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Are harmful cyanobacteria blooms increasing in frequency or intensity in Southern Portugal reservoirs?

Harmful Algal Blooms and Climate Change
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INTRODUCTION: Several authors blamed global climate change and aquatic ecosystem eutrophication for the biogeographic expansion of some toxigenic cyanobacteria and for increasing CyanoHAB frequency. In freshwater systems, CyanoHAB occurrence and the presence of unexpected toxigenic species create a complex problem to water resources management authorities, since ecological and human health impacts of cyanotoxins have been well documented worldwide. In Southern Portugal, as consequence of the Mediterranean torrential climate, high hydraulic residence, prolonged sun exposure, warm waters, alternating droughts and flood periods and high nutrient loadings during floods promote phytoplankton growth and increased turbidity, favoring cyanobacteria dominance in freshwater reservoirs.

OBJECTIVE: This study addressed available monitoring data for 31 major reservoirs in Southern Portugal, aiming to discriminate eutrophication and climate change impacts on CyanoHAB.

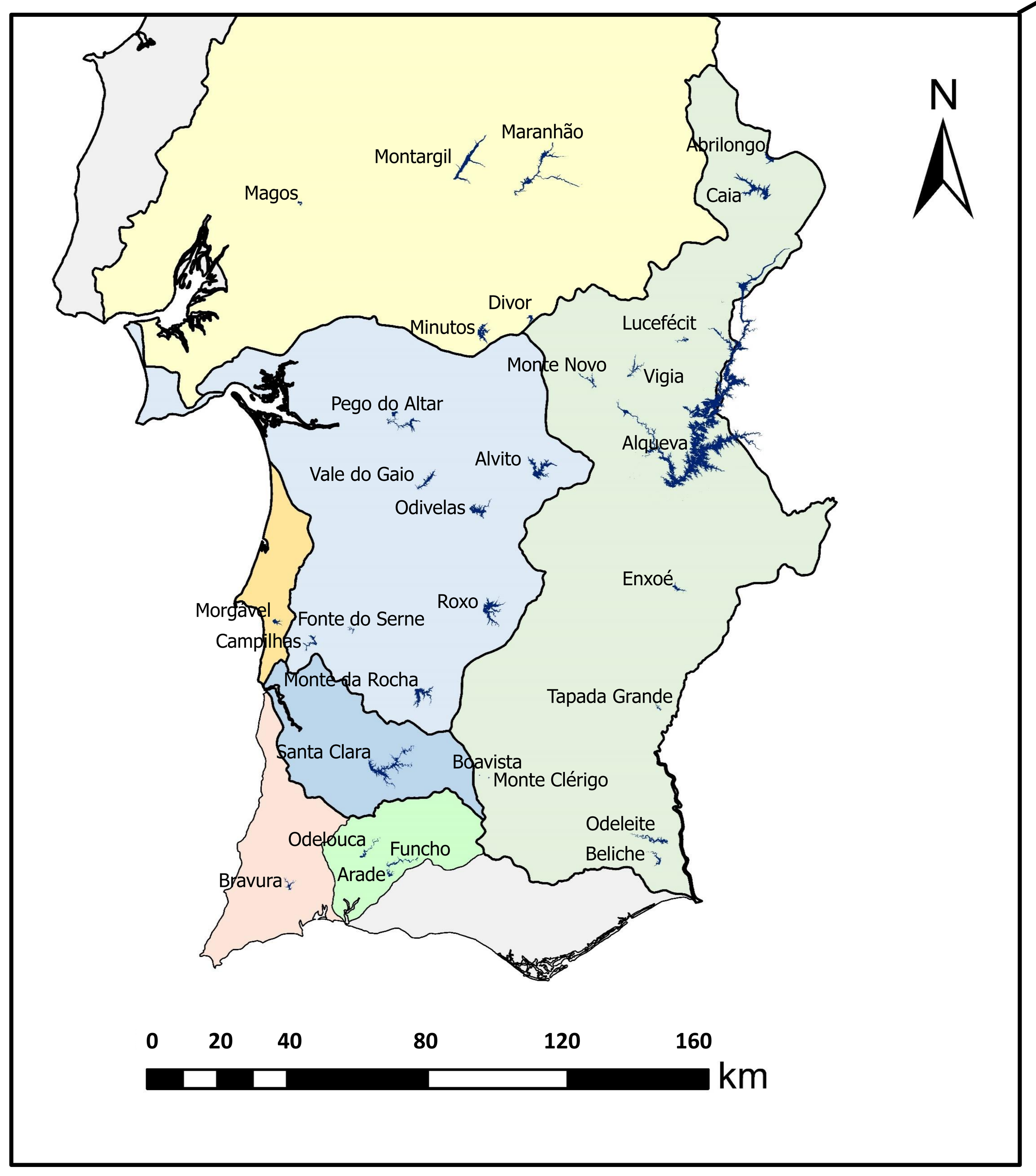
Features of the studied reservoirs:

Reservoir	Year of completion	Main river watershed	Stream	Drained area (km^2)	Reservoir area ($x10^3m^2$)	Effective storage capacity ($x10^3m^3$)	Mean annual rainfall (mm)	Mean surface water temperature (ºC)	Maximum surface water temperature (ºC)	Mean Chlorophyll-a (µg/L)	Geometric mean of Chlorophyll-a (µg/L)
Montargil	1958	Tejo	Sôr	1186	16460	142700	825	18.1	30.5	16.9	9.3
Maranhão	1957	Tejo	Seda	2282	19600	180900		18.5	28.4	9.4	5.4
Divor	1965	Tejo	Divor	43	2650	11890		17.3	28.9	38.2	25.4
Magos	1938	Tejo	Magos	104.8	900	3000	500	18.2	28.2	82.8	26.8
Minutos	2003	Tejo	Almansor	95	5300	50000	750	16.7	26.0	1.9	1.2
Alvito	1977	Sado	Odivelas	212	14800	130000	693	18.9	28.4	6.7	5.6
Odivelas	1972	Sado	Odivelas	430	9730	70 000	640	21.1	27.0	4.2	3.1
Roxo	1967	Sado	Roxo	351	13780	89 511	549	17.6	27.0	5.7	5.3
Campilhas	1954	Sado	Campilhas	109	3330	26156	729.8	21.4	28.0	15.9	5.8
Fonte do Serne	1976	Sado	Vale Diogo	30	1050	3650	720	21.6	25.0	4.7	3.8
Monte da Rocha	1972	Sado	Sado	246	11000	99500	599	20.1	29.0	12.7	6.5
Pego do Altar	1949	Sado	Alcáçovas	743	6550	93600	550	19.2	27.5	11.6	6.4
Vale do Gaio	1949	Sado	Xarrama	509	5500	55000	558	19.2	29.0	38.5	17.1
Caia	1967	Guadiana	Caia	571	19700	192300		17.7	29.8	27.4	10.4
Monte Novo	1982	Guadiana	Degebe	267	2770	14780	635	18.6	27.8	17.7	10.6
Vigia	1981	Guadiana	Vale de Vasco	125	2620	15 580	656	16.7	30.0	6.0	4.9
Alqueva	2002	Guadiana	Guadiana	53912	250000	3150000		19.2	28.7	9.9–25.2	4.4–10.5
Enxoé	1998	Guadiana	Enxoé	60.8	2050	9500	602	18.7	28.3	49.5	27.4
Boavista	1982	Guadiana	Degebe	267	2770	14780	635	17.6	26.9	6.4	3.4
Odeleite	1997	Guadiana	Odeleite	347.5	7 200	117 000	722	19.5	27.9	1.0	0.7
Beliche	1986	Guadiana	Beliche	117	2920	47600	644	18.9	30.0	1.9	1.1
Monte Clérigo	1989	Guadiana	Adão	3.27		389	658	18.0	28.3	4.4	3.5
Tapada Grande	1882	Guadiana	S. Dopmingos	33		5000	526	18.8	29.0	6.1	3.7
Abrilongo	2000	Guadiana	Abrilongo	124	2950	18900	720	---	---	6.0	5.2
Lucefécit	1982	Guadiana	Lucefécit	257	1690	9000	665	18.1	29.2	25.0	11.7
Morgável	1980	Morgável	Morgável	25	3400	27000	743	19.6	26.3	1.9	1.3
Santa Clara	1968	Mira	Mira	520	19860	240300	618	18.5	27.8	2.6	1.7
Bravura	1958	Odeáxere	Odeáxere	76.6	2850	32260	821	18.9	26.4	2.4	1.2
Odelouca	2009	Arade	Odelouca			134000		20.2	24.1	3.4	2.2
Funcho	1993	Arade	Arade	213	3600	42750	744	19.2	27.9	1.5	0.9
Arade	1956	Arade	Arade	12.4	1820	28400	637	19.3	30.5	2.0	0.3

Source: http://snirh.pt/ and http://cnpgb.inag.pt/ and for Algarve reservoirs means of 10 year monthly data.

oligotrophic | mesotrophic | eutrophic | hypereutrophic

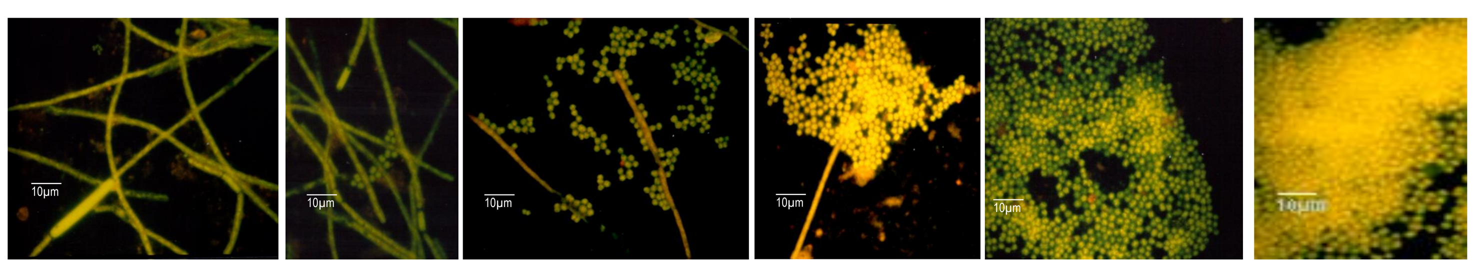
Location of the studied reservoirs:



METHODS: Monitoring data, obtained through standard European protocols as recommended by the Portuguese Environmental Agency (APA) and the European Union Standards (CEN), was gathered in a common database, containing specific phytoplankton abundance and biovolumes as well as physical and chemical data for phytoplankton supporting elements.

Organized data was processed both graphically and numerically using an adequate statistical software.

Scums produced during a winter bloom in an oligotrophic reservoir (Funcho)



Evolution of a mixed *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* bloom

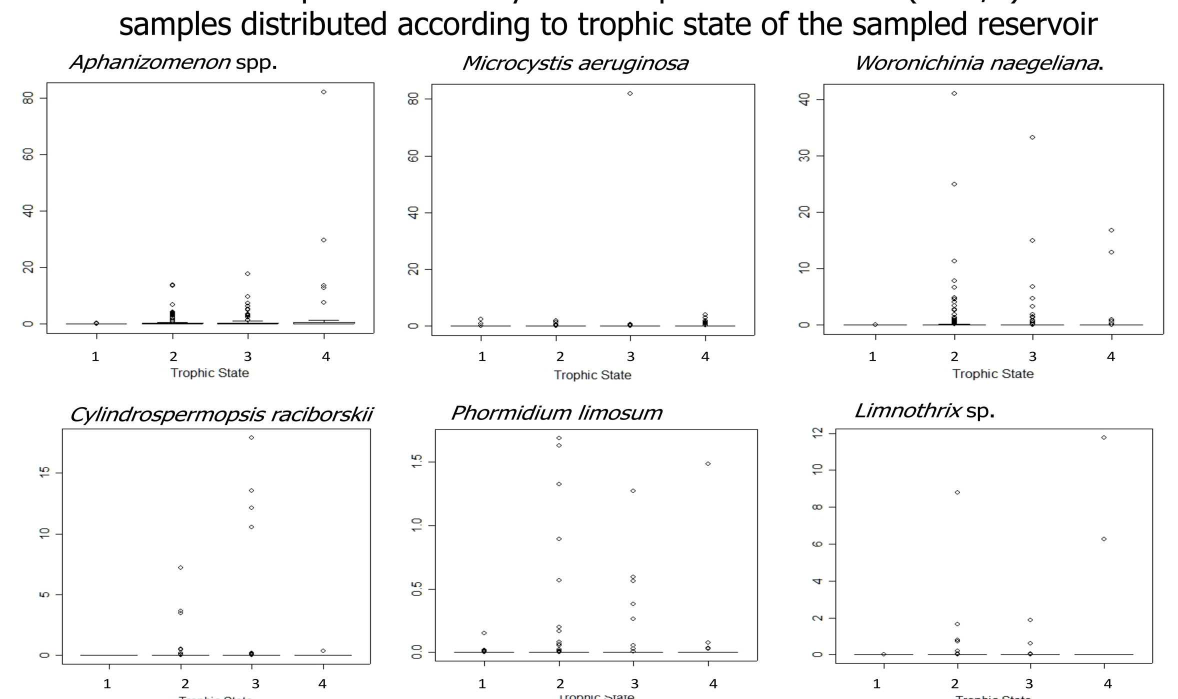
RESULTS:

CyanoHAB species surpassing 10^5 cell/mL in the last 5 years in Southern Portugal reservoirs (61 oc.)

Nº of occurences per *taxon*	Involved *taxon*	Abundance (Cell/mL)	Total cyanobacteria *biovolume* (mm^3/L)	Biovolume proportion of Cyanobacteria *versus* total phytoplankton (%)	Sampling date	Reservoir	Main river bassin
2	*Anabaena cylindrica*	1.3E+05	6.490	55.5	4/8/10	Maranhão 1	Tejo
		4.6E+05	20.523	65.6	3/8/10	Maranhão 2	
1	*Anabaena* sp.	1.3E+05	6.829	94.0	9/7/14	Enxoé	Guadiana
13	*Aphanizomenon flos-aquae*	1.6E+05	20.523	65.6	4/8/10	Maranhão 2	Tejo
		1.4E+05	7.649	61.0	7/6/11	Montargil	
		1.6E+05	6.074	75.1	17/5/11		
		1.9E+05	3.513	77.0	18/5/10	Alvito	Sado
		1.0E+05	4.021	92.8	9/9/14	Monte da Rocha	
		4.6E+05	13.996	98.2	25/9/13	Roxo	
		1.8E+05	3.346	83.9	18/5/10	Caia	Guadiana
		2.8E+05	12.129	99.0	27/6/10		
		5.3E+05	13.581	66.9	23/6/10	Enxoé	
		1.3E+06	29.789	30.7	10/9/12		
		1.6E+06	82.167	98.9	10/9/14		
		2.0E+05	7.536	9.2	30/8/11	Monte Novo	
7	*Aphanizomenon* sp.	2.0E+05	7.493	50.9	8/6/11	Maranhão 2	Tejo
		1.1E+05	13.317	41.3	14/9/10		
		1.6E+05	3.444	26.8	15/9/10	Montargil	
		3.5E+05	11.111	57.9	19/9/10	Vale do Gaio	Sado
		1.1E+05	7.858	87.4	31/7/12	Caia	Guadiana
		5.2E+05	25.967	62.5	24/8/10	Enxoé	
		3.1E+05	16.370	94.3	21/9/10		
1	*Aphanocapsa delicatissima*	5.5E+05	8.669	78.9	26/7/11	Caia	
2	*Aphanocapsa incerta*	1.2E+06	8.669	78.9	26/7/11		
		4.2E+05	7.858	87.4	31/7/12		
3	*Aphanocapsa* sp.	1.1E+05	n.a.	n.a.	19/9/11	Montargil	Tejo
		1.1E+05	2.280	67.0	19/9/10	Odivelas	Sado
		1.0E+05	0.859	80.3	2/11/10		
1	*Aphanothece minutissima*	1.4E+05	7.858	87.4	31/7/12	Caia	Guadiana
6	*Cylindrospermopsis raciborskii*	2.4E+05	7.459	94.0	28/9/11	Alqueva - Alcarrache	
		1.1E+05	4.113	84.7	20/9/12		
		3.9E+05	20.051	93.5	28/9/11	Alqueva - Lucefécit	
		6.2E+05	13.961	88.9	19/9/12		
		4.3E+05	12.541	99.3	29/9/11	Alqueva - Mourão	
		4.0E+05	10.617	88.3	20/9/12		
6	*Limnothrix* sp.	1.6E+05	5.561	64.0	23/8/10	Caia	
		5.9E+05	n.a.	n.a.	24/8/09	Enxoé	
		1.7E+05	n.a.	n.a.	28/9/09		
		8.3E+05	25.967	62.5	24/8/10		
		5.4E+05	16.370	94.3	21/9/10		
		6.7E+05	13.317	41.3	14/9/10	Maranhão 2	Tejo
1	*Microcystis aeruginosa*	3.7E+06	97.674	98.5	28/6/11	Caia	Guadiana
4	*Oscillatoria tenuis = Phormidium limosum*	1.3E+05	n.a.	n.a.	3/11/09	Enxoé	
		2.1E+05	n.a.	n.a.	25/8/11	Magos	Tejo
		3.2E+05	n.a.	n.a.	25/8/09	Pego do Altar	Sado
		1.4E+05	n.a.	n.a.	29/9/09		
1	*Planktolyngbya* sp.	3.0E+05	7.110	71.1	13/9/11	Caia	Guadiana
4	*Planktothrix agardhii*	1.3E+05	n.a.	n.a.	24/8/11	Maranhão 1	Tejo
		1.8E+05	n.a.	n.a.	24/8/11	Maranhão 2	
		1.4E+05	n.a.	n.a.	22/9/11	Maranhão 2	
		1.5E+05	11.111	57.9	19/9/10	Vale do Gaio	Sado
9	*Woronichinia naegeliana*	3.9E+05	n.a.	n.a.	21/9/09	Abrilongo	Guadiana
		8.5E+05	n.a.	n.a.	2/11/09		
		2.2E+05	97.674	98.5	28/6/11	Caia	
		2.0E+05	7.110	71.1	13/9/11		
		2.0E+05	34.602	98.4	12/4/11	Monte Novo	
		1.4E+05	3.690	75.6	2/7/13		
		1.2E+05	25.176	94.2	27/6/10	Vigia	
		1.6E+05	15.226	93.5	3/8/10	Magos	Tejo
		2.7E+05	n.a.	n.a.	7/11/11		

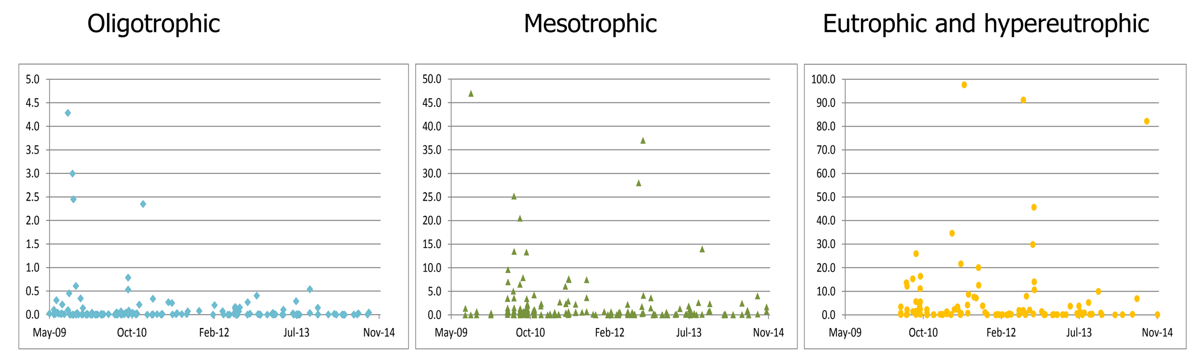
n.a. Not available

Conditional boxplots of main CyanoHAB species biovolume (mm^3/L) with all samples distributed according to trophic state of the sampled reservoir



Trophic State: 1 – oligotrophic; 2 – mesotrophic; 3 – eutrophic; 4 – hypereutrophic.

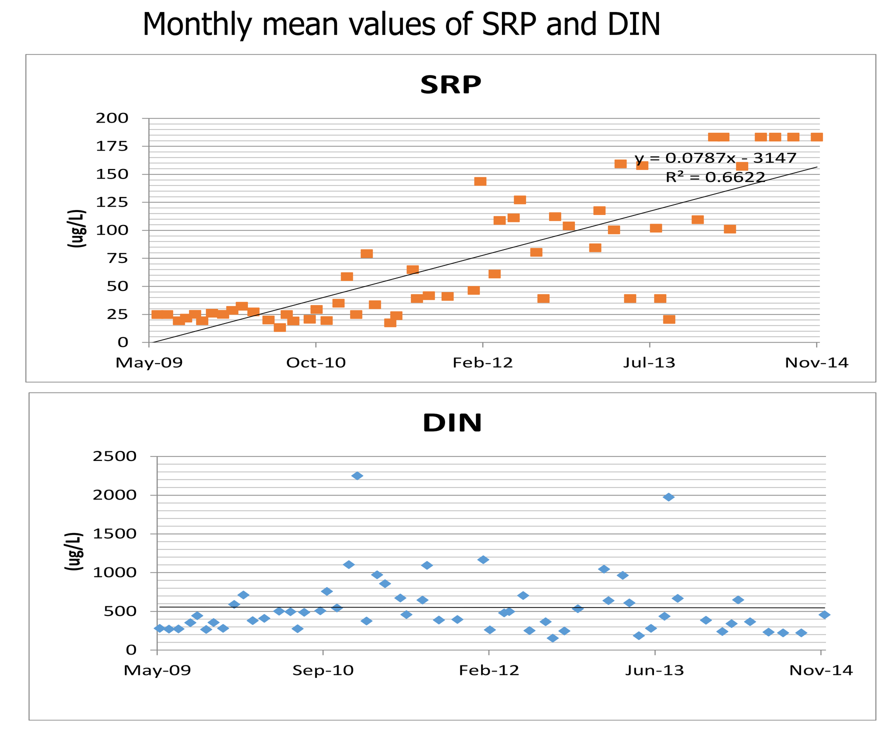
Temporal variation of Cyanobacteria biovolume (mm^3/L) per type of reservoir



Temporal variation of Cyanobacteria biovolume is presented separately for the oligotrophic, mesotrophic and eutrophic reservoirs, allowing for needed growing scales.

DISCUSSION: Conditional boxplots associate *Aphanizomenon* spp. blooms to eutrophication and hypereutrophication, while *W. naegeliana*, *C. raciborskii* and *Limnothrix* sp. needed at least mesotrophic conditions to form CyanoHABs. *M. aeruginosa* and *P. limosum* also bloomed in oligotrophic systems, but with weaker intensity. Further blooming cyanobacteria with densities above 5 x 10^4 cell/mL were *Cuspidothrix issatschenkoi*, *Dolichospermum spiroides*, *Merismopedia tenuissima*, *Microcystis* spp., Oscillatoria / Planktothrix spp. and unidentified Chroococcales. Despite SRP decrease in oligotrophic reservoirs (data not shown), mean monthly values of SRP for the whole set of reservoirs have increased. DIN values followed a healthy cyclic tendency.

Monthly mean values of SRP and DIN



Thus, available data reveals an increase in frequency and intensity of CyanoHABs in eutrophic reservoirs, while such occurrences in oligotrophic reservoirs have decreased in intensity, but still maintain a regular summer periodicity.

In mesotrophic reservoirs regular late summer blooms, are increasingly dominated by new toxigenic species (e.g. *Cylindrospermopsis raciborskii*), bringing up new health risks, since toxins produced by such species are not regularly screened.

CONCLUSION: Data did not allow to discriminate any climate change impacts on CyanoHABs in Southern Portugal, since long term data was only available for the Algarve reservoirs, which are all oligotrophic and dominated, during summer, by Chroococcales of low specific biovolume. Eutrophication plays an important role, not only in intensifying CyanoHABs, but also in triggering higher toxicity for these events. Understanding CyanoHAB management still requires research in many different areas. Molecular Biology and Microbial Ecology seem promising in detecting toxigenic genes in natural samples and elucidating their regulation.