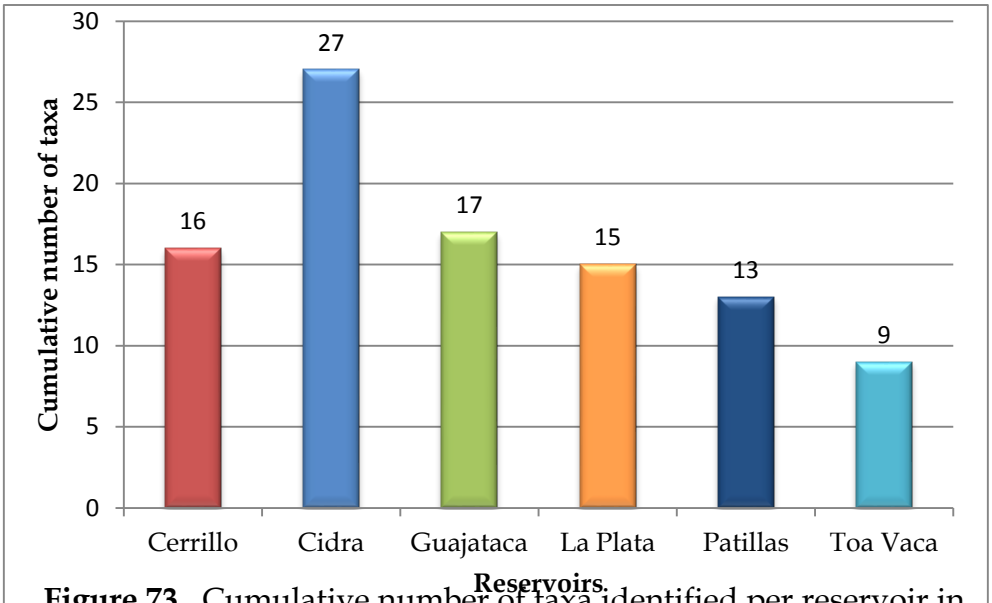


Figure 73. Cumulative number of taxa identified per reservoir in the third sampling of the second year of study (2013).

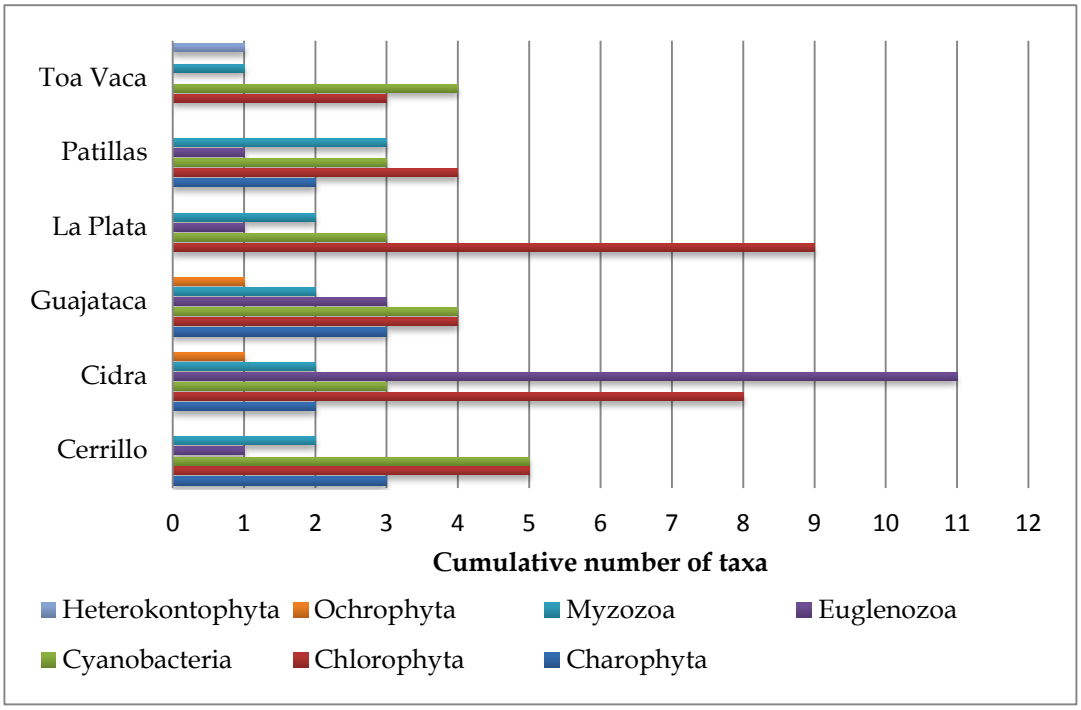


Figure 74. Cumulative number of taxa identified per phylum in each reservoir during the third sampling of the second year of study (2013).

Table 34. Soft phytoplankton identified during the third sampling of the second year of study (2013) in six reservoirs.

Taxon	Cerrillos	Cidra	Guajataca	La Plata	Patillas	Toa Vaca
Actinastrum sp.				X		
Coelastrum sp.		X				
Coelastrum astroideum	X					
Coelastrum cambricum						
Coelastrum proboscideum	X					
Cosmarium sp.	X	X	X		X	
Crucigenia tetrapedia						X
Colonial cyanobacterium	X	X	X			X
Filamentous, screw-like, curved cyanobacterium	X	X	X	X	X	X
Filamentous straight cyanobacterium	X	X	X	X	X	X
Cylindrospermum sp.				X	X	
Dinobryon sp.		X	X			
Euastrum sp.	X		X			
Eudorina sp.						
Eudorina sp.		X				
Euglena acus		X				
Euglena sp.			X			
Euglena sp.		X				
Golenkinia radiata				X		
Goniochloris sp.						X
Lepocinclis sp.		X				
Micractinium sp.		X		X	X	
Micractinium pusillum						
Microcystis sp.			X			
Pandorina sp.	X		X	X		
Pediastrum simplex	X	X	X		X	X
Pediastrum simplex var. *echinulatum*		X	X			
Peridiniopsis sp.	X	X	X	X	X	X
Peridiniopsis sp. (small)	X				X	
Peridinium sp.		X				
Phacus sp.		X				
Phacus sp. (small)		X				
Phacus cf. *pleuronectes*		X				
Phacus cf. *longicauda* var. *insecta*		X				
Platydorina caudata				X		
Polyedriopsis spinulosa				X		
Scenedesmus cf. *quadricauda*		X		X		
Staurastrum sp.	X	X	X		X	
Strombomonas sp.		X			X	
Treubaria cf. *schmidlei*		X		X		
Tetraedron minimum	X	X	X		X	X
Tetrastrum sp.						

Trachelomonas sp.	X	X		X		
Trachelomonas sp.(dark lorica)						
Trachelomonas sp. (small)			X			
Trachelomonas cf. *hispida* var. *crenulatocollis*		X				
Unknown cyanobacteria						
Merismopediaceae						
Unknown Chlorophyta						
Unknown Chroococcaceae	X					X
Unknown Euglenozoa		X	X			
Unknown Noctocacceae	X					
Unknown dinoflagellate			X	X	X	
Unknown circular solitary chlorophyte				X	X	
Total	**16**	**27**	**17**	**15**	**13**	**9**

7.2.2.4. Overall results for the soft phytoplankton analysis during the second year of study (2013)

Some 76 taxa, in thirty-five genera, were observed in the six reservoirs during the second year of study. Among these, 53% were Chlorophyta, 19% Euglenozoa and 13% Cyanobacteria (fig. 75).

When compared to the first sampling, during the second sampling the number of taxa increased for 4 of the six reservoirs, where Guajataca reservoir had the highest number of species. There was a reduction in richness during the third sampling for 3 reservoirs. However, species richness increased in Cidra and Cerrillos reservoirs during the third sampling (fig.76).

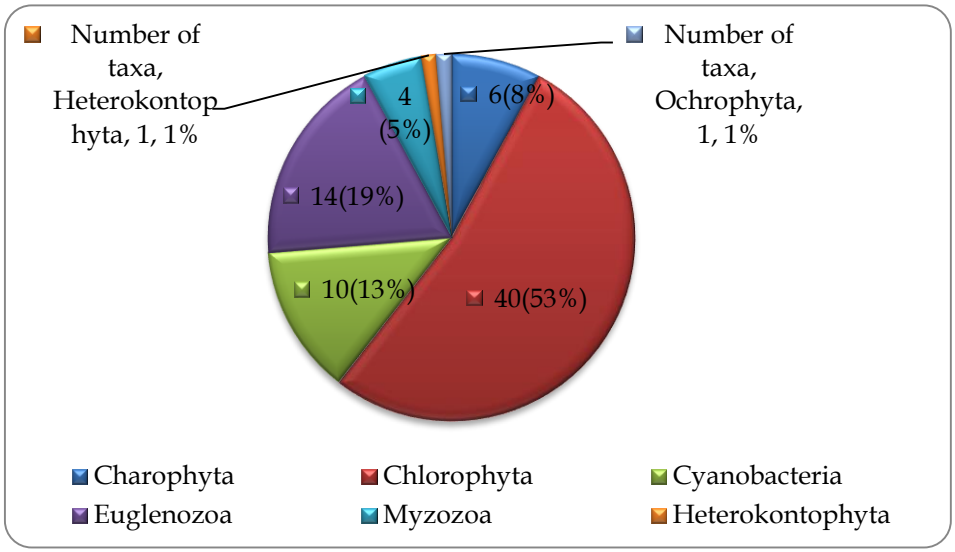


Figure 75. Phytoplankton composition (Phyla) during the second year of study (2013).

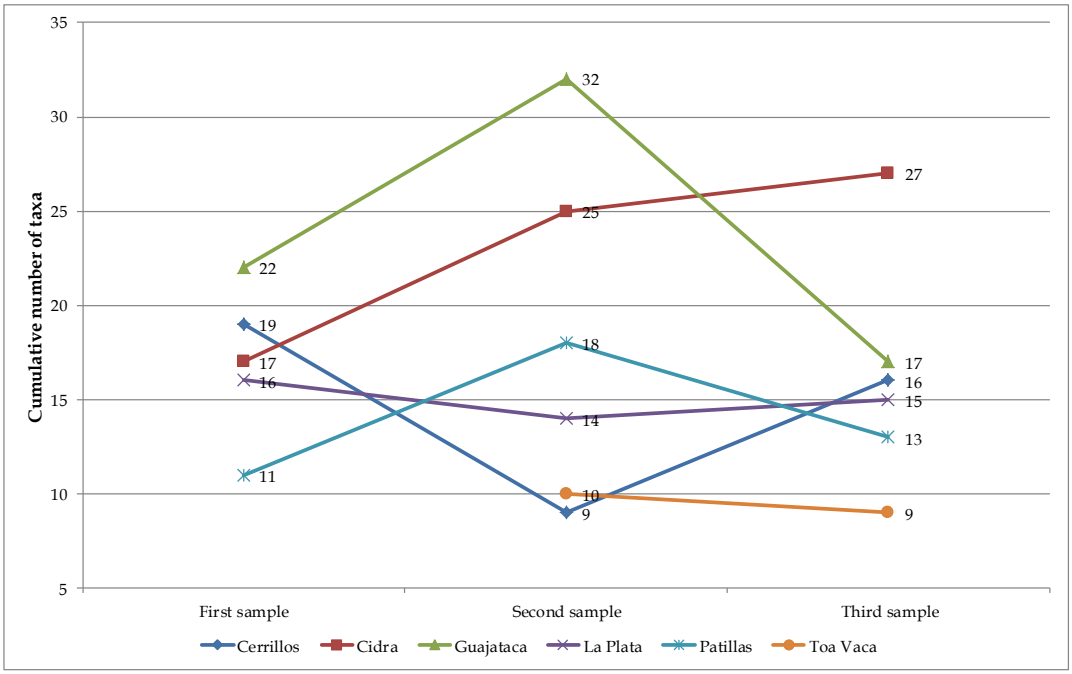


Figure 76. Pattern observed in cumulative number of phytoplankton taxa per sampling during the second year of study (2013) in the six reservoirs

Diatoms were the most abundant group in Cerrillos during the first two samplings; but, regardless of the presence of diatoms, cyanobacteria dominated in the third sampling. However, if we exclude the diatom and analyze only soft phytoplankton, we will observe that *Staurastrum* (Charophyta) and *Tetraedron minimum* (Chlorophyta) dominated in the first sampling, and *Pediastrum simplex* (Chlorophyta) and Cyanobacteria were the dominant taxa in the second sampling. In the third sampling, filamentous cyanobacteria and *Peridiniopsis* (Myzozoa) increased their abundances. We found higher diversity of chlorophytes in the first and third samplings, and an equal number of taxa for Charophyta, Chlorophyta, Cyanobacteria and Myzozoa during the second sampling campaign (fig. 77).

Cidra was one of the reservoirs with relatively high richness during the second year. In this reservoir, the phyla Chlorophyta and Euglenozoa were the most diverse taxa in the three samplings. In terms of density (cells/l), the dinoflagellates, like *Peridiniopsis* and *Peridinium*, were the most abundant in 2013. The green alga *Pediastrum simplex* and the ochrophyte *Dinobryon* were second in abundance in the first and second samplings, respectively.

Another reservoir with high diversity was Guajataca, where we observed an increase in diversity during the second sampling and a drastic reduction towards the third sampling. *Pediastrum simplex* dominated in the first and third samplings, but straight filamentous cyanobacteria dominated in the second sampling.

In La Plata, Chlorophyta dominated the three samplings during this year; comprising 50% of the organisms in the first sampling, 64% in the second sampling and

60% in the third sampling. The dominant species in the first sampling was a diatom; but, considering only the soft phytoplankton, it was *Pandorina* (Chlorophyta) followed by *Peridiniopsis* (Myzozoa). In this reservoir, the most abundant taxon in the second and third samplings was *Peridiniopsis*.

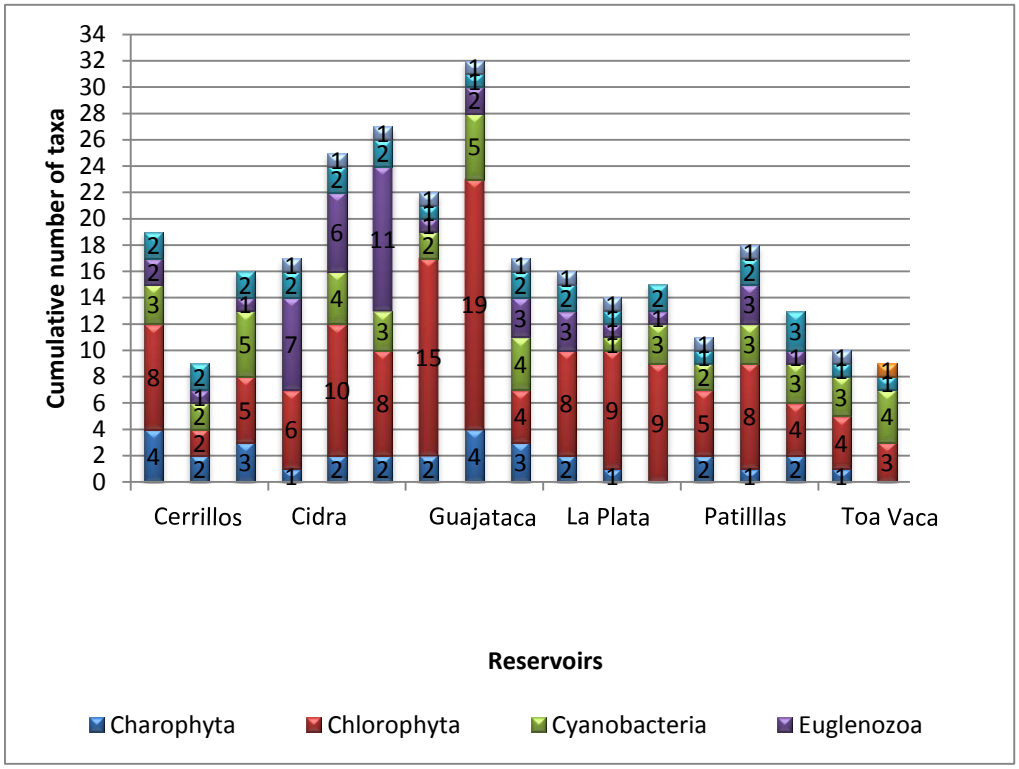


Figure 77. Cumulative number of taxa and contribution of each phylum for the phytoplankton of the six reservoirs during the second year of study (2013).

During 2013, Patillas was the only reservoir with a noticiably different value for the index of diversity; indeed, very low for in the first sampling (table 35). The similarity indexes between reservoirs were consistently lower than 0.5 (table 36). Each reservoir had a relatively unique algal community.

Table 35. Shannon Index (H') for the diversity of the six reservoirs in the second year (2013)

Samples	Cerrillo	Cidra	Guajataca	La Plata	Patillas	Toa Vaca
1	2.47	1.97	2.36	1.56	**0.77**	-----
2	1.56	2.97	2.94	2.24	2.24	2.17
3	2.50	1.62	2.44	2.36	2.50	2.66

Table 36. Jaccard Similarity index for the six reservoirs in the secon year of monitoring (2013)

Reservoirs	Cerrillos	Cidra	Guajataca	La Plata	Patillas	Toa Vaca
Cerrillos	1	0.35	0.29	0.27	0.31	0.32
Cidra	0.35	1	0.37	0.4	0.35	0.25
Guajataca	0.29	0.37	1	**0.45**	0.34	0.23
La Plata	0.27	0.4	0.45	1	0.42	0.2
Patillas	0.31	0.35	0.34	0.42	1	0.23
Toa Vaca	0.32	0.25	0.23	0.2	0.23	1

7.2.2.5. Overall results for the analysis of diatoms during the second year of study (2013) [with further analyses for the 2012 data].

7.2.2.5.1 Summary of diatom diversity per reservoir in 2013

A total of 21 taxa were identified, belonging to 13 genera, of which 14 were identified to species level. Dominant taxa present in oligotrophic (based on Carlson's Index) reservoirs were *Achnanthidium minutissimum*, centric diatoms, *Navicula* sp., and *Ulnaria acus*, *Ulnaria ulna*. For mesotrophic reservoirs, the dominant taxa were *Navicula* sp., *Synedra* sp., *Ulnaria acus* and *Ulnaria ulna*. In eutrophic reservoirs, centric diatoms, *Synedra* sp., and *Ulnaria ulna* were the dominant species.

Ulnaria ulna was the most common and abundant species, present in all six reservoirs, always above 25% of relative abundance regardless of the trophic state. A summary of the diversity indexes in each reservoir during the second year of study (2013) is given below, under each locality.

CERRILLOS

Ulnaria ulna had 62.3%, 99.5% and 35.6%, respectively, for the three sampling events in 2013. In the last sampling *Achnanthidium minutissimum* had a 44% of abundance.

CIDRA

Ulnaria ulna had 65.9%, 86.7% and 41.7%, respectively, for the three sampling events in 2013. In the last sampling *Synedra* sp. was 33.2% abundant.

GUAJATACA

Ulnaria ulna had 59.1%, 74.7% and 52.1%, respectively, for the three sampling events in 2013. *Ulnaria acus* had 40.1% of relative abundance in the second sampling.

LA PLATA

Ulnaria ulna had 91.5 and 79.3% of relative abundance in the first and third sampling events, respectively.

PATILLAS

Navicula sp. had 47.6, 69.6 and 69.6, respectively, for the three sampling events in 2013. *Ulnaria ulna* had 42.6% of relative abundance in the first sampling event.

TOA VACA

In the first sampling event, *Ulnaria acus* presented 20.4% of abundance and *Ulnaria acus* 34%. *Synedra* sp. had 95% of abundance in the second sampling.

7.2.2.5.2. Details on selected taxa

Achnanthidium minutissimum

This species was present in all the reservoirs, but was abundant only in Cerrillos. *A. minutissimum* is found to be sensitive to trophic conditions (oligo-mesotrophic to mesotrophic in indices like Trophy D, TDI and Rott), pH, oxygen, saprobity (Van Dam et al., 1994), physical disturbance or

toxic substances (Barbour et al., 1999; Charles et al., 2006), and is also known as an early colonizer (Biggs *et al*., 1998; Rimet *et al*., 2007). Has high tolerance of several environmental factors (Ponader & Potapova, 2007), occurs under a wide range of ecological conditions, being found in oligo- to hypereutrophic systems (Luttenton & Lowe, 2006). A trophic scaling of indifferent might thus be the best.

Ulnaria acus

This species was present in all reservoirs, not abundant in Cidra and Patillas. This species is eutrophication tolerant and has been associated with eutrophication in tropical streams.

Ulnaria ulna

This species was present and abundant in all the reservoirs. Van Dam and Mertens (1993) have accepted *U. ulna* as an indicator for eutrophic lakes.

7.2.2.5.3. Graphical depiction of idenxes

The following indexes were calculated: Jaccard (J), Margalef (M), Pollution Tolerance Index (PTI) and Shannon-Weaver (S-W).

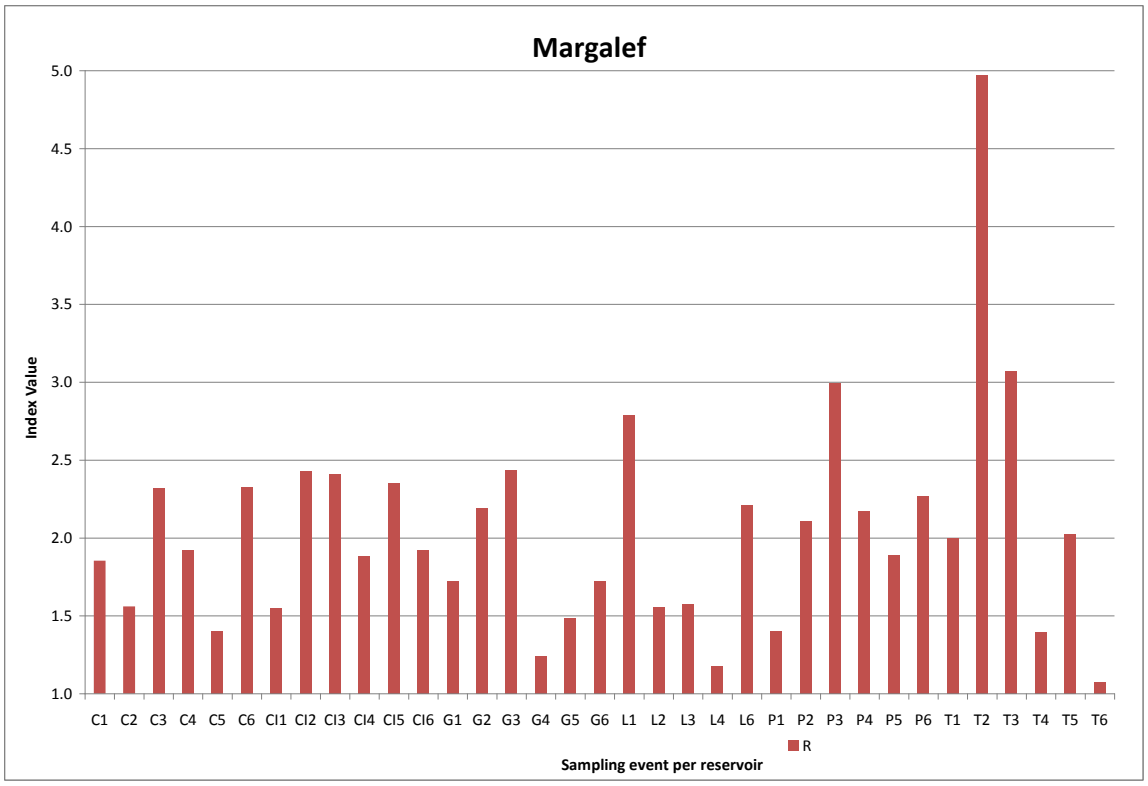


Figure 78. Margalef index for six sampling events in each reservoir.

Margalef (R) is a richness index; it is a measurement of the number of species or taxa per sampling. We could expect higher values for less impacted reservoirs. In general the values were mostly between 1 and 2.5, which could indicate that the community is under stress. The highest values were found in La Plata, Patillas and Toa Vaca. The following L1, P3 and T2 were oligotrophic (Carlson's index) and T3 was mesotrophic. The third sampling for Toa Vaca is closer to 5, this value was influenced by the amount of individuals in the sample, which were lower than the other samples. [First row of C's is Cerrillos; second row of CI's is Cidra]

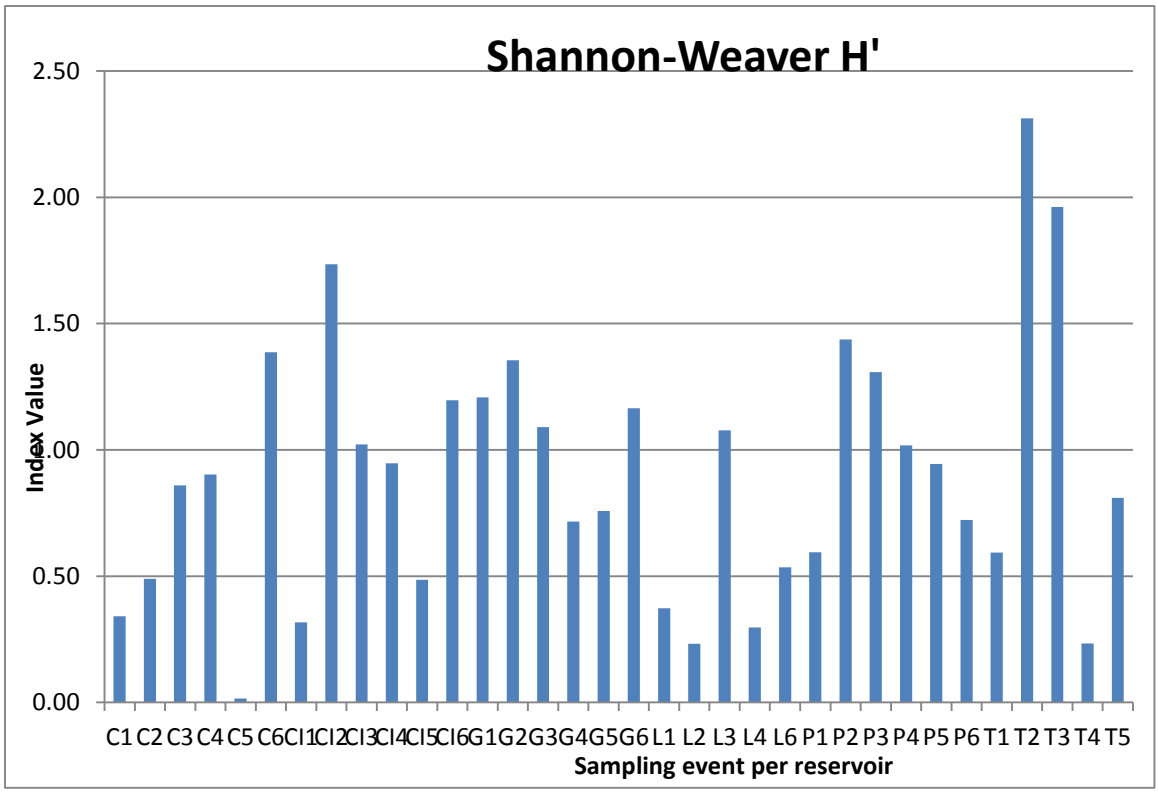
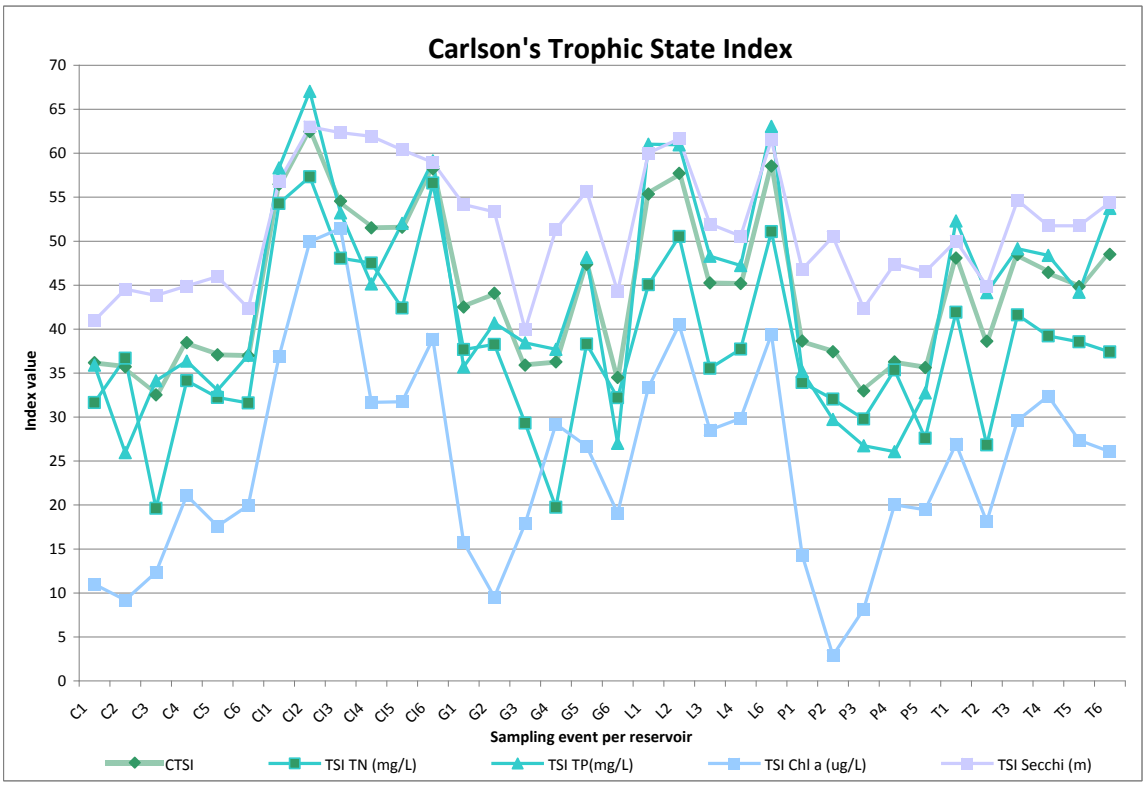


Figure 79. Shannon-Weaver H' index for six sampling events in each reservoir.

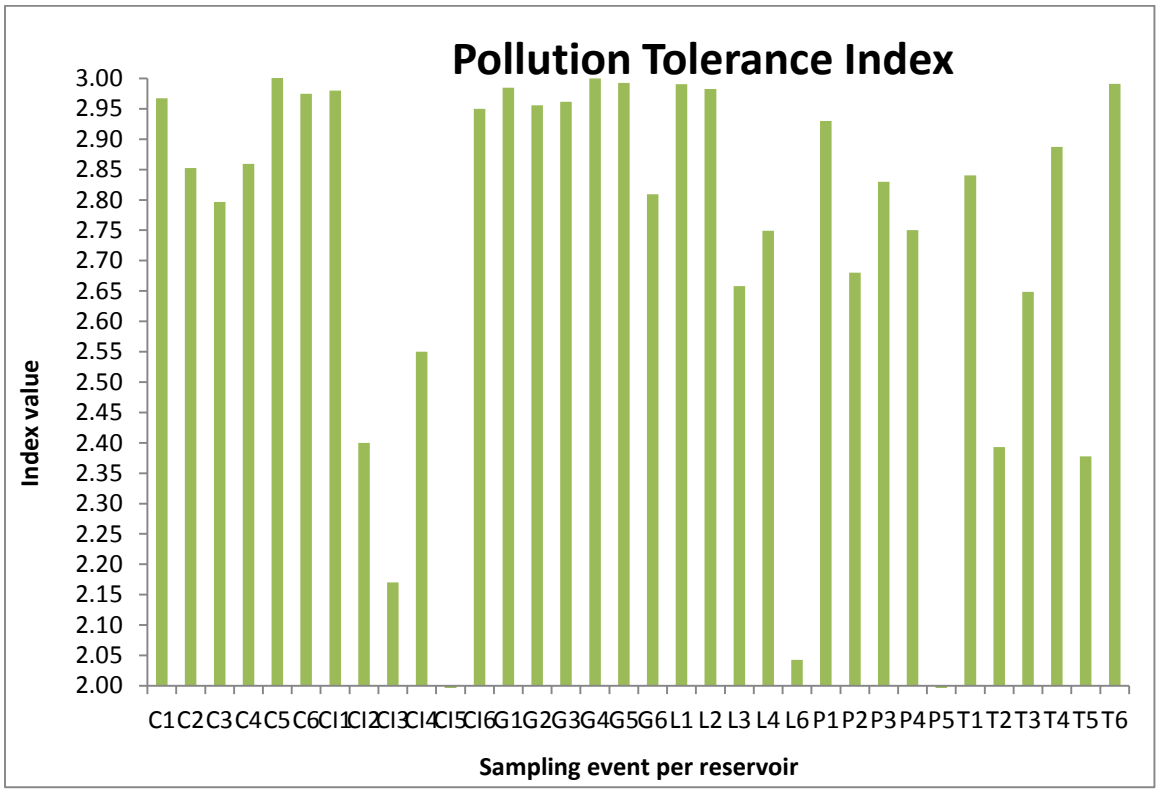
Diversity index Shannon Weaver allows the study of community composition taking into account the number and the evenness of the species present. The index increases as both the richness and the evenness of the community increase. Values were between .296 and 2.313, most values were less than 1. [First row of C's is Cerrillos; second row of CI's is Cidra]

Figure 80. Carlson's Trophic Index for six sampling events in each reservoir.



Carlson's trophic state index was calculated. For 2013, all samples from Cerrillos and Patillas were oligotrophic and the first two sampling events from Guajataca. Mesotrophic conditions were present in all sampling events in La Plata, Toa Vaca and the last sampling event from Guajataca. [First row of C's is Cerrillos; second row of CI's is Cidra]

Figure 81. Pollution Tolerance Index for six sampling events in each reservoir.



The Pollution Tolerance Index has been used previously in Puerto Rico by Brynne Bryan (2008) with periphyton. In our study most of the values were between 2 and 3 indicating the presence of moderately tolerant species. [First row of C's is Cerrillos; second row of CI's is Cidra]

Table 37. Relative abundance (in percent) of all the net-plankton diatom species present for 2012.

2012	C1	C2	C3	CI1	CI2	CI3	G1	G2	G3	L1	L2	L3	P1	P2	P3	T1	T2
D1	0.5	0.2	69.9		4.8	11.4	0.8	2.5	59.4	0.9				1.5			1.8
D2			0.2		0.2					0.2							7.1
D3	0.8	4.9	6.8		17.0	26.5	0.5	0.8			0.5	7.4	2.3	3.8	4.4	5.3	8.9
D4			0.2							0.3							
D5			0.3					0.2		0.5							5.4
D6									1.9	0.3							
D7									0.5	0.5							
D8	0.2																
D9						0.4									0.2		
D10			0.2		4.2	1.8	20.7	3.1	1.0	0.3	0.2			4.0	0.9		3.6
D11	0.5					0.2		0.8						0.8			1.8
D12																	3.6
D13															0.2		
D14															0.1		5.4
D15															0.4		
D16																	1.8
D17			0.2														
D18	5.2	0.3	0.5	0.5	33.3	22.0	52.3	33.6	3.9	0.8			18.5	14.1	44.4	9.0	5.4
D19									1.0						1.9	0.2	1.8
D20					1.5					0.2						0.2	
D21				0.2	0.6	0.8		0.2		0.2	0.2	3.2	0.2	9.5	0.2		1.8
D22												5.8					
D23										0.2							
D24															0.4		
D25	0.3																
D26			0.2												1.6	0.2	
D27															0.6	0.2	
D30		87.2	21.7	6.4	23.7	21.4	20.6	39.3	29.5	93.6	94.9	20.2		54.5	11.2	0.8	10.7
D31				0.6	2.1	0.4									0.5		10.7
D32	92.6	7.4		92.3	12.7	15.2	5.0	19.5	2.9	2.2	4.3	63.5	79.0	11.8	32.9	84.3	30.4

Table 38. Relative abundance (in percent) of all the net-plankton diatom species present for 2013

2013	C4	C5	C6	CI4	CI5	G4	G5	G6	L4	L5	L6	P4	P5	T3	T4
D1	7.2	0.2	44.0	0.9			14.0	5.8		0.9	0.8			0.6	
D2														2.8	
D3	0.6		0.9	14.8	6.7		0.2	6.4	8.4	31.3	1.1	8.0	11.6	7.9	3.8
D4												0.5	0.3		
D5		0.2	6.0									0.3	0.2		
D7			0.5												
D9										0.2					
D10			1.6	0.2								0.3		5.1	
D12			0.5							0.2					
D13														0.8	
D14							0.1					0.3	0.2		
D18	4.3	0.2	1.3	17.8		0.8	10.9	32.1	0.1	2.8	6.2	47.6	69.6	14.4	0.3
D19														5.1	
D20										1.4					
D21										0.2				2.0	
D27	0.2													4.0	

D28															95.0
D29														0.3	
D30	21.3		7.7	0.3		40.1		3.6		54.7	12.5			20.4	
D31	4.1		1.9	0.2	6.7							0.5	3.6	2.5	
D32	62.3	99.5	35.6	65.9	86.7	59.1	74.7	52.1	91.5	8.3	79.3	42.6	14.5	34.0	0.9

Table 39. Relative abundance (in percent) of all the net-plankton diatom species present for 2014

2014	C7	C8	C9	CI6	CI7	CI8	G7	G8	L7	L8	P7	P8	T5	T6
D1			0.3		0.6	10.4	3.4	46.1	0.8	0.2				
D2														
D3	0.3	0.2	0.3	1.6	1.7	7.8		0.4	1.1	3.5	0.3	2.0	19.5	0.3
D4					1.2									
D10		0.3			1.2								0.2	
D12											0.2			
D13														
D14								2.6			0.2			
D18		0.9	0.3	22.1	14.5	74.8	79.8	10.8	6.2	2.0	49.1	6.2	0.7	
D20		0.6						0.6		0.5				
D21													0.8	
D23													1.0	
D25		0.3		0.3										
D27							1.3	3.4			0.2		0.3	
D28	34.8			33.2										
D29														
D30		92.0	98.7	1.0	4.0		12.1	2.5	12.5	1.7	43.1	71.2	51.8	72.5
D31														
D32	64.8	5.6	0.4	41.7	76.9	7.0	3.4	33.6	79.3	92.1	7.1	20.6	25.7	27.2

Table 40. Species present in 25% of relative abundance or more in oligotrophic sampling events

		C1	C2	C3	C4	C5	C6	G4	G5	L1	P2	P3	P4	P5	T2
Achnanthidium minutissimum	D1			69.9			44.0								
Navicula sp.	D18											44.4	47.6	69.6	
Ulnaria acus	D30		87.2					40.1		93.6	54.5				
Ulnaria ulna	D32	92.6			62.3	99.5	35.6	59.1	74.7			32.9	42.6		30.4

Table 41. Species present in 25% of relative abundance or more in mesotrophic sampling events

		G2	G3	G6	L4	L6	P6	T1	T3	T4	T5	T6
Achnanthidium minutissimum	D1		59.4									
Navicula sp.	D18	33.6		32.1			69.6					
Synedra sp.	D28									95.0		
Ulnaria acus	D30	39.3	29.5						20.4		51.8	72.5
Ulnaria ulna	D32			52.1	91.5	79.3		84.3	34.0		25.7	27.2

Table 42. Species present in 25% of relative abundance or more in eutrophic sampling events

	CI1	CI2	CI3	CI4	CI5	CI6	G1	L2	L3	P1

Centric diatoms	D3						26.5													
Navicula sp.	D18			33.3		22.0							52.3							
Synedra sp.	D28											33.2								
Ulnaria acus	D30														94.9					
Ulnaria ulna	D32	92.3						65.9	86.7	41.7						63.5	79.0			

Table 43. Tolerance for the net plankton species in samples from 2012 to April 2014

Species	TKN-N (mg/L)		NO3-N (mg/L)		TN (mg/L)		TN/TP		TP(mg/L)		Chl a (ug/L)		DO (% sat)		DO (mg/L)		Sechi (m)		pH (std units)	
code	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
D1	0.14	1.41	0.00	0.07	0.14	1.43	6.94	58.41	0.00	0.07	0.85	174.80	57.1	148.5	4.75	11.50	0.8	3.8	7.15	9.09
D2	1.32	1.32	0.01	0.01	1.33	1.33	21.31	21.31	0.07	0.07	110.25	110.25	106.7	106.7	8.43	8.43	2.8	2.8	8.50	8.50
D3	1.78	1.78	0.06	0.06	1.78	1.78	78.24	78.24	0.09	0.09	174.80	174.80	151.5	151.5	11.76	11.76	3.5	3.5	9.09	9.09
D4	0.11	1.41	0.00	0.04	0.11	1.43	9.82	60.33	0.00	0.06	1.94	174.80	79.8	109.7	6.50	8.82	1.0	2.8	7.64	8.39
D5	0.11	0.84	0.00	0.05	0.11	0.85	9.31	60.33	0.00	0.05	1.93	32.37	59.9	137.0	4.89	10.83	0.9	3.2	7.15	9.09
D7	0.43	0.84	0.00	0.01	0.44	0.85	16.07	17.73	0.02	0.05	15.30	32.37	106.7	137.0	8.43	10.83	0.9	1.5	8.27	9.09
D8	0.22	0.22	0.00	0.00	0.22	0.22	19.82	19.82	0.01	0.01	2.45	2.45	100.0	100.0	8.32	8.32	3.5	3.5	8.21	8.21
D9	0.33	1.27	0.00	0.01	0.33	1.28	17.73	78.24	0.00	0.07	1.24	106.82	91.7	148.5	6.95	11.50	0.9	3.3	7.64	8.82
D12	0.15	1.27	0.00	0.01	0.16	1.28	9.31	19.17	0.01	0.07	3.66	40.57	90.5	148.5	6.97	11.50	0.9	3.2	7.67	8.82
D10	0.01	1.41	0.00	0.06	0.02	1.43	3.53	78.24	0.00	0.07	0.85	174.80	79.8	137.0	6.50	10.83	0.8	3.8	7.44	9.09
D13	0.33	0.33	0.01	0.01	0.33	0.33	78.24	78.24	0.00	0.00	1.24	1.24	91.7	91.7	6.95	6.95	3.3	3.3	7.64	7.64
D14	0.11	0.33	0.00	0.04	0.11	0.33	9.31	78.24	0.00	0.02	1.24	14.03	88.4	124.7	6.95	9.80	1.2	3.3	7.64	8.82
D15	0.33	0.33	0.01	0.01	0.33	0.33	78.24	78.24	0.00	0.00	1.24	1.24	91.7	91.7	6.95	6.95	3.3	3.3	7.64	7.64
D16	0.15	0.43	0.00	0.00	0.16	0.44	9.31	17.73	0.02	0.02	3.66	15.30	90.5	106.7	6.97	8.43	1.5	2.8	8.27	8.40
D17	0.14	0.14	0.01	0.01	0.14	0.14	15.89	15.89	0.01	0.01	1.94	1.94	90.1	90.1	7.02	7.02	2.8	2.8	8.29	8.29
D19	0.15	0.43	0.00	0.01	0.16	0.44	9.31	78.24	0.00	0.02	1.24	15.30	90.5	106.7	6.95	8.43	1.5	3.3	7.64	8.50
D18	0.01	1.41	0.00	0.07	0.02	1.43	3.53	78.24	0.00	0.09	0.85	174.80	57.1	148.5	4.75	11.50	0.8	3.8	7.15	8.84
D21	0.15	1.32	0.00	0.05	0.16	1.33	9.31	78.24	0.00	0.09	1.24	110.25	59.9	151.5	4.89	11.76	0.8	3.3	7.15	9.09
D22	0.85	0.85	0.05	0.05	0.90	0.90	10.29	10.29	0.09	0.09	54.22	54.22	151.5	151.5	11.76	11.76	0.8	0.8	9.06	9.06
D23	0.16	0.32	0.00	0.06	0.16	0.38	11.26	23.87	0.01	0.02	11.29	15.92	86.9	97.2	7.15	8.07	1.8	2.4	7.96	7.99
D20	0.01	1.32	0.00	0.06	0.02	1.33	3.53	44.56	0.01	0.07	3.90	110.25	59.9	148.5	4.89	11.50	0.8	2.8	7.15	8.82
D25	0.01	0.22	0.00	0.02	0.02	0.22	3.53	19.82	0.01	0.01	2.45	3.90	100.0	109.5	8.32	8.80	2.8	3.5	8.21	8.34
D26	0.33	0.33	0.01	0.01	0.33	0.33	78.24	78.24	0.00	0.00	1.24	1.24	91.7	91.7	6.95	6.95	3.3	3.3	7.64	7.64
D27	0.14	0.33	0.00	0.07	0.16	0.38	11.26	78.24	0.00	0.02	1.24	15.92	57.1	103.9	4.75	8.48	1.2	3.3	7.63	8.50
D30	0.01	1.41	0.00	0.07	0.02	1.43	3.53	78.24	0.00	0.09	0.85	174.80	57.1	151.5	4.75	11.76	0.8	3.4	7.15	9.09
D31	0.11	1.78	0.00	0.07	0.11	1.78	9.31	34.25	0.01	0.08	2.93	47.01	57.1	110.0	4.75	8.62	0.9	2.8	7.15	8.50
D32	0.01	1.78	0.00	0.07	0.02	1.78	3.53	58.41	0.00	0.09	0.85	174.80	57.1	151.5	4.75	11.76	0.8	3.5	7.15	9.09

Table 44. Indexes per sampling event in each reservoir

	H'	R	CTSI	PTI	TS	**TSI TN (mg/L)**	**TSI TP(mg/L)**	**TSI Chl a (ug/L)**	**TSI Secchi (m)**
C1	0.341	1.854	36	2.97	O	32	36	11	41
C2	0.490	1.560	36	2.85	O	37	26	9	45
C3	0.859	2.319	33	2.80	O	20	34	12	44
C4	0.903	1.924	38	2.86	O	34	36	21	45
C5	0.015	1.404	37	3.00	O	32	33	18	46
C6	1.386	2.325	37	2.97	O	32	37	20	42
CI1	0.317	1.548	56	2.98	E	54	58	37	57
CI2	1.735	2.429	62	2.40	E	57	67	50	63
CI3	1.022	2.413	55	2.17	E	48	53	51	62
CI4	0.947	1.884	52	2.55	E	47	45	32	62
CI5	0.485	2.352	52	0.00	E	42	52	32	60
CI6	1.196	1.921	58	2.95	E	57	59	39	59
G1	1.207	1.720	55	2.95	E	52	54	45	59
G2	1.354	2.194	43	2.98	M	38	36	16	54
G3	1.089	2.438	44	2.96	M	38	41	10	53
G4	0.716	1.243	36	2.96	O	29	38	18	40
G5	0.758	1.487	36	3.00	O	20	38	29	51
G6	1.165	1.724	47	2.99	M	38	48	27	56
L1	0.372	2.786	34	2.81	O	32	27	19	44
L2	0.232	1.553	55	2.99	E	45	61	33	60
L3	1.078	1.576	58	2.98	E	51	61	40	62
L4	0.296	1.179	45	2.66	M	36	48	29	52
L6	0.535	2.209	45	2.75	M	38	47	30	51
P1	0.594	1.400	59	2.04	E	51	63	39	62
P2	1.437	2.109	39	2.93	O	34	35	14	47
P3	1.307	2.991	37	2.68	O	32	30	3	50
P4	1.017	2.171	33	2.83	O	30	27	8	42
P5	0.944	1.886	36	2.75	O	35	26	20	47
P6	0.723	2.266	36	0.00	O	28	33	19	47
P7	0.593	1.858	45	2.89	M	37	45	31	52
T1	2.313	2.001	48	2.84	M	42	52	27	50
T2	1.962	4.969	39	2.39	O	27	44	18	45
T3	0.234	3.068	48	2.65	M	42	49	30	55
T4	0.809	1.393	46	2.89	M	39	48	32	52
T5	0.588	2.025	45	2.38	M	39	44	27	52
T6	0.341	1.071	49	2.99	M	37	54	26	54

H’: Shannon-Weaver; R: Margalef; CTSI: Carlson’s trophic state index; TSI: Trophic state index; TS: Trophic state; O: Oligotrophic; M: Mesoeutrophic, E: Eutrophic

Table 45. Jaccard's index for similarities between reservoirs

Sample a	Sample b	Jaccard	Similarity (%)
C	CI	0.613	61.3
C	G	0.905	90.5
C	L	0.826	82.6
C	P	0.704	70.4
C	T	0.76	76
CI	G	0.824	82.4
CI	L	0.636	63.6
CI	P	0.609	60.9
CI	T	0.609	60.9
G	L	0.556	55.6
G	P	0.476	47.6
G	T	0.435	43.5
L	P	0.64	64
L	T	0.667	66.7
P	T	0.833	83.3

Table 46. Jaccard's index for similarities between sampling events for each reservoir

Sample a	Sample b	Jaccard
C1	C2	0.875
C1	C3	0.538
C1	C4	0.700
C1	C5	0.778
C1	C6	0.636
C2	C3	0.400
C2	C4	0.667
C2	C5	0.667
C2	C6	0.500
C3	C4	0.833
C3	C5	0.909
C3	C6	0.909
C4	C5	0.857
C4	C6	0.600
C5	C6	0.444
CI1	CI2	0.400
CI1	CI3	0.444
CI1	CI4	0.500
CI1	CI5	0.571
CI1	CI6	0.500
CI2	CI3	0.778
CI2	CI4	0.636
CI2	CI5	0.700
CI2	CI6	0.583
CI3	CI4	0.545
CI3	CI5	0.600
CI3	CI6	0.545
CI4	CI5	0.800

CI4	CI6	0.667
G1	G2	0.800
G1	G3	0.800
G1	G4	0.444
G1	G5	0.667
G1	G6	0.667
G2	G3	0.500
G2	G4	0.333
G2	G5	0.500
G2	G6	0.500
G3	G4	0.400
G3	G5	0.571
G3	G6	0.571
G4	G5	0.778
G4	G6	0.875
L1	L2	0.545
L1	L3	0.545
L1	L4	0.667
L1	L5	0.667
L1	L6	0.500
L2	L3	0.900
L2	L4	0.818
L2	L5	1.000
L2	L6	0.750
L3	L4	0.556
L3	L5	0.833
L3	L6	0.500
L4	L5	0.857
L4	L6	0.500
L5	L6	0.375
P1	P2	0.500
P1	P3	0.714
P1	P4	0.625
P1	P5	0.909
P1	P6	0.714
P2	P3	0.867
P2	P4	0.722
P2	P5	0.929
P2	P6	0.765
P3	P4	0.667
P3	P5	1.000
P3	P6	0.750
P4	P5	0.889
P4	P6	0.800
P5	P6	0.571
T1	T2	0.286
T1	T3	0.250
T1	T4	0.267
T1	T5	1.333
T1	T6	0.571

T2	T3	0.778
T2	T4	0.667
T2	T5	1.000
T2	T6	0.933
T3	T4	0.789
T3	T5	0.938
T3	T6	0.938
T4	T5	0.938
T4	T6	0.882
T5	T6	0.375

Table 47. Species code for each taxon

Species code	Taxon
D1	*Achnanthidium minutissimum*
D2	*Amphora angusta*
D3	*Centric diatoms*
D4	*Cocconeis placentula*
D5	*Cymbella helvetica*
D7	*Denticula* sp.
D8	*Fragilaria goubardi*
D9	*Geissleria decussis*
D12	*Gomphonema gracilis*
D10	*Gomphonema* sp.
D13	*Gomphonema vibrio* var. *pumilum*
D14	*Gyrosigma acuminatum*
D15	*Halamphora coffeaeformis*
D16	*Hantczhia amphioxys*
D17	*Melosira varians*
D19	*Navicula rhynocephala*
D18	*Navicula* sp.
D21	*Nitzchia palea*
D22	*Nitzchia pumilum*
D23	*Nitzchia sigma*
D20	*Nitzchia* sp.
D25	*Rhopalodia gibba*
D26	*Sellaphora pupula*
D27	*Surirella tenera var. nervosa*
D30	*Ulnaria acus*
D31	*Ulnaria biceps*
D32	*Ulnaria ulna*

Table 48. Code for each sampling event per reservoir.

Code	Reservoir	Sampling event	Sampling Date
C1	Cerrillos	1	3/19/2012
C2	Cerrillos	2	4/24/2012
C3	Cerrillos	3	7/2/2012
C4	Cerrillos	4	1/17/2013
C5	Cerrillos	5	5/15/2013
C6	Cerrillos	6	9/26/2013
CI1	Cidra	1	3/21/2012
CI2	Cidra	2	5/1/2012
CI3	Cidra	3	7/12/2012
CI4	Cidra	4	6/11/2013
CI5	Cidra	5	9/3/2013
CI6	Cidra	6	2/5/2014
G1	Guajataca	1	3/6/2012
G2	Guajataca	2	4/19/2012
G3	Guajataca	3	7/10/2012
G4	Guajataca	4	1/2/2013
G5	Guajataca	5	5/22/2013
G6	Guajataca	6	9/17/2013
L1	La Plata	1	3/15/2012
L2	La Plata	2	4/26/2012
L3	La Plata	3	7/11/2012
L4	La Plata	4	1/24/2013
L5	La Plata	5	6/6/2013
L6	La Plata	6	9/10/2013
P1	Patillas	1	3/17/2012
P2	Patillas	2	4/17/2012
P3	Patillas	3	6/27/2012
P4	Patillas	4	1/22/2013
P5	Patillas	5	6/18/2013
P6	Patillas	6	9/19/2013
T1	Toa Vaca	1	3/13/2012
T2	Toa Vaca	2	7/3/2012
T3	Toa Vaca	3	5/8/2013
T4	Toa Vaca	4	9/12/2013
T5	Toa Vaca	5	2/13/2014
T6	Toa Vaca	6	PENDING

7.2.3. Soft phytoplankton analyses for the third year of study (2014)

7.2.3.1. First sampling of 2014

A total of 59 taxa were quantified during the first samplings in the six reservoirs, which included algae from the phyla Charophyta (6), Chlorophyta (34), Cyanobacteria (5), Dinophyta (3), Euglenozoa (10) and Ochrophyta (1). The diatoms were not included at this point, but some information about the diatoms for year 2014 was included in previous section (**7.2.2**). Most of the taxa found during the first sampling of the third year of monitoring belong to the phylum Chlorophyta (58%) (fig. 82). The highest numbers of taxa were recorded in Cidra, with 34, followed by Guajataca reservoir with 30 (fig. 83). The same number of taxa, 17, was determined for Cerrillos and Toa Vaca reservoirs. Patillas reservoir had the lowest number of species, with 15. If we exclude the diatoms, chlorophytes also dominated numerically the phytoplankton in all reservoirs (fig. 84). Representatives of the phyla Charophyta, Chlorophyta, Cyanobacteria and Dinophyta were found in all reservoirs. Euglenozoa was observed in five of the seven reservoirs.

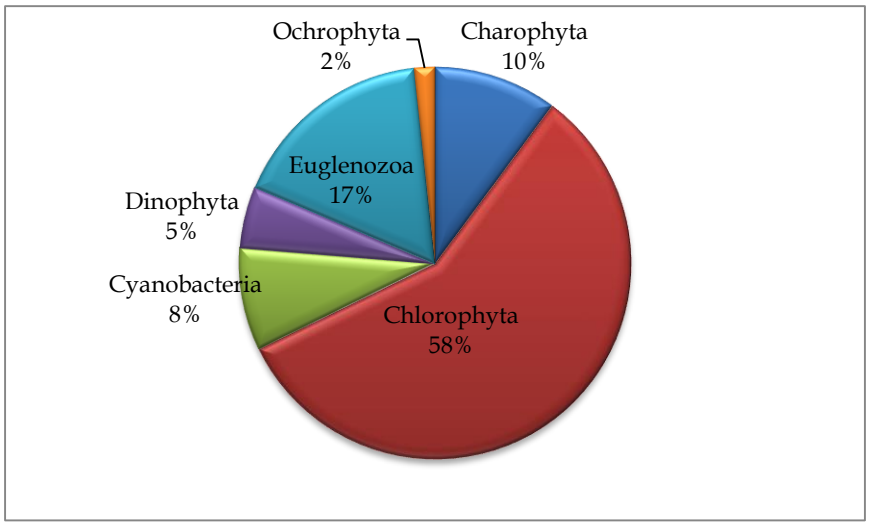


Figure 82. Phylum observed in the six reservoirs during the first sampling of the third year of monitoring (2014).

Pennate diatoms were the dominant group in Cerrillos, but for the soft phytoplankton it was the genus *Peridiniopsis*. Cerrillos was Guajataca reservoirs were similar in terms that the dominant algae were diatoms and the chlorophyte *Pediastrum simplex*. *Peridinium* spp. were the most abundant algae in Cidra reservoir. *Peridiniopsis* was also abundant in La Plata and Toa Vaca reservoirs. The ochrophyte *Dinobryon* was the dominant taxon in Patillas reservoir.

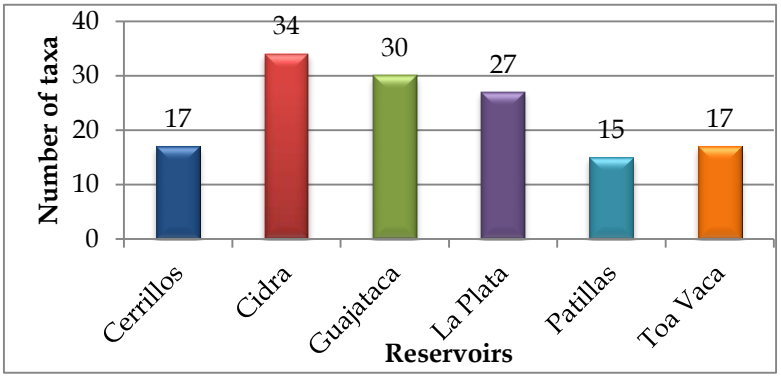


Figure 83. Total number of taxa recorded in each reservoir during the first sampling of the third year of monitoring (2014).

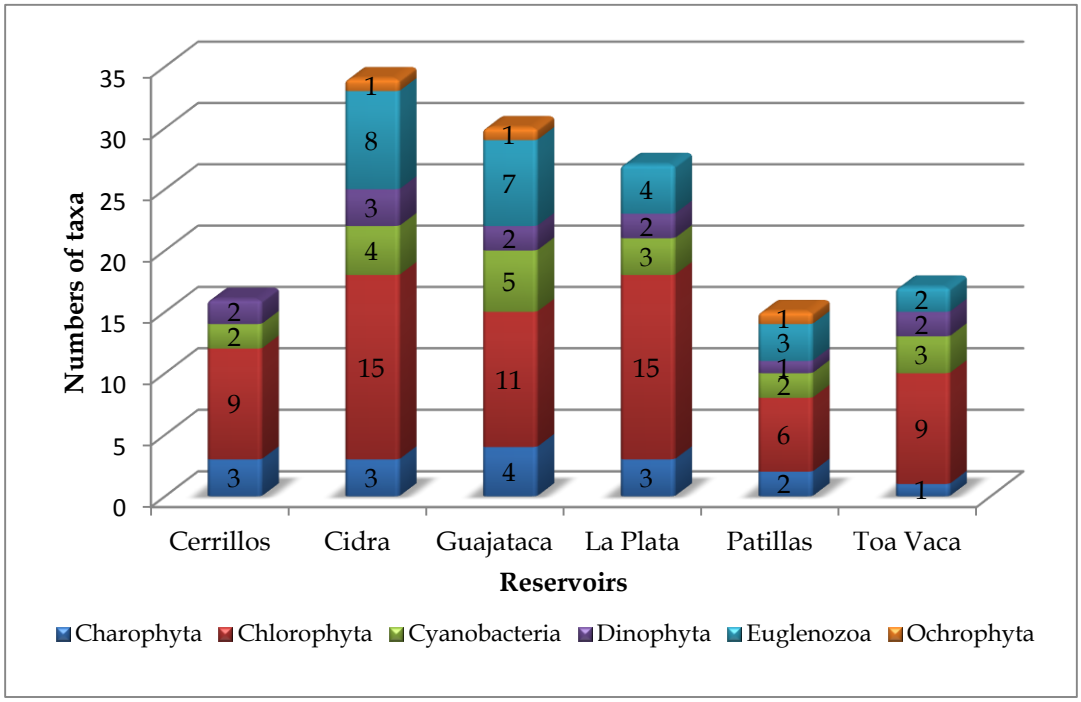


Figure 84. The distribution of taxa per phyla in the six reservoirs during the first sampling of 2014.

7.2.3.2. Second and third samplings (of 2014

The total number of organisms, preliminary identification by major group (Phylum) and, in some cases, to genera and species were made for each sample. Non-overlapping field counts were made along the center of the slide, avoiding starting at the edge, top and/or bottom part of the chamber. A modification made to the counting procedure was to count, instead, strips across the center of the bottom of the chamber to increase and standardize the observed area on the slide. There was not a set minimum of organisms to be counted for the analysis during the second and third year of study. Colonial forms were counted as an individual, as for example, *Pediastrum, Dinobryon, Microcystis, Staurastrum* and *Scenedesmus*.

Table 49. Collection dates during the third year of study (2014).

Reservoir	First sampling	**Second sampling**	**Third sampling**
Cerrillos	February 4, 2014	**April 22, 2014**	**June 19, 2014**
Cidra	February 5, 2014	**April 15, 2014**	**July 8, 2014**
Guajataca	January 28, 2014	**April 8, 2014**	**July 1, 2014**
La Plata	January 21, 2014	**April 10, 2014**	**July 3, 2014**
Patillas	January 30, 2014	**April 29, 2014**	**June 24, 2014**
Toa Vaca	February 13, 2014	**April 24, 2014**	**June 26, 2014**

Table 50. Volume determined for the phytoplankton analysis for each reservoir studied during the third year of monitoring (2014).

Reservoir	**Sample volume**		
	1st sampling	**2nd sampling**	**3rd sampling**
Cerrillos	200 µl	**5 ml**	1 ml
Cidra	5ml	**5 ml**	1 ml
Guajataca	10 ml	**10 ml**	1 ml
La Plata	5 ml	**10 ml**	1 ml
Patillas	10 ml	**10 ml**	1 ml
Toa Vaca	10 ml	**2 ml**	1 ml

Second sampling of third year (2014, cont.)

Most of the taxa found during the second sampling of the third year of monitoring belonged to the Phylum Chlorophyta. A total of 72 taxa were quantified during this second sampling in the six reservoirs; these included algae from the phyla Charophyta, Chlorophyta, Cyanobacteria, Dinophyta, Euglenozoa and Ochrophyta (Chrysophycea). Diatoms were not included at this point.

The highest number of taxa was determined for Cidra reservoir, with 32, followed by Guajataca reservoir with 31. Toa Vaca reservoir had the lowest number of algae species with 18.

"Pennate diatoms" and the dinoflagellates were the dominant groups in Cerrillos, Cidra and Toa Vaca. In Patillas and Guajataca reservoirs were dominated ochrophytes or euglenophytes, as well as the green alga *Pediastrum simplex*.

Table 51. Cumulative number of species per phylum in the six reservoirs during the second sampling of third year (2014).

TAXA	Cerrillos	Cidra	Guajataca	La Plata	Patillas	Toa Vaca
Cyanobacteria	3	5	6	3	3	3
Charophyta	5	4	4	2	4	1
Chlorophyta	8	13	12	14	8	10
Euglenozoa	2	6	6	3	4	2
Dinophyta	3	3	2	3	3	2
Ochrophyta	0	1	1	0	1	0
TOTAL	21	**32**	**31**	25	23	18

In general, as seems the case of our six studied reservoirs, most algal classes or phyla are found in lakes spanning the entire nutrient gradient. The only exceptions to this general rule are chrysophycean algae that are characteristic of nutrient poor waters (González and Quirós, 2011). During the first sampling of 2014, the chrysophyte *Dinopbryon* sp. was among the most abundant taxa in Toa Vaca, and during the second sampling in Patillas.

As noted elsewhere by other researchers, compositional changes due to nutrient enrichment usually become apparent at the generic and species level. Tying the identity of the circular diatoms to a specific taxon is required to relate these algae to trophic conditions. For example, of the diatoms, *Cyclotella* Kutzing species are frequently associated with nutrient poor lakes and *Stephanodiscus* Ehrenberg species tend to dominate following enrichment.

Phytoplankton compositional responses to nutrient load can also be considered in terms of functional groups (Reynolds et al., 2002). Among phytoplankton functional traits, cell size is a key feature, being related to the efficiency of many eco-physiological

processes (nutrient assimilation, photosynthetic efficiency, respiration, buoyancy, etc.), most of which are affected in some way by nutrient changes. The application of the functional group has been expanded to include the total biomass contributed by a particular cohort (Reynolds et al., 2002). Therefore, sizes (expressed as biovolumes) must be calculated to weight the relative contribution of each taxon or functional group to the community's productivity. A next step in our research will be the conversion of algal count to biovolumes.

In the relatively oligotrophic Venezuelan reservoirs (González and Quirós, 2011), Chlorophyta was the dominant phytoplankton group (up to 70% of relative abundance) during almost the whole year with *Cosmarium* sp. (green algae), *Cyclotella* sp. (Bacillariophyta) and *Cryptomonas erosa* (Cryptophyta) as the dominant species. These water bodies were characterized by low nutrient concentrations [less than 10µg/l orthophosphate (PO_4) and less than 100µg/l of DIN]. In another Venezuelan reservoir [this one limited by low PO_4 concentrations (DIN was >100µg/l)], the phytoplankton was dominated by the diatom *Achnanthidium minutissimum* during the mixing period, while the green algae *Staurastrum*, *Cosmarium* and *Tetraedron* increased in abundance during thermal stratification of the reservoir. In future studies with the phytoplankton dataset we will explore the relationships between algal composition and the thermal stratification (according to the temperature profiles) at the moment of sampling.

Cyanobacteria, such as the large colonial and filamentous genera *Microcystis* Kutzing, *Aphanizomenon* Morren, and *Anabaena* Bory also tend to increase in abundance in response to increasing nutrient concentrations (Reynolds, 1984). The positive relationships between the cyanobacterial densities and low nitrogen concentrations are not yet clearly seen in our dataset. Some of the tropical nitrogen-fixing cyanobacteria also exploit their floating capabilities and flourish under thermal stratification conditions. Thus, their exploitation of a low-nitrogen niche is subordinate to thermal conditions. Here, again, the thermal profiles of our six reservoirs need to be correlated with the cyanobacteria.

Enriched tropical reservoirs are usually dominated by diatoms and green algae. The diatoms *Navicula*, *Aulacoseira*, *Cyclotella*, *Stephanodiscus* and *Synedra* were the dominant genera in Venezuelan reservoirs, as was also observed in our local reservoirs. Some green algae (*Monoraphidium*, *Oocystis* and *Schroederia*) have been correlated to nutrient enrichment elsewhere. On the other side, some desmids are related to tropical lakes with low nutrient loads. So far, the desmid *Eustrum* has appeared almost exclusively in Patillas and Guajataca.

Cryptophyta have accounted for more than 60% of the phytoplankton community in some tropical lakes (González and Quirós, 2011). However, these are small algae that are not member of the net-plankton community we have sampled in our study. Dinoflagellates (Dinophyta or Pyrrophyta), on the other hand, were well represented in our samples and there seems to be a positive relation between their relative abundances and reduced Secchi depth (with its causative increase in Chl-a concentrations). Dinoflagellates are mixotrophic and can flourish in turbid waters thanks to their abilities to swim and coupe with reduced light penetration.

Species turnover is particularly high in productive, 'eutrophic' lakes. Eutrophic lakes may be characterized by a number of different taxa and seem to be more dynamic in terms of algal community composition. The high turnover may be one reason why indicators based on selected taxa often fall short in terms of reliability (Ptacnik et al., 2009). These turnovers can be explored for our phytoplankton by calculating similarity indices along time within reservoirs.

Completion of third year (2014)

The relative cumulative biovolumes of the net-size phytoplankton over the 3 sampling years (2012-2014) are shown in figure 52. Dinoflagellates comprised the largest fraction of the biovolumes in all reservoirs, except La Plata, where green algae dominated. Euglenophyte followed in biovolume magnitude in all reservoirs.

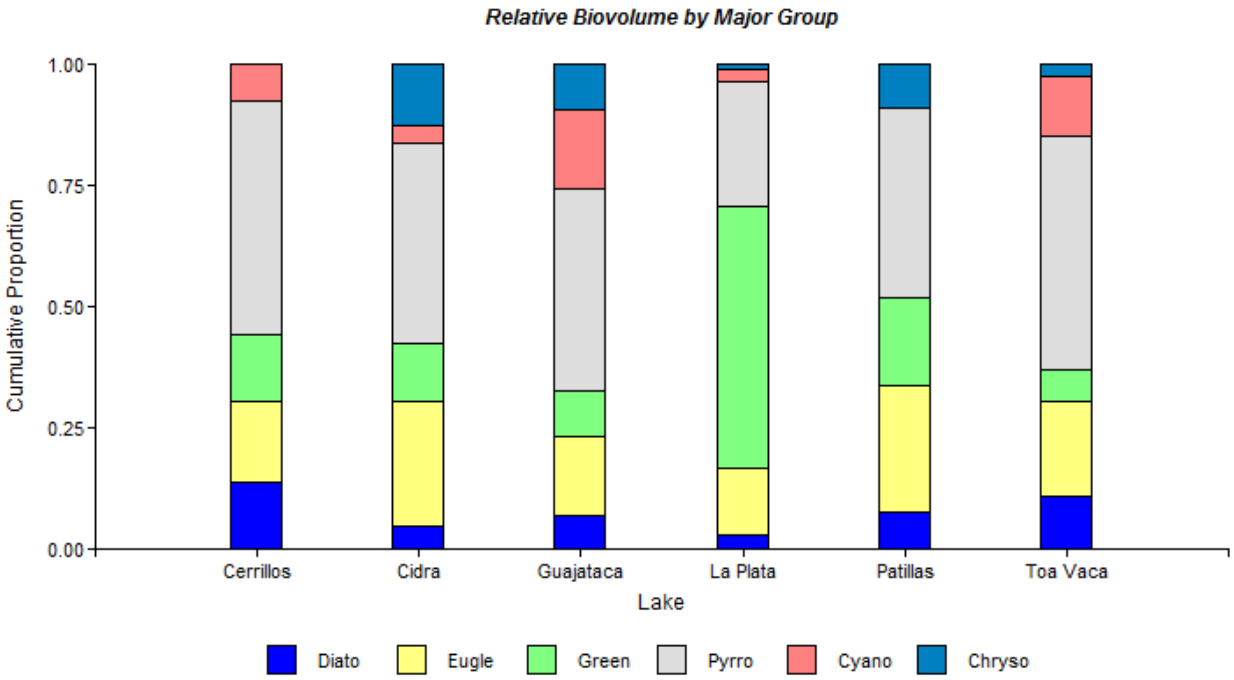


Figure 85. Relative biovolumes (µm3) by major group of the net phytoplankton. Values are cumulative biovolumes.

Cyanobacterial biovolume was relatively important in Guajataca, mainly due to the sporadic blooms of *Microcystis*. However, cyanobacteria were negligible in Patillas. Therefore, the relation between cyanobaterial biovolume and trophic states was not clearly defined. Diatoms were numerically dominant in some reservoirs, like Cerrillos, but when their numbers are converted to biovolumes they felt short to dianoflagellates and green algae.

A triplot analyses for the cumulative relative algal biovolumes by major group, localities (reservoirs) and limnological parameters is shown in figure 86. Green algae

were more responsive to increased nutrient load (TN and TP). All other algal decreased their relative biovolumes at the expense of increased green algae.

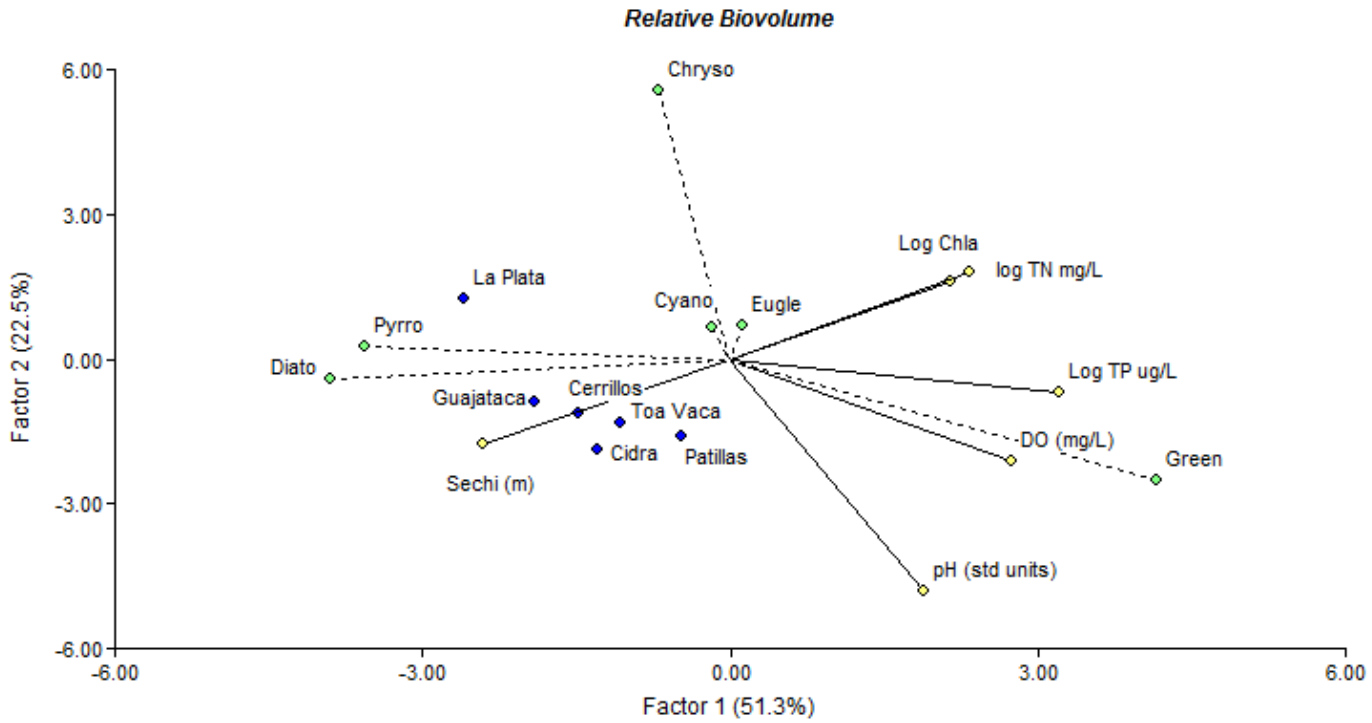


Figure 86. Triplot analyses for the cumulative relative algal biovolumes by major group, locality (reservoirs) and limnological parameters.

Table 52. Algae found in the first sampling during the third year (2014) of monitoring in the six reservoirs.

Taxon	Cerrillos	Cidra	Guajataca	La Plata	Patillas	Toa Vaca
Ankistrodesmus gracillis		X				
Coelastrum cf. *proboscodeum*	X					
Coelastrum reticulatum		X				
Coelastrums cf. *pseudomicrosporum*				X	X	
Coelastrum sp.	X	X	X			
Cosmarium sp.	X	X	X	X		X
Crucigenia tetrapedia	X		X			
Dinobryon sp		X	X		X	
Euastrum sp.			X			
Euglena acus		X	X			
Euglena proxima			X			
Euglena sp.		X	X		X	
Lepocinclis sp.		X	X	X	X	X
Micractinium sp.				X	X	X
Microcystis sp.			X			
Pandorina sp.	X			X		X
Pandorina cf. *morum*	X		X	X		
Pediastrum duplex				X		
Pediastrum simplex		X	X	X	X	X
P. simplex var. *echinulatum*			X	X	X	
Peridiniopsis sp.	X	X	X	X	X	X
Peridiniopsis sp. (small)	X	X				
Peridinium sp.		X	X	X		X
Phacus longicauda		X	X	X	X	
Phacus cf. *pleuronectes*		X				
Phacus sp.		X	X			X

Platydorina caudate				X		
Polyedropsis spinulosa			X	X		
Scenedesmus acuminatus var. *acuminatus*		X	X	X		X
Scenedesmus cf. *acutiformis*						X
Scenedesmus arcuatus						X
Scenedesmus bicaidatus		X				
Scenedesmus denticulatus		X				
Scenedesmus quadricauda		X	X			
Scenedesmus cf. *smithii*		X				
Scenedesmus sp.		X	X			
Scenedesmus cf. *ovalternus*	X					
cf. *Scenedesmus* sp.	X					
cf. *Schroederia setigera*				X		
cf. *Schroederia spiralis*				X		
Spondylosium sp.			X		X	
Staurastrum sp. 1	X	X	X	X	X	
Staurastrum sp. 2	X					
Staurastrum sp. 3		X		X		
Strombomonas sp.		X		X		
Tetraedron cf. *caudatum*		X				
Tetraedron gracile		X				
Tetraedron minimum	X	X	X	X	X	X
Tetraedron trigonum		X				
Tetrastrum sp.						X
Trachelomonas sp.		X	X	X		
Treubaria schmidlei		X		X		X
Treubaria sp.					X	
Treubaria triappendiculata			X			
Unknown solitary cf. Chlorophyta	X			X		
Unknown Cyanobacteria colonial	X	X	X	X		X

Unknown Cyanobacteria cf. Merismopediaceae	X	X	X			X
Unknown Cyanobacteria filament screw like curly		X	X	X	X	X
Unknown Cyanobacteria filament straight		X	X	X	X	
Unknown cf. Euglenozoa	X					
Total	**17**	**34**	**30**	**27**	**15**	**17**

Table 53. Algae found in the second sampling during the third year (2014) of monitoring in the six reservoirs.

Taxon	Cerrillos	Cidra	Guajataca	La Plata	Patillas	Toa Vaca
Anabaena sp.			X			
Actinastrum sp.				X		
Ankistrodesmus sp.			X			
Ankistrodesmus gracillis						
Coelastrum cf. *cambricum*				X		
Coelastrum cf. *proboscideum*						
Coelastrum reticulatum		X				
Coelastrums cf. *pseudomicrosporum*			X	X		
Coelastrum sp.		X			X	X
Cosmarium sp.	X	X	X	X	X	X
Cosmarium tenue		X	X		X	
Crucigenia tetrapedia	X		X			
Cylindrospermum sp.		X		X		
Dinobryon sp		X	X		X	
Euastrum sp.	X		X		X	
Euglena acus			X			
Euglena proxima						
Euglena sp.	X	X	X	X	X	X
Euglena sp. (small)		X				
Lepocinclis sp.		X	X			
Micractinium cf. *pusillum*		X				
Micractinium sp.				X		
Microcystis sp.			X			X
Oocystis sp.				X		
Pandorina sp.	X		X	X		X
Pandorina cf. *morum*	X		X	X		X

Pediastrum duplex						
Pediastrum simplex	X	X	X	X	X	X
P. simplex var. *biwaense*	X					
P. simplex var. *echinulatum*	X	X	X		X	
Peridiniopsis sp.	X	X	X	X	X	X
Peridiniopsis sp. (small)		X		X	X	
Peridinium sp.	X	X	X	X	X	X
Phacus longicauda var. *insect*		X	X	X		
Phacus cf. *pleuronectes*						
Phacus sp.		X	X		X	
Platydorina caudate				X		
Polyedropsis spinulosa						
Scenedesmus acuminatus var. *acuminatus*	X	X	X	X		X
Scenedesmus cf. *acutiformis*						
Scenedesmus arcuatus						
Scenedesmus bicaidatus						
Scenedesmus denticulatus						
Scenedesmus quadricauda		X				
Scenedesmus cf. *smithii*						
Scenedesmus sp.		X	X	X		X
Scenedesmus cf. *ovalternus*						
cf. *Scenedesmus* sp.						
cf. *Schroederia setigera*						
cf. *Schroederia spiralis*		X		X		
Spondylosium sp.	X					
Staurastrum sp. 1	X	X	X		X	X
Staurastrum sp. 2	X					
Staurastrum sp. 3		X		X		
Strombomonas sp.						
Tetraedron cf. *caudatum* var. *longispimum*		X	X		X	

Tetraedron gracile						
Tetraedron minimum	X	X	X	X	X	X
Tetraedron regulare var. *incus*					X	
Tetraedron trigonum		X				
Tetrastrum sp.						X
Trachelomonas sp.	X	X	X	X	X	X
Treubaria schmidlei		X				
Treubaria sp.			X	X	X	
Treubaria triappendiculata						
Unknown solitary cf. Chlorophyta	X				X	
Unknown Cyanobacteria colonial	X	X	X	X	X	
Unknown Cyanobacteria cf. Merismopediaceae	X	X	X			
Unknown Cyanobacteria filament screw like curly	X	X	X	X	X	
Unknown Cyanobacteria filament straight		X	X	X	X	
Unknown cf. Euglenozoa					X	
Total	**21**	**32**	**32**	**26**	**23**	

Zooplankton analyses for years 2012-2014

Despite their considerable potential as effective indicators of environmental change and their fundamental importance in the transfer of energy and nutrient cycling in aquatic ecosystems, the zooplanktonic communities have not been widely used as ecosystem condition indicators (Stemberger & Lazorchak, 1994). Puerto Rico is no exception. Considerable information regarding the effects of abiotic factors on zooplanktonic species has been acquired elsewhere (Arora, 1966; Gannon & Stemberger, 1978; Mäemets, 1983; Blancher, 1984; Berzins & Pejler, 1989).

This part of the investigation was based on the idea that the zooplankton could bioindicate, by its community-level or group-specific composition and structure, the trophic state of six surveyed reservoirs. Zooplankton densities and richness are summarized in tables 54 and 55, respectively.

Table 54. Summary of the zooplankton densities (individuals/m^3) for the whole study (2012-2014)

Reservoir	**Date**	**Zooplankton density (individuals/m^3)**			
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Cerrillos	3/19/2012	7920	560	2000	10480
	4/24/2012	11832	2001	3741	17574
	7/2/2012	6786	1566	2697	11049
	1/17/2013	14181	1566	2610	18357
	5/15/2013	21756	3234	8526	33516
	9/26/2013	13786	1830	4392	20130
	2/4/2014	36600	14030	13725	64355
	4/22/2014	3660	1586	1220	6466
	6/19/2014	14700	6125	3920	24745
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Cidra	3/21/2012	76912	17480	10488	104880
	5/1/2012	253460	39330	69920	362710
	7/12/2012	214375	34125	17500	266000
	1/15/2013	49700	11725	4200	65625
	6/11/2013	199512	44676	26316	270504
	9/3/2013	160344	31212	12852	204408
	2/5/2014	75215	3185	10780	89180
	4/15/2014	79866	11016	13158	104040
	6/3/2014	212976	39780	41004	293760
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Guajataca	3/6/2012	13054	2074	7320	23180
	4/19/2012	11832	2697	8352	22881
	7/10/2012	24500	3500	11550	39550
	2/1/2013	5220	2436	2175	9831
	5/22/2013	29874	9575	13405	52854

	9/17/2013	38556	3464	22032	74052
	1/28/2014	10004	2318	1830	14152
	4/8/2014	37750	4250	4750	46750
	7/1/2014	55080	6732	10404	72216
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
La Plata	3/15/2012	157080	12240	12240	181560
	4/26/2012	280875	20125	21000	322000
	7/11/2012	250250	23625	15750	289625
	1/24/2013	154875	11375	21000	187250
	6/6/2013	276850	26950	24500	328300
	9/10/2013	211278	21434	13779	246491
	1/21/2014	157896	12852	7956	178704
	4/10/2014	174420	9180	9180	192780
	6/12/2014	230724	29376	24480	2845680
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Patillas	3/13/2012	13464	3468	1938	18870
	4/17/2012	26075	10675	6650	43400
	6/27/2012	28000	4725	2625	35350
	1/22/2013	24150	6650	3150	33950
	6/18/2013	41375	14895	4634	60904
	9/19/2013	12740	6125	1225	20090
	1/30/2014	7670	1560	1690	10920
	4/29/2014	13298	2684	3416	19642
	6/24/2014	10614	3294	8784	22692
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Toa Vaca	3/8/2012	18156	612	7344	26112
	5/2/2012	11397	348	3915	15834
	7/3/2012	8004	696	4089	12876
Note: First sampling of 2013 was not conducted		-	-	-	-
	5/8/2013	1342	122	610	2074
	9/12/2013	1647	183	793	2623
	2/13/2014	4941	1098	1281	7320
	4/24/2014	3843	2257	1891	8052
	6/26/2014	3660	1037	1830	6527

Table 55. Summary of the zooplankton richness (number of species) for the whole study (2012-2014)

Reservoir	**Date**	**Richness (Number of Species)**			
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Cerrillos	3/19/2012	9	4	3	16
	4/24/2012	13	8	5	26
	7/2/2012	13	7	5	25
	1/17/2013	13	5	4	22
	5/15/2013	11	7	4	22
	9/26/2013	12	7	4	23
	2/4/2014	10	8	5	23
	4/22/2014	12	8	4	24
	6/19/2014	14	10	5	29
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Cidra	3/21/2012	22	4	3	29
	5/1/2012	21	10	3	34
	7/12/2012	21	10	3	34
	1/15/2013	16	9	6	31
	6/11/2013	18	6	5	29
	9/3/2013	18	8	4	30
	2/5/2014	29	7	5	41
	4/15/2014	31	14	7	52
	6/3/2014	25	7	5	37
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Guajataca	3/6/2012	13	2	5	20
	4/19/2012	11	5	3	19
	7/10/2012	13	5	6	24
	2/1/2013	11	4	4	19
	5/22/2013	11	6	5	22
	9/17/2013	9	6	5	20
	1/28/2014	11	5	5	21
	4/8/2014	9	6	6	21
	7/1/2014	11	6	5	22
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
La Plata	3/15/2012	17	5	3	25
	4/26/2012	21	10	3	34
	7/11/2012	19	7	4	30
	1/24/2013	14	9	3	26
	6/6/2013	18	8	3	29
	9/10/2013	13	8	3	24
	1/21/2014	22	7	4	33
	4/10/2014	26	8	5	39
	6/12/2014	19	7	4	30
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL

Patillas	3/13/2012	9	5	4	18
	4/17/2012	15	6	5	26
	6/27/2012	13	5	4	22
	1/22/2013	9	5	4	18
	6/18/2013	11	5	6	22
	9/19/2013	13	5	4	22
	1/30/2014	10	5	5	20
	4/29/2014	10	6	4	20
	6/24/2014	9	5	6	20
		ROTIFERA	CLADOCERA	COPEPODA	TOTAL
Toa Vaca	3/8/2012	9	1	4	14
	5/2/2012	11	4	4	19
	7/3/2012	12	4	4	20
Note: First sampling of 2013 was not conducted		-	-	-	-
	5/8/2013	6	2	4	12
	9/12/2013	7	3	4	14
	2/13/2014	9	5	4	18
	4/24/2014	7	5	4	16
	6/26/2014	9	4	4	17

7.3.1 Zooplanktonic community composition and structure

The zooplankton community of the reservoirs was characterized by a mix of species already known under similar environmental conditions in the Neotropical region, and a group of species with a totally opposed behavior (especially cladocerans). Decreased water transparency and higher concentrations of nutrients (TP and TN) were related to zooplankton density, particularly the rotifers. Sixty-five zooplanktonic taxa were identified. Rotifera was the richest group with 37 taxa. The cladocerans were represented by 20 taxa and Copepoda by 8 taxa. This pattern is common in tropical freshwaters according to Neves et al. (2003).

The zooplankton community showed a typical structure, and clear rarity of large zooplankters like *Daphnia* spp. The low diversity of *Daphnia* seems to be an outstanding feature of cladoceran assemblages in tropical systems, either oligotrophic or eutrophic (Pinto-Coelho et al., 2005). These micro-crustacenas usually are more diverse in mesotrophic. However, during the present study, cladocerans were more diverse (species-rich) in eutrophic (Cidra and La Plata) reservoirs. The frequent presence of colonial cyanobacteria, like *Microcystis aeruginosa* has been associated with a lower richness and density of Cladocera (Sendacz et al., 1984). This could explain at least the case of low richness of cladocerans in Guajataca.

Copepoda were represented by adults and immature forms, like nauplii and copepodites. According to Hutchinson (1967) and Anderson (1970), the cyclopoid copepods are essentially predators, capturing a variety of planktonic organisms. Cyclopoid copepods have been considered as indicators of eutrophic environments (Gannon & Stemberger, 1978). Blancher (1984) registered an increase in the abundance of cyclopoid species related to an increase of the trophic state of the Florida lakes. In the six reservoirs studied herein, cyclopoids showed a similar distribution pattern, with higher numerical densities at poor environmental quality, decreasing to low values in lakes of a better water quality.

Regarding species of *Thermocyclops*, Reid (1989) related some species (i.e. *T. minutus*) to environments with oligo to mesotrophic characteristics. For Reid et al. (1988), *T. minutus* has a tendency to occur in the less productive waters, or with lower values of electrical conductivity. Rocha et al. (1995) and Landa *et al.* (2007) associated *Thermocyclops minutus* with oligotrophic water and *Thermocyclops decipiens* with more eutrophic water-bodies. In our study, all *Thermocyclops* species were collapsed into a single taxon (*Thermocyclops* spp.); therefore, taxonomic discrimination will be required to assess their bioindicator value.

Differences in the abundance of Copepoda between the reservoirs can also be explained by their trophic state. According to several authors (Pinto-Coelho *et al.* 2005), calanoids are associated with more oligotrophic ecosystems, while cyclopoids are associated with more eutrophic lakes and reservoirs. Nevertheless, even in oligo-mesotrophic ecosystems, dominant Calanoida species can be found. A Calanoida / Cyclopoida ratio has been proposed that reflects the predominance of Cyclopoida (values below 1) mainly in meso-eutrophic condition. Although Calanoida were prevalent in meso-oligotrophic conditions, fish predation in local reservoirs may preclude the use of this index. This index rarely exceeded a value of 1. The most common calanoid species, *Arctodiaptomus dorsalis*, exhibited a variable pattern of occurrence in the systems under study. In Toa Vaca, this species was found in increasing numerical densities related to improved water quality. The disappearance in 2013 and re-occurrence in 2014 of Calanoid copepods in Toa Vaca could be related to the slowly improved environmental conditions within the system after the aeration event.

In this study, small-sized species like rotifers predominated. Nauplii were also common but where not considered as these are below the sampling limit allowed by the 63 um mesh and they are difficult to assign to particular taxa. Among the cladocerans, also small forms, like *Bosmina longirostris* and *Ceriodaphnia cornuta* (*cornuta-rigaudi* complex) occurred frequently in high densities.

Kirk & Gilbert (1990) documented that the presence of sediments in suspension in natural ecosystems can influence the structure of the zooplankton community by favoring rotifers. According to Paggi and Paggi (1990) several species of rotifers tolerate a high concentration of suspended material because they are highly efficient at identifying and selecting the nutritious material, avoiding inorganic particles. Rotifers are opportunistic organisms (r-strategist species adapted to a fast population growth during favorable seasons) whose densities change in a short time (Matsumura-Tundisi et al., 1990).

The highest absolute densities of zooplankton were observed mainly due to the contributions by *Brachionu*s spp. and *Asplanchna* spp., whose total numerical densities were comparable to values from tropical South American reservoirs. Values determined for local reservoirs followed a gradient, decreasing when trophic conditions improved, like in Cerrillos or Patillas, where lower numbers for these species (sometimes less than 100 ind.m3) were detected. Certain species appear benefited by increased eutrophication, mainly in the summer, like *Brachionus* spp. For Ruttner-Kolisko (1974), the genus *Brachionus* mainly inhabits shallow water. Only few species are truly pelagic, and most live near the water sedge, associated to the substratum. All *Brachionus* feed on algae and partially on bacteria. *Brachionus caudatus, B. angularis* and *B. calyciflorus* are benthic species, cosmopolitan in eutrophic waters, especially at locations rich in vegetation, occasionally found in the plankton.

In South American reservoirs, the rotifer *Keratella tecta* is the most abundant species in eutrophic lakes, followed by *K. americana* and *Brachionus havanaensis*; while in the mesotrophic lakes, *Polyarthra dolichoptera, K. cochlearis* and *Trichocerca* spp. dominate. Other species of *Brachionus* have been related there to mesotrophic conditions. In Puerto Rican reservoirs, *Keratella cochlearis* and *B. havanaensis* also seem to prefer mesotrophic conditions, but higher numbers of *Brachionus* were related to increased eutrophication and *Trichocerca* spp. were related to meso-oligotrophic events.

High species richness of Rotifera is also a general condition in tropical reservoirs (Starling 2001). The dominance of rotifers in these habitats is attributed to hydrodynamics, which removes individuals from the deep and littoral zones to the limnetic zone. This is case of genera such as *Lecane*, *Platyas*, *Lepadella*, *Colurella* and *Cephalodella*. The dominance of rotifers in tropical reservoirs cannot be considered the general rule. Although our results may indicate that rotifers are numerically dominant in the reservoirs; it most be pointed out that large numbers of nauplii (immature stages of Copepoda) sometimes occurred. Nevertheless, absolute abundances (instead of relative abundances) of rotifers show a clear increase with increased eutrophication. Copepods are numerically important in our reservoirs at nauplii and copepodid stages, but numbers of adult copepods are well surpassed by numbers of rotifers. According to Lansac-Toha *et al.* (2005), longer retention time (WRT) may favor copepods because of their longer life cycles. However, the reservoir with the longest WRT (Toa Vaca) had among lowest densities of copepods study-wise, probably due to the altered conditions during its aeration process.

Absolute abundances (instead of relative abundances) of rotifers show an increase with increased eutrophication (Figs. 87-90). A sound relationship was observed between *Brachionus* rotifers (ind/L) and phosphorus (lnTP) [Fig. 91]. A segmented curved approach had changepoint

value for total phosphorus (parameter g), estimated as Ln of 3.28 (= 26.58 ppb). Also, an interesting relationship was detected between *Brachionus* rotifers (ind/L) and Secchi depth (m), where the changepoint value for Secchi depth (parameter g) was estimated as 1.16 meter (Fig. 92). This Secchi depth value is a clear sign of impairment for local reservoirs. Because of the wide distributions of some species, however, some authors suggested the use of relative zooplankton abundance within the community as a more sensitive indicator than only their mere presence or absence (McCauley & Kalff 1981; Lathrop & Carpenter 1992). As previously stated, fish fauna also can influence the zooplankton structure because planktivorous fish can consume larger-bodied individuals, resulting in the dominance of smaller copepods and cladocerans (Carpenter *et al.* 1985), even though the microcrustacean biomass may not change. Little is known about predation by fish in our reservoirs.

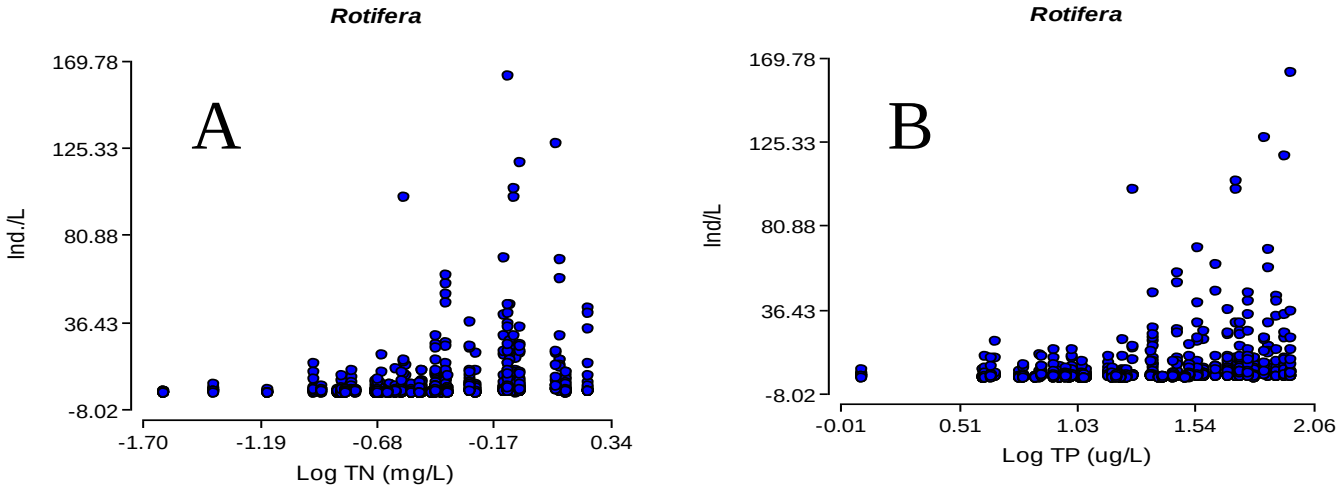


Figure 87 A & B. Relationship between the density of rotifers (ind/L) and nutrients (TN and TP)

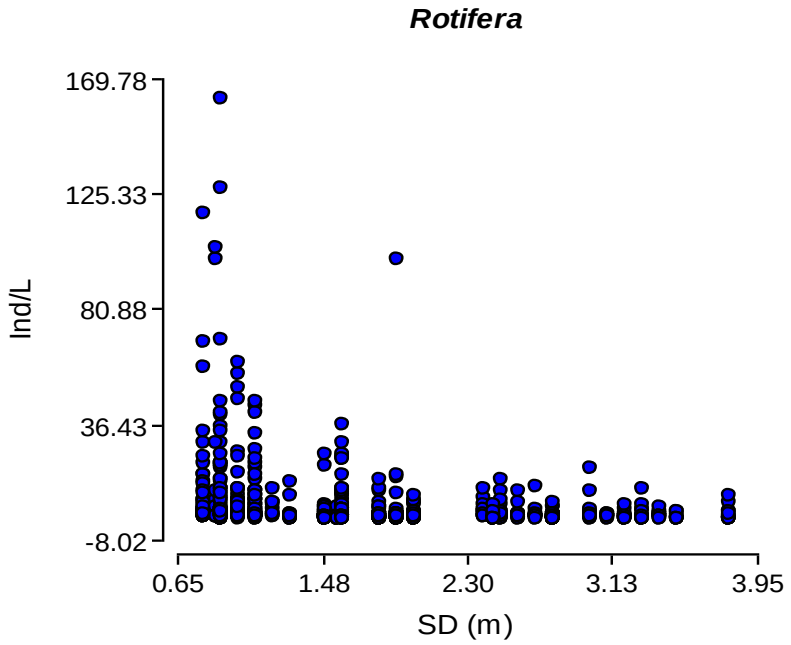
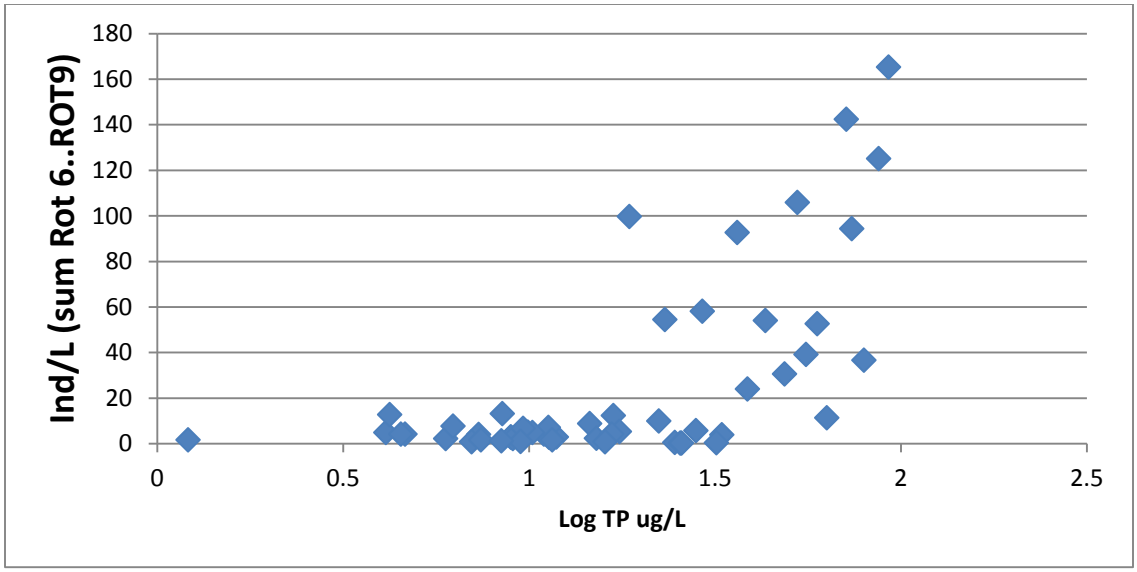
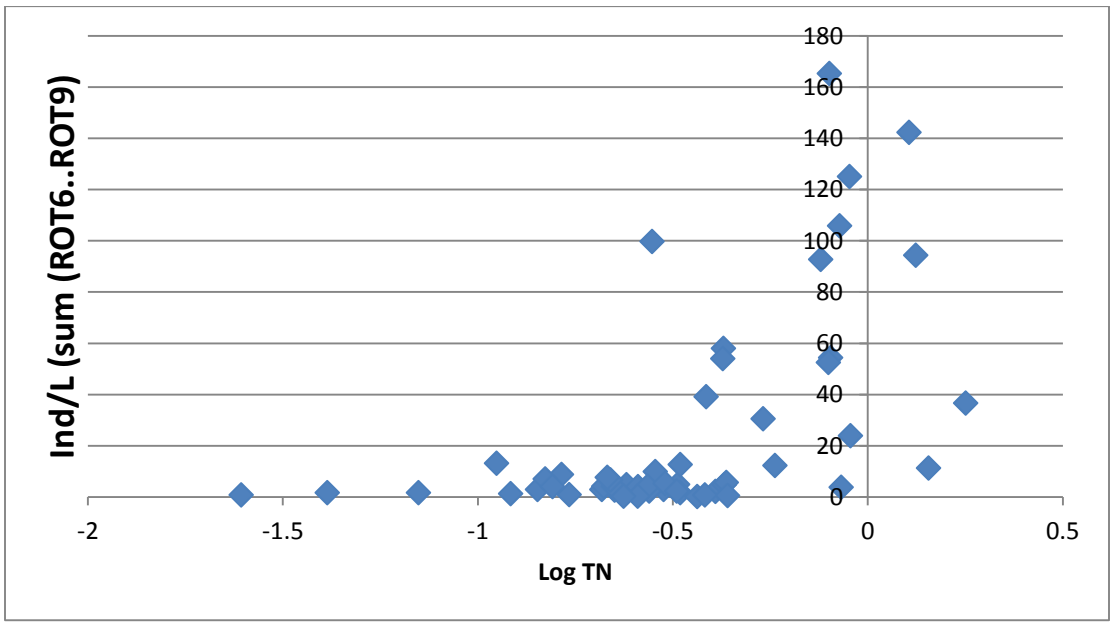


Figure 88. Relationship between the density of rotifers (ind/L) and Secchi depth (SD).

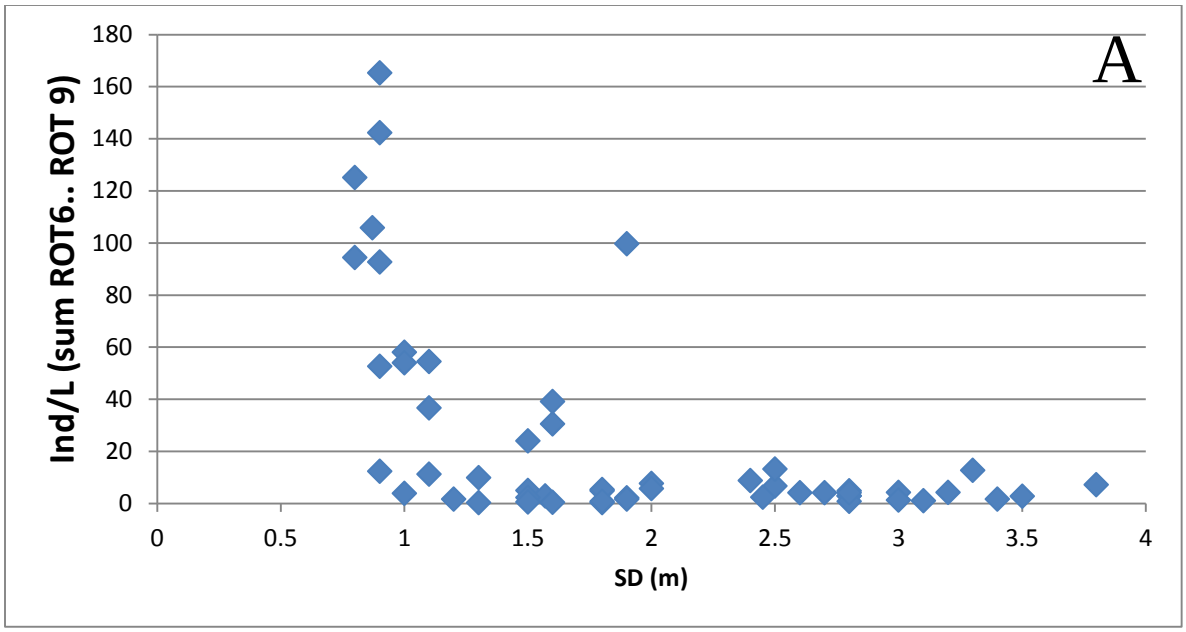
A





B

Figure 89. A & B. Relationship between the density of rotifers belonging to the genus *Brachionus* (ind/L) and nutrients (TP and TN).



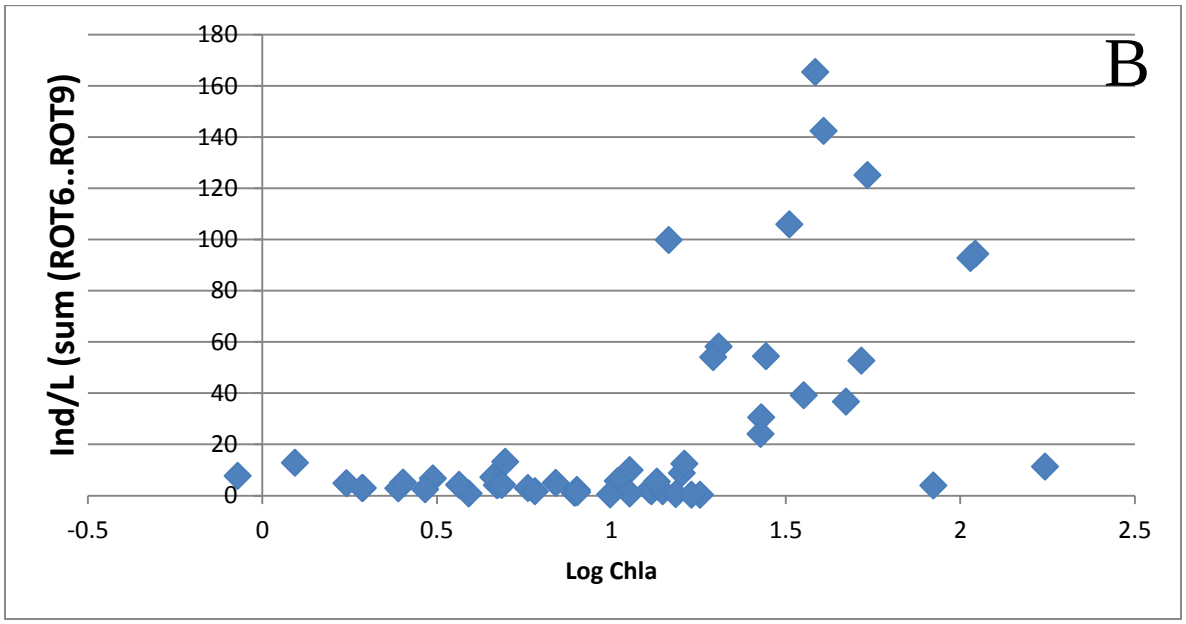


Figure 90. A & B. Relationship between the density of rotifers belonging to the genus *Brachionus* (ind/L) and Secchi depth (SD) and chlorophyll-a concentration.

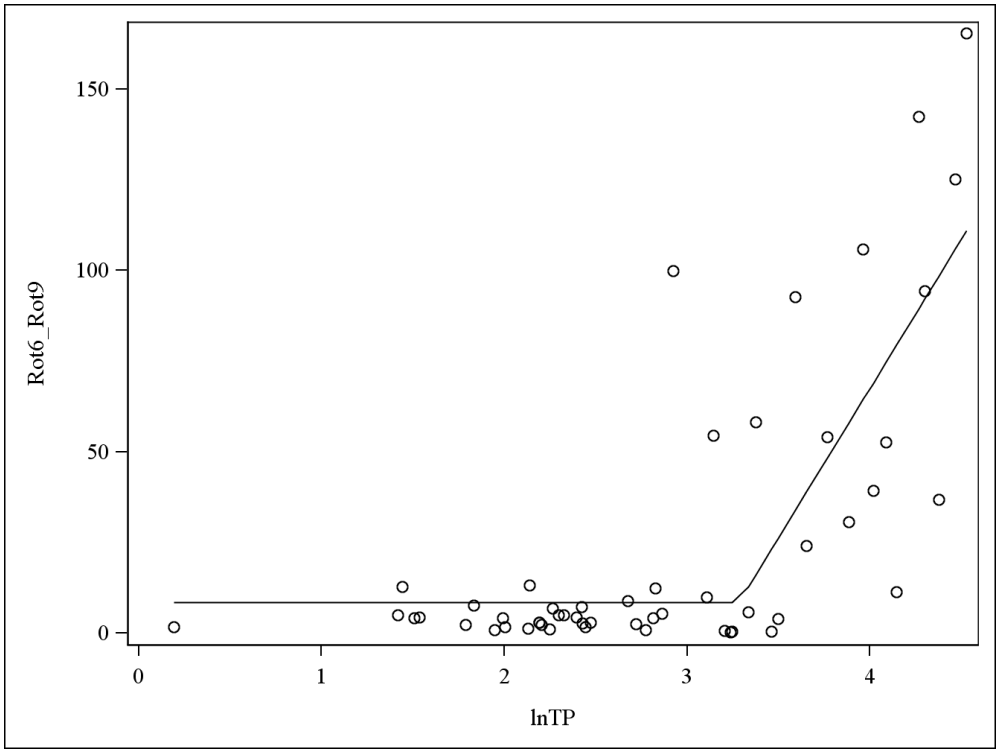


Figure 91: Relationship between *Brachionus* rotifers (ind/L) and phosphorus (lnTP). Line represents the best fit of a segmented curved approach. The changepoint value for total phosphorus (parameter g), was estimated as Ln of 3.28 (= 26.58 ppb).

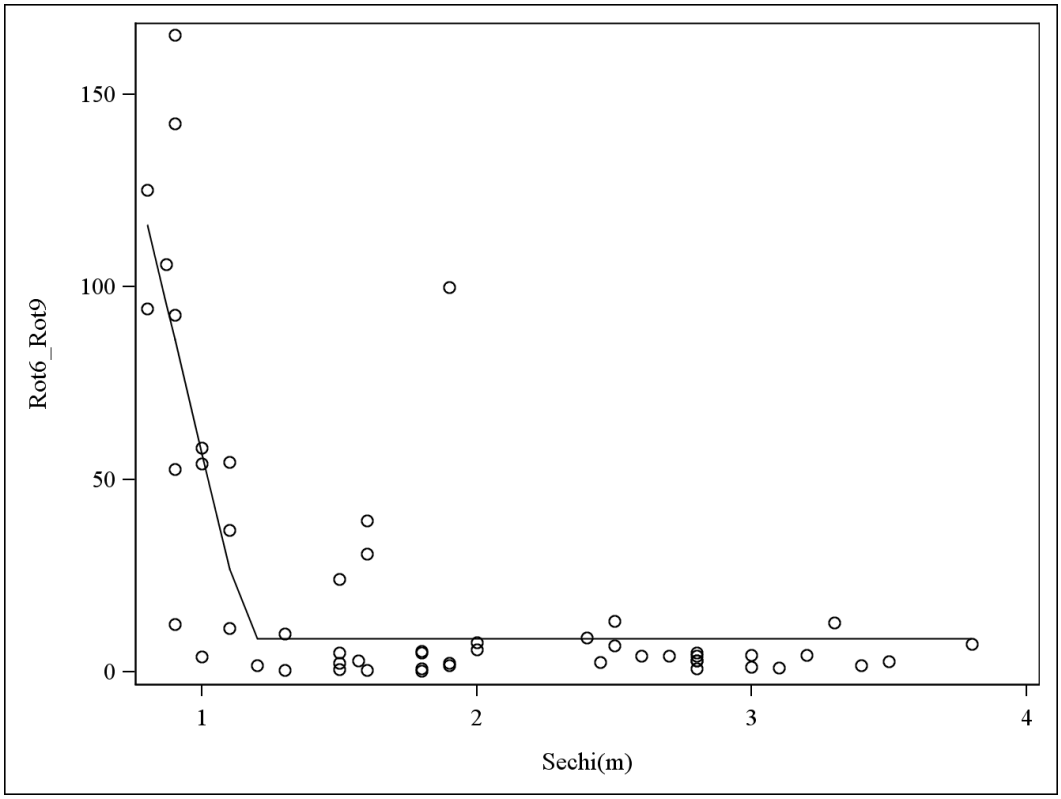


Figure 92: Relationship between *Brachionus* rotifers (ind/L) and Secchi depth (m). Line represents the best fit of a segmented curved approach. The changepoint value for Secchi depth (parameter g), was estimated as 1.16 meter.

8.0 Literature Cited

1) Anderson, R.S. 1970. Predator-prey relationships and predation rates for crustacean zooplankers from some lakes in western Canada. Can. J. Zool., 48:1229-1240.
2) Arcifa, M.S. 1984. Zooplankton composition of the reservoirs in southern Brazil. Hydrobiologia, 113:137-145.
3) Arora, H.C. 1966. Rotifera as indicators of trophic nature of environments. Hydrobiologia, 27:146-159.
4) Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers, Periphyton, Benthic Macroinvertebrates, and Fish, 2nd edn. U.S. EPA, Office of Water, Washington, DC, 841-B-99-002.
5) Battarbee, R.W., Jones, V.J., Flower, R.J., Cameron, N.G., Bennion, H., Carvalho, L., and Juggins, S. 2001. *Diatoms Tracking Environmental Change Using Lake Sediments*. Vol.3. Terrestrial, Algal, and Siliceous Indicators (eds. J.P. Smol, H.J.B. Birks & W.M. Last), pp. 155–202. Kluwer Academic Publishers, Dordrecht, the Netherlands.
6) Berzins, B. & Pejler, B. 1989. Rotifer occurrence and trophic degree. Hydrobiologia, 182:171-180.
7) Biggs, B.J F. 1995.The contribution of flood disturbance, catchment geology and land use to the habitat template of periphyton in stream ecosystems. Freshwater Biology, 33: 419–38.
8) Blancher, E.C. 1984. Zooplankton-trophic state relationships in some north and central Florida Lakes. Hydrobiologia, 109:251-263.
9) Campbell, K.L., and D.R. Edwards. 2001. Phosphorus and Water Quality Impacts: In Agricultural Nonpoint Source Pollution. Chapter 4. Edited by: W. F. Ritter and A. Shirmohammadi. CRC Press. Lewis Publishers.
10) Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Ocenography. 22(2):361-369.
11) Carpenter S.R., J.F. Kitchell and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity. *Bioscience* 35, 634–9.
12) Charles, D.F., Acker, F.W., Hart, D.D., Reimer, C.W., and Cotter, P.B. 2006. Large-scale regional variation in diatom–water chemistry relationship, rivers of the eastern United States. Hydrobiologia 561: 27–57.
13) Denys, L. 1991. A check-list of the diatoms in the Holocene deposits of the western Belgian coastal plain with a survey of their apparent ecological requirements. I. Introduction, ecological code and complete list. *Prof. Pap. Geol. Surv. Belgium*, 246, 1-41.

14) Felip, M; J. Catalan. 2000. The relationship between phytoplankton biovolume and chlorophyll in a deep oligotrophic lake: decoupling in their spatial and temporal maxima. Journal of Plankton Research. 22 (1): pp. 91-105.
15) Fernandes-Cunha, D. G.; M. d Carmo-Calijuri; M. Condé-Lamparelli. 2013. A trophic state index for tropical/subtropical reservors (TSI_{trs}). Ecological Engineering. 60: 126-134.
16) Gannon, J.E. & Stemberger, R.S. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Am. Microsc. Soc., 97:16-35.
17) González, E.J., and R. Quirós. 2011. Eutrophication of Reservoirs inVenezuela: Relationships between Nitrogen, Phosphorus and Phytoplankton Biomass. Oecologia Australis, 15(3): 458-475.
18) Håkansson, H. 2002. A compilation and evaluation of species in the genera *Stephanodiscus*, *Cyclostephanos* and *Cyclotella* with a new genus in the family Stephanodiscaceae. Diatom Research, 17: 1-139.
19) Huszar, V.L.M.; N. F. Caraco; F. Roland; J. Cole. 2006. Nutrient-chlorophyll relationships in tropical-subtropical lakes: do temperate models fit? Biogeochemistry. 79 (1) pp. 239-250.
20) Hutchinson, G.E. 1967. A treatise on limnology. Introduction to lake biology and limnoplankton. John Wiley & Sons, New York. v.2, 1115p.
21) Kirk, J.T.O. 1996. Light and Photosynthesis in Aquatic Ecosystems, 2nd. Ed. Cambridge University Press, Cambridge.
22) Kirk, K.L. & Gilbert, J.J. 1990. Suspended clay and the population dynamics of plankton rotifers and cladocerans. Ecology, 71:1741-1755.
23) Koste, W. 1978. Rotatoria: die rädertiere mitteleuropas ein bestimmungswerk begründet von max voigt. Aul. Gebrüber Borntraeger, Berlin. 637p. (Uberordnung monogononta, 2).
24) Krammer, K., and H. Lange-Bertalot. 1991. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In: *Sußwasser Flora von Mitteleuropa, Bd. 2/3*. H. Ettl, J. Gerloff, H. Heynig & D. Mollenhauer (eds.). Gustav Fischer Verlag, Stuttgart.
25) Kruk, C., V. L. M. Huszar, E. T. H. M. Peeters, S. Bonilla, L. Costa, M. Lurling, C. S. Reynolds, and M. Scheffer. 2010. A morphological classification capturing functional variation in phytoplankton. Freshwater Biology, 55:614-627.
26) Lampert W. 1987. Laboratory studies on zooplankton cyanobacteria interactions. *N. Z. J. Mar. Freshwater Res.* 21, 483–90.
27) Landa G.G., F.A.R. Barbosa, A.C. Rietzler, and P.M. Maia-Barbosa. 2007. *Thermocyclops decipiens* (Kiefer, 1929) (Copepoda, Cyclopoida) as indicator of water quality in the state of Minas Gerais, Brazil. *Braz. Arch. Biol. Technol.* 50, 695–705.
28) Lansac-Toha F.A., C.C. Bonecker, and L.F.M. Velho. 2005. Estrutura da Comunidade Zooplanctonica em Reservato´ rios. In: Biocenoses em Reservato rios: Padro˜es Espaciais e Temporais (eds L. Rodrigues, S. M. Thomaz, A. A. Agostinho & L. C. Gomes) pp. 115–27. Rima, Sao Carlos.

29) Lewis, W.M. Jr. 1996. Tropical lakes: how latitude makes a difference. Perspectives in Tropical Limnology: 43- 64.
30) Lobo, E.A., V.L. Callegaro, and P. Bender.2002. *Utilizaciao de algas diatomáceas epilíticas como indicadoras da qualidade da agua em ríos e arroios da Regiao Hidrograca do Guába, RS, Brasil*. Santa Cruz do Sul: EDUNISC. 127 pp.
31) Lurling, M. 2003. The effect of different zooplankton species and fish on the induction of defensive morphology in the green alga *Scenedesmus obliquus*. Journal of Plankton Research, 25:979-989.
32) Luttenton, M.R., and R. Lowe, 2006. Response of lentic periphyton community to nutrient enrichment at low N:P ratios. Journal of Phycology, 42: 1007–1015.
33) Mäemets, A. 1983. Rotifers as indicators of lake types in Estonia. Hydrobiologia, 104:357-361.
34) Martínez, G.A., D. Sotomayor-Ramírez, S. Whitmire, and M. Alfaro. 2011. 2011 Accomplishments Report (AD-421) of Research Project: Ecological significance of an aquatic invasive species (*C. fluminea*) on cyanobacteria and their associated toxins in tropical reservoirs, U.S. Dept. of Agriculture, State Agricultural Experiment Stations and Other Institutions.
35) Martínez, G.A., D. Sotomayor-Ramírez, and L. Pérez-Alegría. 2005. Development of Numeric Nutrient Criteria in lakes and Reservoirs of Puerto Rico. Final Report Submitted to The Environmental Quality Board of Puerto Rico. October, 2005.
36) Matsumura-Tundisi, T., S. Neumann-Leitão, L.S. Aguena, and J. Miyahara. 1990. Eutrofização da represa de Barra Bonita: estrutura da comunidade de Rotifera. Rev. Bras. Biol., 50:923-935.
37) Mazumder, A., 1994. Phosphorus-Chlorophyll Relationships under contrasting herbivory and thermal stratification: Predictions and Patterns. Can. J. Fish. Aquat. Sci. 51: 390-400.
38) McCauley E., and J. Kalff. 1981. Empirical relationships between phytoplankton and zooplankton biomass in lakes. *Can. J. Fish. Aquat. Sci.* 38, 458–63.
39) Neumann-Leitão, S., and F.B.V.A. Souza. 1987. Rotíferos (Rotatoria) planctônicos do açude de Apipucos, Recife-Pernambuco (Brasil). Arq. Biol. Tecnol., 30:393-418.
40) Neves, I.F., O. Rocha, K.F. Roche, and A.A. Pinto. 2003. Zooplankton community structure of two marginal lakes of the river Cuibá (Mato Grosso, Brazil) with analysis of Rotifera and Cladocera diversity. Braz. J. Biol., 63:329-343.
41) Nürnberg, G.K. 1996. Trophic State of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Journal of lake and reservoir management 12 (4): 432-447.
42) NOAA. 2006. NOAA. Atlas 14. Precipitation Frequency Atlas of the United States. Puerto Rico and the US Virgin Islands. Volume 3, Version 4. Maryland.
43) Ortiz-Zayas, J., F. Quiñones, S. Palacios, A. Vélez, and H. Más. 2004. Características y condición de los embalses principales en Puerto Rico. Informe en

Borrador sometido a ELA-DRNA. Oficina del Plan de Aguas. 180 p. con apéndices.
44) Paggi, J.C., and S. Jose De Paggi. 1990. Zooplâncton de ambientes lóticos e lênticos do rio Paraná médio. Acta Limnol. Bras., 3:685-719.
45) Pantoja-Agreda, F., C. Santos-Flores, G. A. Martinez, and D. Sotomayor. 2009. Phytoplankton Dynamics of the Guajataca Reservoir. Proceedings. 30th Congress of the International Association of Theoretical and Applied Limnology. August 12-18, Montreal, Canada. Verh. Internat. Verein. Limnol. 2009, vol. 30, Part 7, p. 1096–1100, Stuttgart, July 2009.
46) Patrick, R., and N.A. Roberts. 1979. Diatom communities in the Middle Atlantic States, U.S.A. Nova Hedwigia Beih., 64: 265-283.
47) Passy, S.I. 2007. Diatom ecological guilds display distinct and predictable behavior along nutrient and disturbance gradients in running waters. Aquatic Botany, 86:171–178.
48) Paul, J. F., and M.E. McDonald. 2005. "Development of Empirical, Geographically Specific Water Quality Criteria: A Conditional Probability Analysis Approach." *Journal of the American Water Resources Association* 41 (2005): 1211-23.
49) Pinto-Coelho, R., B. Pinel-Alloul, G. Méthod, and K.E. Havens. 2005. Crustacean Zooplankton in lakes and reservoirs of temperate and tropical regions: variation with tropic status. Can. J. Fish. Aquat. Sci., 62:348-361.
50) Ponader, K.C., and M.G. Potapova, 2007. Diatoms from the genus Achnanthidium in flowing waters of the Appalachian Mountains (North America): ecology, distribution and taxonomic notes. Limnologica, 37: 227–241.
51) Praire, Y. T; C. M. Duarte; and J. Kalff. 1989. Unifying Nutrient-Chlorophyll Relationships in lakes. Can. J. Fish Aquat. Sci. 46: pp. 1176-1182.
52) Prescott, G. W. 1970. How to know the fresh water algae. M.C. Brown Company Publishers. Dubuque, Iowa.
53) Ptacnick, R. A., A. G. Solimini & P. Brettum, 2009. Performance of a new phytoplankton composition metric along a eutrophication gradient in Nordic lakes. Hydrobiologia, 633: 75–82
54) Puerto Rico Environmental Quality Board. 2008. Puerto Rico water quality inventory and list of impaired waters. 2002 305(b)/303(d) Integrated Report.
55) Qian, Song S., R. S. King, and Curtis J. Richardson. 2003. "Two Statistical Methods for the Detection of Environmental thresholds." Journal of Ecological Modeling 166: 87-97.
56) Radwan, S. 1976. Planktonic rotifers as indicators of lake trophy. Ann. Univ. Mariae Curie-Sklodowska, 31:227-235.
57) Reid, J.W. 1985. Chave para identificação e lista de referências bibliográficas para espécies continentais sulamericanas de vida livre da Ordem Cyclopoida (Crustacea, Copepoda). Bol. Zool., 9:17-143.

58) Reid, J.W. 1989. The distribution of species of the genus *Thermocyclops* (Copepoda Cyclopoida) in the western hemisphere, with description of *T. parvus*, new species. Hydrobiologia, 175:149-174.
59) Reynolds, C.S. 1988. Functional morphology and adaptive strategies of freshwater phytoplankton. In: C.D. Sandgren (ed.), Growth and Reproductive Strategies of Freshwater Phytoplankton, pp. 388-433. Cambridge University Press, New York.
60) Reynolds, C.S. 1997. Vegetation Process in the Pelagic: A Model for Ecosystem Theory. Excellence in Ecology. Ecology Institute Oldendorf/Luhe.
61) Reynolds, C.S., V. Huszar, C. Kruk, L. Naselli-Flores, and S. Mello. 2002. Towards a functional classification of the freshwater phytoplankton. Journal of Plankton Research, 24(5):417-428.
62) Rimet, F., Goma, J., Cambra, J., Bertuzzi, E., Cantonati, M., Cappelletti, C., Ciutti, F., Cordonier, A., Coste, M., Delmas, F., Tison, J., Tudesque, L., Vidal, H., and L. Ector. 2007. Benthic diatoms in Western European streams with altitudes above 800 m, characterization of the main assemblages and correspondence with ecoregions. Diatom Research, 22:147–188.
63) Rocha, O., S. Sendacz, and T. Matsumura-Tundisi. 1995. Composition, biomass and productivity of zooplankton in natural lakes and reservoirs of Brazil. In: Limnology in Brazil. ABC/SBL, Rio de Janeiro. p.151-166.
64) Rocha, O., T. Matsumura-Tundisi, and E.V. Sampaio. 1997. Phytoplankton and Zooplankton community structure and production as related to trophic state in some Brazilian lakes and reservoirs. Verh. Int. Verein. Limnol., 26:599-604.
65) Ruttner-Kolisko, A. 1974. Plankton rotifers. Biology and taxonomy. Die binnengewässer. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. 146p.
66) Santos-Flores, C.J. 2001. Taxonomy and distribution of freshwater micro-crustaceans and green algae of Puerto Rico, three contributions to American cladocerology, and a bibliography on West Indian limnology. Ph.D. Thesis, University of Wisconsin-Madison. 1421 pp.
67) Sendacz, S., E. Kubo, and L.P. Fujiara. 1984. Further studies on the zooplankton community of a eutrophic reservoir in sourthern Brazil. Verh. Int. Verein. Limnol., 22:1625-1630.
68) Soler-López, L.R., R. M.T. Webb, and F. Pérez-Bair. 1997. Sedimentation Survey of Lago Patillas, April 1997. USGS Water Resources Report 99-4030.
69) Soler-López, L.R. 1997. Sedimentation Survey of Lago Cidra, November, 1997. USGS Water Resources Report 99-4144.
70) Soler-López, L.R., R. M.T. Webb, and R. A. Carrasquillo-Nieves. 2000. Sedimentation Survey of Lago Guajataca, January, 1999. USGS Water Resources Report 00-4044.
71) Soler-López, L.R., R. M.T. Webb, and R. A. Carrasquillo-Nieves. 2000. Sedimentation Survey of Lago La Plata, October, 1998. USGS Water Resources Report 00-4045.

72) Soler-López, L.R. 2004. Sedimentation Survey of Lago Toa Vaca, June-July 2002. USGS Scientific Investigation Report 2004-5035.
73) Soler-López, L.R. 2008. Sedimentation Survey of Lago La Plata, July, 2006. Scientific Investigation Map 2006-3021. USGS.
74) Soler-López, L.R. 2010. Sedimentation Survey of Lago Cidra, August, 2007. Scientific Investigation Map. USGS.
75) Soler-López, L.R. 2010. Sedimentation Survey of Lago Patillas, March, 2007. Puerto Rico. Scientific Investigation Map. USGS.
76) Soler-López, L.R. 2011. Sedimentation Survey of Lago Cerrillos, April-May 2008. USGS Scientific Investigation Report 2011-5057.
77) Sotomayor, D., G.A. Martínez, and F. Pantoja-Agreda. 2008. Limnological Assessment of two Reservoirs of Puerto Rico. Verh. Internat. Verein. Limnol. vol. 30, Part 4, p. 521–527, Stuttgart, September 2008.
78) Starling F. L. R. M. 2001. Comparative study of the zooplankton composition of six lacustrine ecosystems in Central Brazil during the dry season. *Braz. J. Biol.* 60, 101–11.
79) Stemberger, R.S., and J.M. Lazorchak. 1994. Zooplankton asemblage responses to disturbance gradients. Can. J. Fish. Aquat. Sci., 51:2435-2447.
80) Stoermer, E.F., and J.P. Smol. 1999. The Diatoms: Applications for the Environmental and Earth Sciences, Cambridge University Press, Cambridge.
81) Szczepocka, E., and B. Szulc. 2009. The use of benthic diatoms in estimating water quality of variously polluted rivers. Oceanological and Hydrobiological Studies. International Journal of Oceanography and Hydrobiology, 38(1): 17-26.
82) Townsend, S.A. 1999. The seasonal pattern of dissolved oxygen, and hypolimnetic deoxygenation, in two tropical Australian reservoirs. Lakes & Reservoirs: Research and Management. 4: 41 – 53.
83) Townsend, S.A. 2000. Seasonal pattern and inferred phosphorus limitation of phytoplankton biomass in two tropical reservoirs in northern Australia. Marine and freshwater research. 51(1): 91-96
84) USEPA. 1999. Protocol for developing nutrient TMDLs. Office of Water. EPA 841-B-99-007. November 1999.
85) USEPA. 2000. Nutrient Criteria Technical Guidance Manual. EPA-822-B00-001. Office of Water, USEPA, Washington, D.C.
86) USEPA. 2009. U.S. Environmental Protection Agency (USEPA). 2009. National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.
87) U.S Geological Survey. 1998. Geology, Geochemistry, Geophysics, Mineral Occurrences and Mineral Resource Assessment for the Commonwealth of Puerto Rico. Open-File Report 98-38. Walter J. Bawiec (Ed.).

88) Van Dam, M.A., and J. Sinkeldam J. 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Journal of Aquatic Ecology, 28(1):177-133.
89) Velho L. F. M., Lansac-Toha F. A., Bonecker C. C., Bini L. M. & Rossa D. C. 2001. The longitudinal distribution of copepods in Corumba Reservoir, State of Goias, Brazil. *Hydrobiologia* 453⁄454, 385–91.
90) Wehr, J.D., and R.G. Sheath. 2003. Freshwater Algae of North America. Academic Press. xvi + 918 pp.
91) White, E. 1989. Utility of relationships between lake phosphorus and chlorophyll a as predictive tools in eutrophication control studies. New Zealand Journal of Marine and Freshwater Research. 23: 35-41.
92) Wojtal, A.Z., and J. Kwandrans. 2006. Diatoms of the Wyzyna Krakowsko-Czestochowska upland (Poland)-Coscinodiscophyceae (Thalassiosirophycidae). Polish Botany Journal, 51: 177-207.

APPENDIX A: QAPP Title and Approval Page

12/22/11
5th version

TITLE AND APPROVAL PAGE

NUTRIENT LEVELS ASSOCIATED WITH ECOLOGICAL THRESHOLDS OF IMPAIRMENT IN RESERVOIRS OF PUERTO RICO

(Project Name)

ENVIRONMENTAL QUALITY BOARD

(Responsible Agency)

01/10/2012

(Date)

PREQB Overall Project Officer

Roberto Ayala /Date 01/10/2012

PREQB Project QA Officer Signature

Juan Luis Osorio /Date 01/10/2012

USEPA Project Officer Signature

Yasmin Idaguer/Date 12/29/11

USEPA QA Officer Signature

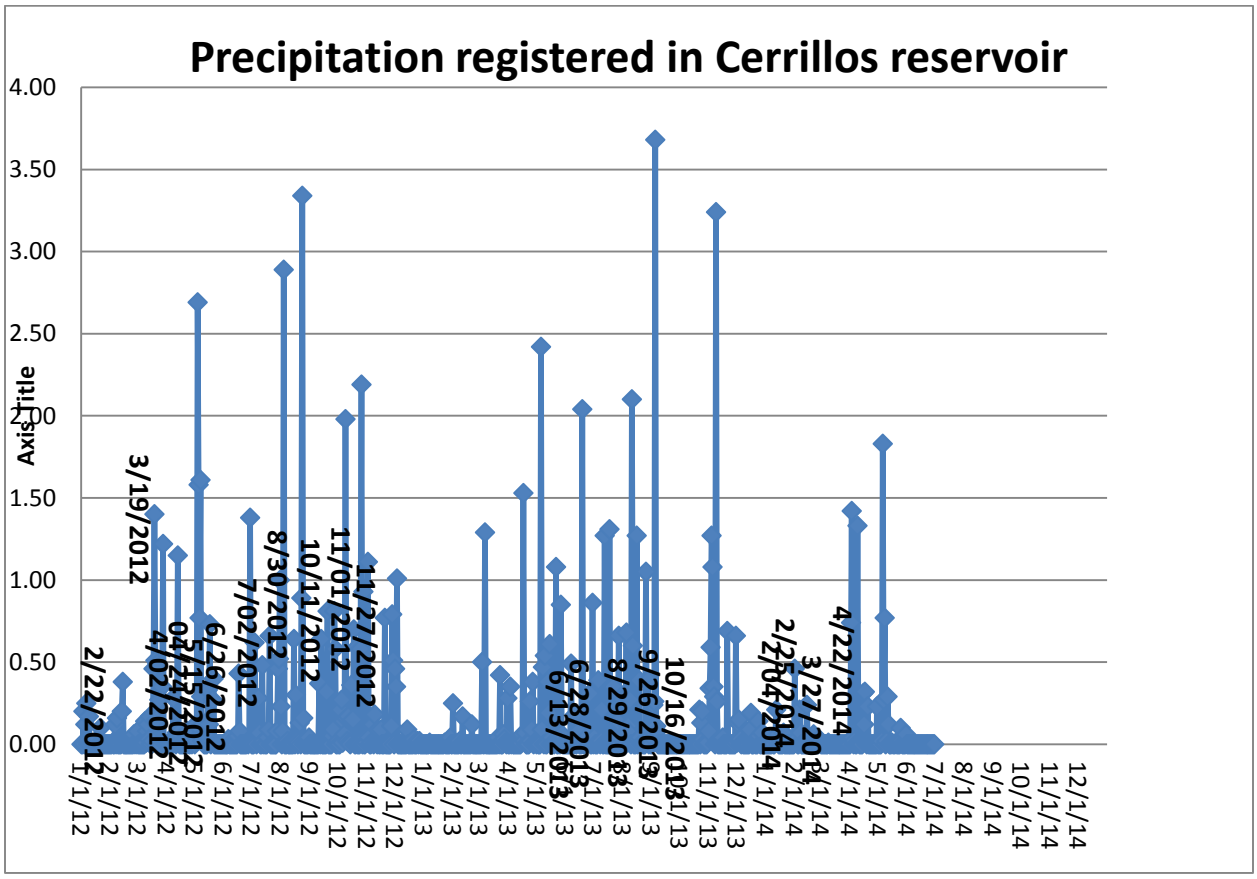
Carol Lynes/Date 12/29/11

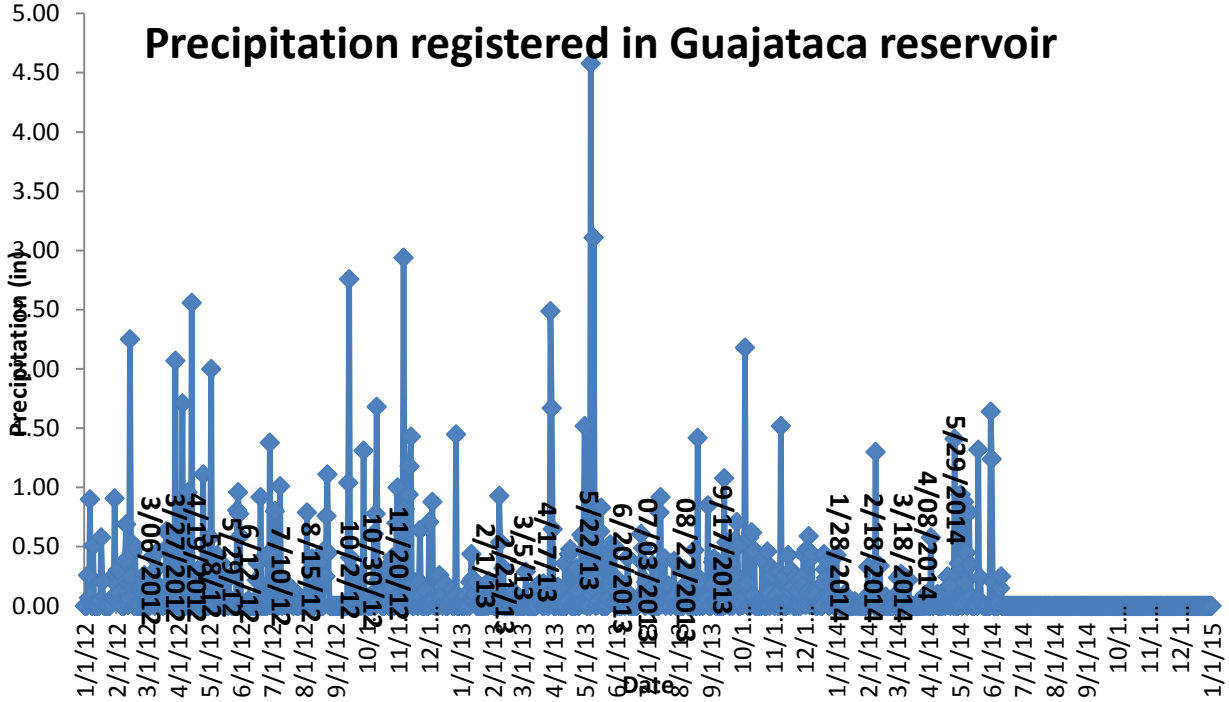
APPENDIX B: Reservoir Sampling Coordinates –NAD83

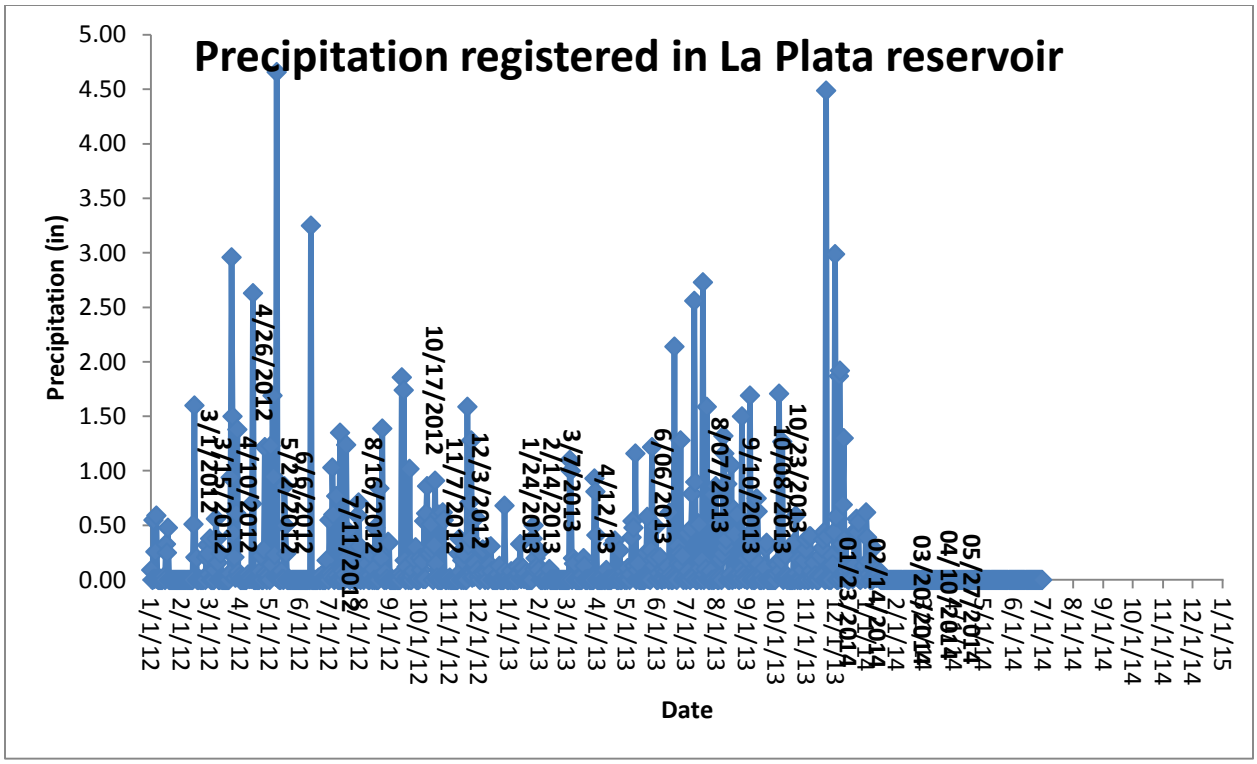
Reservoir	lat	Long
Guajataca	-66.919465	18.378627
Guajataca	-66.919750	18.378266
Guajataca	-66.919146	18.378962
Cerrillos	-66.578574	18.087485
Cerrillos	-66.579047	18.087491
Cerrillos	-66.578101	18.087495
Toa Vaca	-66.474393	18.100895
Toa Vaca	-66.474534	18.100462
Toa Vaca	-66.474270	18.101334
La Plata	-66.237477	18.332969
La Plata	-66.237856	18.333251
La Plata	-66.237199	18.332500
Cidra	-66.139217	18.190523
Cidra	-66.139411	18.190653
Cidra	-66.139022	18.190395
Patillas	-66.019197	18.021678
Patillas	-66.019695	18.021742
Patillas	-66.018405	18.021596

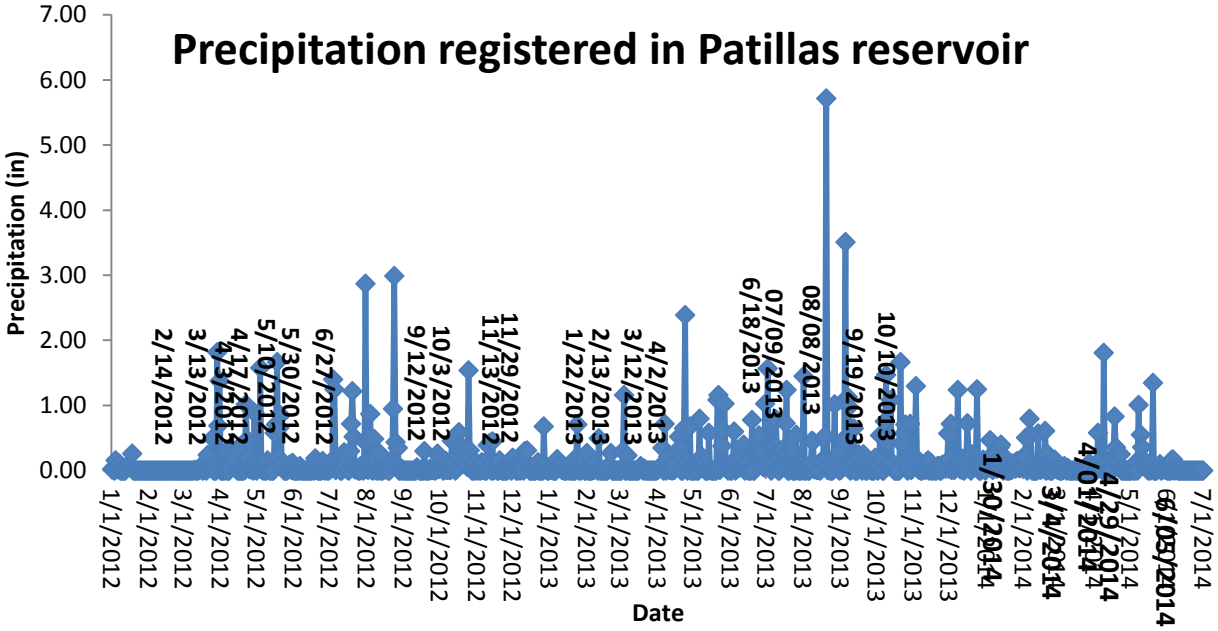
APPENDIX C: Precipitation Frequency Estimates (NOAA, 2006), and Precipitation Records (sampling dates in inserts) at the Selected Reservoirs

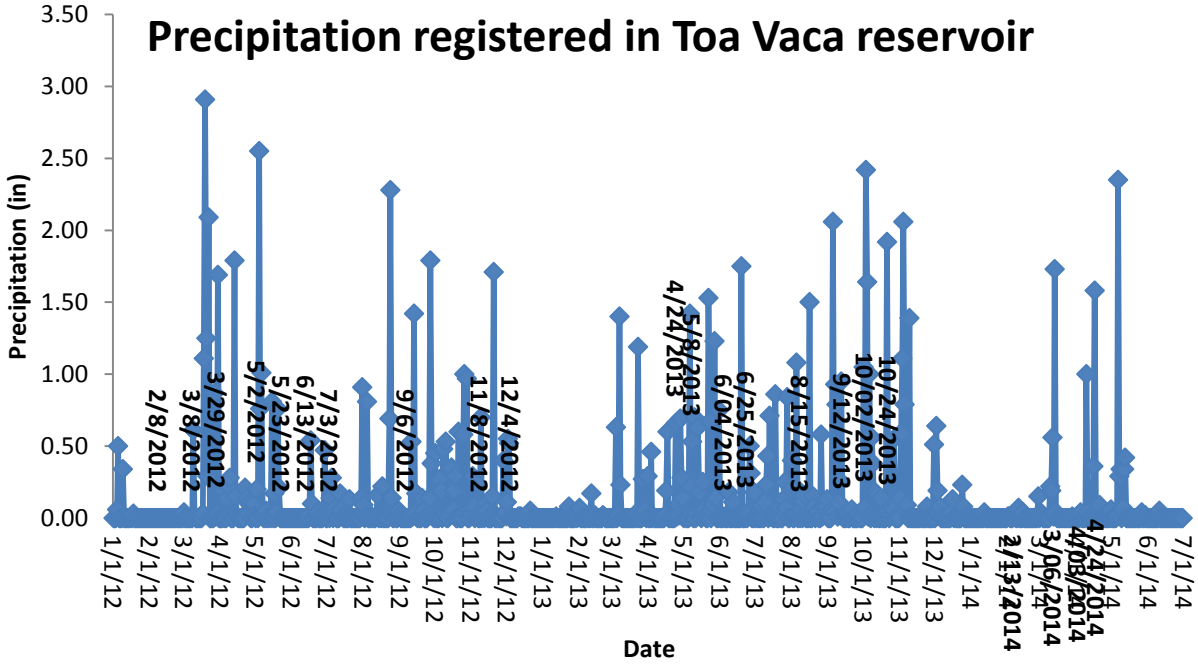
Lake	Latitude	Longitude	HU	DA (mi2)	USGS	Precipitation Frequency Estimates (NOAA, Atlas 14, Vol. 3, Ver. 4) (90 % Confident Interval)		
						2yr-24hr	10yr-24hr	25yr-24hr
Cidra	18.199167	-66.141389	21010005	8.26	50047550	5.45	9.63	12.50
La Plata	18.344444	-66.236111	21010005	181	50045000	5.46	8.84	11.00
Cerrillos	18.078056	-66.577222	21010004	17.4	50113950	5.66	10.40	13.90
Guajataca	18.400556	-66.923611	21010002	24.6	50010800	4.98	6.82	8.04
Toa Vaca	18.088056	-66.502500	21010004	21.9	50111210	5.28	9.58	12.70
Patillas	18.019686	-66.019050	21010004	25.6	50093045	5.03	8.93	11.60

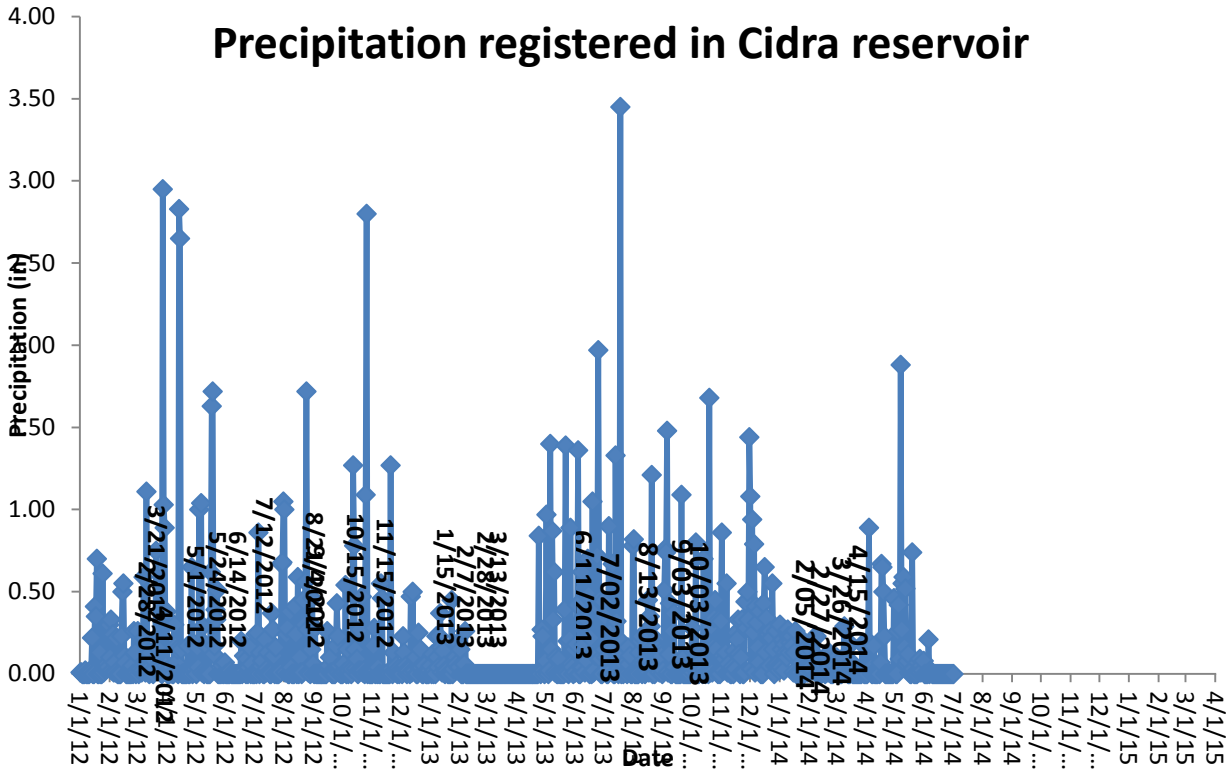



Precipitation registered in Guajataca reservoir
Precipitation (in)
Date


Precipitation registered in La Plata reservoir
Precipitation (in)
Date


Precipitation registered in Patillas reservoir
Precipitation (in)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Date
1/1/2012
2/1/2012
3/1/2012
4/1/2012
5/1/2012
6/1/2012
7/1/2012
8/1/2012
9/1/2012
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
3/1/2013
4/1/2013
5/1/2013
6/1/2013
7/1/2013
8/1/2013
9/1/2013
10/1/2013
11/1/2013
12/1/2013
1/1/2014
2/1/2014
3/1/2014
4/1/2014
5/1/2014
6/1/2014
7/1/2014
2/14/2012
3/13/2012
4/13/2012
5/10/2012
5/30/2012
6/27/2012
9/12/2012
10/3/2012
11/29/2012
11/13/2012
1/22/2013
2/13/2013
3/12/2013
4/2/2013
6/18/2013
07/09/2013
08/08/2013
9/19/2013
10/10/2013
1/30/2014
3/4/2014
4/01/2014
4/29/2014
6/05/2014


Precipitation registered in Toa Vaca reservoir
Precipitation (in)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Date
1/1/12
2/1/12
3/1/12
4/1/12
5/1/12
6/1/12
7/1/12
8/1/12
9/1/12
10/1/12
11/1/12
12/1/12
1/1/13
2/1/13
3/1/13
4/1/13
5/1/13
6/1/13
7/1/13
8/1/13
9/1/13
10/1/13
11/1/13
12/1/13
1/1/14
2/1/14
3/1/14
4/1/14
5/1/14
6/1/14
7/1/14
2/8/2012
3/8/2012
3/29/2012
5/2/2012
5/23/2012
6/13/2012
7/3/2012
9/6/2012
11/8/2012
12/4/2012
4/24/2013
5/8/2013
6/04/2013
6/25/2013
8/15/2013
9/12/2013
10/02/2013
10/24/2013
2/13/2014
3/06/2014
4/08/2014
4/24/2014


Precipitation registered in Cidra reservoir
Precipitation (in)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
3/21/2012
4/11/2012
5/1/2012
5/24/2012
6/14/2012
7/12/2012
8/29/2012
10/15/2012
11/15/2012
1/15/2013
2/7/2013
3/13/2013
6/11/2013
7/02/2013
8/13/2013
9/03/2013
10/03/2013
2/05/2014
3/26/2014
4/15/2014
1/1/12
2/1/12
3/1/12
4/1/12
5/1/12
6/1/12
7/1/12
8/1/12
9/1/12
10/1/...
11/1/...
12/1/...
1/1/13
2/1/13
3/1/13
4/1/13
5/1/13
6/1/13
7/1/13
8/1/13
9/1/13
10/1/...
11/1/...
12/1/...
1/1/14
2/1/14
3/1/14
4/1/14
5/1/14
6/1/14
7/1/14
8/1/14
9/1/14
10/1/...
11/1/...
12/1/...
1/1/15
2/1/15
3/1/15
4/1/15
Date

APPENDIX D- Legend for Land Use Figures

Legend

Class_Name

- Mature secondary lowland moist alluvial evergreen forest
- Young secondary lowland moist alluvial evergreen forest
- Lowland moist alluvial shrubland and woodland
- Young secondary moist limestone evergreen and semideciduous forest
- Moist limestone shrubland and woodland
- Mature secondary lowland moist noncalcareous evergreen forest
- Young secondary lowland moist noncalcareous evergreen forest
- Lowland moist noncalcareous shrubland and woodland
- Lowland moist abandoned and active coffee plantations
- Mature secondary montane wet alluvial evergreen forest
- Young secondary montane wet alluvial evergreen forest
- Montane wet alluvial shrubland and woodland
- Mature secondary montane wet noncalcareous evergreen forest
- Mature primary Palo Colorado and secondary montane wet noncalcareous evergreen forest
- Mature primary Sierra Palm and secondary montane wet noncalcareous evergreen forest
- Mature primary elfin woodland and secondary montane wet noncalcareous evergreen cloud forest
- Young secondary montane wet noncalcareous evergreen forest
- Montane wet noncalcareous evergreen shrubland and woodland
- Montane wet evergreen abandoned and active coffee plantation
- Moist grasslands and pastures
- Riparian and other natural barrens
- High-density urban development
- Low-density urban development
- Artificial barrens
- Freshwater

APPENDIX E- Turbidity, Specific Conductivity and Nutrient Isopleths

Turbidity Isopleth

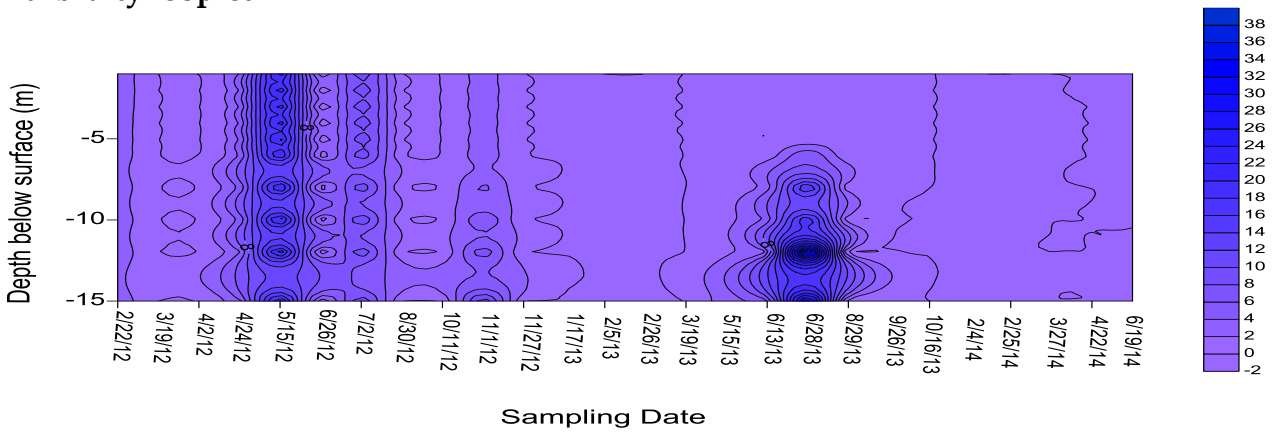


Figure E-1: Turbidity isopleth for Cerrillos

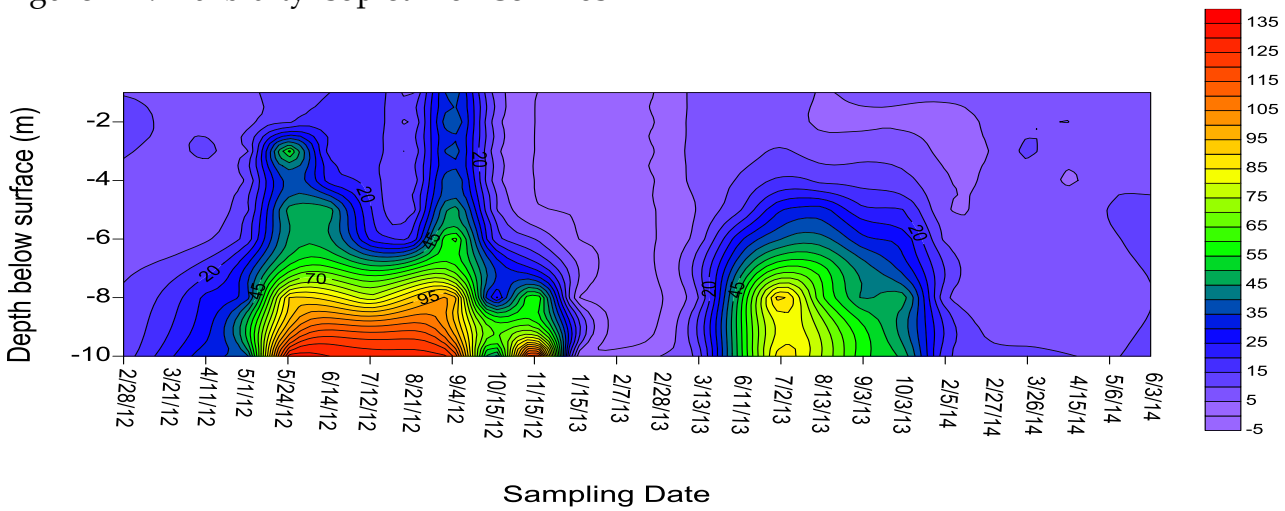


Figure E-2: Turbidity isopleth for Cidra

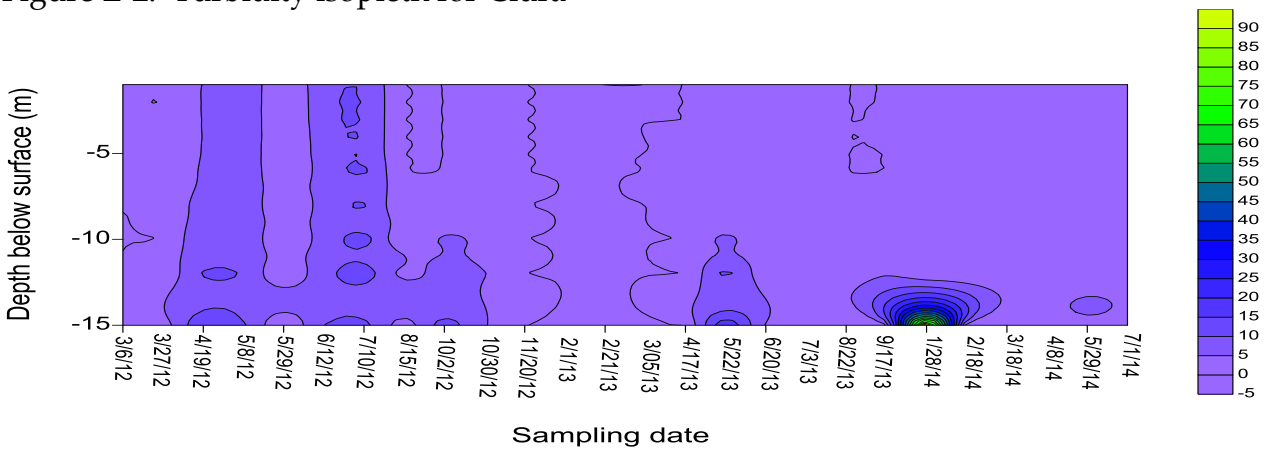


Figure E-3: Turbidity isopleth for Guajataca

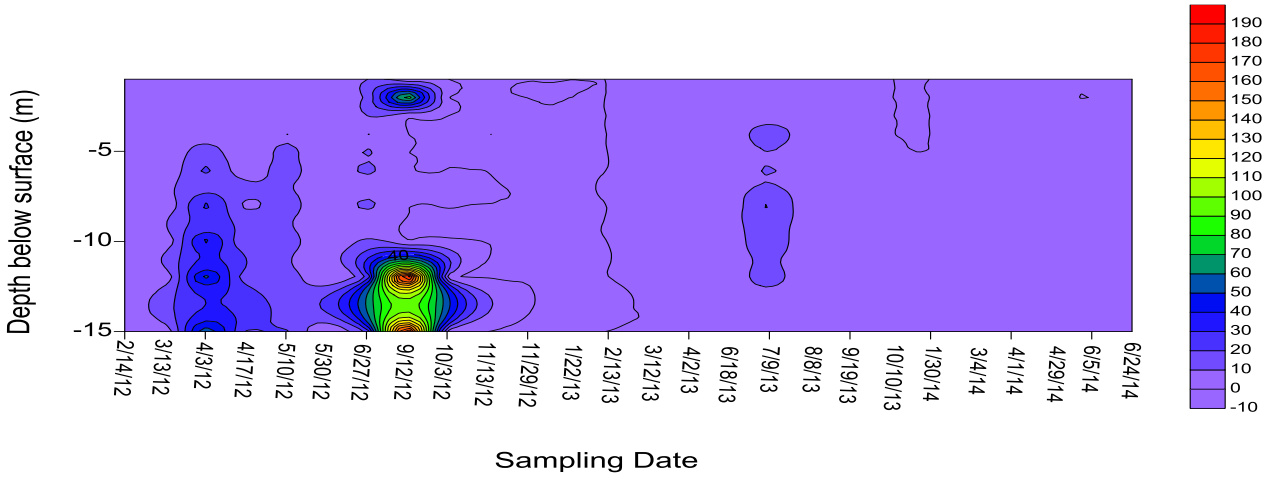


Figure E-4: Turbidity isopleth for Patillas

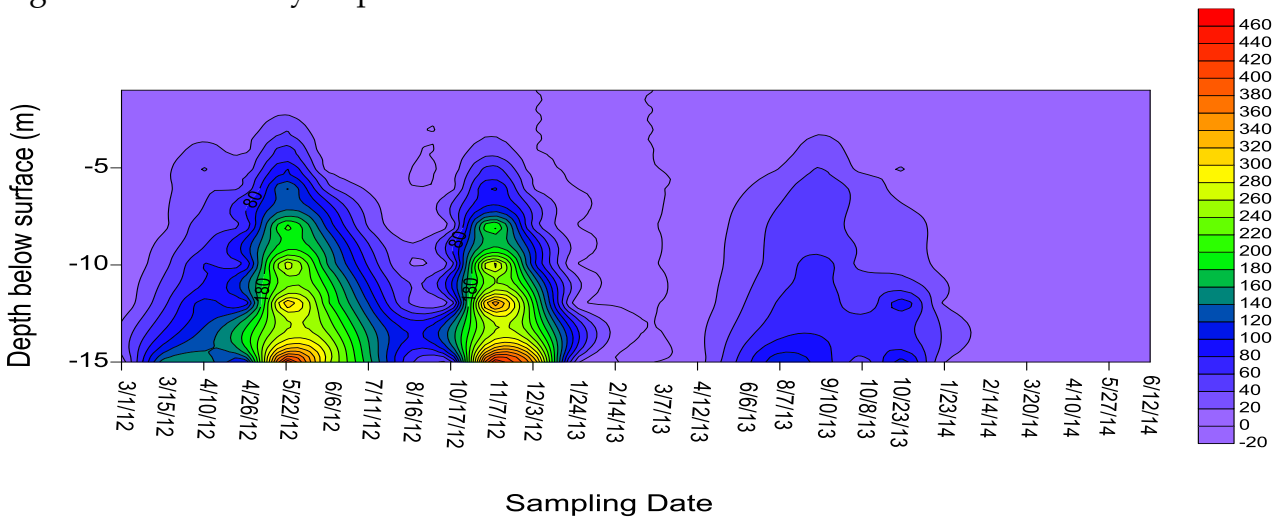


Figure E-5: Turbidity isopleth for La Plata

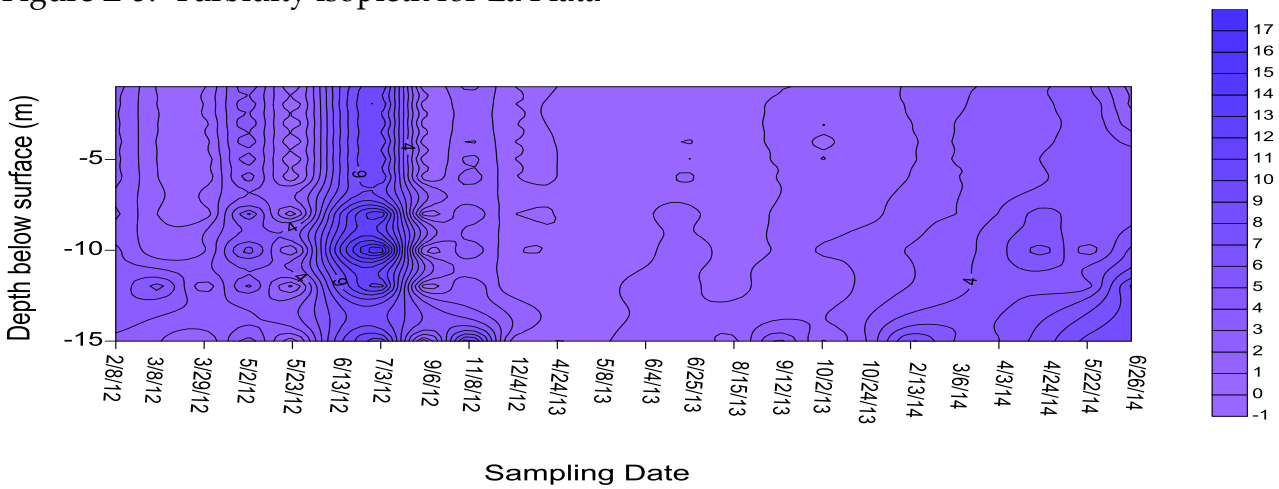


Figure E-6: Turbidity isopleth for Toa Vaca

SPECIFIC CONDUCTIVITY ISOPLETH

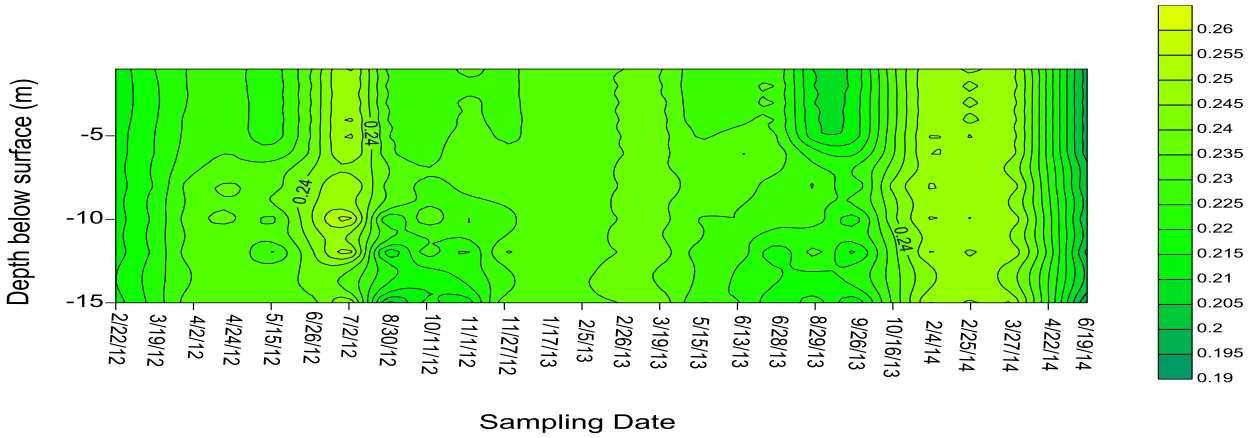


Figure E-7: Specific conductivity isopleth for Cerrillos

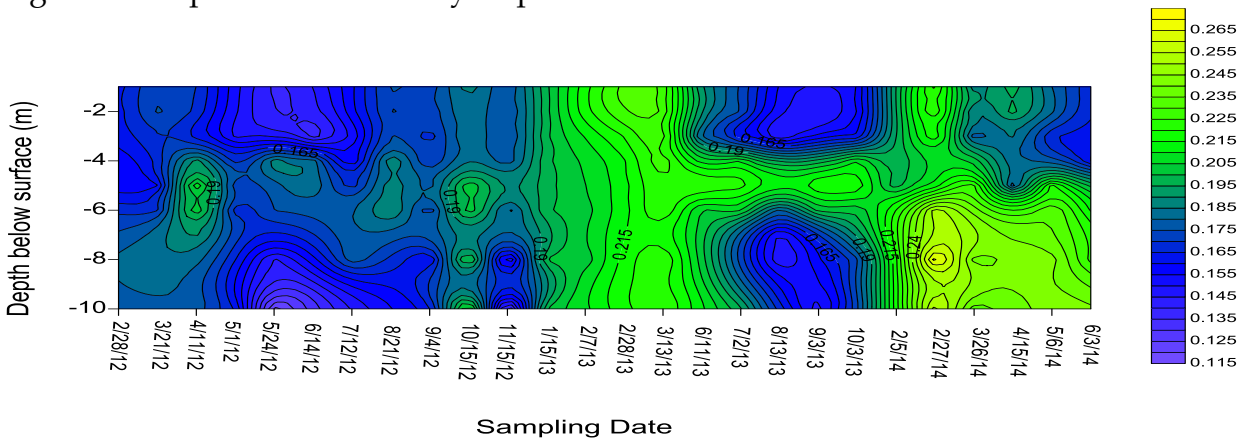


Figure E-8: Specific conductivity isopleth for Cidra

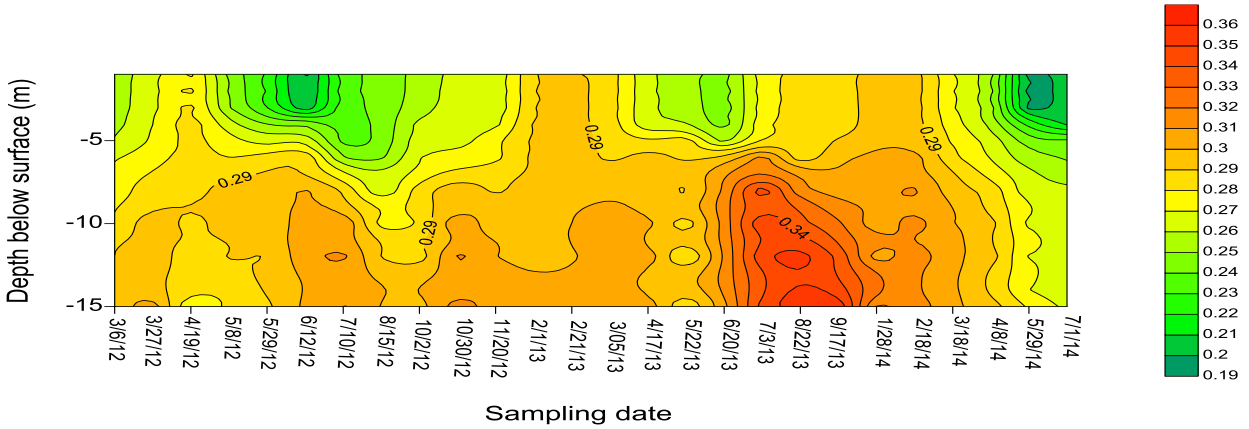


Figure E-9: Specific conductivity isopleth for Guajataca

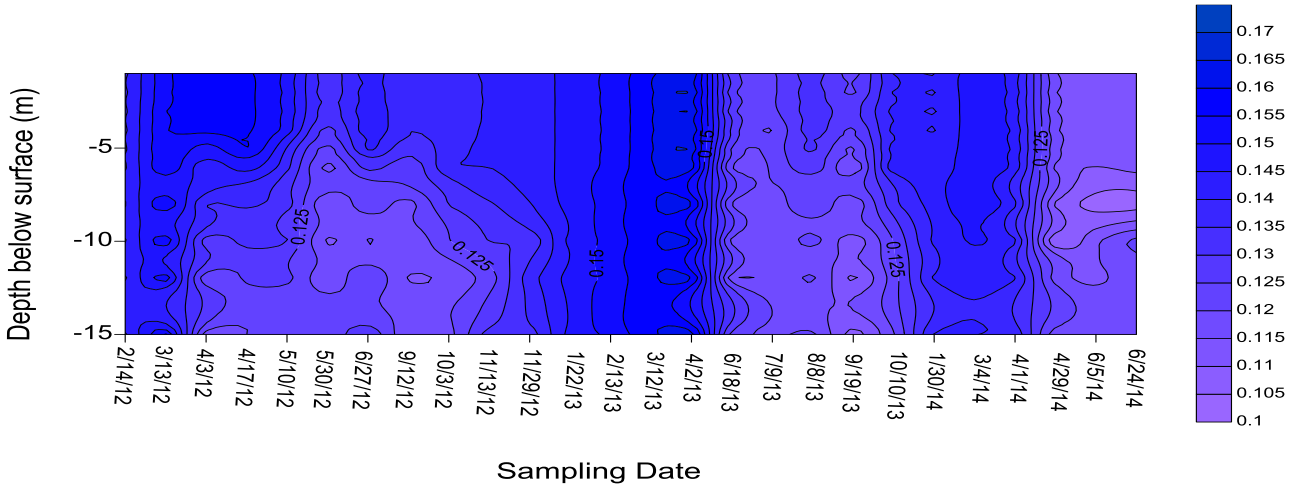


Figure E-10: Specific conductivity isopleth for Patillas

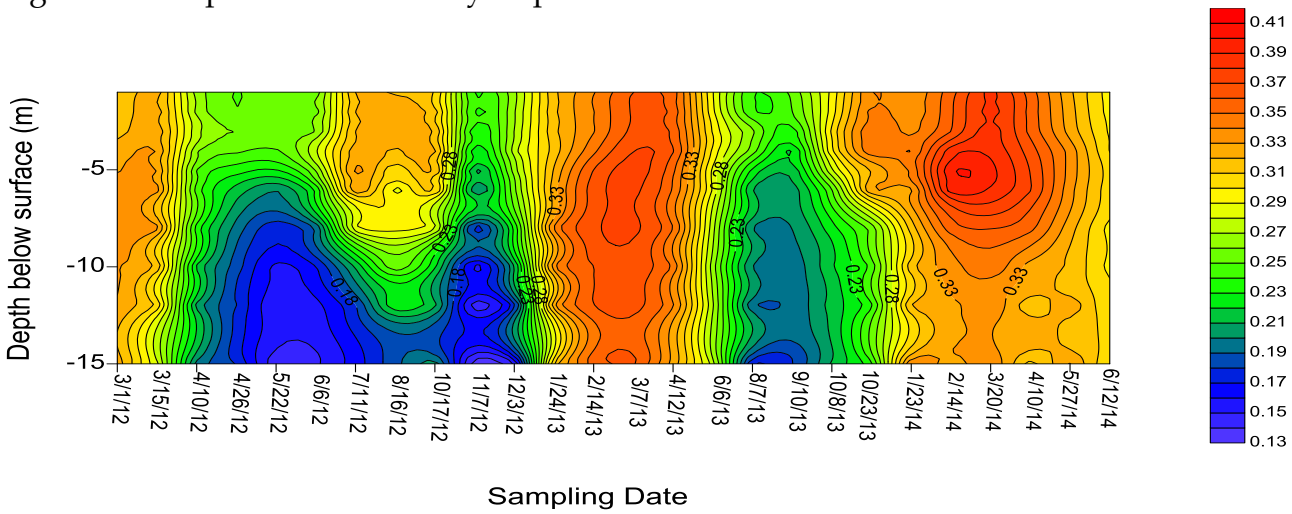


Figure E-11: Specific conductivity isopleth for La Plata

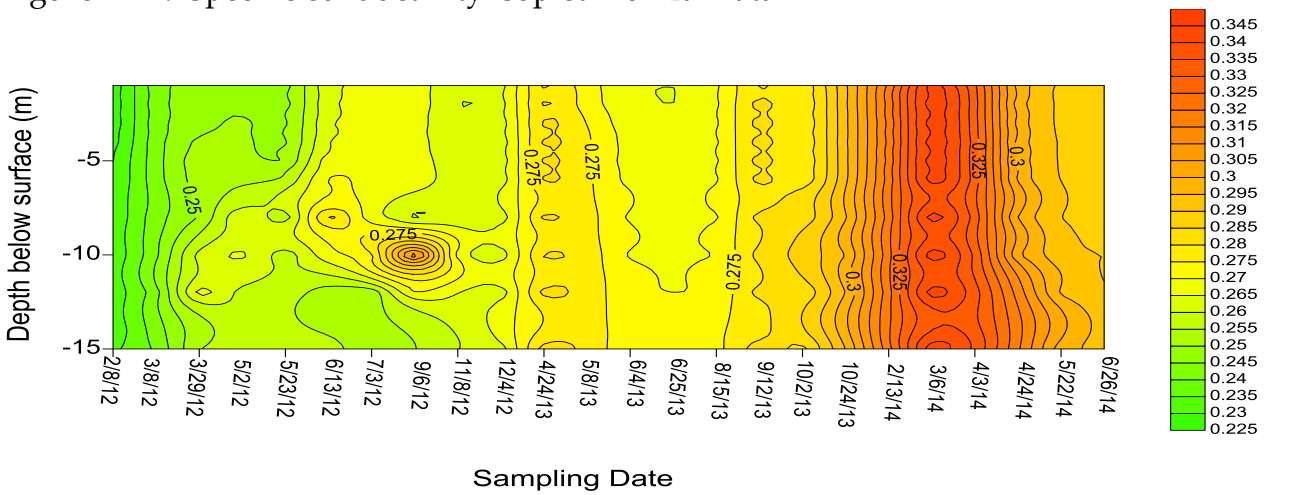


Figure E-12: Specific conductivity isopleth for Toa Vaca

TOTAL NITROGEN ISOPLETH (scale differs between reservoirs)

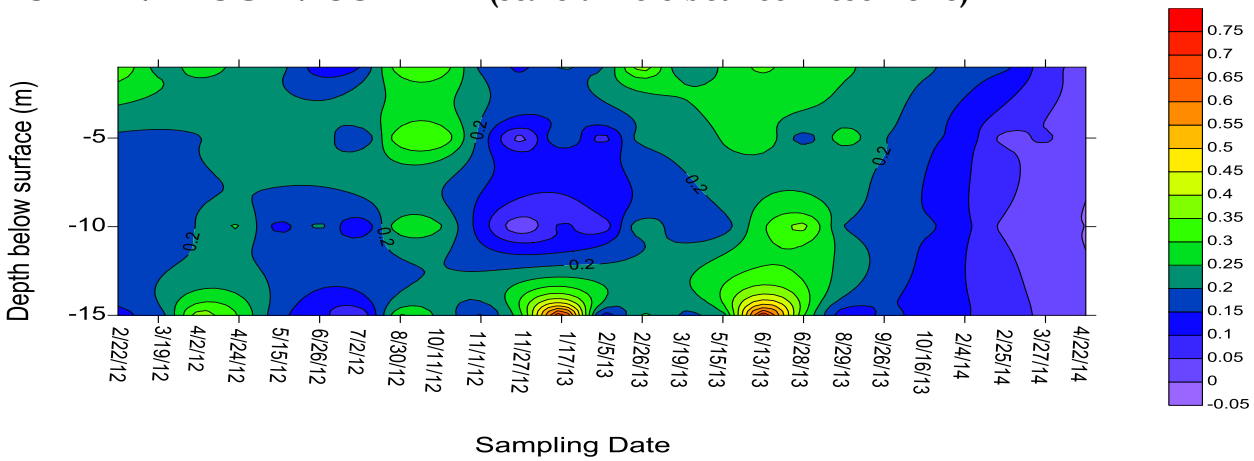


Figure E-13: Total Nitrogen isopleth for Cerrillos

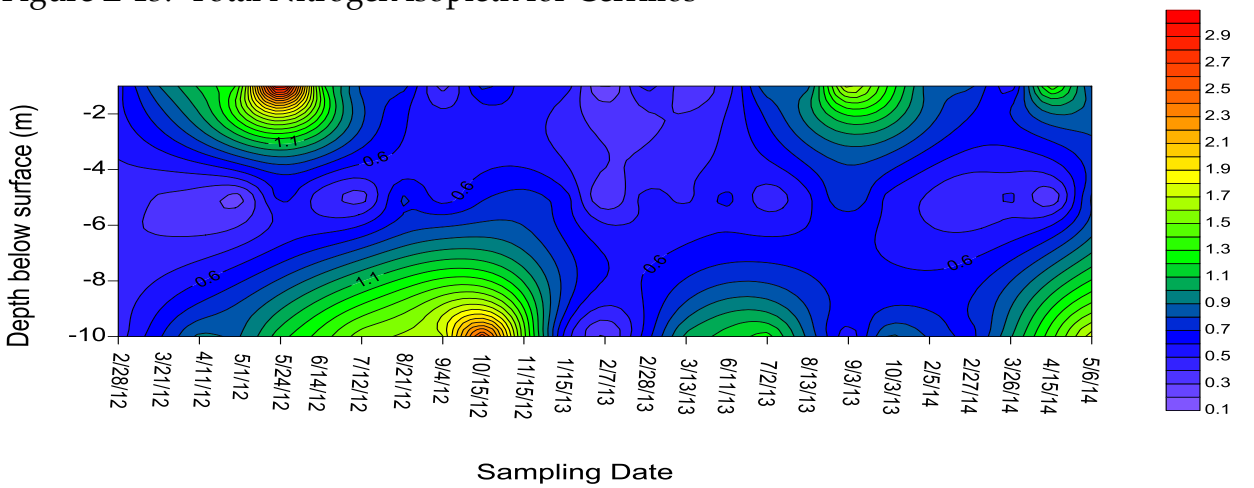


Figure E-14: Total Nitrogen isopleth for Cidra

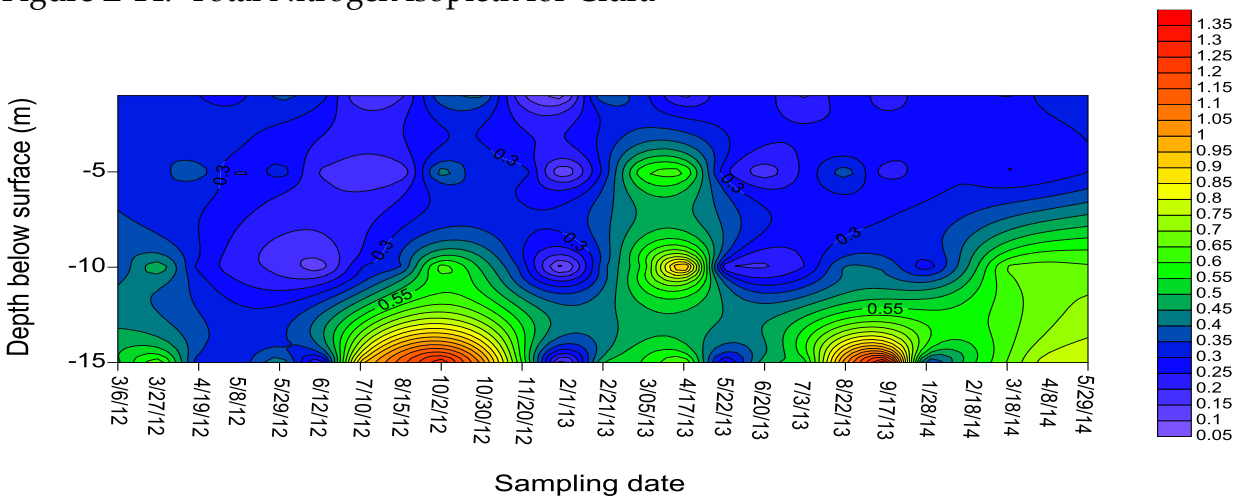


Figure E-15: Total Nitrogen isopleth for Guajataca

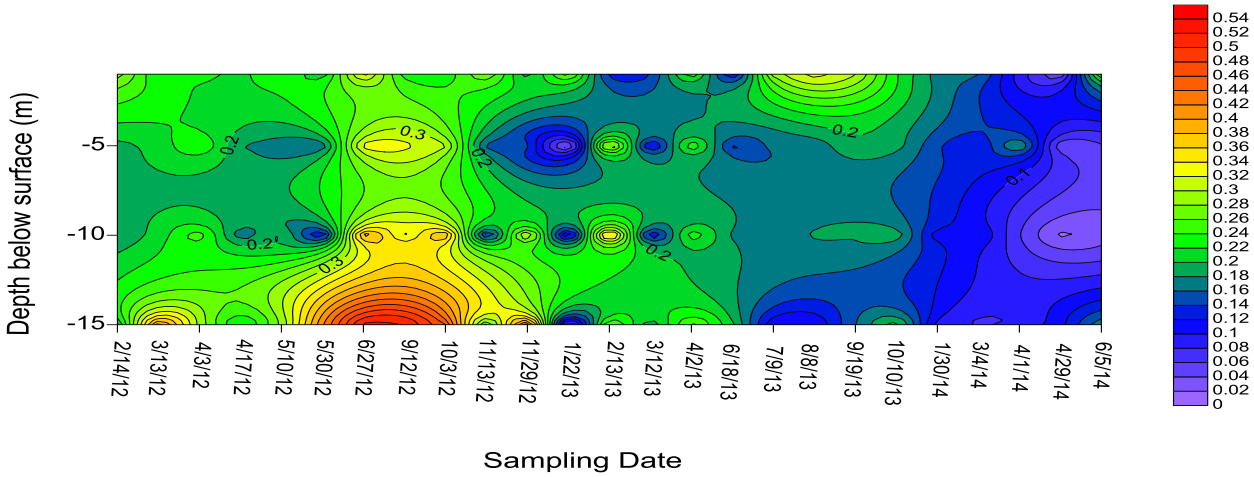


Figure E-16: Total Nitrogen isopleth for Patillas

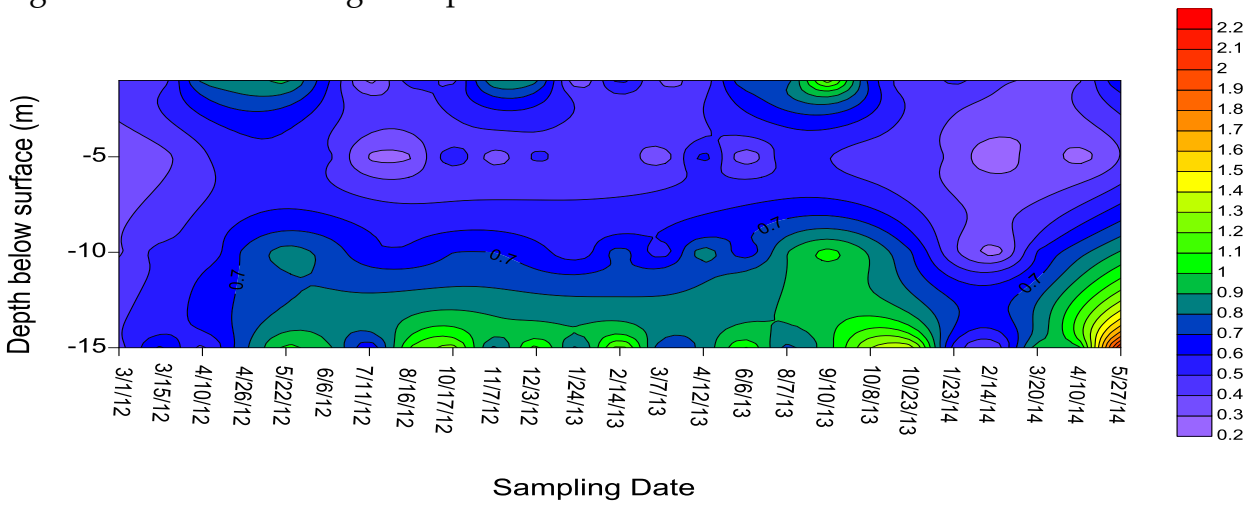


Figure E-17: Total Nitrogen isopleth for La Plata

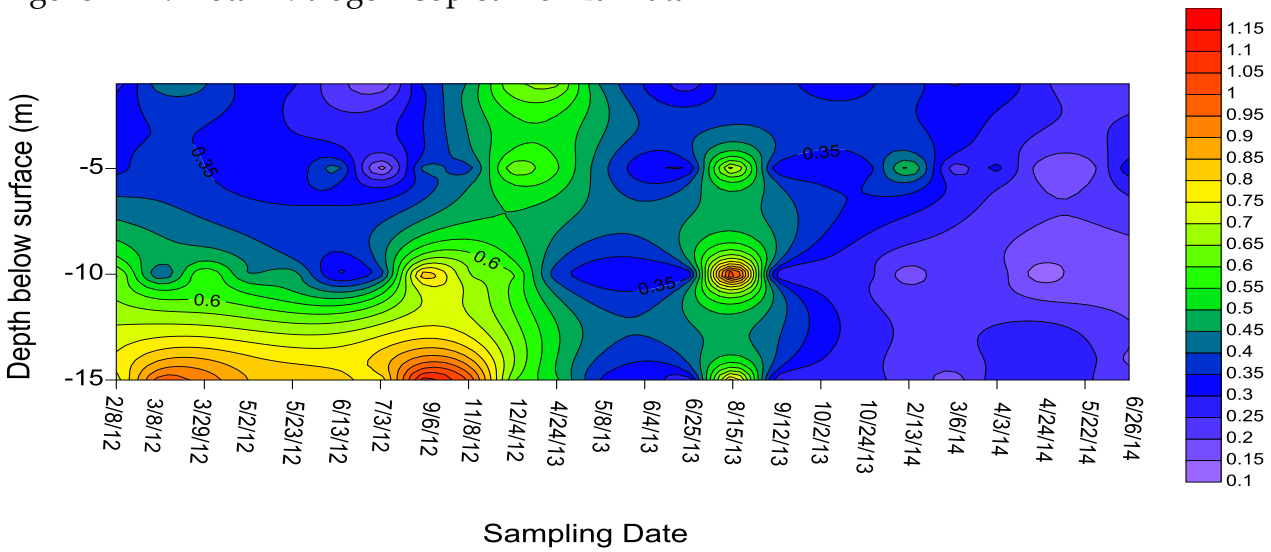


Figure E-18: Total Nitrogen isopleth for Toa Vaca

TOTAL PHOSPHORUS ISOPLETH (scale differs between reservoirs)

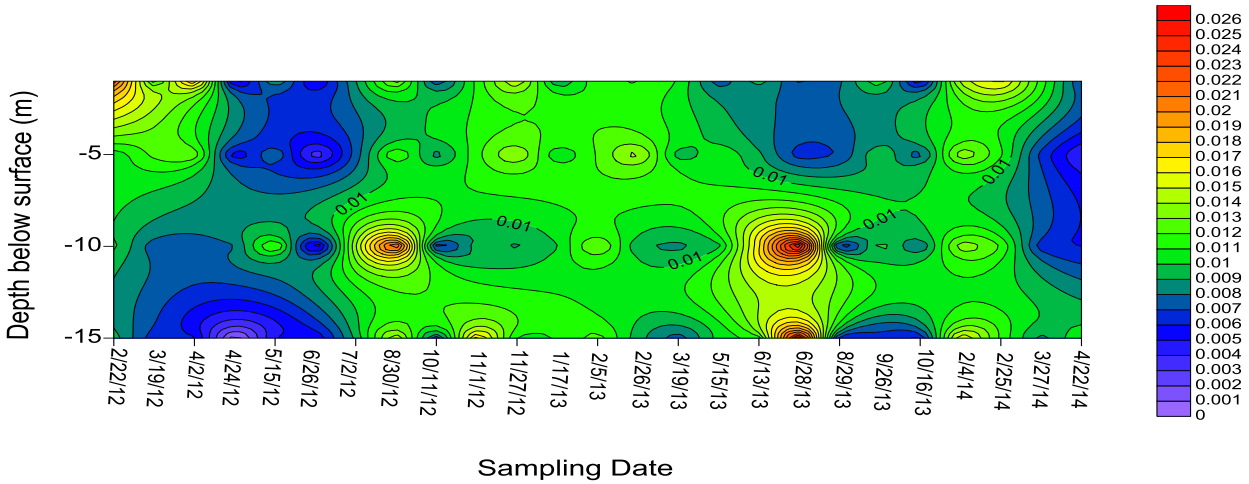


Figure E-19: Total Phosphorus isopleth for Cerrilllos

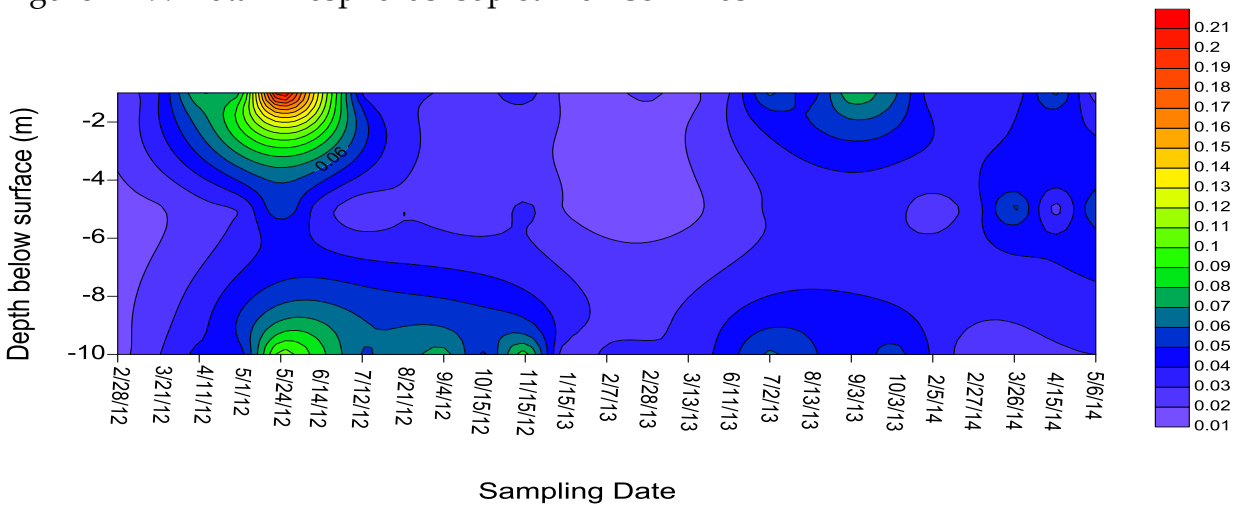


Figure E-20: Total Phosphorus isopleth for Cidra

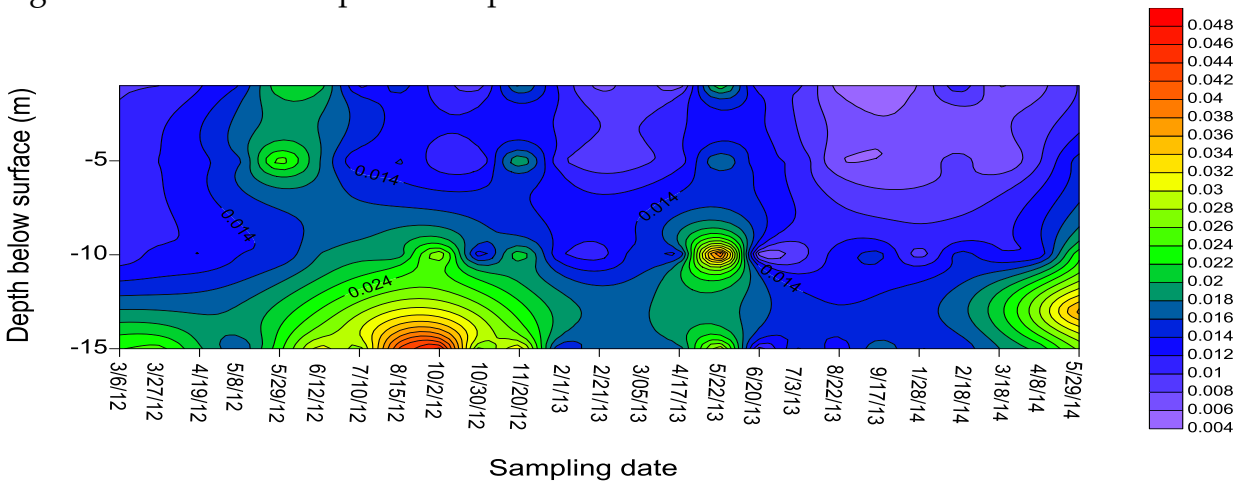


Figure E-21: Total Phosphorus isopleth for Guajataca

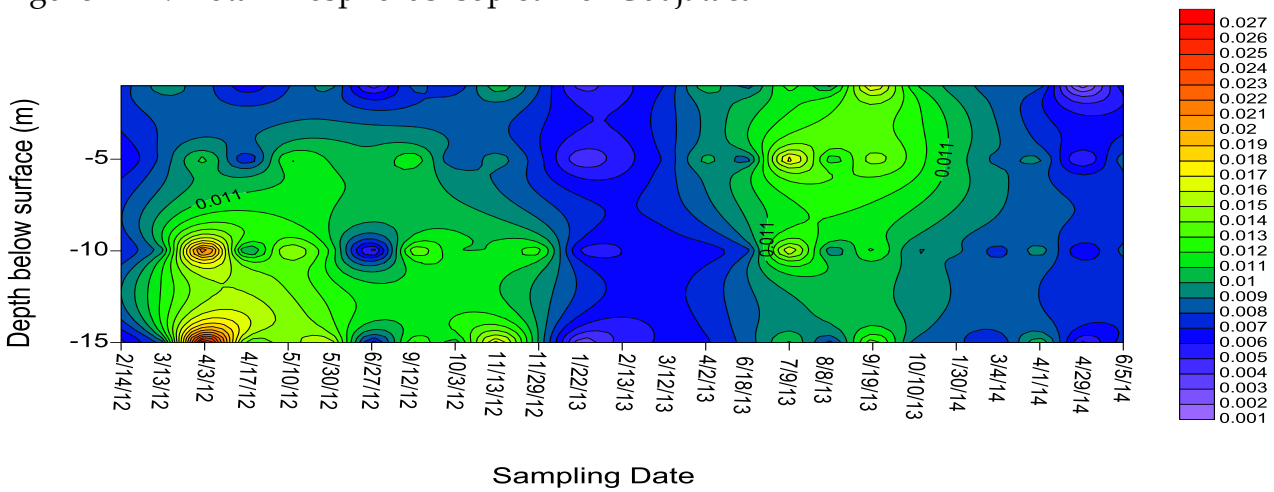


Figure E-22: Total Phosphorus isopleth for Patillas

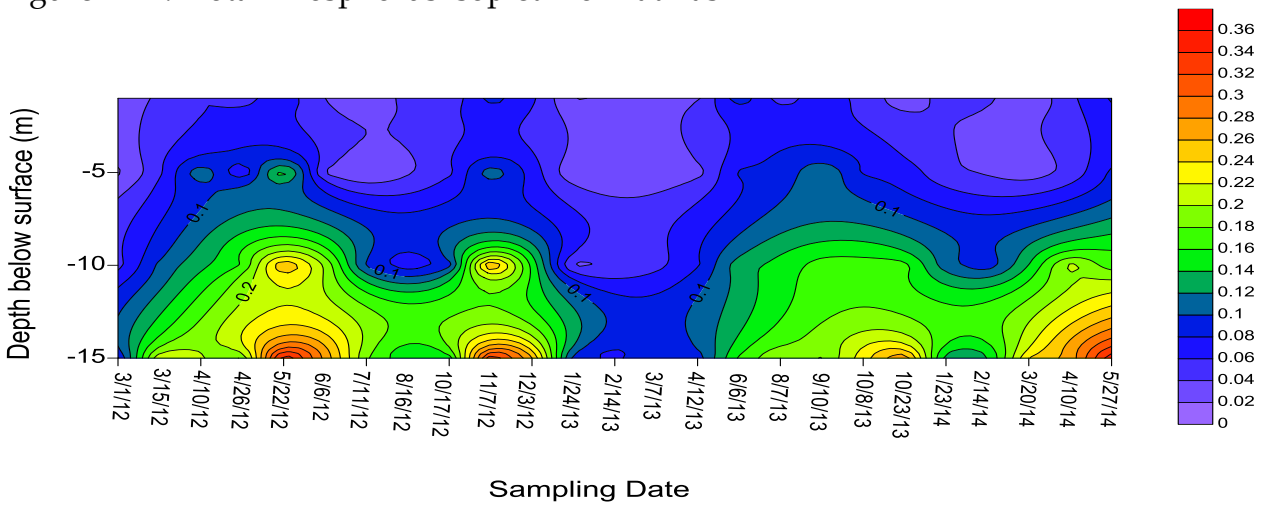


Figure E-23: Total Phosphorus isopleth for La Plata

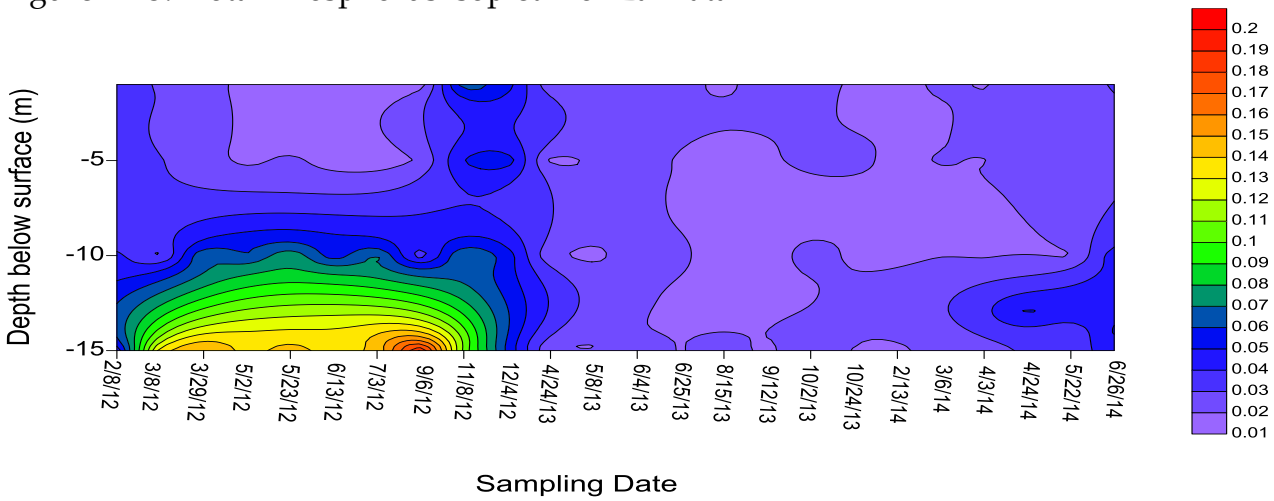


Figure E-24: Total Phosphorus isopleth for Toa Vaca

APPENDIX F: Depth-Time concentration isopleth of selected elements in reservoir waters

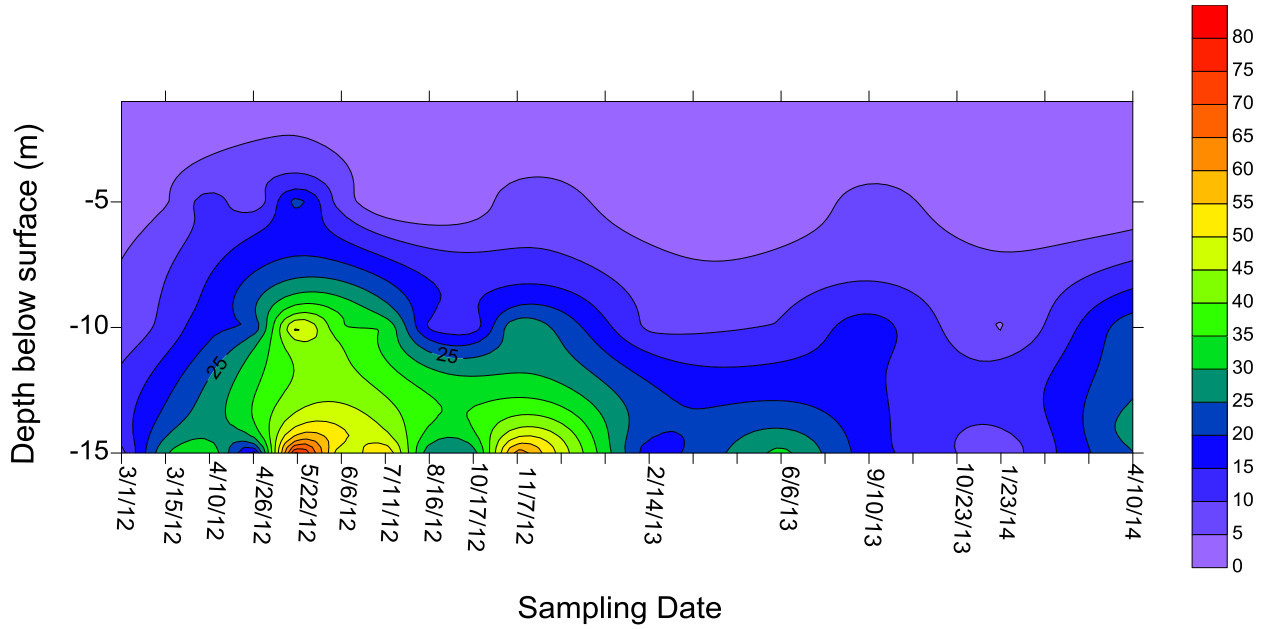


Figure F-1: Fe (µM) isopleth for La Plata

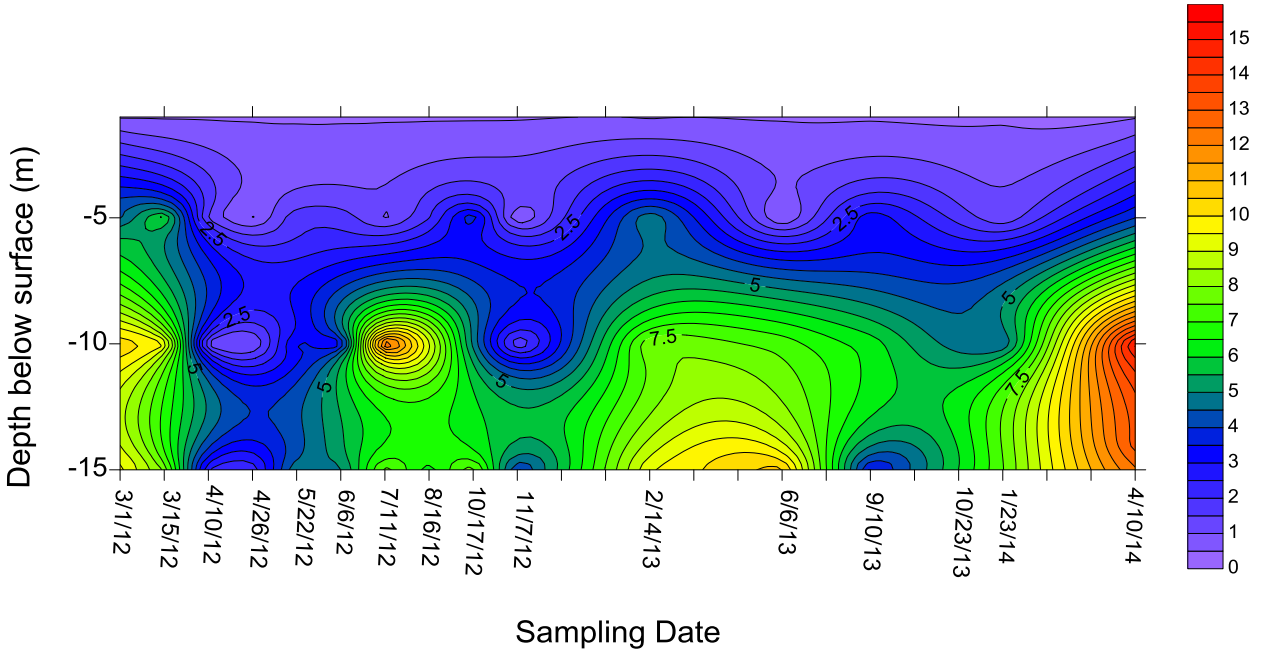


Figure F-2: Mn (µM) isopleth for La Plata

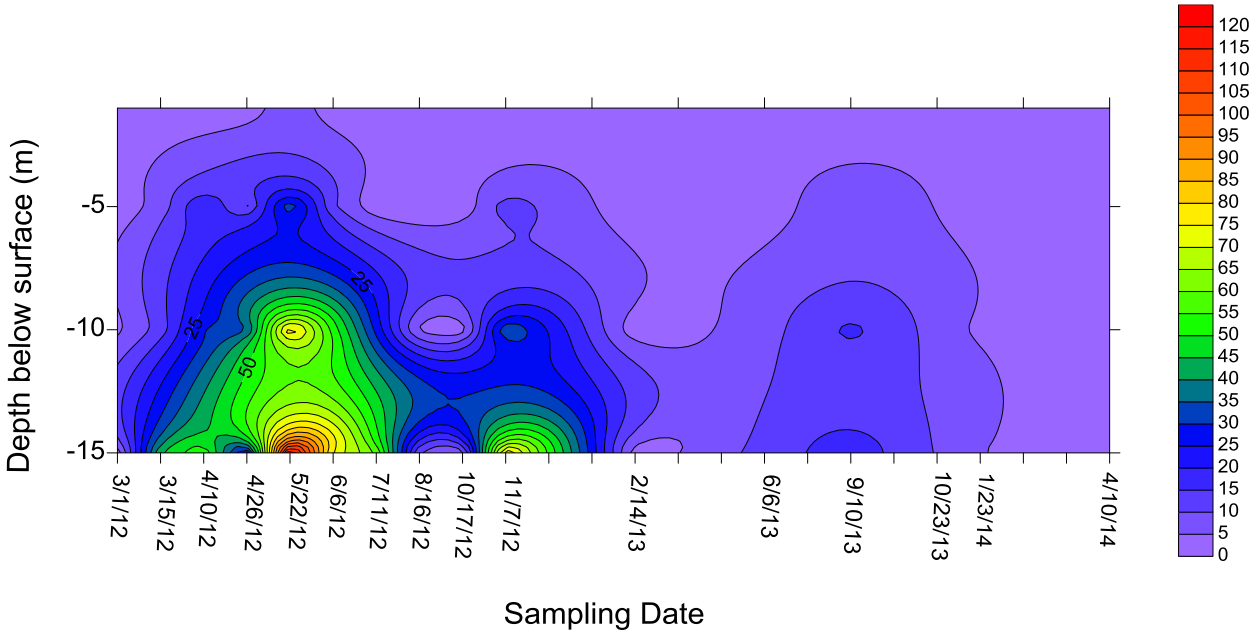


Figure F-3: Al (µM) isopleth for La Plata

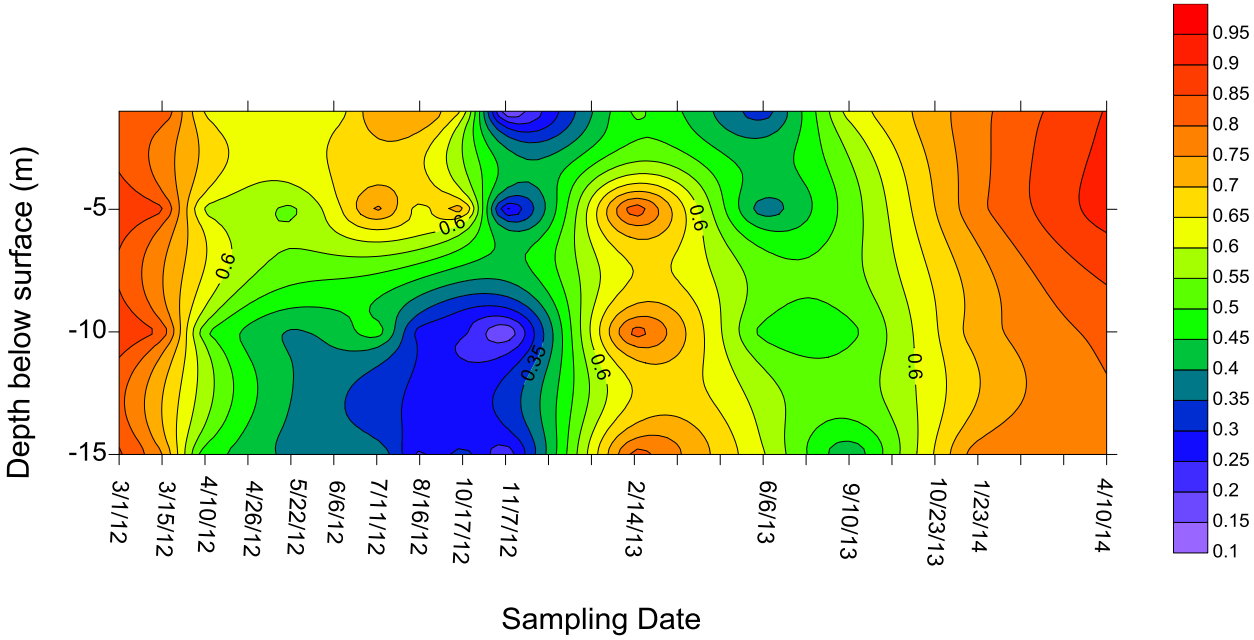


Figure F-4: Ca (mM) isopleth for La Plata

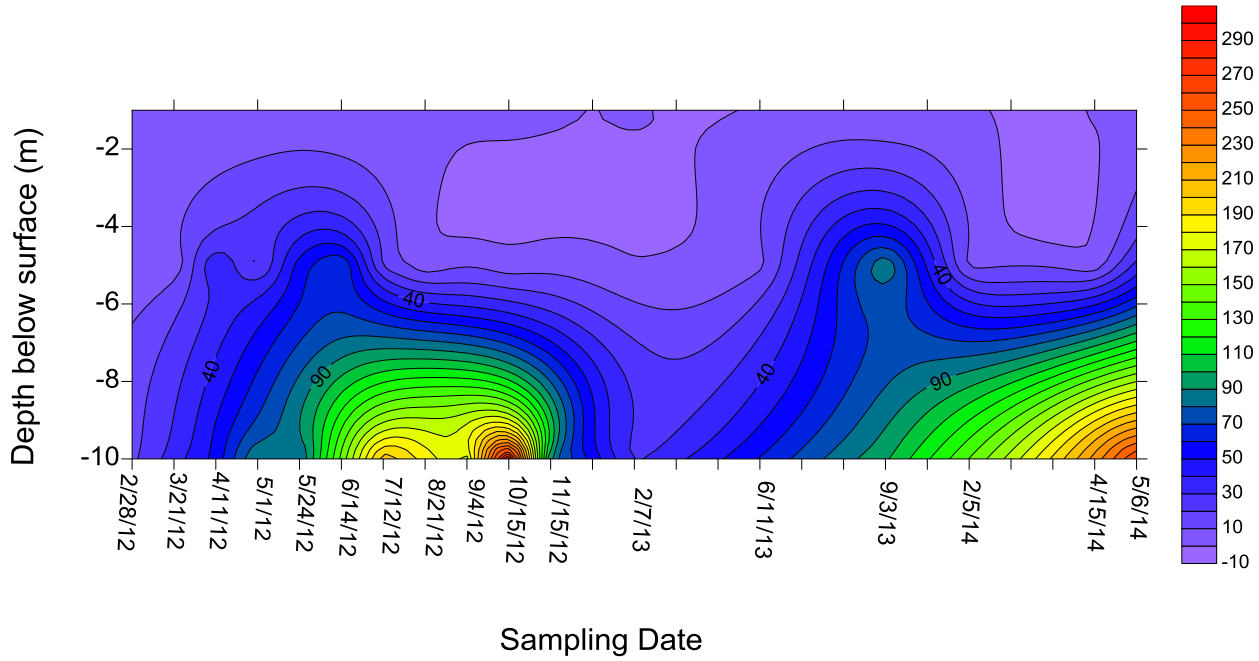


Figure F-5: Fe (µM) isopleth for Cidra

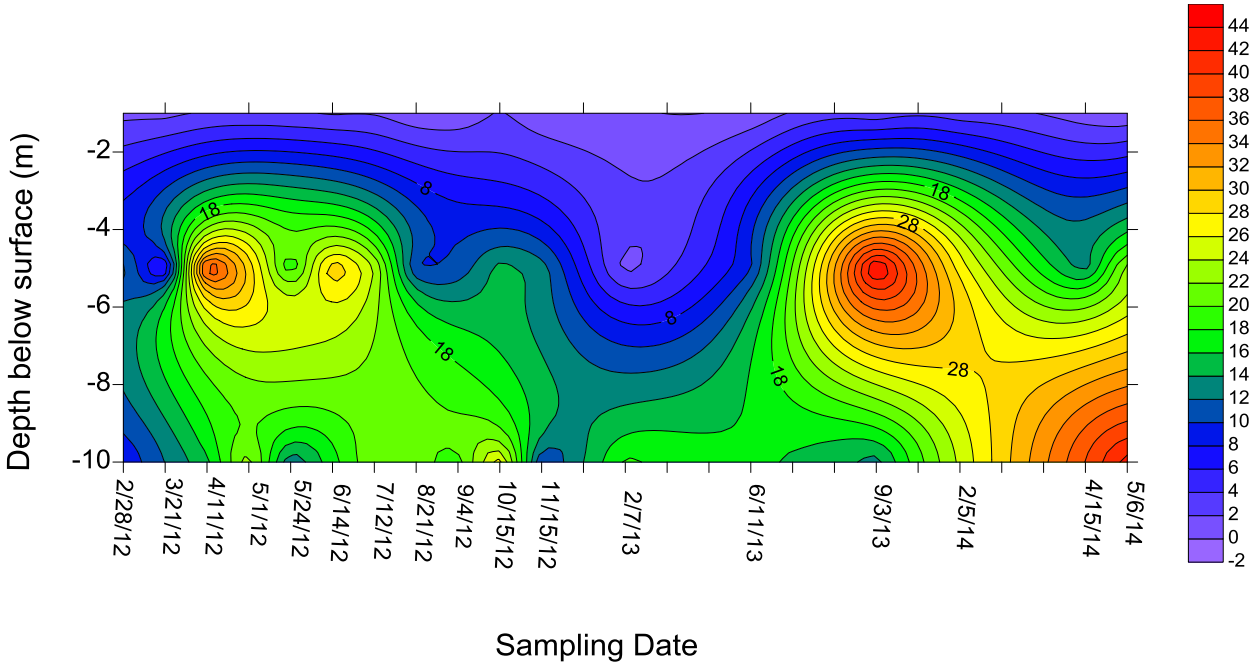


Figure F-6: Mn (µM) isopleth for Cidra

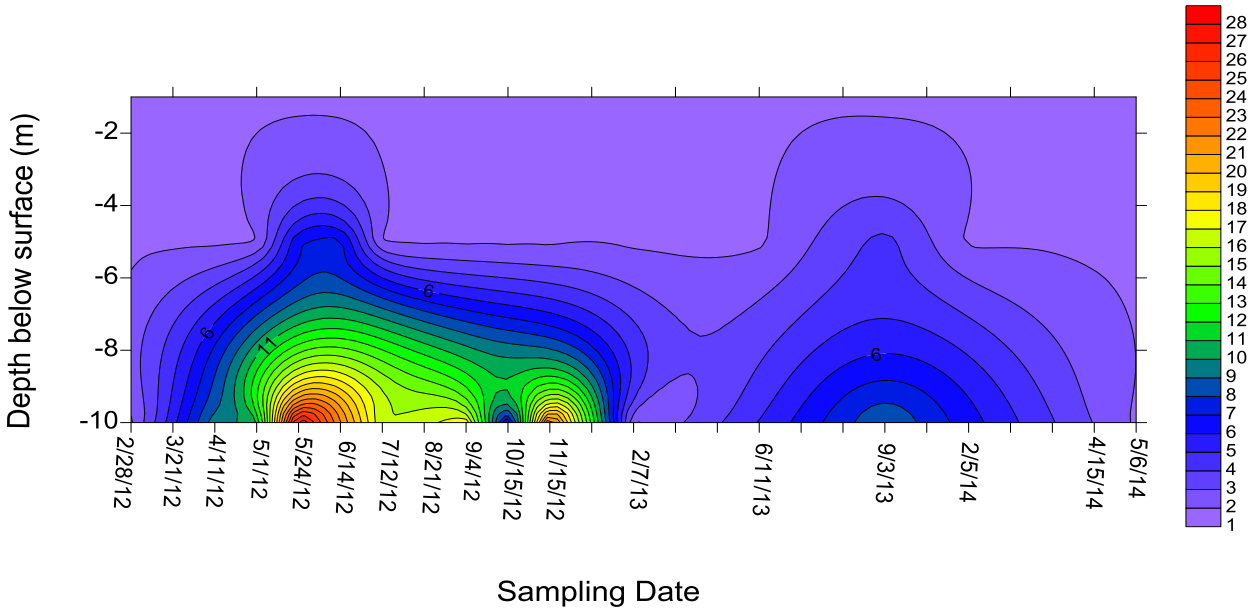


Figure F-7: Al (µM) isopleth for Cidra

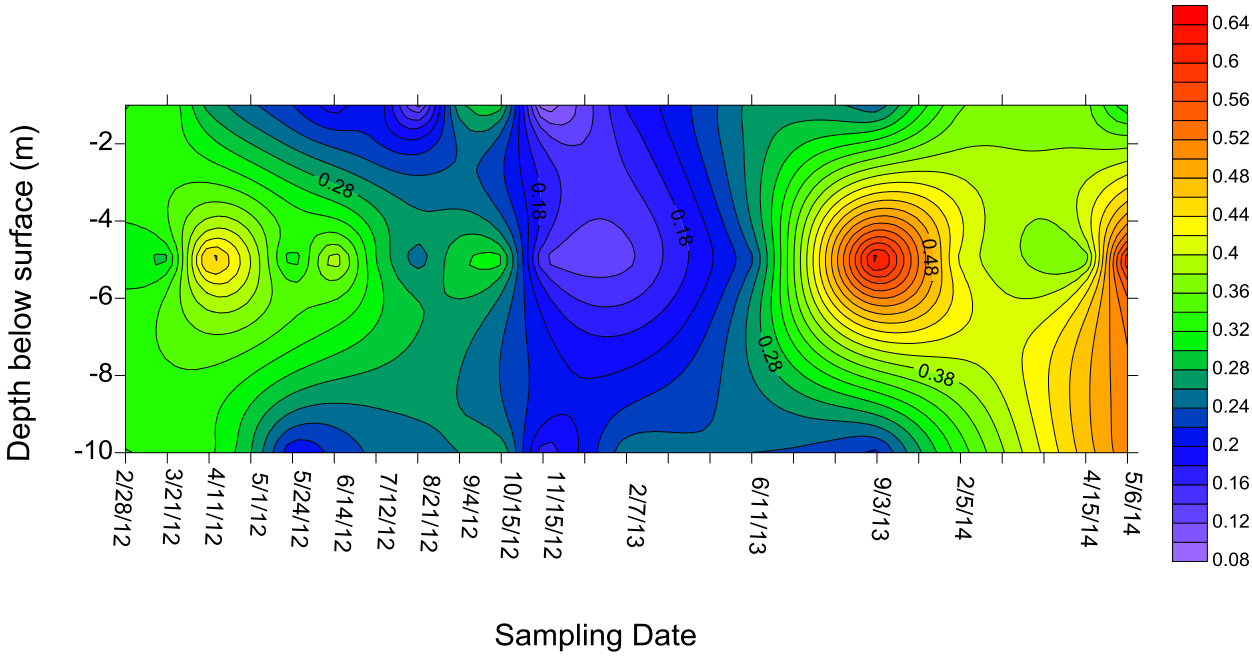


Figure F-8: Ca (mM) isopleth for Cidra

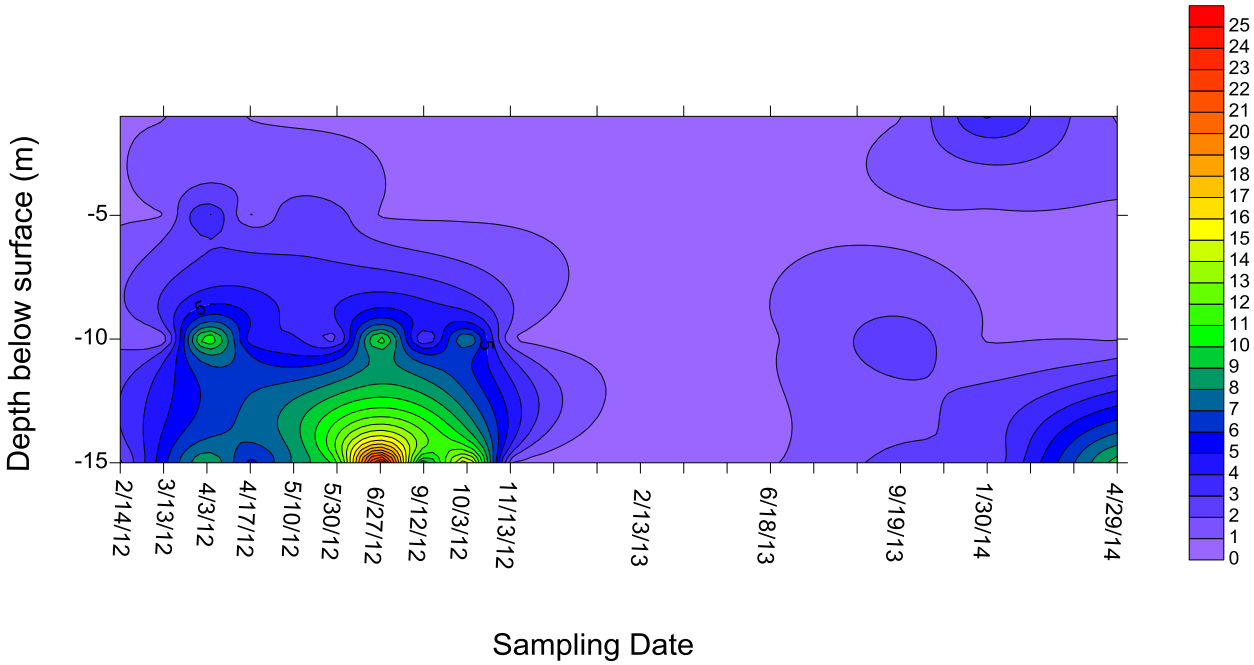


Figure F-9: Fe (µM) isopleth for Patillas

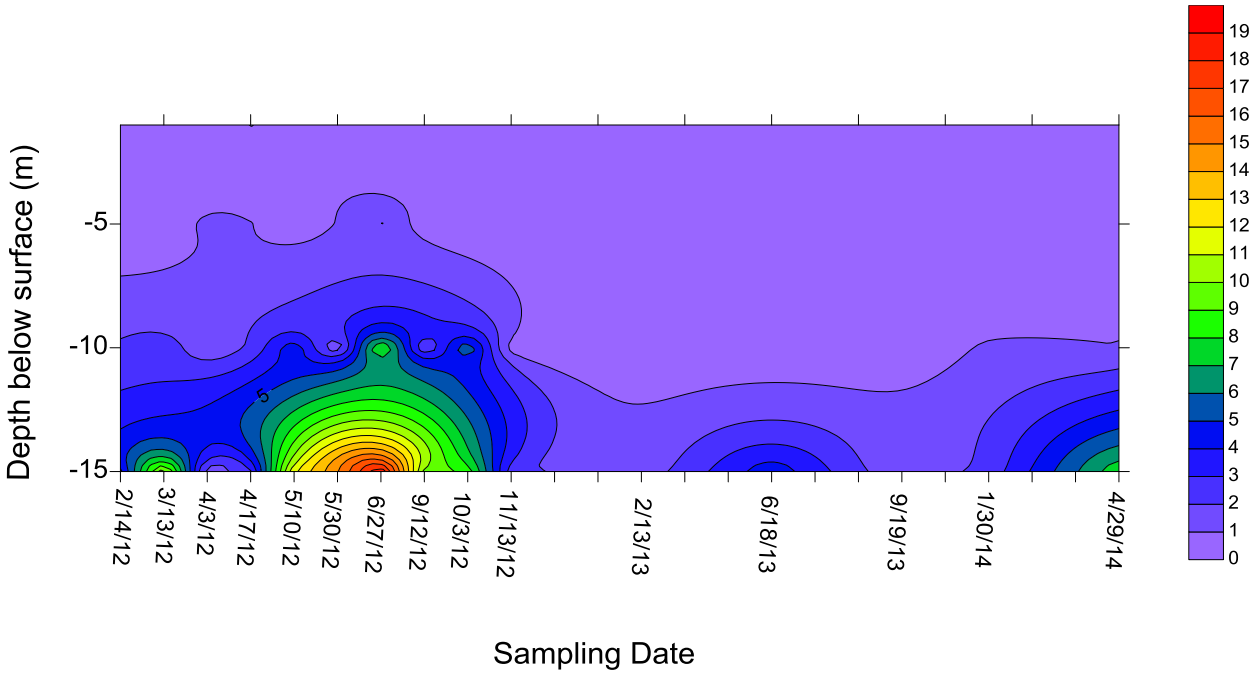


Figure F-10: Mn (µM) isopleth for Patillas

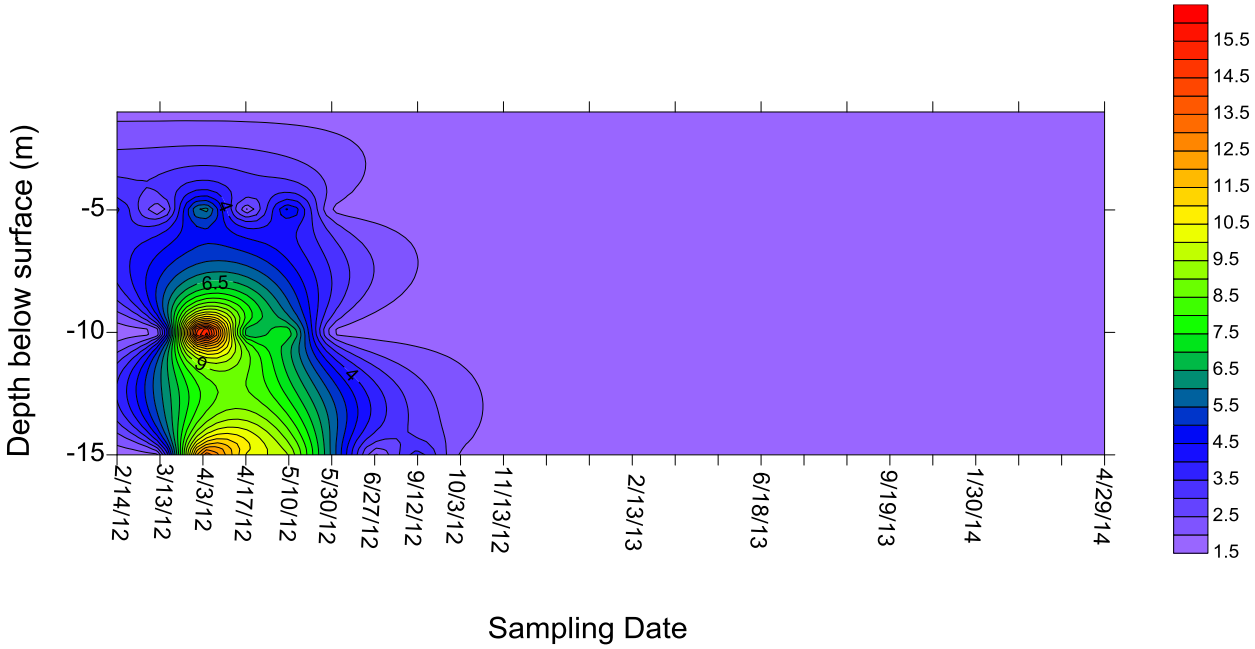


Figure F-11: Al (µM) isopleth for Patillas

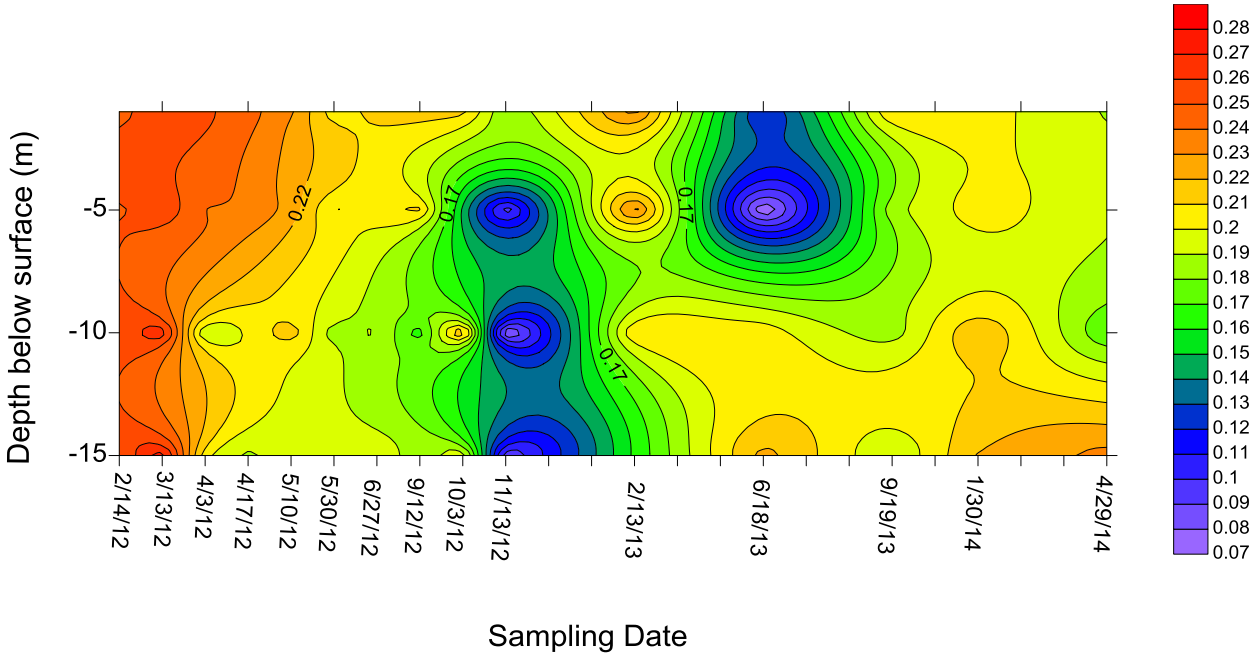


Figure F-12: Ca (mM) isopleth for Patillas

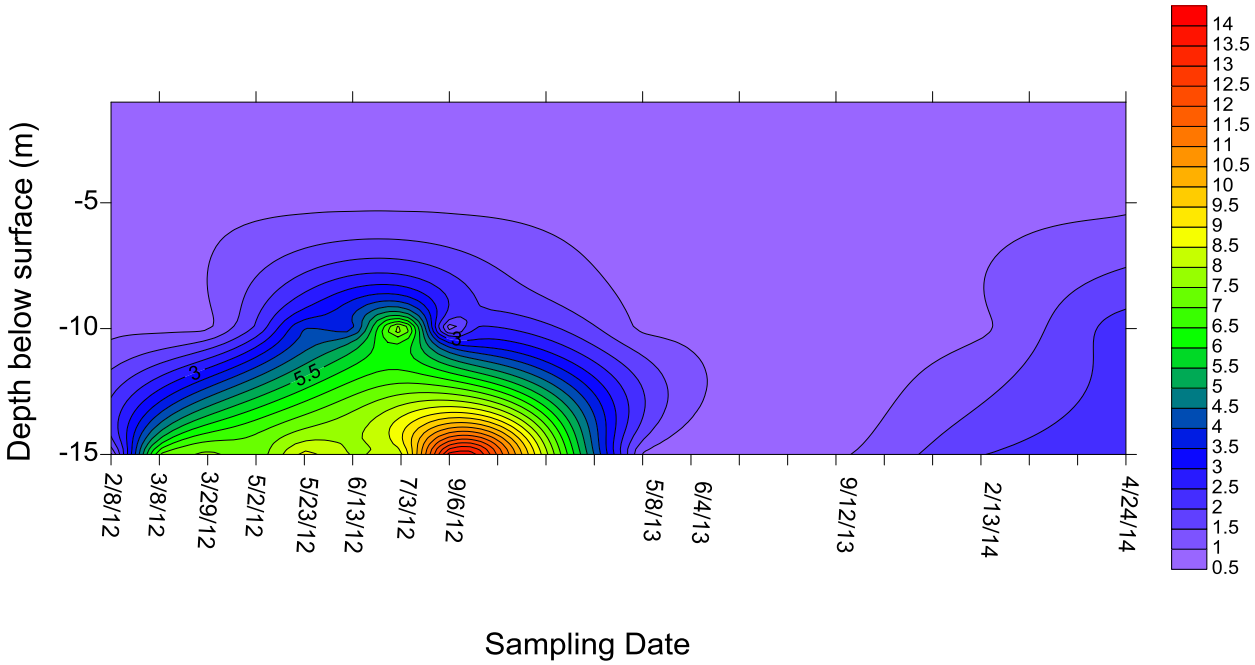


Figure F-13: Fe (µM) isopleth for Toa Vaca

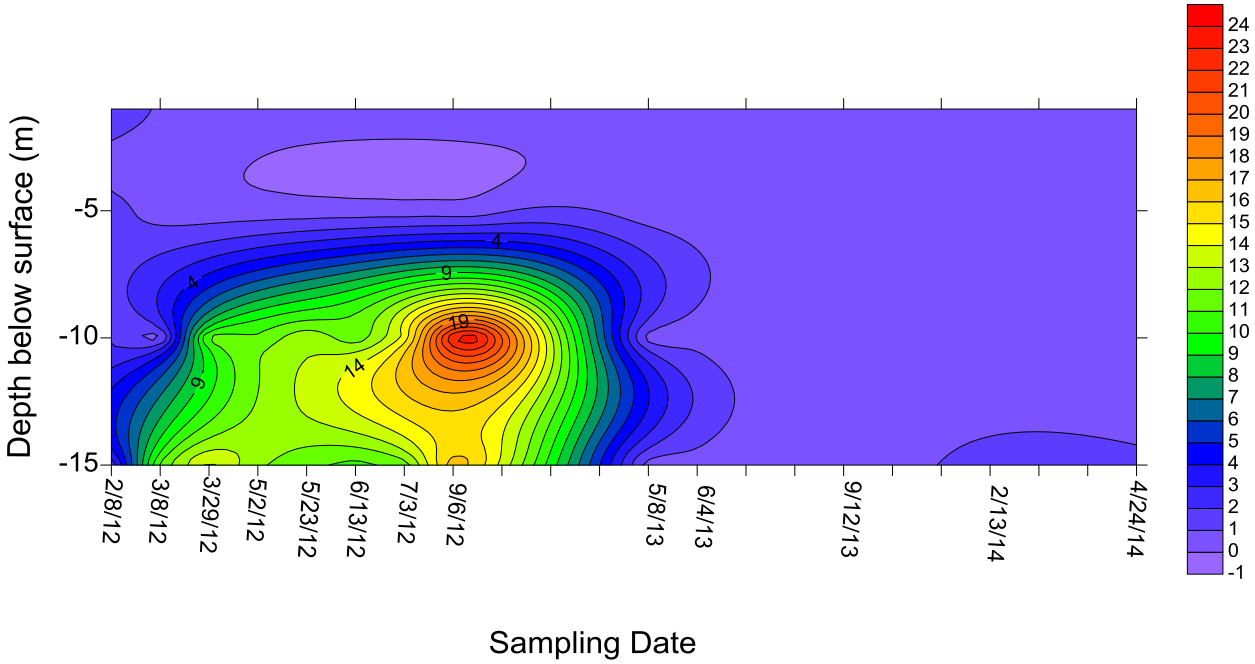


Figure F-14: Mn (µM) isopleth for Toa Vaca

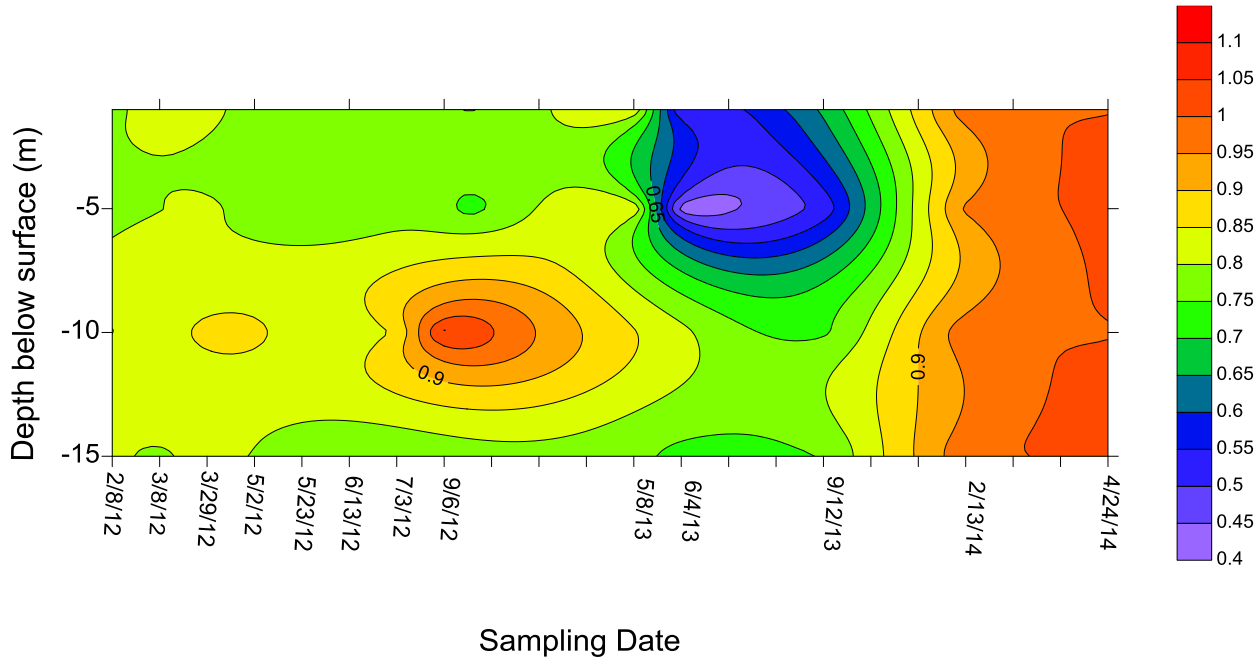


Figure F-15: Ca (mM) isopleth for Toa Vaca

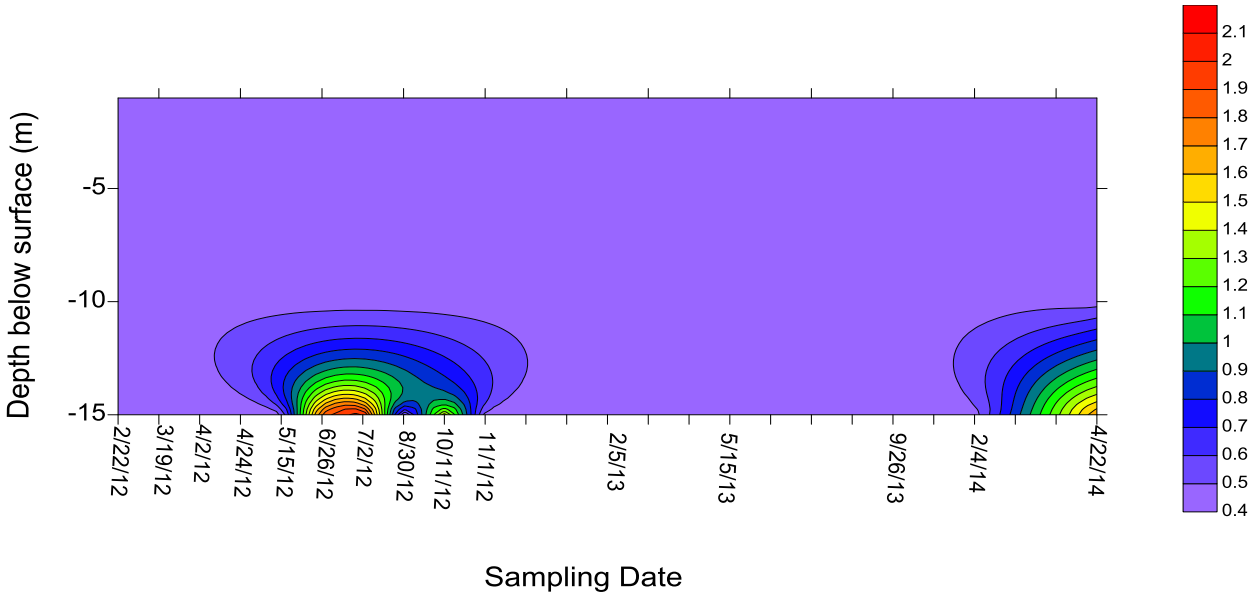


Figure F-16: Mn (µM) isopleth for Cerrillos