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ON THE OCCURRENCE OF CYANOBACTERIA IN THE MADEIRA RIVER IN THE BRAZILIAN AMAZON

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Abstract

The spatial-temporal variation of cyanobacteria was studied from 2002 to 2007 on the Madeira River, a river with muddy waters of Amazon origins in the Andes, whose main characteristics are the massive amount of material in suspension and relative wealth of nutrients and inorganic ions. The presence of cyanobacteria in Madeira River was not associated with high levels of pollution or organic contents. Unique species of white waters and typical species of clear waters were found. The genera *Oscillatoria* and *Anabaena* were predominant, with a significant concentration of species (46.8%), highest number of taxa (63%) and higher values of species richness (S) and diversity index (H_0) on the headwaters during the high water levels. About 57% of the identified taxa were considered accidentals. The traditional communities consume water from the river without prior treatment, so it can not be ruled out intoxication by cyanotoxins.

Keywords: *cyanobacteria, microbiology, ecological diversity, cyanotoxin, Amazon.*

1. Introduction

The composition of the phytoplankton community in aquatic environments varies in function of changes in underwater radiation, temperature and other ecological factors of the environments (Straškraba and Tundisi, 2000). The heterogeneity and abundance of phytoplankton also varies in space and in time as a result of the limnological characteristics of the environment.

The composition and abundance of the different phytoplankton groups are of ecological interest in order to prevent or control incompatible or undesirable situations especially in bodies of water destined for public use (CETESB, 2005). When correctly analyzed the changes in the phytoplankton community can have a predictive characteristic with regards to the possible changes in the environment where they occur (Huszar, 1994). Among the different phytoplankton groups the cyanobacteria are particularly important indicators of water quality and can present quick answers to changes in the environment.

Cyanobacteria are common organisms in all aquatic environments due to their strategic adaptations (Wehr and Sheath, 2003). A large number of genetic, physiological and reproductive adaptations have allowed these primitive organisms to inhabit not only aquatic but terrestrial systems as well; from rocks to soil, tree trunks, seas, estuaries, lagoons, lakes and rivers. In freshwater bodies of water they are the principal group responsible for sanitation problems due to the production of toxins (Werner, 2002). Cyanobacteria can produce hepatoxins or neurotoxins that, depending on the manner and quantity ingested, can cause the death of animals and humans (Gilroy *et al*., 2000; Carmichael *et al*., 2001).

Within the last few years there has been an expressive increase in cyanobacteria blooms in various places in Brazil and the presence of cyanotoxins and other compounds affecting the taste and smell of the water have been detected (Cybis *et al*., 2006). The risk of the occurrence of cyanobacteria which produce cyanotoxins is particularly dangerous in reservoirs and water treatment plants. Cyanobacteria do not only occur in polluted or eutrophic bodies of water, they also occur naturally in “clean” lakes and rivers and in these environments it is important to study and understand their distribution and abundance.

Limnological studies of the composition, diversity, and spatial-temporal variation of cyanobacteria in the Brazilian Amazon are still few. This study intends to 1) analyze the seasonal occurrence of the cyanobacteria populations occurring in the Madeira River in the Brazilian Amazon particularly with respect to the limnological characteristics of the water and 2) establish ecological criteria for the diversity and species richness of cyanobacteria in the Madeira River.

2. Materials and Methods

2.1 Study area

The Madeira River is 3600 kilometers long, but only about half, 1700 kilometers, are in Brazil. It is included in the region know as Amazonia Occidental that corresponds to a vast lowered area characterized by a topographic fall in the SO – NE direction from the Pre-Andean region to the Amazon River. Below the Santo Antonio waterfall, the Madeira

River bed is very flat. It drops only 1.7 cm km^{-1} in the 1,040 kilometers between Porto Velho and the mouth of the river where it meets the Amazon River a little below the city of Manaus (Fig 1). The relief surrounding landscape is relatively homogenous without major topographical declivities with predominance of interfluvial tabular (flat top), crests (top continuous) and hills (top slightly convex) with different orders of magnitude and depth of drainage, usually separate by flat-bottomed valleys and eventually through valleys in a "V" shape. Yellow and yellow-red clays are the predominant types of soil followed by yellow-red podzols, hydromorphic quartz sands, hydromorphic laterites and alluvial soils. According to Köppen the climate is predominantly "*Am*", which is transitional between equatorial and a hot and humid tropical climate. In the upper reaches of the river there are a great number of rapids and waterfalls and the alluvial vegetation is made up primarily of herbaceous shrubs. In the middle and lower reaches of the river, as has been mentioned, there are no accentuated declivities and the river is safe for navigation from Porto Velho to the mouth of the river (Fig 1).

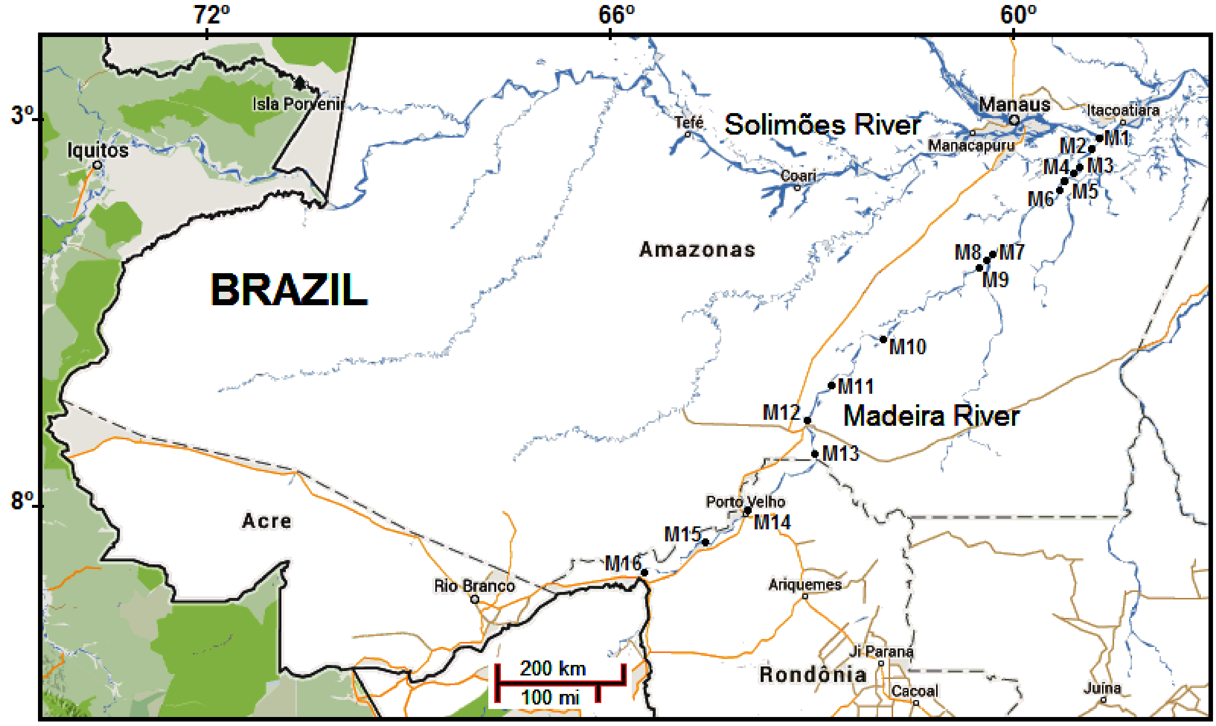

Fig 1: The Madeira River and the locality of the sampling stations.

2.2 Analytical Procedures

Sampling was undertaken at 16 stations along the Madeira River which is known as the Madeira River as of the confluence of the Beni and Mamoré Rivers (10°23´14.54´´S and 65°23´29.51´´W) to its mouth, where it runs into the Amazon River (Fig 1). Four sampling programs were undertaken during the high water period and four were undertaken during the low water period between the years 2002 and 2007. At each sampling station temperature (°C), pH, conductivity (µS$_{25}$ cm^{-1}), dissolved oxygen (mg l^{-1}) and total dissolved solids (mg l^{-1}) were measured with a multi parameter WTW and YSI probe. Water transparency was measured with a Secchi disk. Turbidity (NTU) was determined with a portable turbidity meter. Fixed and volatile solids were determined by the difference is dry matter before and after incinerating in a muffle oven at 500 °C. Analyses of Na, K, Ca and Mg (mg l^{-1}) ions were determined by an atomic absorption spectrophotometer. Total N (TN mg l^{-1}) and total P (TP µg l^{-1}) were determined according to Valderrama (1981). Chlorophyll (Chl-a µg l^{-1}) was determined according to Golterman *et al.* (1978) and APHA/AWWA/WEF (2012).

The phytoplankton samples were collected with a 45 µm plankton net at the surface of each sampling station and fixed immediately with 1% acetic lugol´s solution (Vollenweider, 1974). They were kept in the dark until analyzed. For identification of the cyanobacteria the material was examined with a phase contrast binocular microscope and the following were consulted: Prescott (1962), Bourrelly (1970), Mera (1997), Round (1971), Van Den Hoeck (1994) and Van Den Hoeck *et al*. (1995). The nomenclature was checked according to the Guiry and Guiry´s (2013) Algae Base. The material was quantified according to Utermöhl (1958) with an inverted microscope and 5 ml sedimentation chambers. Cells, colonies and filaments were quantified according to Uhelinger´s (1964) random fields´ method. Based on the minimum area method and considering the samples with the greatest number of species, a constant number of fields were counted, in this case, thirty. For the community structure analyses the following were considered: species richness (S = total number of taxons found), population density (D = ind m l^{-1}), calculated according to Weber (1973), equitability (J_s) according to Pielou (1966), relative abundance (A_r %), total abundance (A_t %) and frequency of occurrence along the river (F_{river} %) and as a function of the hydrological cycle (F_{hydro} %). The Shannon-Wiener specific diversity index (H_0) (Shannon and Weaver, 1963), the species richness index (Margalef – S_g; Menhinick – S_n) and the Dajoz constancy index (Dajoz, 1978) were also calculated in accordance to the descriptor analysis of Poole (1974), Magurran (1988) and Krebs (1999). The modification rate of the community was estimated by the sucessional rate described by Lewis (1978). The relationship between the abiotic limnological parameters and the cyanobacteria was determined by a principle component analysis (PCA) with a Varimax rotation.

3. Results and Discussion

Differences in the limnological parameters of the Madeira River were observed between the high water period and low water periods especially with regards to conductivity, TDS, turbidity, dissolved ions and chlorophyll a, which reflects the seasonal variation of the hydrological cycle (Table 1). Considering the different regions of the Madeira River there was actually little variation in the values of pH (Table 1). However, it is interesting to note that there always was a longitudinal decrease in pH, from upper reaches to lower, with a maximum of 1.2 pH units during the low water periods (Table 1). It should be noted that, despite this low amplitude of variation in pH, it represents a variation of up to 16 times the molar concentration of [H$^+$]. These major changes in pH can be due to the loss of CO$_2$ to the atmosphere as a consequence of the turbulence of the water as it flows through the innumerous water falls in the upper reaches of the river. The increase in conductivity and of the ions Na, K, Ca and Mg in the low water periods reflects the increase in the concentration of suspended sediments which come not only from the fluvial discharge of the Andean and Pre-Andean regions, but also from the re- suspension of bottom sediments. Differences were also noted in the special distribution of the limnological parameters with a tendency for reduced concentrations in direction of the mouth of the river.

Table 1: Limnological parameters of the Madeira River water during the high and low water level periods between 2002 to 2007.

	High water level			Low water level		
Course	**headwaters**	**middle**	**lower reaches**	**headwaters**	**middle**	**lower reaches**
Temp (ºC)	26.5±0.8	27.6±0.6	28.3±0.5	29.2±0.2	29.7±0.6	30.5±0.6
pH	7.12±0.03	6.38±0.15	6.08±0.53	7.14±0.20	6.25±0.17	5.94±0.53
EC (µS cm^{-1})	67.17±2.51	57.00±1.63	60.77±3.33	78.47±7.31	65.78±2.71	67.27±3.92
DO (mg l^{-1})	6.34±1.33	4.69±0.28	4.74±0.84	4.83±0.13	4.05±0.27	4.11±0.84
TDS (mg l^{-1})	263.3±41.4	149.3±20.9	156.8±31.3	398.7±22.8	287.8±17.9	287.7±39.5
FS (mg l^{-1})	205.7±45.8	111.6±12.8	120.1±21.2	258.0±9.0	188.4±13.0	195.6±31.8
VS (mg l^{-1})	56.3±3.9	35.3±9.1	35.3±10.3	139.6±25.5	97.7±7.9	91.2±7.4
Secchi (m)	0.10±0.05	0.15±0.00	0.18±0.06	0.10±0.05	0.10±0.07	0.13±0.06
Z$_{eu}$ (m)	0.27±0.00	0.41±0.00	0.48±0.15	0.27±0.00	0.27±0.03	0.35±0.14
Tb (NTU)	82.83±2.17	75.83±3.85	60.01±13.77	111.54±2.18	85.96±4.99	82.77±11.67
Na (mg l^{-1})	2.99±0.12	2.81±0.39	2.20±0.66	3.17±0.54	3.37±0.39	2.76±0.65
K (mg l^{-1})	1.63±0.28	1.15±0.16	1.20±0.29	1.43±0.30	1.48±0.17	1.52±0.26
Ca (mg l^{-1})	4.33±0.84	3.03±0.61	2.61±1.06	4.59±0.20	3.90±0.66	3.45±1.07
Mg (mg l^{-1})	2.17±0.14	1.71±0.31	1.31±0.47	2.38±0.29	2.33±0.31	1.90±0.47
TN (mg l^{-1})	0.82±0.14	0.54±0.08	0.61±0.21	0.18±0.01	0.18±0.04	0.23±0.18
TP (µg l^{-1})	2.0±1.8	2.0±1.0	1.0±0.0	3.0±2.6	2.4±2.0	2.1±1.1
Chl-a (µg l^{-1})	2.90±0.62	2.63±0.12	2.77±0.14	3.95±0.58	3.51±0.15	3.47±0.16

Headwater region (sampling stations M14 to M16), Middle region (sampling stations M10 to M 13), Lower region of the river (sampling stations M1 to M9).

In general the cyanobacteria community was made up of typical muddy water species. Species typical of small clear water streams were identified at stations located near tributaries of the Madeira River such as the Mutumparaná e Jaciparaná Rivers. Twenty three taxons were identified. 8 belong to the order Chroococcales, 13 to the order Nostocales and 2 to the order Stigonematales. Worth noting are the 5 species of *Oscillatoria* and 4 species of *Anabaena*. With respect to seasonality a greater number of taxons were found during the high water periods. The frequency of occurrence was 63%.

Longitudinally there was a slight tendency for the number of taxons to decrease from the upper stations (M16) to the lower stations (M1). This tendency was also noted for the total abundance values (Table 2). There was a significant concentration of species in the upper reaches of the river (frequency of occurrence – 46.8%) where several clear water tributaries drain into the Madeira. As one travels down river there is a reduction in the concentration of oxygen (Table 1) most probably as a consequence of the absence of rapids and waterfalls in this region. The diminished number of taxons can be a function of dilution given the greater volume and area of the river bed corroborated by the reduction of A$_t$ (Table 2) and Chl-a (Table 1).

Table 2: Ecological attributes applies to the analysis of the cyanobacteria community structure.

Course	**headwaters**		**middle**		**lower reaches**	
	H	**L**	**H**	**L**	**H**	**L**
S (n)	18	10	14	8	11	7
D (ind ml^{-1})	10.3	6.5	7.0	3.5	5.3	3.3
J$_S$	0.12	0.13	0.12	0.11	0.12	0.11
A$_r$ (%)	61.4	38.6	66.7	33.3	61.5	38.5
A$_t$ (%)	28.7	18.1	19.4	9.7	14.8	9.3
F$_{river}$ (%)	46.8		29.2		24.1	

F_{hydro} (%)	63.0	37.0	63.0	37.0	63.0	37.0
H_0 (bits ind^{-1})	0.52	0.45	0.46	0.33	0.41	0.32
S_g	3.7	2.0	3.1	1.7	2.5	1.5
S_n	1.8	1.0	1.8	1.0	1.5	1.0
SDI	0.032	0.029	0.046	0.041	0.015	0.011

H= high water level; L= low water level.

The specific diversity represented by the diversity index (H_0) is a function of the number of species and equitability and resulted in values between 0.32 bits ind^{-1} in the lower reaches of the river during the low water periods and 0.52 bits ind^{-1} in the upper reaches of the river during the high water period (Table 2). This tendency was also observed for the equitability values. The equitability or evenness measure compares the Shannon-Wiener diversity to the distribution of the observed species. In this study the Shannon-Wiener diversity index values were low, but coherent with what could be expected for muddy, lotic Amazonian systems with limited light penetration. For example, the euphotic zone was calculated to be 0.48±0.15 m (Table 1).

The influence of nutrients on the abundance, species richness and diversity of algal species in aquatic systems is relatively well known. According to CETESB (2005), clean water systems with low concentrations of nutrients tend to have a sparse phytoplankton community with high diversity while waters rich in nutrients tend to have a large number of organisms but less species. According to Hillebrand *et al*. (2007) ecosystems with sources of enrichment are favored by an increase in diversity and species richness because rare species have access to new resources. Focal points of pollution were not identified in the main channel of the Madeira River. These could represent complementary nutrient input, particularly of phosphorous which a limiting growth factor for algae. The greatest values of specific richness (S), equitability (J_S) and diversity (H_0) were determined in the upper Madeira at sampling stations M14 and M16 during the high water periods (Fig 2).

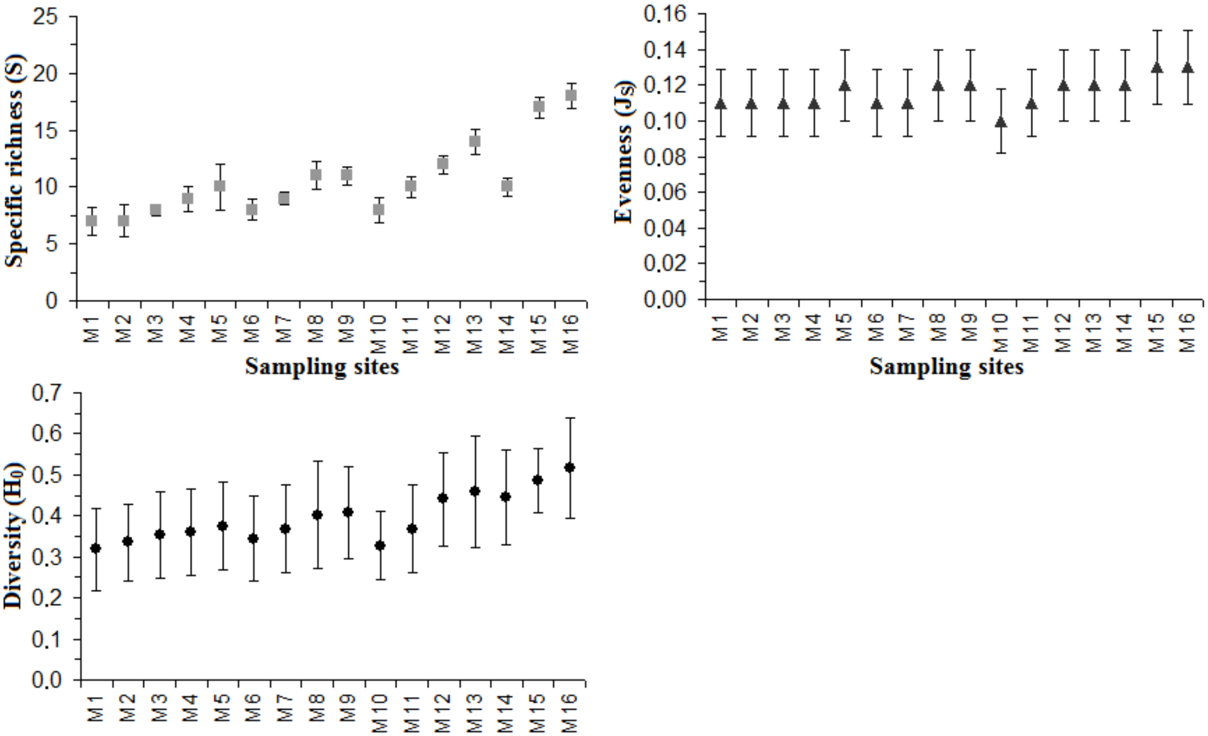

Fig 2: Specific richness (S), evenness (J_S) and diversity (H_0) of cyanobacteria in the main channel of the Madeira River in the Brazilian Amazon.

Although equitability was low (< 0.15), dominance of any one species was not detected (Table 3). Well know for potentially forming algal blooms the genera *Oscillatoria* e *Anabaena* however, were well distributed throughout the river channel. Under natural conditions cyanobacteria such as the genus *Aphanothece* can occur as single cells, or unicellular colonial forms such as *Gomphosphaeria*, *Merispmopedium* and *Microcystis* or be organized as filaments such as *Anabaena* and *Oscillatoria*.

The diversity indices were calculated to describe the biological communities in terms of species richness and uniformity. These are comparative analysis between the different structures and ecological processes involved in the organization up of the communities. Observing the data in Table 2 it can be seen that the species richness index values have different total richness. With respect to the Menhinick (S_n) index, which varied from 1.5 to 1.8 during the high water period and around 1.0 during the low water season, there was no seasonal difference or any difference between the upper, middle and lower courses of the Madeira River. The Margalef index was slightly higher in the upper and middle courses of the river suggesting less species richness near the mouth of the river (M1 to M9) for both hydrological periods. The greatest values of the index were detected during the high water periods with values varying between 2.5 e 3.7 (Table 2). A comparative analysis between the species richness curve was developed (Fig 3) for the high water and low waters levels. There was a greater range of variation in species richness during high water levels.

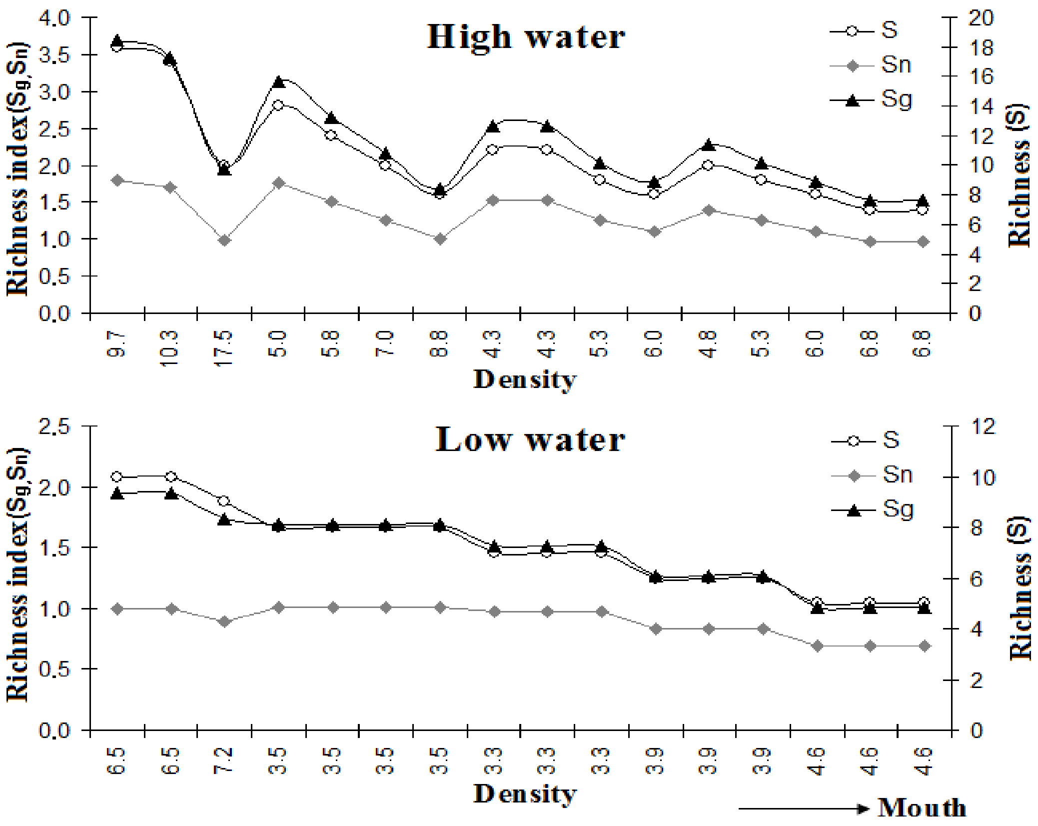

Fig 3: Richness and richness indexes curves for taxa identified in the Madeira River basin.

Table 3: Descriptive species of the cyanobacteria community with the indication of presences at the sampling stations in the Madeira River.

CYANOPHYTA	H	M	L
Class Cyanophyceae			
Order Chroococcales			
Aphanothece sp.	X		
A. clathrata West & G.S. West	X		
A. saxicola Nägeli	X		
Chroococcus minutus (Kützing) Nägeli			X
Gomphosphaeria sp.	X		
Merismopedia elegans A. Braun ex Kützing	X		
M. tenuissima Lemmermann		X	
Microcystis aeruginosa Kützing		X	X
Order Nostocales			
Anabaena sp.		X	
A. circinalis Rabenhorst ex Bornet et Flahault	X	X	X
A. flos-aquae Brébisson ex Bornet & Flauhault	X	X	X
A. spiroides Klebahn	X	X	X
Aphanizomenon flos-aquae Ralfs ex Bornet & Flahault		X	
Lyngbia sp.	X		
Oscillatoria limosa C. Agardh	X	X	X
O. sancta Kützing ex Gomont	X	X	X
O. splendida Greville	X	X	X
O. tenuis C. Agardh	X	X	X
O. terebriformis C. Agardh	X	X	X
Scytonema crustaceum C. C. Agardh	X		
Spirulina subsalsa Oersted	X	X	
Order Stigonematales			
Fischerella sp.	X		
Hapalosiphon aureus West & G.S. West	X	X	X

(X) present; H = headwaters, M = middle and L = lower reaches.

The succession rate of added differences (SDI) of Lewis´s (1978) is a measure of the quantitative of the variation of abundance by the biomass of the community and the results are presented in Table 2. They show a great spatial-temporal variation. The analysis of variance ($p < 0.05$) confirmed that there were no significant changes in the changes in the community between the high and low water periods neither between the upper, middle and lower courses of the river although the calculated values were always higher during the high water periods. This can be explained by the fact that species abundance was always lower during the low water periods. According to Lewis (1978) the index is not sensitive to changes in the size of the community without changes in the relative abundance of the species. In general the limnological conditions of the Madeira River are relatively constant throughout the hydrological cycle although there can be a slight increase in sediment load during low water periods. Also this does not alter the important limnological properties of the water such as conductivity, pH and dissolved oxygen. The succession rate of the cyanobacteria is very low throughout the year. High succession rates can be expected in other environments where the physical and chemical characteristics of the water vary greatly during a hydrological cycle such as what happens in the flood plain lakes subjected to the flood pulse of the Amazon River, for example.

The constancy index illustrates the similarity in the composition of the communities in the Madeira River (Fig 4). 26% or 6 taxons in a total of 23 were constant, 17% or 4 were accessories and 56% or 13 were accidental. The constant species are the ones that better describe the environment given that they can be considered to be the most adapted.

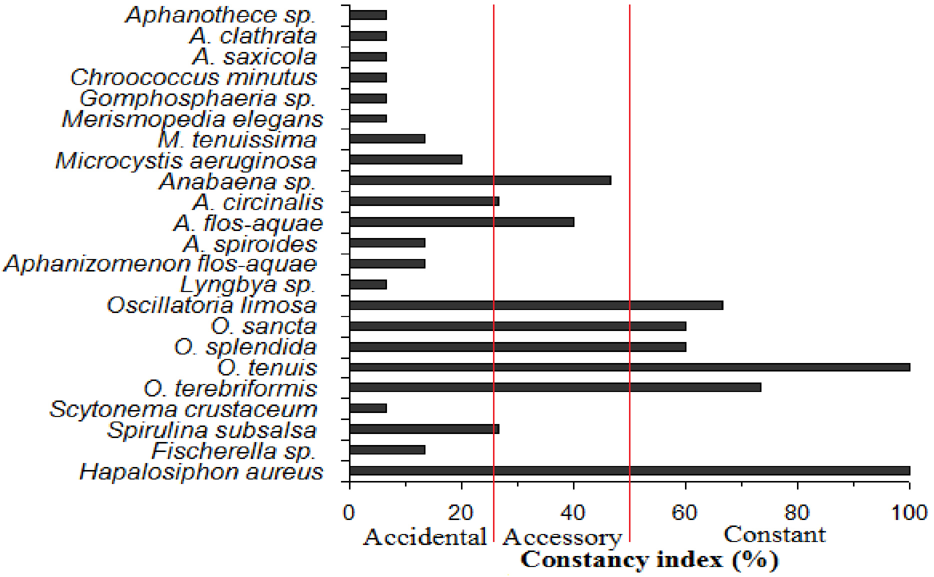

Fig 4: Dajoz constancy index (Dajoz, 1978) for the taxons identified in the Madeira River.

The results of the statistics corroborate the ecological analysis. The principle components analyses showed a separation between the limnological parameters for the high and low water periods especially conductivity, total solids, transparency, turbidity, calcium and magnesium. However, as demonstrated by the SDL analysis this separation was not sufficient to indicate a succession rate of cyanobacteria species. The 1 axis was responsible for 52.5% of the explanation of the distribution pattern of the cases against 15.9% of the 2 axis (Table 4). Both axes however, contribute to explain the slight seasonal difference that occurred in the river. It is interesting to note that the special pattern, specifically for the upper Madeira River (stations M14 to M16), was shown by axis 2.

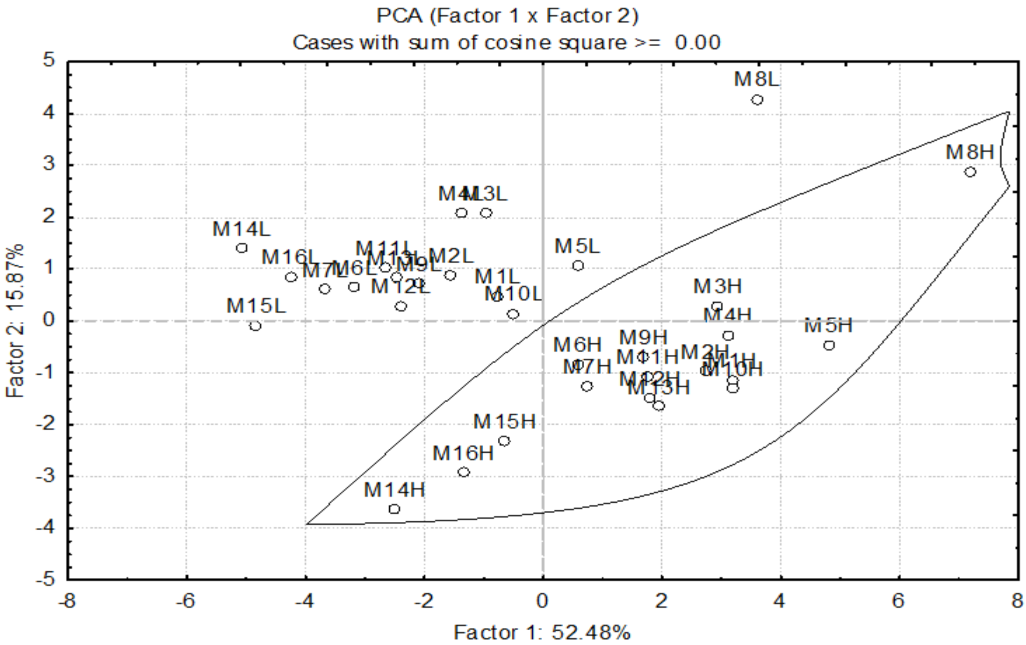

Fig 5: Principal component analysis for limnological variables measured in the Madeira River basin between 2002 and 2007.

Table 4: Principal component analysis (PCA) of the limnological variables*.

Axis	Eigenvalue	Total variance (%)	Cumulative Eigenvalue	Cumulative (%)	Meaning
1	8.9	52.5	8.9	52.5	Temporal trend
2	2.7	15.9	11.6	68.4	Spatial-temporal trend

*17 active variables to 16 sampling sites and 128 active cases.

3.1 Hydrological and sanitary role of cyanobacteria

Some species of cyanobacteria are terrestrial, living on rocks or humid soil. Most use atmospheric nitrogen and are of great importance when associated to vascular plants (Aguiar, 1992). Some groups are very resistant to variations in temperature and salinity which contributes to their wide distribution in all biomes. When they multiply excessively in eutrophic environments and form blooms they merit attention for several reasons (Dagnino *et al*., 2004). Cyanobacteria can produce disagreeable odors and taste in water. In eutrophic reservoirs with high phosphorous and nitrogen concentrations cyanobacteria can form large blooms in a matter of hours upsetting environmental equilibrium. In Tabocas and Tapacurá, for example, two reservoirs located in the Zona da Mata region and the Agreste region of the northeastern state of Pernambuco cyanobacteria blooms were observed by the authors and most probably were the result of an accumulation of nutrients in the water column (unpublished data). In the Billings and Guarapiranga reservoirs in the state of São Paulo algal blooms are common (Carvalho *et al*., 2013) and algaecides are often applied to contain algal growth. The high concentrations of organic composts stimulate the increase of decomposing microorganisms in the water and bottom sediments that take up dissolved oxygen and favoring the photosynthetic activity of the cyanobacteria. Several papers have correlated the presence and abundance of cyanobacteria to organic pollution especially by phosphorous (Chorus & Mur, 1999). The genera *Euglena*, *Navícula*, *Nitzschia*, *Microcystis*, *Oscillatoria* and *Scenedesmus* are directly associated to water pollution (Palmer, 1980; Das & Panda, 2010) and, in this sense, have been used as bio indicators of pollution (Round, 1965; Sawhney, 2008).

Monitoring nutrient concentrations, especially phosphorous, different forms of nitrogen, water transparency and the hydrological characteristics of the environments help understand the why certain species are dominant in particular ecosystems (Cybis *et al*., 2006). It should be noted that, in terms of nutrient concentrations, the Madeira River does not present high concentrations of phosphorous and nitrogen nor concentrations of Na, K and Mg ions (Table 2). In fact the presence of cyanobacteria in the muddy waters of the Madeira River is not associated with high concentrations of organic material nor are they indicative of any type of pollution. As mentioned previously, in this study we did not observe any indication of dominance by any species of cyanobacteria.

Among the cyanobacteria species found in the Madeira River, the species of the genus *Anabaena* are important in terms of sanitation because they can potentially produce mirocistines that can affect the liver and anatoxins and saxitoxins that are neurotoxins. Others are *Microcystis* that can produce microcistines; *Lyngbia* that can produce saxitoxins and *Aphanizomenon* that can produce anatoxins and saxitoxins, neurotoxins, and cilindrospermopsines, which acts on the liver (Sivonen & Jones, 1999; Fernandes *et al*., 2005; Carvalho *et al*., 2013). The genus *Microcystis* is responsible for the greatest unmber of animal and human intoxications. The genus is cosmopolitan and is common in Brazil, where is commonly found infesting reservoirs (Gilroy *et al*., 2000, Carmichael, *et al*., 2001; Dagnino *et al*., 2004). In the Madeira River this genus was observed in the middle and lower reaches of the river where the declivity of the river bed and consequently currant, are much reduced.

Considering its dimensions, there are not many cities on the edges of the Madeira River. More people are found in the upper river region. A point in common of some populations is that they use water from lakes near the communities. To the best of our knowledge there are no sanitation studies in these areas, but based on personal observations we can say that, with the possible exception of the city of Porto Velho, most communities use the Madeira River water without adequate treatment. During the low water periods, it is common to observe the people from the riverside communities collect water more to the middle of the river because of the decomposition of marginal aquatic macrophytes. In terms of the socio-economic and cultural aspects the risk of contamination to the local population by the consumption of water containing cyanobacteria cannot be discarded even knowing that the phytoplankton is this lotic system is continuously being removed.

In Brazil cyanobacteria and cyan toxins have been included as parameters to be measured in monitoring programs since the publication of the Portaria nº 1.469 of the Ministry of Health (Brasil, 2000), substituted later by the Portaria n° 518 (Brasil, 2004). After the unfortunate episode that became known as “the Caruaru hemo dialysis case” in the state of Pernambuco in 1966, that resulted in the death of patients in a clinic due to the presence of cyanobacteria in the dialysis solution, it became obvious that these organisms and their byproducts need to be monitored.

4. Conclusion and Future Perspectives

The Madeira River has a singular characteristic in that is basically divided into two stretches. The first, which is from the mouth of the Beni River, one of the rivers along with that the Mamoré and Guaporé rivers, that “make up” the Madeira, to the Santo Antonio waterfall, (about 350 kilometers), has an inclination of about 70 meters, that is, 20cm km^{-1}, and thus, a great number of waterfalls and rapids. The second is from the Santo Antonio waterfall to the mouth of the Madeira where it runs into the Amazon River, about 150 kilometers downriver from the city of Manaus. This stretch, of about 1040 kilometers, is very flat, with an inclination of about 1.7cm km^{-1}. The limnological parameters of the river water reflect the geochemistry of the basin and also can vary according to the hydrological cycle of the river.

23 taxons of cyanobacteria were identified in this study, but, as to be expected in a lotic system, not many individuals. However, it is worth recalling, that in standing waters such as lakes and reservoirs, cyanobacteria can be a problem. Some species can give a bad taste and a bad smell to the water, and others produce cyano toxins capable of killing animals and humans.

It is also worth mentioning that two very large hydroelectric reservoirs, the Santo Antonio reservoir (8°48'8.71"S; 63°57'16.04"W) and the Jirau reservoir (9°19'42.07"S; 64°43'57.75"W) are being built above the Santo Antonio waterfall, in the rapids stretch mentioned above. These reservoirs will be practically interconnected and will cover an area of about 600 kilometers square (60,000 ha). With basically no currant, the water is these reservoirs will deposit the sediment load, become clearer and with good nutrient concentrations, constitute a very apt environment for phytoplankton growth, including cyanobacteria.

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