**Comparative limnology of reservoirs of the Juramento (Salta) and Salí-Dulce (Tucumán) Basins of Argentina**

Brief Title: Reservoirs of Juramento and Salí-Dulce basins

María Mónica Salusso1

Facultad Ciencias Naturales Universidad Nacional Salta

Avenida Bolivia 5150- 4400 Salta (Argentina)

mmsalusso@gmail.com

1. Autor para correspondencia

Liliana Beatriz Moraña

Facultad Ciencias Naturales Universidad Nacional Salta

Avenida Bolivia 5150- 4400 Salta (Argentina)

lilymorana@gmail.com

**ABSTRACT**

Because of their geographical location, basin morphology and limnological features, the reservoirs of the upper Juramento basin (Cabra Corral and El Tunal) and those of the Salí-Dulce basin (El Cadillal, Río Hondo and Escaba) have certain peculiarities which are compared in the algal bloom period occurred between 2002 and 2008 through analysis of the main physicochemical parameters and ecological attributes of phytoplankton assemblages with standard methods. Tucuman reservoirs differ in most variables with higher values ​​of conductivity, nutrients and algal biomass. In terms of the hydrological cycle, El Cadillal exhibited the lowest biomass average (2.74 mg Chl.m-3) during maximum water flows whereas the Cabra Corral dam exhibited the highest biomass average (63.36 mg Chl.m-3) during minimum water flows. During the same period, the Cabra Corral dam exhibited lower phytoplankton diversity and richness (1.37 and 9, respectively), in accordance with dinophyte bloom recrudescence. In all the reservoirs, the following biological variables showed a significant contrast in the hydrological cycle: highest phytoplankton biomass during minimum water flows (35.68 mg Chl-*a* m-3) vs. waterfloods (13.68 mg Chl-*a* m-3) (T=3.42, *p*=0.001). During minimum water flows, richness (14.30 sp.) and equitability (0.51) were lower vs. waterfloods (20.23, 0.59, respectively) (T=2.36; *p*=0.0196) as a result of the allochthonous algal inocula provided by the main tributaries.

***Key words***: physicochemical variables, phytoplankton, water quality, northwestern.

Resumen

Los embalses de la Alta Cuenca del Juramento (Cabra Corral y El Tunal) y del Salí-Dulce (El Cadillal, Río Hondo y Escaba) por su ubicación geográfica, por la morfología de sus cubetas y características limnológicas muestran ciertas peculiaridades que son comparadas en el período de relevantes floraciones algales acaecidas entre 2002 y 2008, mediante análisis de los principales parámetros fisicoquímicos y atributos ecológicos de los ensambles del fitoplancton por empleo de técnicas estandartizadas. Los embalses de Tucumán se diferenciaron en la mayoría de las variables con valores más elevados de conductividad, nutrientes y biomasa algal. En función del ciclo hidrológico, El Cadillal en aguas altas presentó el promedio más bajo de biomasa (2.74 mg Cl.m-3) y por contraste la presa del Cabra Corral en estiaje el promedio más elevado (63.36 mgCl.m-3). En éste último, en el mismo período, también la diversidad y riqueza de especies del fitoplancton fueron menores (1.37 y 9 respectivamente), en coincidencia con el recrudecimiento de floraciones de dinófitos. Las siguientes variables biológicas en el conjunto de embalses presentaron un contraste significativo en el ciclo hidrológico: biomasa del fitoplancton más elevada en estiaje (35,68 mg Cl *a*. m-3) versus crecidas (13.68 mg Cl *a*. m-3) (T=3.42; p =0.001). En estiaje, la riqueza (14.30 sp) y equitatividad (0.51) fueron menores versus crecidas (20.23, 0.59, respectivamente)(T=2.36;p=0.0196), debido al aporte alóctono de inóculos algales por los tributarios principales.

Palabras clave: Parámetros fisicoquímicos – fitoplancton – calidad del agua – noroeste.

**IntroducTION**

The physiochemical composition of the water in lentic water bodies is influenced by human activities and the interactions between climatic and geochemical variables in the drainage basin zone.

The reservoirs of Cabra Corral and El Tunal (upper Juramento basin, Salta) and those of El Cadillal, Escaba and Río Hondo (Salí-Dulce river basin, Tucumán) are strategic for the socio-economic development of the provinces of Salta, Tucumán and Santiago del Estero.

The endorheic basin of the Salí-Dulce river is the second most polluted Argentine basin after the Riachuelo basin (Buenos Aires). In contrast, the Juramento basin exhibits a continued deterioration which has accelerated over the last decade.

The main population settlements or industrial development poles, including mining processing and activities related to intensive agriculture, livestock rising and deforestation are located on either side of the basins.

As a result, they are amenable to point and non-point pollution, which is currently increasing the level of deterioration in reservoirs and affecting the current uses of the resource (hydroelectric power production, irrigation, recreation and fishing) and, in the case of El Cadillal, water supply for the 60% of the population in the Tucumán capital.

Although there are previous isolated studies conducted on the reservoirs dating back more than ten years (Locascio Mitrovich *et al*. 1997; Tracanna *et al*. 1991, 1996, 1999, 2006, 2014a,b; Salusso, 2005, 2010; Salusso y Moraña, 2000, 2014a,b), comparative studies on the reservoirs of both basins have not been published.

This paper compares the water quality status and phytoplankton biomass in the Cabra Corral (CC) and El Tunal (ET) reservoirs of the upper Juramento basin (UJB) and in the El Cadillal (EC), Escaba (Es) and Río Hondo (RH) reservoirs of the Salí-Dulce basin (SDB) in order to establish the relative level of deterioration.

**study area and methodology**

The endorheic SDB has a dense network of rivers extending virtually all across the province of Tucumán. The tributaries originating in and flowing down from the Calchaquí summits and the Aconquija Mountain drain their water into the Mar Chiquita Lake (Córdoba). The basin exhibits two artificial reservoirs on the main tributary, the Salí River: EC and RH and, as part of the Marapa River sub-basin, the Es reservoir which receives its water from the Singuil and Chavarría permanent watercourses.

The reservoirs of the SDB are located as follows: Es 27o39′31.6″ S, 65o45′46.3″ W, EC 26o40′ S, 65o7′ W, and RH 27o30′ S, 65o45′ W.

The UJB is the most significant contribution zone to the Salado system. It covers a large area in the province of Salta and comprises the Calchaquí, Lerma and Metán Valleys; the latter two valleys represent the areas with greater economic turnover and population density (>50% of provincial population). The Cabra Corral dam (CCP) is the largest in the UJB and receives its water from two main tributaries, the Guachipas river (CCG) in the south and the Arias-Arenales river (CCA) in the north, and drains into the Juramento river. ET is located in the Chaco-Salteño Plain and receives 70% of its water from the Juramento river. The reservoirs of the UJB are located as follows: CC 25o17′43.3″ S, 65o20′48.8″ W and ET 25o14′43″ S, 64o28′35.8″ W.

The EC and Es (province of Tucumán), RH (the border between Tucuman and Santiago del Estero), and CC and ET (province of Salta) reservoirs were sampled on three different dates; the first one during the months of minimum water flows (October or November) and the other two in the floodwater period (February and May) during 2002-2008, totaling 21 dates. In ET, Es and EC, the samples were collected in the dams themselves (ETP, EsP and ECP) whereas for ET (ETC) and EC (ECC) the sampled were collected in the major tributary inflows or “*colas”*. In CC, the dam itself and the CCG and CCA river inflows were sampled. For all sites, the samples were collected at depths of one Secchi disk.

The following physicochemical variables were measured: transparency (m), pH (units of pH), conductivity (uS.cm-1), turbidity (NTU), temperature (T °C), dissolved oxygen (mg/L and % saturation), nitrate (N-NO3-/L), soluble phosphate and total phosphate (P-PO43=/L) using the APHA methods (2005), chlorophyll-*a* corrected for phaeophytins with 90% acetone extraction (Wetzel & Likens, 1991) and phytoplankton density (ind/ml) with the Utermöhol technique (1958).

The results were analyzed through InfoStat software (Di Rienzo *et al.* 2013). In the case of nonnormal distribution data for the comparison between the sites, the nonparametric Kruskal-Wallis (H) test was used. This test replaces ANOVA when normal distribution and/or homogeneous variances assumptions are not met (Bartlet test). For the comparison of the hydrological cycle stages or that of the two basins, the Student’s t-Test or Mann-Whitney U-Test was used, as appropriate.

Correlations between the variables were made (Pearson coefficient, *p*<0.05). The Principal Component Analysis was carried out considering the sites in both hydrological cycle stages and 16 limnological variables: phytoplankton biomass (expressed in density of individuals ml-1, and in chlorophyll-*a* concentration mg.m-3) as well as the various algal community attributes: diversity (H), number of species (R) and species equitabilities (J) and the physicochemical variables pH, conductivity, transparency, total suspended solids (TSS), T °C, % O2 saturation, dissolved oxygen (DO), turbidity, and nitrate, orthophosphate and total phosphorus concentrations.

The distinctive features of the monitored reservoirs are shown in Table 1. The reservoirs of both basins are located in environments well-differentiated by their geomorphology, climate, phytogeography and human influence. The temperature of the region differs as a result of its topographical location, but during the winter and in all cases is above 4°C (Table 2). The water bodies exhibit a typically monomictic winter mixing period. The average records of the environmental temperature were greater in RH, with the lowest temperatures in Es (Table 2).

The average annual rainfall in the various basins is sufficient to produce soil erosion, as it exceeds 400 mm (Ryding y Rast, 1992).

Orographic conditions are determined by the strong Andean relief and the Sub-Andean and and Pampas mountain ranges, and play an important role in the region’s climate by establishing the rainfall distribution, which concentrates between November and March each year (Table 2).

In general, the water bodies’ dammed volumes are minimum in spring and maximum in summer-fall in accordance with the rainfall distribution.

The seasonal rainfall pattern restricted to the warm summer months provides significant water volumes that permit the reservoirs to reach their peak between April and May. Located in the piedmont of the cloud forest or *yungas*, the Es reservoir is prone to greater relative rainfall (reaching 2171 mm annually); at the other end are the water bodies located in the most arid region of the xerophytic Chaco (ET may show values <400 mm annually and RH 512 mm in total). In all water bodies pronounced differences in the levels are noted with the deepest levels at 30 m as the water is used for irrigation during dry periods or for human supplies in places such as EC. Because of its ionic composition, the water in the reservoirs of the UJB is calcium-bicarbonate-type (Salusso, 2005), sodium- to calcium-bicarbonate-type in Es, sulfate-sodium-calcium-bicarbonate-type in EC and bicarbonate-sodium-calcium-sulfate-type in RH (Tracanna *et al*. 2014a).

**RESULTS**

The reservoirs exhibit differential morphological and hydrological features (Table 1), RH presenting the largest relative surface area and CC with the largest water depth and residence time. On the other hand, Es presents the lowest relative surface area and volume.

On the basis of the winter mixing and summer stratification, the reservoirs are characterized as warm monomictic (Salusso, 2005; Tracanna *et al*. 2006); in this study, no differences in their sites were found regarding the values for water temperatures with an average 22.56°C, a peak of 31.80°C in March 2008 in the case of the water flowing from the Juramento river into the ET reservoir.

In all the reservoirs, the pH values ranged on the neutral to alkaline scale, suggesting an appropriate buffer capacity (Table 3) with no significant differences among the water bodies. The lowest pH relative value (7.71) was found for Es in May 2002 and the highest value for CC in the dam itself (9.52) in February 2004.

The highest turbidity was found in RH both in the dam itself and in the Salí river inflow or *cola* (RHC); on the other hand, the Es and CC dams showed the lowest turbidity values, separating themselves from the others.

EC showed the highest conductivity average (987.67 µS.cm-1), significantly distinguishing itself from the others. RH, ET and CC are in a descending salinity gradient with no statistical differences. Es is at the other extreme, showing the lowest conductivity value (205.44 µS.cm-1). RH, ET and EC exhibited the lowest transparency average, significantly different from CC and Es (Table 4).

The transparency values were lower in the RHTC (0.67 m) and in the ET (0.70 m) and EC (0.73 m) river inflows; the highest value was found in the CC dam (2.03 m) (Table 4). In other words, the Secchi disk was lower in those reservoirs showing a lower volume-to-surface ratio such as RH with 4.17 and ET with 7.62.

Differences between the remaining variables that determine trophy have also been found among the reservoirs (Table 4). In connection with nutrients, the reservoirs of the UJB exhibited lower nitrate values compared with those of the Salí-Dulce basin. EC exhibited the highest nitrate contents. Unlike the other reservoirs, soluble and total phosphorus contents were significantly higher in RH alone.

The reservoirs with higher average biomass levels were Cabra Corral in all of its sites during minimal water flows or *estiaje* (CCPE=63.36 mg Chl-*a* m-3; CCAE=54.62 mg Chl-*a* m-3 and CCGE=36.74 mg Chl-*a* m-3) and Escaba (EsPE=51.32 mg Chl-*a* m-3).

The Principal Component Analysis carried out in the sites during both stages of the hydrological cycle and the 16 limnological variables allowed the reduction to two components, explaining the 49% of the cumulative variance. The first component explained the 32.3% of the variability of the data, the most contributing parameters being the ecological attributes and phytoplankton biomass, dissolved oxygen, soluble nitrate, and transparency (Table 5, Fig. 1). This component contributed to a separation of the sites according to the various stages of the hydrological cycle: samples obtained during waterfloods were located toward the extreme positive end, when most reservoirs exhibited higher values for species diversity (H) with a peak in the RH river inflow (RHC) (H=3.41) and for species richness (30 spp.). The uniformity of distribution of abundance among the species was maximum in EC (J=0.75). In this period, the lowest biomass values were found, particularly in EC (*cola* 2.74 mg Chl-*a* m-3 and dam 3.79 mg Chl-*a* m-3). During waterfloods the values for dissolved oxygen were found to be lower, e.g. in Es (EsPC=55%) as were the values for transparency in tributary inflows, e.g. in ET (ETC=0.59 m) and EC (ECPC=0.64 m). EC exhibited the highest nitrate contents (dam 0.49 N-NO3= and *cola* 0.48 mg N-NO3=).

On the extreme negative end of the first component, the collected samples were distributed during the stage of minimum water flows as the longer water residence time favored an increased algal biomass, particularly in the CCP (CCP=63.36 mg Chl-*a/*m3) and Arias-Arenales river inflow (CCA=54.62 mg Chl-*a/*m3). In general, a higher chlorophyll concentration was also found in other dams during that same stage, e.g. EC (53.61 mg Chl-*a/*m3), Es (51.32 mg Chl-*a/* m3) and ET (25.58 mg Chl-*a/* m3).

The second component explained the 16.5% of total variance, with the most contributing parameters being TP, turbidity and its total suspended solids, reactive soluble phosphorous (RSP) and algal density (Table 5). The separation of the site in this axe was mostly according to nutrients: toward the positive end, RH is notable for its phosphorus level (TP=0.77 mg/L; PRS=0.44 mg/L) during dry periods when endogenous release of nutrients is higher with low-to-negative redox potentials. Turbidity in the Salí reservoir inflow during the dry periods is also higher (NTU 67.51) as a result of agroindustrial effluents during these periods in accordance with lower transparency values (0.52 m). On the extreme negative end of the second component, floods in the EsP and ECP are noted with higher average nitrate values (N-NO3= 0.51 and 0.49 mg/L, respectively).

A common scenario for the phytoplankton was noted in all the reservoirs as dominance variance was scarce: diatoms in mixis, and chlorophytes and cyanobacteria in stratification with a few abundant species, including Bacillariophyta: *Aulacoseira granulata, Cyclotella meneghiniana;* Chlorophyta: *Chlamydomonas spp., Planktosphaeria gelatinosa, Sphaerocystis schroeterii, Oocystis spp., Monoraphidium spp., Closterium spp., and* Cyanobacteria: *Dolichospermum flos-aquae, Microcystis aeruginosa, M. flos-aquae*, *Lyngbya* spp., *Chroococcus spp.,* Cryptophyta: *Rhodomonas minuta*, and Dinophyta (*Ceratium hirundinella*).

In dry periods phytoplankton abundance is higher in the water flowing from Salí river into the RH dam (RHPE) and in that flowing from the Guachipas river into the CC dam (CCGE). Although Es exhibited the highest value for floods (3175 ind/ml), other high point values were also registered during floods in CCP (66227 ind/ml, March 2007) and ET (13236 ind/ml, May 2008).

The higher frequency of species diversity in all the reservoirs was between the range 1.71 and 2.32, with ends of 0.18 found in ECC in December 2005 and 0.22 in CCP in October 2003, and 4.46 in RHT in March 2005 and 4.26 in ECT in May 2005. The reservoirs of the UJB exhibited the lowest species diversity averages at low flows: CCP 1.37 and ETP 1.59. During floods, the Salí-Dulce reservoir exhibited higher specific diversities in the water flowing from both the RH and EC rivers into the Salí reservoir with averages of 3.41 and 3.09, and in the reservoirs 3.05 and 3.04, respectively.

All reservoirs distinguished themselves in terms of the following biological variables of the hydrological cycle stages: higher phytoplankton biomass at low flows (35.68 mg Chl-*a* m-3) vs. floods (13.68 mg Chl-*a/* m3) (T=3.42; *p*=0.001). During minimum water flows, species richness (14.30 sp) and equitability (0.51) were lower vs. floods (20.23, 0.59, respectively) (T=2.36; *p*=0.0196). No differences in abundance were noted among the phases; this is not a suitable measure for the relative contribution as it is not expressed in cell biovolumes.

**DISCUSSION**

As the reservoirs exhibited an appropriate buffer capacity, the acidification processes pose no current problems; the converse would be true as a result of mining and industry promotion and partly of wind-borne volcanic ashes. The lowest relative pH value was found in Es during floods when decomposing plant material contribute with humic-fulvic substances as a result of the production of organic acids that slightly acidify the water.

Differences in physicochemical variables concerning the basin geochemistry were found among the reservoirs. The substrate’s crystalline basement exhibits limited mineralization in the Es basin and its nature is reflected in hydrochemical status of its water. Here the conductivity values are the lowest as a result of a virtually preserved forest which serves as a barrier mitigating the erosive effect. The highest average was found in an increasing gradient in EC, where the high salinity contents result from the combination between hydrogeochemistry (tertiary sedimentary rocks with sandstones, silts and gypsum banks) (Tracanna *et al*. 2006) and the mesoxerophitic climatic condition, which favors ion lixiviation from recently deforested farmland.

In RH, the maximum suspended material concentration is the result of both the bioseston and the non-sestonic material that generate similar turbidity in the entire water body with no differentiation of the various hydrological cycle stages. The significant volume of allochthonous material received is produced by point source and non-point source of anthropic pollution in spite of the temporary sedimentation processes that occur as its tributaries lose speed when flowing into the plain.

In ET, the sedimentation values are mainly a result of the basin geomorphological nature as well as of the laminar erosion of the topsoil in the surrounding soy plantation area. Dissolved ions originate when the Juramento river is filled with salts in flowing through tertiary sedimentary rocks in Sierra de Lumbrera, a meterorization effect accentuated by surrounding steep slopes (Sierras de Metán, Guanacos and Lumbrera). The suspended solid contents and turbidity in EC are the result of the steep slopes of the summits (Calchaquí Valley and Medina) with readily erodible limo loessian soils and scarce vegetation cover, typical of the semi-arid microclimate in the Tapia-Tranca Valley (Adler, 2004).

Nutrients were higher in the Salí-Dulce basin with the highest nitrate average found in EC and that of phosphorus in RH, as reported in previous papers during 1988-1992 (Locascio de Mitrovich *et al*., 1997). These values are mainly a result of the reception of citrus, alcohol and sugar industry effluents and wastewater discharges especially during July-August (Tracanna *et al*. 1996).

The reservoirs in the plains exhibited less biomass production: mostly at the expense of the suspended solids in ET and in RH also as a consequence of the impact of inflowing pollutants. In EC algal biomass production is also limited on the basis of the erodible material and dissolved salts received.

An overall climatic pattern of greater algal biomass concentration was found at low flows when water mass stabilization is achieved, which favors phytoplankton development.

A clear pattern of nitrogen records has been observed in relation to the hydrological cycle stages, the highest values being found during floods (0.28 mgN/L) vs. minimum water flows (0.18 mgN/L) (T=2.73; *p*=0.0069). Although in reservoirs with lower surface area and volume (Es, EC, ET) the exogenous nitrogen reception increases during high water phases, those with greater surface area and volume (CC and RH) tend to exhibit higher contents at low flows as a possible result of mineralization and inner regeneration.

The comparison between limnological variables among the basins yielded higher values for nitrate, electrical conductivity, density, diversity and species richness in the SDB. If Esc is not considered, the same is true for the phosphorus values.

In addition, significant correlations were noted between nitrate contents and chlorophyll concentration (*p*=0.0001) and nitrogen vs. species diversity and richness (*p*=0.013) in the SDB. In RH, cyanobacterial blooms were recorded during the sugarcane harvest period, which was favored by high temperatures, lack of winds and high nutrient concentrations. *Dolichospermum flos-aquae, Microcystis aeruginosa and M. flos-aquae* were the species that most frequently contributed to it.

In the UJB, algal density was positively correlated to phosphorus (*p*=0.0015). Cyanobacteria blooms (*Microcistys* spp., *Dolichospermum spiroides, D. circinalis*) were related to high temperature events and increased residence time (Salusso y Moraña, 2014). Total biomass, especially in ET, was conditioned by hydrometric level management.

During the period 2002-2008, the reservoirs with greater depths and volume-to-surface ratio (CC and Es) exhibited more significant average biomass productions in spite of their considerable differences in the contribution basin zone and the anthropic impact received. On the other hand, final collecting water body (RH and ET) held the highest species diversity and richness attributes.

The location of the reservoirs within the basins had an impact on phytoplankton as the species diversity and richness were higher in the reservoirs (ET and RH) in the stretches of plains at the end of the systems. Both of these have the lowest relative depths and may incorporate benthic species through resuspension in the water column after thunderstorm events, fish bioturbation, or resuspension and activation of resistance states from sediments (Verspagen *et al.* 2005). In addition, the lateral connectivity provided by the tributaries allows increased species richness (Tracanna *et al*. 1996, 1999; Salusso, 2005).

The multiple uses of the reservoirs in combination with the anthropic impacts on the basins as well as the lack of management programs have favored an artificial eutrophication which led to the loss of water quality and biodiversity (Salusso, 2005; Tracanna *et al*. 2014b). As for the hydrological cycle, an intense rainfall during floods (summer and fall) produces a diminished phytoplankton biomass, also typical in Brazilian reservoirs (Tundisi y Matsumura-Tundisi, 2008) with increased diversity in rainy seasons and decreased diversity in dry seasons (Souza, 20014). The hydrometric level is reduced by the continued use of water in the reservoirs in the August-December period, with the subsequent elevation of pH, alkalinity, salt and nutrient concentration values during the dry season (Salusso y Moraña, 2000).

In most reservoirs, a permanent eutrophic condition induces cyanobacterial growth as favored by scarce transparency and elevation of temperatures, nutrient concentrations (especially nitrogen and phosphorus), pH, alkalinity and water residence time (Salusso y Moraña, 2014a; 2015; Tracanna *et al.* 2014b). Competition for nutrients with dinophytes may be one of the reasons for the lack of cyanobacterial blooms at certain times in the Juramento reservoir (Salusso, 2010), as it was the case for the Brazilian reservoirs (Barbosa *et al*. 2012; Moura y Henry Silva, 2015).

Higher *Ceratium spp.* biomass have been reported since 1999 in eutrophic tropical and sub-tropical waters (Nishimura *et al*. 2014). Dinoflagellate populations immobilize large quantities of nutrients and slow down both the total activity of the ecosystem (Serruya *et al*. 1980) and the competition for nutrients, which may be one of the reasons for the lack of cyanobacterial blooms (*Microcystis*) in some Brazilian reservoirs and at certain times in the UJB.

In a comparative study between sub-tropical Brazilian and Argentine reservoirs (Salusso y Moraña, 2014b), morphometric variables such as surface area, average depth and geographical location (latitude) were not found to be decisive for algal biomass as the phytoplankton biomass was regionally regulated by the relative availability of nutrients (especially nitrogen) regardless of the water body distribution (altitude, substrate typology and relative anthropic pressure).

The resulting nutrient enrichment permits the recruitment of new species and the increase in diversity, as documented for northwestern Argentine reservoirs.

The semi-arid regions’ values for trophic variables in the reservoirs of Northwestern Argentine exhibit greater variations throughout the year and are dependent on the inflowing external loads of nutrients during the floods periods of the hydrological cycle (Salusso, 2010). In general, aridity increases autotrophy when biomass-concentrating damned volumes are reduced.

Furthermore, studies at wide geographical scale in the northern hemisphere demonstrate a positive correlation between the surface area of lentic bodies and species richness, and negative correlation between the surface area of lentic bodies and depth (Stomp et al., 2011). In the five reservoirs studied, concordance was only found between species number and depth; interestingly, CC is the second largest surface area, but exhibits the lowest species average. When the volume-to-surface ratio were linked to the number of species, the reservoirs with values >20 were found to be exhibit lower species richness (Table 1) and are unlikely to incorporate benthic inocula.

Weather and climate conditions play a key role in the dynamics of these aquatic systems as changes in the hydrological cycle induce modifications of the main limnological variables which in turn modify the phytoplankton structure.

**REFERENCES**

* Adler, F. J. 2004. Embalse El Cadillal (Provincia de Tucuman), situación actual y futura. CET. *Revista Fac.Cienc.Exactas Tecnol*.UNT.27:49-56.
* APHA (American Public Health Association). 2005. Standard methods for the examination of water and wastewater. 21th ed.Washington. 1030 pp.
* Barbosa, L.J.E., Medeiros, F.E.S., Brasil J., da Silva Cordeiro, R., Crispim M.C. & Gonzaga da Silva G.H. 2012. Aquatic systems in semi-arid Brazil: limnology and management. *Acta Limnol.Bras*. 24(1): 103 – 118.
* Di Rienzo J.A., Casanoves F., Balzarini M.G., Gonzalez L., Tablada M. & Robledo C.W., InfoStat, 2013. [Online] Available: http://www.infostat.com.ar (August 12, 2013)
* Locascio de Mitrovich, C., A. Villagra de Gamundi, B.C. Tracanna, C. Seeligmann & C. Butí. 1997. Situación actual de la problemática limnólogica de los embalses de la provincia de Tucumán. Seminario Internacional sobre Evaluación de la calidad de pequeñas cuerpos de agua en los trópicos y subtrópicos de Sudamérica. La Paz, Bolivia.
* Moura, R.S.T. & G.G.Henry Silva. 2015. Limnological characteristics of a hydrographic basin of the Brazilian semiarid region. *Acta Limnol. Bras*. 27 (1): 51 – 59.
* Nishimura P.Y., Meirinho P.A., Moschini-Carlos V. & M.L.M.Pompeo. 2014. Does the plankton community follow the horizontal water quality heterogeneity in a tropical urban reservoir (Guarapiranga reservoir, Sao Paulo, Brazil)? *Limnetica* 33 (2): 263 – 280.
* Ryding S. & Rast W. 1992. El control de la eutrofización en lagos y pantanos. Ed. Pirámide, Madrid. 375 pp.
* Salusso, M.M. 2005. Evaluación de la calidad de los recursos hídricos superficiales en la Alta Cuenca del Juramento (Salta). Tesis doctoral, Universidad de Buenos Aires.203 p. [Online] Available: http://bl.fcen.uba.ar. (octubre 2015).
* Salusso M.M. 2010. Caracterización limnológica de una cuenca subtropical árida del noroeste argentino. Editorial Académica Española, 126 pp. España.
* Salusso M.M. & Moraña L.B. 2000. Características físicas, químicas y fitoplancton de ríos y embalses de la Alta Cuenca del río Juramento (Salta, Argentina). *Natura* *Neotropicalis* 31(1-2): 20- 44.
* Salusso,M.M.& Moraña L.B. 2014a. Fitoplancton de embalses subtropicales del noroeste argentino. *Gestión y Ambiente* 17 (1): 209-222.
* Salusso, M.M, & Moraña L.B. 2014b. Relaciones entre biomasa algal y nutrientes en embalses subtropicales de Argentina y Brasil. *Lhawet* 3(3): 49 – 54.
* Serruya C., Edelstein M. & Pollingher U. 1980. Lake Kinneret: carbon flow patterns and ecosystem management. *Archiv. fur Hydrobiologie* 88: 265 – 302.
* Souza, M.da C. 2014. Influencia das mudancas climáticas na estructura funcional da comunidade fitoplanctonica em um reservatorio da regiao do semiárido. Pp.33. Universidade Federal do Río Grande do Norte. Natal, Brasil.
* Stomp M., Huisman J., Mittelbach G.G., Litchman E. & Klausmeier Ch. 2011. Large-scale biodiversity patterns in freshwater phytoplankton. *Ecology* 92 (11): 2096 – 2107.
* Tracanna B.C., Villagra de Gamundi A., Seeligman C. ,Locascio de Mitrovich, C. & Drago E. 1991. Limnologia del embalse el Cadillal (Tueumán, Argentina). I. Variables morfométricas y fisico-quimicas. *Rev. Hiydrobiol. trop*. 24 (4): 269-286.
* Tracanna B.C., Seeligman C., Mirande V. 1996. Estudio comparativo de la comunidad fitoplanctónica de dos embalses del noroeste argentino. *Rev. Asoc. Cienc. Nat. Litoral* 27(1): 13 – 22.
* TracannaB.C., Seeligman C.T., Mirande V., Benítez de Parra L., Torres de Plaza M. &Molinari FM. 1999. Cambios espaciales y temporales del fitoplancton en el embalse Río Hondo (Argentina). *Bol. Soc. Argent. Bot.* 34 (1-2): 101-105.
* Tracanna B. C., Martínez De Marco S. N., Amoroso M. J., Romero N., Chaile P. & A. Mangeaud. 2006. Physical, chemical and biological variability in the Dr. C. Gelsi reservoir (NW Argentine): A temporal and spatial approach. *Limnetica* 25 (3): 787-808.´.A
* Tracanna B.C., Martínez De Marco S.N., Taboada M. A., Mirande V., M.L. & S.C. Isasmendi. 2014a. Assessment of the physicochemical variables of a subtropical reservoir in the northwest of Argentina. *Acta Limnol.Bras*. 26(4): 367- 380.
* Tracanna B.C., Seeligmann C.T., Mirande V., Martínez De Marco S.N. & S.C.Isasmendi. 2014b. Peri-Pampean Sierras aquatic systems in Tucumán Province. *Advanc. Limnol*. 65: 199 – 213.
* Tundisi, J.G. y Matsumura-Tundisi, T. 2008. Limnologia. Oficina de Textos, Sao Paulo, Brazil. 631 pp.
* Wetzel R.G. & Likens G.E.1991. Limnological analyses. 2nd edition. Springer-Verlag. New York. 891 p.
* Utermöhl H. 1958. On the perfecting of quantitative phytoplankton method. Inter. Assoc. of Tehor.and Appl. Limn. Proc. V. 9, 38 p.
* Verspagen, J. M. H., Van de Waal, D. B., Finke, J. F., Visser, P. M., Donk, E. V., and Huisman, J. 2014. Rising CO2 levels will intensify phytoplankton blooms in eutrophic and hypertrophic lakes. *PLoSONE*9:e104325.doi: 10.1371/journal.pone.0104325

**Table 1.Morpho-Hydrometric Features of Reservoirs**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Reservoir | Area (km2) | Volume (Hm3) | Zmax(m) | Tw(yrs.) | Drainage basin (km2) | Zav(m) | V/S(volume/surface) | Heightasl |
| El Cadillal | 13.6 | 240 | 50 | 0.51 | 5,200 | 17.6 | 17.65 | 610 |
| Río Hondo | 340 | 1600 | 25 | 0.48 | 10,000 | 4.0 | 4.71 | 260 |
| Escaba | 5.85 | 126 | 65 | - | 800 | 21.5 | 21.54 | 650 |
| C. Corral | 113.6 | 2904 | 50 | 1.5-2.5 | 30,000 | 27.5 | 25.56 | 945 |
| El Tunal | 22.83 | 174 | 35 | 0.25 | 5,900 | 7.6 | 7.62 | 475 |

Zmax: maximum depth Zav: average depth

Tw: hydraulic residence time

Height asl: height above sea level

**Table 2. Climatic Variables for Reservoirs of Salí-Dulce and Juramento Basins**

|  |  |
| --- | --- |
| Rainfall. | Monthly Air Temperature Averages (T ºC) |
| Reservoir | mm | Jan. | Feb. | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Year |
| Escaba | 1200 | 23.8 | 23.0 | 20.9 | 17.5 | 14.4 | 10.9 | 10.7 | 12.5 | 15.2 | 18.8 | 21.4 | 23.4 | 17.7 |
| El Cadillal | 1000 | 24.3 | 23.5 | 21.6 | 18.2 | 15.2 | 11.8 | 11.6 | 13.5 | 16.3 | 19.8 | 22.2 | 24.0 | 18.5 |
| Río Hondo | 512 | 26.8 | 25.8 | 23.5 | 19.9 | 16.6 | 13.0 | 12.9 | 15.0 | 18.3 | 22.1 | 24.6 | 26.6 | 20.4 |
| Cabra Corral | 416 | 23.8 | 22.9 | 21.2 | 18.1 | 15.0 | 11.9 | 11.7 | 13.8 | 16.7 | 20.1 | 22.1 | 23.6 | 18.4 |
| El Tunal | 667 | 25.6 | 24.6 | 22.9 | 19.6 | 16.7 | 13.4 | 13.2 | 15.2 | 18.1 | 21.7 | 23.8 | 25.3 | 20.0 |

**Table 3. Water Physicochemical Variables in the Sampling Sites of the Reservoirs, Period 2002-2008**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Site | pH | SD | Turbidity | SD | Conductivity | SD |
| CCA | 8.86 | 0.33 | 23.92 b | 35.73 | 365.59 ab | 60.64 |
| CCG | 8.67 | 0.37 | 16.72 ab | 16.72 | 367.96 bc | 56.22 |
| CCP | 8.81 | 0.52 | 13.35 a | 17.53 | 427.45 ab | 58.95 |
| ECC | 8.57 | 0.23 | 25.39 b c | 23.55 | 987.67 e | 320.42 |
| ECP | 8.44 | 0.30 | 28.56 b c | 38.75 | 945.94 e  | 326.49 |
| ETC | 8.76 | 0.28 | 21.02 b c | 15.54 | 568.11 cd | 75.77 |
| ETP | 8.63 | 0.49 | 20.45 b c | 18.15 | 529.89 bcd | 83.24 |
| RHC | 8.42 | 0.50 | 48.61 c | 66.71 | 655.40 d | 167.02 |
| RHP | 8.45 | 0.38 | 38.03 c | 58.00 | 657.35 d | 161.93 |
| Es | 8.20 | 0.45 |  6.96 a | 4.16 | 205.44 a | 40.44 |
|  | Not significant |  | H= 27.80*p*= 0.001 |  | F= 39.69*p*<0.0001 |  |

*Different letters in each column indicate highly significant differences among the sites*

**Table 4. Mean Trophic Variable Values in the Reservoirs of Both Basins, Period**

**2002-2008**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Secchi (m) | N-NO3= | P-PRS | P-TP | Chl-*a*\* |
| Cabra Corral | 1.77 a | 0.20 a | 0.16 a | 0.65 a |  15.18 a |
| El Tunal |  0.86 b | 0.17 a | 0.13 a | 0.63 a |  8.61 b |
| Escaba | 1.12 a |  0.23 ab | 0.09 a | 0.15 a |  15.57 a |
| El Cadillal |  0.91 b | 0.37c | 0.16 a | 0.22 a |  6.72 b |
| Río Hondo |  0.78b |  0.26 b |  0.43 b | 0.77 b |  6.74 b |
|  | *p* <0.0001 | *p* <0.0001 | *p* =0.0001 | *p* <0.0001 | *p* =0.023 |

(\*) *Median*

**Table 5. PCA eigenvector matrix of the main limnological variables estimated**

**in northwestern reservoirs**

Variables e1 e2

pH -0.25 0.22

Conductivity 0.05 0.17

T ºC 0.20 0.14

% DO -0.33 0.14

Turbidity 0.15 0.39

Secchi -0.30 0.08

NNO3 0.21 -0.31

P-PRS 0.14 0.37

P-TP 0.05 0.44

Chl-*a* -0.36 0.03

Algal density -0.05 0.38

Diversity 0.39 -0.02

Richness 0.33 0.09

Equitability 0.36 -0.06

**Table 6. Trophic Variable Values in the Reservoirs, Period 2002-2008**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Reservoir | Chl-*a* | Dens.\*(ind./ml) | H\* | Nro. Sp.\* | Nro. Sp. |
| C.C. | 29.88a | 1657b | 2.08a | 14ª | 15.76a |
| E.T. |  13.07 b | 1619b |  2.60 b | 18.5 b | 19.86 b |
| Es | 33.38a | 1467ab | 2.12ab | 15 ab | 17.17 ab |
| E.C. | 19.96 b | 784a | 2.19ab | 17ab | 18.13ab |
| R.H. | 12.35 b | 698ab | 2.61 b | 21.5b | 21.79 b |
| Nivel sig. | 0.023 | 0.046 | 0.029 | 0.049 | 0.049 |

*(\*Medians) Different letters in each column indicate highly significant differences among the sites*

**Fig. 1. PCA of main limnological variables and hydrological phases in relation to phytoplankton descriptors in reservoirs of Juramento and Salí-Dulce Basins**

-5.00

-2.50

0.00

2.50

5.00

CP 1 (32.3%)

-5.00

-2.50

0.00

2.50

5.00

CP 2 (16.5%)

CCAC

CCAE

CCGC

CCGE

CCPC

CCPE

ECdCC

ECdCE

ECdPC

ECdPE

EsPC

EsPE

ETCC

ETCE

ETPC

ETPE

RHCC

RHCE

RHPC

RHPE

CCAC

CCAE

CCGC

CCGE

CCPC

CCPE

ECdCC

ECdCE

ECdPC

ECdPE

EsPC

EsPE

ETCC

ETCE

ETPC

ETPE

RHCC

RHCE

RHPC

RHPE