

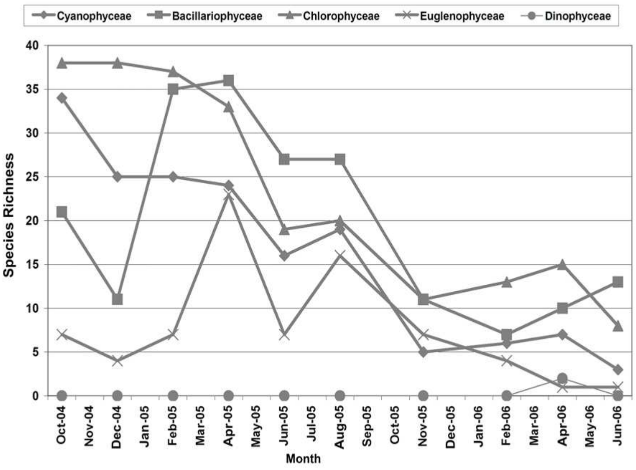

Figure 4. *Temporal Variation in Species Richness, by Taxonomical Class*

The peaks in Cyanophyceae and Chlorophyceae were related to low average of nitrates concentrations and high average of phosphates concentrations (0.563 mg/L and 1.298 mg/L, respectively) in October 2004, while the diatoms were related to low phosphates concentrations and high nitrates concentrations (0.295 mg/L and 2.133 mg/L, respectively) in April 2005.

Overall, the groups with the highest species richness were Chlorophyceae at 4CEN, 5BM and 6PT and diatoms at 2CON, 3BCON, 7LR and 8TAX.

To identify the spatial relationships between the phytoplanktonic species and the sites, a similarity analysis was performed using presence-absence data (Figure 5), finding that sites 4CEN, 5BM, 6PT and 7LR represented the group with the highest amount of Chlorophyceae, followed by Cyanophyceae, Bacillariophyceae and Euglenophyceae. This differed from sites 1SS, 2CON and 3BCON, where diatoms were predominant, followed by Cyanophytes, Chlorophytes, and Euglenophytes. At site 8TAX, the predominant group was diatoms, followed by Chlorophyceae, Cyanophyceae and Dinophyceae.

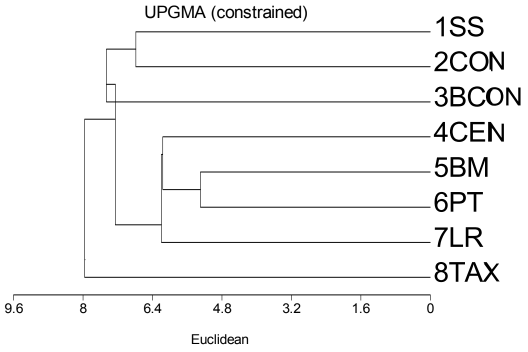

Figure 5. *Similarity Analysis Grouping Sampling Sites according to Phytoplanktonic Species Presence-Absence*

The canonic correspondence analysis (CCA $p<0.05$) included main water quality parameters which defined distribution patterns and phytoplanktonic community composition. The variables that determined species presence were sulfates, total suspended solids, nitrates and phosphates, which together represented 42.6% of variability (Figure 6 and Table 2); the latter two are the nutrients that influence growth and proliferation of phytoplanktonic species [22], [34], [35], [36].

The analysis also shows that certain taxa can be associated to environmental quality, as indicated by specific sites where they were collected. For example, Navicula cuspidata was present at 3BCON and Microcystis aeruginosa at sites 4CEN, 5BM, 6PT, in the section which receives most of the wastewater from San Juan del Rio and Tequisquipan towns and most water flowing from the two cascaded reservoirs. Amphiprora ornata was found at 8TAX, among others, which receives water from springs, improving its quality.

Table 3 shows the taxonomic species classification and their corresponding codes.

Table 2. *Canonic Correlations of Environmental Variables with respect to Phytoplankton*

	Axis 1	**Axis 2**	**Axis 3**
Eigenvalue	0.368	0.342	0.309
Percentage	22.139	20.554	18.597
Accumulated Percentage	22.139	42.692	61.289
Canonic Correlations	0.992	0.655	0.533

Table 3. *Taxonomical Classification of Species by Sampling Site and Identification Code*

	River		**River**		**Reservoir-River-Reservoir**		**River**
Code	**1SS**	**Code**	**3BCON**	**Code**	**4CEN 5BM 6PT**	**Code**	**7LR**
39	Cymbella sp.	15	Oscillatoria animalis	2	Gomphosphaeria aponina	21	Phormidium tenue
90	Chroococus refenscens	19	Phormidium foveolarum	7	Anabaena spiroides	33	Cyclotella antiqua
97	Haematococcus lacustris	35	Cyclotella glomerata	9	Aphanocapsa grevillei	60	Nitzschia hungarica
105	Pediastrum duplex	37	Cymbella aspera	13	Microcystis aeruginosa	83	Closterium venus
106	Pediastrum duplex	38	Cymbella prostrata	20	Phormidium retzii	99	Kirchneriella obesa
107	Pediastrum tetras	40	Cymbella tumida	23	Pleodorina californica	100	Microactinum pusillum
108	Rhizoclonium fontanum	42	Cymbella ventricosa	25	Spirulina jenneri	110	Scenendesmus acuminatus
117	Schroederia setigera	43	Diatoma anceps	26	Spirulina gomontiana	113	Scenedesmus dimorphus
121	Staurastrum gracile	48	Fragilaria crotonensis	61	Nitzchia linearis	114	Scenedesmis quadricauda
129	Volvox carteri	50	Gomphoneis herculeana	62	Nitzschia sp.	125	Tetraedron muticum
133	Euglena oxyuris	52	Gyrosigma kuetzingii	65	Pinularia parva		River
	Reservoir	53	Hantzschia amphioxus	71	Surirella guatemalensis	Code	8TAX
Code	2CON	54	Melosira juergensii	78	Carteria multifilis	4	Ceratium hirundinella
6	Anabaena spiroides	57	Navicula cuspidata	79	Closterium acutum	5	Ceratium longipes
34	Cyclotella sp.	69	Surirella biseriata	84	Coelastrum reticulatum	10	Leponcinelis ovum
55	Melosira sp.	70	Surirella didyma	85	Closterium turgidum	29	Achnanthes exilis
64	Pinularia parra	74	Surirella spiralis	86	Closteriopsis longissima	30	Amphora normani
75	Synedra dorsiventralis	82	Closterium sp.	87	Coelastrum sphaericum	31	Amphiprora ornata
77	Actinastrum hanztzschii	89	Chlorotylium sp.	88	Cosmarium sp.	36	Cymatopleura elliptica
95	Gonium pectorale	96	Hormidium flaccidum	93	Dactylococus infusionum	44	Ephitemia sp.
101	Mougeotia scalaris	128	Treubaria crassispina	94	Dictyosphaerium sp1	45	Ephitemia zebra
103	Oocystis borgei			102	Oocystis sp.	59	Nitzschia closterium
126	Tetraedron trigonum			104	Phacotus lenticularis	63	Pinnularia nobilis
134	Euglena oxyuris			112	Scenedesmus bijuga	66	Pinnularia sp1
135	Euglena sanguinea			116	Scenedesmus protuberans	67	Rhoiscosphenia curvata
141	Phacus pleuronectes			118	Sphaerocystis schroeteri	71	Surirella guatemalensis
144	Traquelomonas ensifera			123	Stauroneis gracilis	72	Surirella ovalis
				124	Stingeoclonium lubricum	80	Closterium didymotocum
				131	Euglena elongata	92	Crusigenia rectangularis
				136	Euglena sp.	98	Hormidium klebsi
				137	Euglena spirogyra	119	Spirogyra pratensis
				138	Euglena viridis	120	Spirogyra rectangularis
				139	Phacus torta	127	Tetraedron trigonum
				140	Phacus longicauda	143	Traquelomonas armata
				142	Phacus pyrum		
				146	Traquelomonas volvocina		

Table 4. *Most common phytoplankton Species and Locations*

1SS, 2CON and 3BCON	4CEN, 5BM, 6PT and 7LR	8TAX
Navicula sp (diatom)	Closterium venus (chlorophyte)	Amphipora ornata (diatom)
Fragilaria capucina (diatom)	Scenedesmus dimorphus (chlorophyte)	Fragilaria construens (diatom)
Schroderia setigera (chlorophyte)	Scenedesmus quadricauda (chlorophyte)	Fragilaria capucina (diatom)
Lyngbya sp. (cianophyte)	Anabaena variabilis (cianophyte)	Navicula cuspidata (diatom)
	Microcystis aeruginosa (cianophyte)	Synedra ulna (diatom)
	Cyclotella antiqua (diatom)	Scenedesmus dimorphus (chlorophyte)
	Fragilaria capucina (diatom)	Scenedesmus quadricauda (chlorophyte)
	Euglena sanguinea (euglena)	Lyngbya sp (cianophyte)
		Merismopedia convoluta (cianophyte)

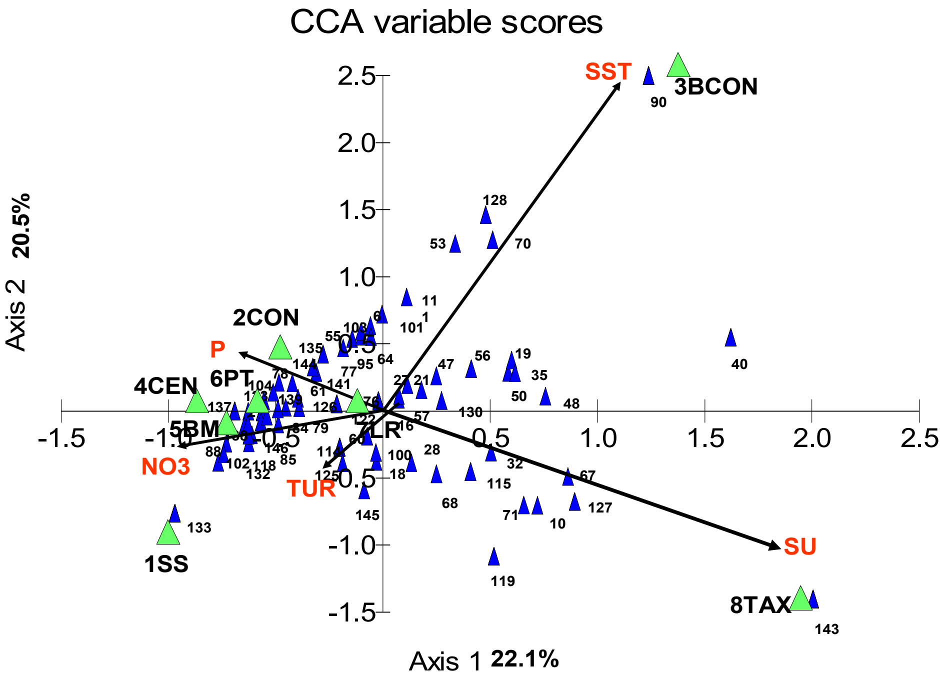

Figure 6. *Canonical Correspondence Analysis and Species Relationship with Water Quality at Sampling Sites*

According to the classification by [20], phytoplankton composition in the reservoirs was: H1 for Anabaena variabilis, A. spiroides; M for Microcystis aeruginosa; S2 for Spirulina gomonantina, S. jenneri, S. major; D for Stephanosicus hantzschii; J for Scenedesmus protuberans, S. bijuga; W1 for Euglena cautisima, E. elonga, E. oblonga, E. oxyuris, E. sanguinea, E. sporigyra, E. viridis y W2 for Traquelomonas ensifera, T. volvocina. The composition is consistent with cascaded reservoirs because they are deep, enriched by nutrients and eutrophic.

The most common species are indicated in Table 4. These are considered indicators of eutrophic conditions and are tolerant to contamination by organic matter; they include Fragilaria capuchina, F. construens, Navicula cuspidata, Coelastrum venus, Scenedesmus dimorphus, Synedra ulna, Mycrocistis aeruginosa and Anabaena variabilis. A study by [37] found that these were also present in the Zimapan reservoir where the San Juan River enters .

5. Discussion

The phytoplankton in the cascaded reservoir system was represented by Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae, and Dinophyceae; the latter was the least significant.

At the sites where Chlorophytes and Cianophytes species were found (4CEN, 5BM, 6LR and 7PT), environmental conditions with high concentrations of nutrients determined their composition; in addition, 4CEN and 7PT were sites where the cascaded reservoirs retain water. Diatoms were dominant at sites 2CON, 3BCON and 8TAX primarily due to high concentrations of nutrients. In addition, these sites had constant water flow and the 2CON reservoir released water most of the time; giving connectivity between the first two sites. Water flow was constant at the third site where river behaved as a lotic system because it is the final part of the San Juan River; this portion also received water from springs. The community structure in the San Juan River sub-basin was similar to found in other studies of lakes and reservoirs [38], [39], [22], [40] and [41].

The seasonal succession dynamics of taxonomic groups reflected a greater dominance of chlorophytes towards the end of fall and throughout winter, decreasing in the spring. Since this behavior is related to the availability of nutrients, the opportunistic C-strategists organisms were dominant because of their rapid growth and reproduction.

Similar seasonal behavior was identified for cianophytes, which are considered S-strategists because of their tolerance to stress. Nevertheless, these were less dominant than findings by other studies [41] op.cit; [21], [34] in which cianophytes dominated towards the end of summer and fall. This may have been due to competition for nutrients between the groups as well as the absence of chlorophyte predators such as zooplankton, which were not found in the system.

The diatoms were dominant in the spring and summer. In spring, water is saturated with biogenic substances that lead to the dominance of small organisms that grow rapidly, as well as those adapted to environments with large water flows variability, which is characteristic of R-strategists algae [22] op. cit.

According to the canonical correspondence analysis, at sites 1SS, 2CON, 4CEN, 5BM, 6PT and 7LR the variation in phytoplankton composition and structure was influenced by nitrites, sulfates and turbidity, common characteristics of eutrophic environments. Meanwhile, at 3BCON and 8TAX, phytoplankton was influenced by total suspended solids and sulfates, respectively.

6. Conclusions

The conditions identified in the San Juan River's cascaded reservoir system included the hydrological management and disturbances, caused by continuous discharges by municipalities and industries, as well agriculture. These conditions determined the composition and structure of the river's biotic communities, resulting in patches or clusters, and the connectivity between these depended on the hydrological management of reservoirs. For example, connectivity existed at the 2CON reservoir because water releases from dam. While releases did not occur at the 4CEN and 6PT sites during the dry season and connectivity was therefore lost downstream from the dam.

In a cascaded system, the probability of phytoplankton being transported to another location depends on connectivity. In turn, connectivity depends on seasonal patterns, which are subject to the magnitude and frequency of water avenues and dry periods. Therefore, the presence of dams limits or decreases the longitudinal connectivity of a lotic system, as described by [15]. In the San Juan River cascaded reservoir system, connectivity was observed only at the Constitucion dam (2CON) because its hydraulic management and water release in the deep zone, enabled downstream transport, including nutrients.

In general, the spatial distribution throughout the sampling cycle was dominated by Chlorophyceae, followed by Bacillariophyceae, Cyanophyceae and lastly Euglenophyceae. This occurred for two reasons. First, Bacillariophyceae and Cyanophyceae generally tolerate high concentrations of calcium, which is indirectly represented by pH values over 8, creating alkaline conditions in the reservoir system. And second, high evaporation in the sub-basin causes salts precipitation.

Phytoplankton succession indicated the presence of species with C-strategists characteristics in fall and winter, which were replaced by R-strategists in spring. An important aspect was a lack of alternation of S-strategists, which were reported as predominant in summer. This suggests alterations in the system that prevented succession from occurring, probably due to the absence of predators and contamination from municipalities, agriculture and industrial wastewater discharges affecting the San Juan River.

Based on species classification from the cascaded reservoirs, the system was identified as having deep reservoirs that were eutrophic and enriched by nutrients, which determined the presence of phytoplankton characteristic of environments undergoing changes in flow and water quality.

References

[1] D. J. Rapport, "On the transformation from healthy to degraded aquatic ecosystems," Aquatic Ecosystem Health & Management, vol. 2, no. 2. pp. 97–103, 1999.

[2] J. G. Darrel, J. Lee, D. W. Waller, and R. E. Carlson, "Multivariate analysis of the ecoregion delineation for aquatic systems," Environ. Manage., vol. 29, no. 1, pp. 67–75, 2002.

[3] A. Brismar, "River systems as providers of goods and services: A basis for comparing desired and undesired effects of large dam projects," Environ. Manage., vol. 29, no. 5, pp. 598–609, 2002.

[4] A. H. Al-Momani, "Monitoring and Analysis of Tabuk Sewage Treatmentplant," Int. J. Environ. Monit. Anal., vol. 1, no. 3, pp. 84–90, 2013.

[5] H. F. Hemond and E. J. Fechner-Levy, Chemical Fate and Transport in the Environment, 1st ed. New York: Academic Press, 1994, pp. 217–227.

[6] E. I. L. Silva and F. Schiemer, "Human Factor: the Fourth Dimension of Reservoir Limnology in the Tropics," in Reservoir and Culture-Based Fisheries: Biology and Management, 2001, no. February 2000, p. 390.

[7] G. Friedl and A. Wüest, "Disrupting biogeochemical cycles - Consequences of damming," Aquatic Sciences, vol. 64, no. 1. pp. 55–65, 2002.

[8] B. D. Richter, A. T. Warner, J. L. Meyer, and K. I. M. Lutz, "A collaborative and adaptive process for developing environmental flow recommendations," River Res. Appl., vol. 22, no. 3, pp. 297–318, Mar. 2006.

[9] M. Gomes Nogueira, "Phytoplankton composition, dominance and abundance as indicators of environmental compartmentalization in Jurumirim Reservoir (Paranapanema River), São Paulo, Brazil," Hydrobiologia, vol. 431, no. 2–3, pp. 115–128, 2000.

[10] C. T. Robinson, U. Uehlinger, and M. T. Monaghan, "Effects of a multi-year experimental flood regime on macroinvertebrates downstream of a reservoir," Aquatic Sciences, vol. 65, no. 3. pp. 210–222, 2003.

[11] V. Draštík, J. Kubečka, M. Tušer, M. Čech, J. Frouzová, O. Jarolím, and M. Prchalová, "The effect of hydropower on fish stocks: Comparison between cascade and non-cascade reservoirs," in Hydrobiologia, 2008, vol. 609, no. 1, pp. 25–36.

[12] Environmental Protection Agency (EPA), “Environmental indicators of water quality in the United States,” Washington, D.C., 1996.

[13] N. Mercado-Silva, J. Lyons, G. Maldonado, and M. Nava, “Validation of a fish-based index of biotic integrity for streams and rivers of central Mexico,” Rev. Fish Biol. Fish., vol. 12, no. 2–3, pp. 179–191, 2002.

[14] J. V. Ward and J. A. Stanford, “The Serial Discontinuity Concept of Lotic Ecosystems,” in Dynamics of lotic ecosystems, Illustrate., T. D. Fontaine and S. M. Bartell, Eds. California, US: Ann Arbor Science, 1983, pp. 29–42.

[15] J. A. Wiens, “Riverine landscapes: Taking landscape ecology into the water,” Freshw. Biol., vol. 47, no. 4, pp. 501–515, 2002.

[16] V. Straskrabová, J. Hejzlar, L. Procházková, and V. Vyhnálek, “Eutrophication in stratified deep Reservoirs,” Water Sci. Technol., vol. 30, no. 10, pp. 273–279, 1994.

[17] H. Quiroz-Castelán, O. Solís-Pérez, and J. García-Rodríguez, “Variación de Componentes fitoplanctónicos en utilizado para acuicultura extensiva en Norte del México - Variation of phytoplanktonic components ponds used for extensive aquaculture in north of Mexico un bordo temporal Estado de Guerrero , in a temporary e,” Rev. Electrónica Vet., vol. VII, no. 11, pp. 1–25, 2006.

[18] DEP Bureau of Laboratories, “The Role of Ecological Assessments in Environmental Management.,” 1998.

[19] G. De la Lanza-Espino, S. H. Pulido, and J. L. C. Pérez, Organismos indicadores de la calidad del agua y de la contaminación (bioindicadores). Plaza y Vald{é}s, 2000, p. 633.

[20] C. S. Reynolds, V. Huszar, C. Kruk, L. Naselli-Flores, and S. Melo, “Towards a functional classification of the freshwater phytoplankton,” J. Plankton Res., vol. 24, pp. 417–428, 2002.

[21] L. De León and G. Chalar, “Abundancia y diversidad del fitoplancton en el Embalse de Salto Grande (Argentina – Uruguay). Ciclo estacional y distribución espacial,” Limnetica, vol. 22, pp. 103–113, 2003.

[22] M. C. Calijuri, A. C. A. Dos Santos, and S. Jati, “Temporal changes in the phytoplankton community structure in a tropical and eutrophic reservoir (Barra Bonita, S.P.—Brazil),” J. Plankton Res., vol. 24, no. 7, pp. 617–634, 2002.

[23] K. Ha, H. W. Kim, and G. J. Joo, “The phytoplankton succession in the lower part of hypertrophic Nakdong River (Mulgum), South Korea,” Hydrobiologia, vol. 369–370, pp. 217–227, 1998.

[24] D. Roelke and Y. Buyukates, “Dynamics of phytoplankton succession coupled to species diversity as a system-level tool for study of Microcystis population dynamics in eutrophic lakes,” Limnol. Oceanogr., vol. 47, no. 4, pp. 1109–1118, 2002.

[25] Ê. Wocyli-Dantas, M. C. Bittencourt-Oliveira, and A. Nascimento-Moura, “Dynamics of phytoplankton associations in three reservoirs in northeastern Brazil assessed using Reynolds’ theory,” Limnologica, vol. 42, no. 1, pp. 72–80, 2012.

[26] E. García, “Apuntes de climatología,” Mexico, D.F., 1980.

[27] PROFEPA, “Sinopsis geográfica del estado de Querétaro e Hidalgo.,” 2002. [Online]. Available: http://www.profepa.gob.mx/deleg/sinhgo.htm.

[28] L. H. Tiffany and M. E. Britton, The algae of Illinois,. Chicago: University of Chicago Press, 1952, p. 407.

[29] G. W. Prescott, Algae of the western great lakes area, Revised. Brow Co. Pub, 1962, p. 977.

[30] P. Bourrelly, Les Algues d’eau douce : initiation à la systématique. Tome II, p Les Algues jaunes et brunes. Chrysophycées, Phéophycées, Xanthophycées et Diatomées Tome II, p Les Algues jaunes et brunes. Chrysophycées, Phéophycées, Xanthophycées et Diatomée. Paris: Editions N. Boubée & Cie, 1968, p. 572.

[31] P. Bourrelly, Les Algues d’eau Douce: Initiation a la Systematique, Tome III: Les Algues bleues et rouges, Les Eugleniens, Peridiniens et Cryptomonadines. Paris: Editions N. Boubée & Cie, 1970, p. 512.

[32] D. Chapman, “Water Quality Assessments - A guide to use of biota, sediments and water in enviromental monitoring,” Oms, Pnuma, p. 609, 1996.

[33] G. A. Burton and R. Pitt, Stormwater Effects Handbook. CRC Press, 2001, p. 929.

[34] E. López-López, “Regional limnology of ten reservoirs in the Lerma Basin, Mexico.,” Int. Vereinigung fuer Theor. und Angew. Limnol. Verhandlungen, vol. 274, pp. 2288–2293, 2000.

[35] N. R. B. Razzak, A. Z. Siddik, and M. Ahmeduzzaman, “Evaluation of Water Quality of Ramna and Gulshan Lakes,” Int. J. Environ. Monit. Anal., vol. 1, no. 6, pp. 273–278, 2013.

[36] I. Monney, R. Boakye, R. Buamah, F. O. K. Anyemedu, S. N. Odai, and E. Awuah, “Urbanization and Pollution of Surface Water Resources in the Two Largest Cities in Ghana,” Int. J. Environ. Monit. Anal., vol. 1, no. 6, pp. 279–287, 2013.

[37] A. Gutiérrez-Hernández, “Análisis limnológico e ictiofaunístico del embalse Zimpán Querétaro-Hidalgo,” Universidad Autónoma de Querétaro, 2003.

[38] E. Díaz-Pardo, G. Vazquez, and E. López-López, “The phytoplankton community as a bioindicator of health conditions of Atezca Lake, Mexico,” Aquat. Ecosyst. Health Manag., vol. 1, no. 3, pp. 257–266, Jan. 1998.

[39] E. Lopez-López and J. Á. Serna-Hernández, “Variación estacional del zooplancton del embalse Ignacio Allende, Guanajuato, México y su relación con el fitoplancton y factores ambientales Eugenia López- López y José Angel Sema-Hemández,” Rev. Biol. Trop., vol. 47, no. 4, pp. 643–657, 1999.

[40] A. K. Çetin and B. Sen, “Seasonal Distribution of Phytoplankton in Orduzu Dam Lake (Malatya , Turkey),” Turk. J. Botany, vol. 28, no. 3, pp. 279–285, 2004.

[41] J. P. Antenucci, A. Ghadouani, M. A. Burford, and J. R. Romero, “The long-term effect of artificial destratification on phytoplankton species composition in a subtropical reservoir,” Freshw. Biol., vol. 50, no. 6, pp. 1081–1093, 2005.