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Aquatic ecology

Resilience of phytoplankton community in the Andean Papallacta Lagoon and its tributaries, eight years after an oil spill

Resiliencia de la comunidad fitoplanctónica en la laguna andina de Papallacta y sus afluentes, ocho años después de un derrame petrolero

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Abstract

In April 2003, there was an oil spill in the Papallacta zone (Ecuador: northern Andes), after the disaster bioremediation work was carried out in the lagoon and in its tributaries. We analyze the phytoplankton community as bioindicator of the current quality of the water body, considering 28 places in tributaries and in the lagoon, both in the dry season, transitional and rainy season, from December 2010 to July 2011, we identified and counted the genera of phytoplankton found in each sampling point, also considering the natural history of each group of algae. Diatoms, cyanobacteria and green algae were the major groups, the first of them was the most widely distributed with higher values in richness and abundance. The correlations between genera and abiotic variables showed differences related to seasonality. However, there was the constant presence of certain genera as Synedra and Oscillatoria, high organic load indicators. This research also provides information about the genera that now dominate both in the lagoon and its tributaries and the characteristics that influence their distribution and allow to determine the ecological health of Laguna de Papallacta, now it can be classified as mesotrophic. The presence of oil is restricted on specific points on the bottom of the lagoon, allowing that primary productivity in the photic zone develops normally
Keywords: limnology, Andean lagoons, oil spill, phytoplankton, bioindicator, water quality.

Resumen

En abril de 2003 se produjo un derrame de crudo en la zona de Papallacta (región andina norte de Ecuador), luego del desastre se realizaron labores de biorremediación tanto en la laguna como en sus afluentes. El presente trabajo abordó la comunidad fitoplanctónica como bioindicadora de la calidad actual del cuerpo de agua, considerando 28 sitios en ríos afluentes y en la laguna, tanto en época seca, como en la de transición y lluviosa, desde diciembre 2010 hasta julio 2011. Se identificaron y contabilizaron los géneros de fitoplancton encontrados en cada sitio, abordando paralelalmente la historia natural de cada grupo de algas. Los géneros pertenecieron a tres grupos: diatomeas, cianobacterias y algas verdes; el primero es el grupo con mayor distribución y con los valores de riqueza y abundancia más altos. Las correlaciones entre géneros y variables abióticas presentaron diferencias relacionadas con la estacionalidad. Sin embargo, se observó la constante presencia de géneros indicadores de alta carga orgánica como Synedra y Oscillatoria. Se aporta también información acerca de los géneros que ahora predominan tanto en la laguna como en sus afluentes, y las características que influyen en su distribución y que permiten determinar el estado de salud ecológica de la Laguna de Papallacta, que ahora se la puede catalogar como mesotrófica. La presencia actual de crudo del derrame se concentra en puntos específicos en el fondo de la laguna, permitiendo que la productividad primaria en la zona fótica se desarrolle con normalidad.

Palabras claves: limnología, lagunas andinas, derrame petrolero, fitoplancton, bioindicador, calidad del agua.

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1 Introduction

The number of phytoplankton species in the world is still unknown, in the ocean are estimated 5 000, this number may be higher in continental aquatic ecosystems as lagoons, because they do not form a single body of water (Molina Santos, 2013), being systems (River-Lagoon) relatively isolated from each other, unlike the ocean which is a larger area but with relatively similar characteristics. This is how lagoons and rivers are often influenced by seasonal changes and inconstant abiotic variables, which can be determinants for the diversity of phytoplankton (O'Sullivan y Reynolds, 2004; Escobar, Terneus y Yánez, 2013).

The quality and quantity of phytoplankton in a body of water allow inferring attributes of the habitat state, such as nutrient balance, availability of food for minor heterotrophs, light quality, water movements, among others. These characteristics make the study of their populations essential to understand the state of a water system (O'Sullivan y Reynolds, 2004).

Several factors cause stress on phytoplankton and their communities, including ultraviolet radiation, acidification, eutrophication and the global warming; which can act by modifying the structure and dynamics of such communities (Delgado-Molina *et al*., 2009; Belinger y Sigee, 2010).

1.1 Phytopkankton as an bioindicator

Phytoplankton usually has certain tolerance to organic contamination and it allows to know the changes that occur in water bodies in which pollution has occurred (Arce *et al*., 2006), this event can even help in the determination of species capable of degrading organic matter or purifying the environment through photosynthesis, which adds dissolved oxygen to the system, useful for other organisms and for the oxidation of that matter (Arce *et al*., 2006; Suthers y Rissik, 2009; Terneus, 2018).

On the other hand, phytoplankton is usually the first group affected by heavy metals, this triggers a problem not only for it but also for the higher groups: by absorbing metals at the cellular level, it triggers a bio-magnification in the herbivores of the first order that consume it and then in the carnivores consuming these (Bahnasawy, Khidr y Dheina, 2011; González-Dávila, 1995).

The affectation level of phytoplankton depends on factors such as oxygen concentration, temperature, pH and water salinity as it obtains its nutrients; so water can be considered the main source of phytoplankton contamination (Bahnasawy, Khidr y Dheina, 2011).

1.2 The oil spill in Papallacta and the objectives of this research

On April 8, 2003 at 4h00, there was a crude oil spill in the Andean zone of Papallacta, generated by a rupture of the pipeline of the Transecuadorian pipeline system (SOTE), managed by Petroecuador; such an event provoked an affectation on the streams of the rivers Cachalarca, Tambo and Sucus (PetroEcuador, 2006), as well as in Papallacta Lagoon (Figure 1). The area of the spill was in the sector known as the Guango at 3 631 masl (Armisen, Cruz y Larrosa, 2005), coordinates UTM N 9 959 586 and E 812 820 (WGS84), near the Sucus river.

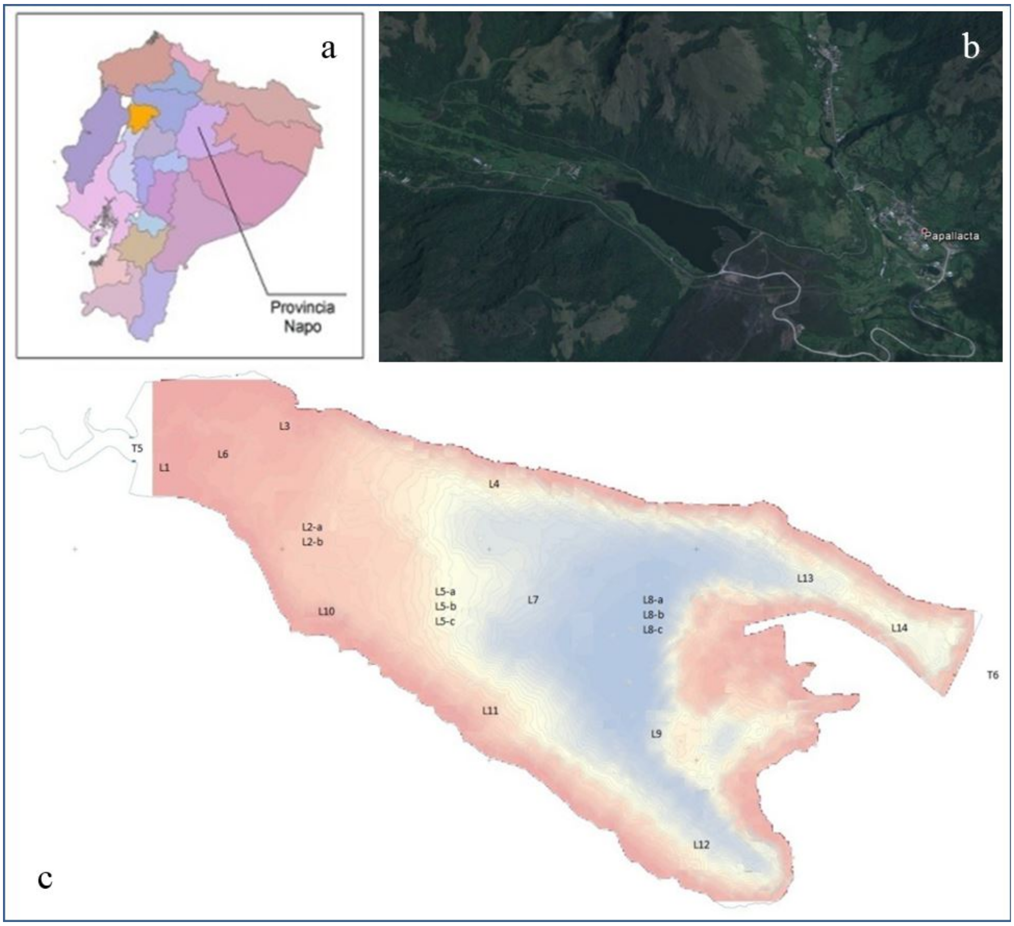

Figure 1. Geographical location of the Papallacta Lagoon and the sampling sites: A. Napo, Andean-Amazonian province in relation to continental Ecuador; B. Satellite image of the lagoon (Google Earth, January 2013); C. Location of sampling points in different areas of the lagoon.

22 000 barrels were spilled; a part of this oil was dissolved in the water, producing a continuous flow through the Tambo and Sucus rivers towards the lagoon. At the beginning, it was possible to see a layer of oil between 0.1 and 70.0 cm thick in approximately 6.5 hectares of the lagoon; then by natural processes, the crude precipitated to the bottom (Pino *et al*., 2005). It was also observed that near the site of the spill, the soil was covered with a layer of oil with six centimeters thick, affecting not only the water but also the flora and the fauna of the place (Armisen, Cruz y Larrosa, 2005; Molina Santos, 2013; PetroEcuador, 2006).

Petroecuador launched the contingency plan to stop the effects on the ecosystem; after the corresponding evaluation, it began with the bioremediation program, consisting in the development of works at the area of the spill, the banks of the rivers Sucus and Tambo, water and soil contaminated to the border and in the same lagoon, all as part of the restoration process of the affected ecosystems (PetroEcuador, 2006; Molina Santos, 2013).

Within this context, the current research was raised by seeking:

- To determine the composition of the phytoplankton community in aquatic ecosystems in the area affected by the oil spill.
- To categorize the phytoplankton groups according to their bioindication characteristics.
- To evaluate the current ecological health state of the Papallacta Lagoon, considering the phytoplankton community as a bioindicator.

2 Materials and methods

2.1 Area under research

The Papallacta Lagoon (Figure 1) and its tributaries, the Tambo and Sucus rivers are located in the Napo province, in a glacial valley located 70 km east of Quito, at the southwestern end of the Cayambe-Coca National Park, at an altitude of approximately 3 350 masl.

The local average temperatures oscillate between 6 °C to 8 °C; the average annual precipitation is between 1 250 to 1 400 mm/year (PRAA, 2007).

Specimen collection sites were located in several areas, from shortly before the site of the spill (UTM E 812 856, N 9 959 639) to a point in the lagoon effluent (UTM E 816 860, N 9 958 048). 28 sampling points were established (19 in the Lagoon and 9 in the river); samples were taken considering the physical conditions of the ecosystem, using two different methods according to the area. The lagoon samples were collected from a boat, while the river samples were collected directly from the substrate. The points of the lagoon are identified with the letter L and the points of the river with the letter T (Figure 1).

Sampling points in the lagoon were established based on a previous bathymetric analysis; in this way the depths of each point and its topography were determined with better precision, which helped to identify the sites where the crude oil can accumulate to the bottom.

The area of Papallacta possesses characteristics of herbaceous paramo, being dominant in the landscape the Calamagrostis sp. and Stipa sp., as well as moss; eventually is observed the grow of trees and shrubs of irregular growth of the genera *Oreopanax, Gynoxys, Axinaea, Brachyotum, Hypericum, Buddleja, Polylepis* (Yánez, 2014).

The fish diversity is low in the moorlands of the study area, the trout (*Oncorhynchus mykiss*) (Molina Santos, 2013) stands out as an element introduced and used for food and commercial purposes.

2.2 Methods

Samplings were carried out in periods corresponding to three seasons of the year: dry (December 2010), transition (March 2011) and rainy (July 2011). The seasonal analysis is usually very important, since the changes influence the life patterns of the phytoplankton organisms when the water temperature changes, its movement, and light availability (Marshall, 1965).

A stratified random sampling was carried out in the lagoon using a Van Dorn bottle which descends vertically to the desired depth. The bottle collected at a time two liters of water, and were then filtered through a 30 micron phytoplankton network with a beaker screwed to the end. This process allowed collecting the largest amount of plankton, facilitating further analysis in the laboratory. Three subsamples were taken for each site between 1.0 to 1.5 m deep. Specimens were preserved in 4% formalin and stored in amber-colored containers.

A Surber net with 85 microns was used in the rivers, since the phytoplankton is presented in another way in this ecosystem, because it tends to stick in the rocks or riparian plants in the form of periphyton and epiliton; the depth of the river did not surpass 0.8 m (highest depth in the rainy season). In this way, samples were taken up to 0.2 m of depth; the net used consists of two frames each one of 30 cm x 30 cm, joined by clamps; a frame is placed on the surface to be sampled and a net of 60 cm joined to the second frame which allows collecting the sample (Alberta Environment, 2006). With this tool, was collected the periphyton attached to the stones and in certain cases also on the shores.

Both in the river and in the Lagoon the data were taken in situ, with an oxygen meter and a digital multi-parameter: pH, conductivity, suspended solids, dissolved oxygen, water temperature, total depth of the point and depth of the Secchi disc. Additionally, samples were sent from each site to a laboratory for the biochemical oxygen demand (BOD) analysis, chemical oxygen demand (COD), chromium, barium, lead, vanadium, phenols, global nitrogen, dissolved solids, turbidity and total petroleum hydrocarbons (TPH).

2.3 Sample analysis in the laboratory

Two techniques were used, the first consisted of using separating funnels of 250 ml and 500 ml, in which the sample was left in decanting between 24 and 72 hours to separate the phytoplankton from the solids in suspension, the separated sediment which remained in test tubes was dropped; this technique is viable when it comes to river samples because they have a higher sediment load that should be decanted. The second technique was centrifugation, which was used when there were low concentrations of phytoplankton, for this were taken 200 ml of homogenized sample and centrifuged at low speed for 20 minutes, in order to process more samples in less time.

The identification of the phytoplankton was carried out in the laboratory of Universidad Internacional del Ecuador. Olympus CX21FS1 microscopes were used for the count and identification. Each observed sample had the same volume, for this were placed three drops of 100 µ L of each sample on a concave plate with several slits, allowing a relatively fast count. Each drop was analyzed meticulously, for this the drop was divided into nine parts using a grid, obtaining the current number of genera and individuals per drop. The final result of the count was expressed in number of colonies per milliliter (NCM).

For the taxonomic identification were used the keys of (Belinger y Sigee, 2010; Canter-Lund, 2012; California Academy of Sciences, 2012; Fourtanier y Kociolek, 2009).

2.4 Data analysis

The sampling sites, depending on their abiotic characteristics, were subjected to a similarity analysis (Cluster analysis) (Hill, Lewicki y Lewicki, 2006), based on Euclidean distances between sites according to the recommended by (Yánez, 2005).

For the analysis of the phytoplankton biota was applied the tolerance index to Palmer's organic contamination, in which is proposed 20 genera as the most tolerant of this type of pollution and are assigned a tolerance value; to characterize a site the individual indexes are summed and according to the total value obtained is determined the organic load in the site. Palmer determined that a site index value higher than 20 indicates a high organic load, a result between 15 and 19 indicates a probable evidence of high organic contamination, and lower values may indicate little organic load, non-representative sample or certain particular factors are influencing the presence of phytoplankton (Hern *et al*., 1979).

To compare the sites according to their phytoplankton composition, Steinhaus similarity index (Bray-Curtis) was used, recommended by (Goslee, Urban *et al*., 2007; Yoshioka, 2008), from which were created the corresponding cladograms were created.

Finally, a canonical correspondence analysis was conducted to identify the relationship between the abiotic variables with respect to the composition of the biological community of interest in the sites (Ter Braak y Verdonschot, 1995). For this analysis only the most abundant genera were taken into account.

3 Results and discussion

3.1 Phytoplankton groups registered

Three large groups of phytoplankton were found (in the Papallacta Lagoon and Tambo and Sucus tributaries): diatoms (Bacillariophyta), green-blue algae or cyanobacteria (Cyanophyta) and green algae (Chlorophyta), distributed in 21 genera (Table 1).

Table 1. Microalgae genera registered in Papallacta in tributaries and Lagoon (total abundances are shown estimated by sampling time and total abundance in number of colonies per milliliter = NCM)

Group	Classification	No.	Genre	Dry season	Transiton transición	Rainy lluvia	Total NCM
Diatoms	Central	1	*Cyclotella*	3000	9000	0	12000
		2	*Melosira*	5415000	1508000	194000	7117000
	Penales	3	*Campylodiscus*	72000	0	0	72000
		4	*Cymbella*	625000	374000	183000	1182000
		5	*Diploneis*	13000	12000	3000	28000
		6	*Frustulia*	1000	3000	0	4000
		7	*Hantzschia*	2742000	663000	289000	3694000
		8	*Navicula*	6092000	4121000	551000	10764000
		9	*Neidium*	5000	1000	6000	12000
		10	*Nitzschia*	8964500	1662000	353000	10979500
		11	*Pinnularia*	57000	0	0	57000
		12	*Rhopalodia*	49000	23000	0	72000
		13	*Surirella*	12000	2000	2000	16000
		14	*Synedra*	4215500	1255000	455000	5925500
Cyanobacteria	Cyanophyta	15	*Microcystis*	158000	16000	0	174000
		16	*Oscillatoria*	268000	138000	451000	857000
		17	*Spirulina*	0	0	3000	3000
Greesn Algae	Chlorophyta	18	*Ankistrodesmus*	1000	41000	9000	51000
		19	*Mougeotia*	95000	38000	0	133000
		20	*Rhizoclonium*	9000	4000	92000	105000
		21	*Spirogyra*	2000	0	0	2000

3.2 Classification analysis of the áreas in function of their abiotic characteristics

It was possible to distinguish three types of sites during the dry season (Figure 2), marked with the letter L for those of the land T for river; the largest is formed by 21 sites (L10 to L13), among which is T5, corresponding to the mouth of the river and T6 to the exit of the effluent from the lagoon. These 21 sites are similar because the conductivity values, suspended solids and dissolved oxygen are similar.

Another group is formed by three river points (T1A, T0 and T1B), with similar values of conductivity, temperature, dissolved oxygen and suspended solids. The last group is also formed by three river points (T3B, T2B and T3A), with similar values of turbidity, conductivity, depth and PH.

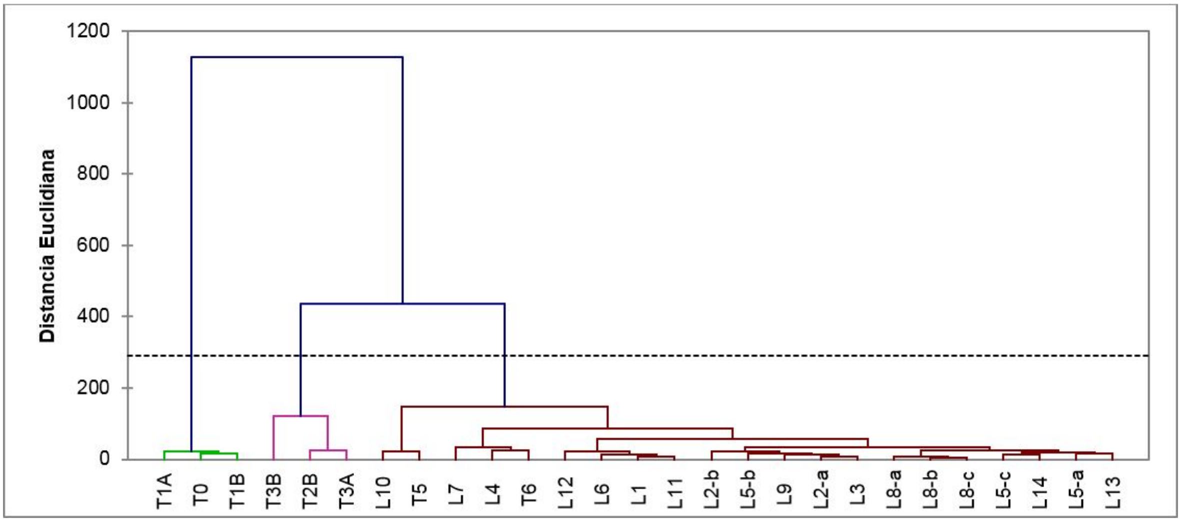

Figure 2. Cladogram of the sites sampled during the dry season, according to their abiotic data (agglomerative method, complete link, based on Euclidean distances).

For the rainy season (Figure 3), most of the points are in the group of L7 to L8-B, corresponding to 19 sites in the Lagoon, one in the river (T3B) and the same at the exit (T6) and entrance to the lagoon (T5), the values of the variables temperature, conductivity, dissolved oxygen and suspended solids are quite similar among them.

The group formed by T2B, T1A and T1B presents similar values of DBO, DQO, pH and depth. The last group (T3A, T0 and T2A) has similar values of dissolved oxygen, PH and suspended solids.

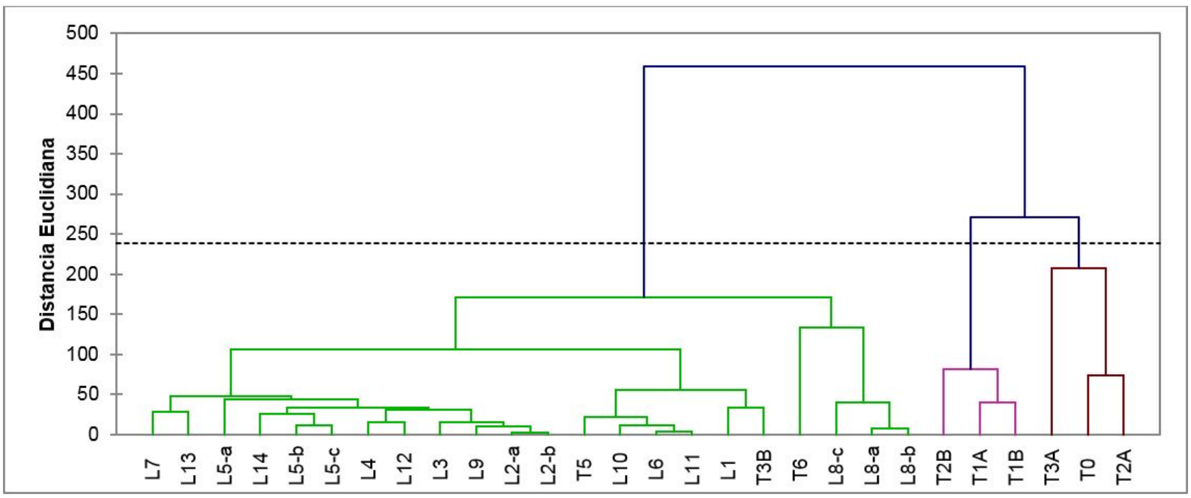

Figure 3. Cladogram of the sites sampled during the rainy season; according to their abiotic data (agglomerative method, complete link, based on Euclidean distances).

3.3 Phytoplankton biota and Palmer index

The result of this index (IP) was = 17 (Table 2); this is an indication of an average organic load (values of 15-19 show indirect evidence of probable organic contamination, according to (Taylor *et al.*, 1979). The genera present in the lagoon and the river are mostly the same in the three sampling periods.

Table 2. Palmer index for registered phytoplankton, with cumulative data from the three sampling periods

Genera in Papallacta	Index value (Laguna+Río)	Genera in Papallacta	Index value (Laguna+Río)
Ankistrodesmus	2	*Neidium*	0
Campylodiscus	0	*Nitzschia*	3
Cyclotella	1	*Oscillatoria*	5
Cymbella	0	*Pinnularia*	0
Diploneis	0	*Rhizoclonium*	0
Frustulia	0	*Rhopalodia*	0
Hantzschia	0	*Spirogyra*	0
Melosira	1	*Spirulina*	0
Microcystis	0	*Surirella*	0
Mougeotia	0	*Synedra*	2
Navicula	3	Total IP	17

3.4 Classification analysis of the sites in function of their phytoplankton characteristics

In the dry season (Figure 4), the most relevant groups of sites were:

The largest (T3A to L2-B), consisting of eight sites of Lagoon and four of river (T3A, T5, T2A and T1A). This group presents similar abundance values of emphMelosira, Navicula, Nitzschia, Synedra, Microcystis, Oscillatoria and *Hantzschia*.

A second formed by eight sites, seven from the lagoon (L4 to L9) and one from the river (T2B), with the following genera: *Navicula*, *Neidium*, *Nitzschia*, *Synedra* and *Oscillatoria.* .

A third group, formed by five sites (L1, L13, T6, L11 and T0) with three sites of the lagoon, an effluent of this (T6) and a point in the river (T0), with similar abundances of *Melosira*, *Hantzschia*, *Navicula*, *Nitzschia*, *Synedra*, *Rhizoclonium* and *Cyclotella*.

On the other hand, L6 is shown separate due to its greater abundance of *Cyclotella* and *Rhopadolia*. While two river sites (T1B and T3B) record greater abundances of *Campylodiscus*, *Pinnularia* and *Mougeotia*, which are absent in the other sites.

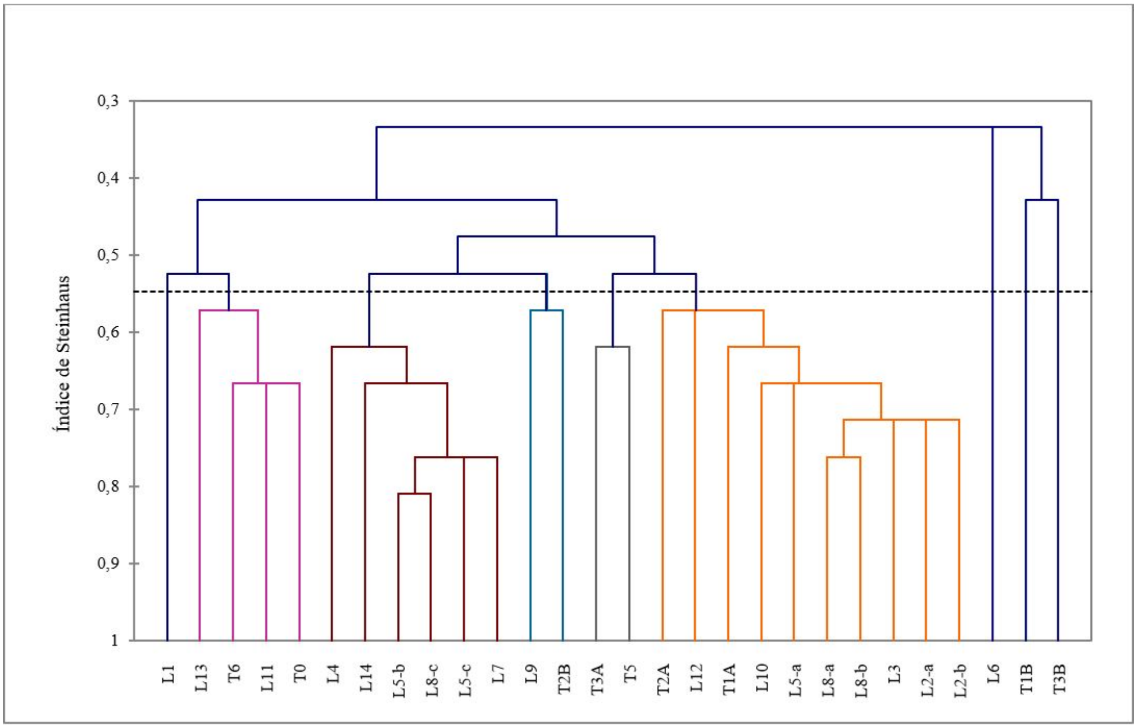

Figure 4. Cladogram of sites sampled in the dry season, depending on the phytoplankton data (agglomerative method, complete link, based on the index of Steinhaus).

For the rainy season (Figure 5) three better defined groups are observed:

The largest (T5 to L8-B) formed only by sites of the lagoon (L) plus a tributary of this one (T5), characterized by more abundance of *Navicula, Nitzschia* and *Synedra*.

The second group (T1A to T0) was mostly composed of river sites, plus two of the lagoon (L2-B and L11) and a lagoon effluent (T6); predominating *Melosira, Cymbella, Navicula, Nitzschia, Synedra* and *Oscillatoria.*

Finally, the last group was formed by two points of the river (T1B and T3B), and with similar abundances of *Navicula* and *Spirulina*.

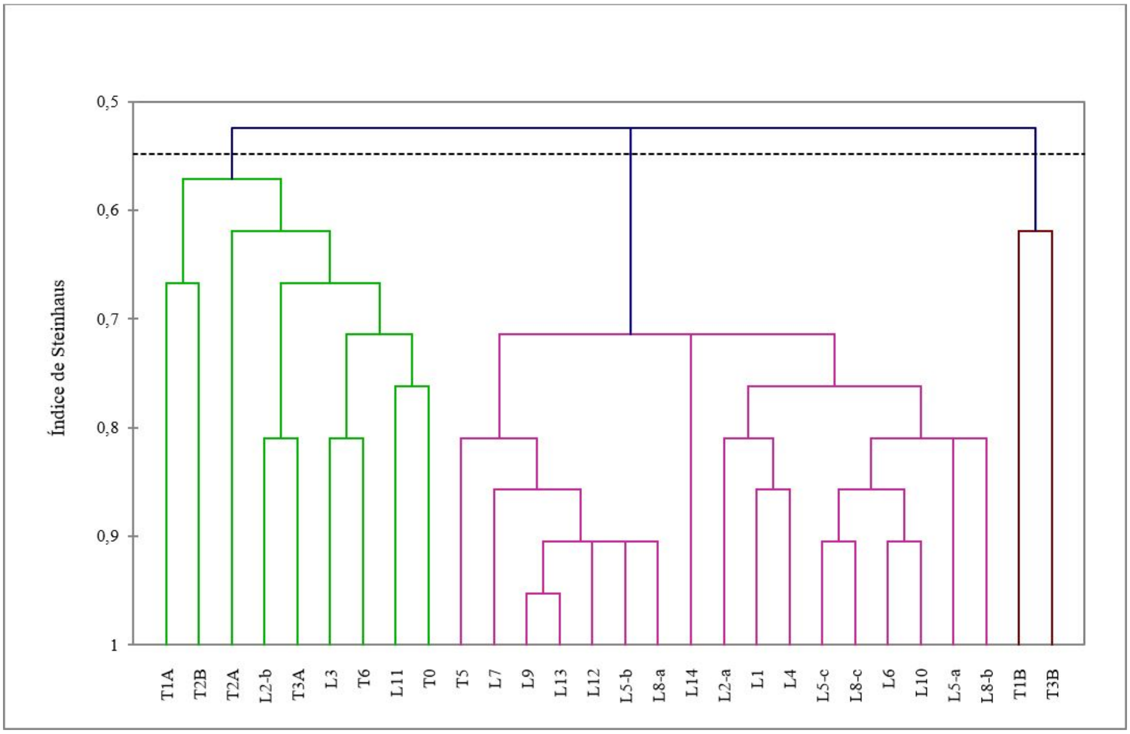

Figure 5. Cladogram of the sites sampled during the rainy season, depending on the phytoplankton data (agglomerative method, complete link, based on the Steinhaus index).

3.5 Canonical analysis of correspondences

The most influential parameters that defined the greater presence and abundance of phytoplankton in the sampling sites were: the surface temperature of the water (temp SUP) and the conductivity (COND), the suspended solids (SOLD), the transparency of the water determined by Secchi disk (TRANSP), The depth of the water column (PROF) and finally the DBO and DQO. Only these abiotic variables are shown as vectors in Figures 6 y 7, the other variables generated vectors of very little length so they were not plotted.

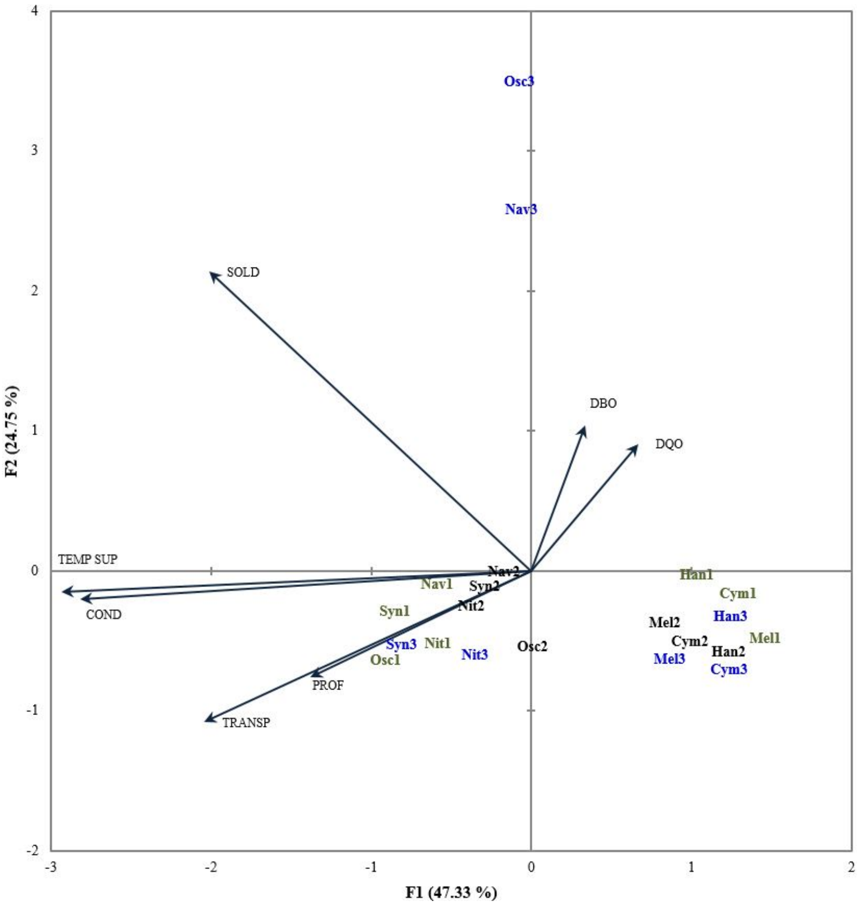

Figure 6. Classification plan of phytoplankton genres (marked only with their first three letters) in relation to physical-chemical variables of water generated by a canonical analysis of correspondences, with data from the three sampling periods: in green are the genera in the dry season accompanied by the number 1; in black are the same during the transition with number 2, and in blue are the same during the rainy season with the number 3.

The genera that depend or that are in correlation with higher values of surface temperature, conductivity, transparency and total depth are *Synedra* (Syn) and *Nitzschia* during the three seasons sampled (Figure 6). *Navicula* (Nav) and *Oscillatoria* (OSC) are equally influenced by these variables; however, during the rainy season, both move away from this group and apparently at this time their presence is more influenced by suspended solids. It is interesting how Oscillatoria during the transition time moves away from the vectors, which may indicate a little influence of the abiotic variables in this genus.

The group formed by *Melosira* (Mel), *Cymbella* (Cym) and *Hantzschia* (Han) does not seem to depend on any abiotic variable in specific, during the three seasons the group shows a negative correlation to the variables.

A consistent distribution can be observed by analyzing the abiotic variables in relation to the sampling sites (Figure 7): the Lagoon sites (L) are grouped together in a close manner, with similar values of surface temperature, conductivity, total depth and transparency of the water. T0, T3A, T6, T5 and T2B (River points), they are also associated with these same vectors, which indicate an important influence of these variables on them. It should be emphasized that the genera *Synedra*, *Navicula* and*Nitzschia* present high abundance values in the aforementioned sites.

The site T2A does not have a clear relationship with the majority of variables, except with suspended solids, which also coincides with a higher distribution of *Navicula* and *Oscillatoria* in the rainy season, it is important to emphasize that the abundances of these two genera during this season present the highest values at this point.

The last group is formed by T1B and T1A, which show low values of all the abiotic variables, this coincides with higher presence and abundance of *Melosira, Cymbella* and *Hantzschia* in these points.

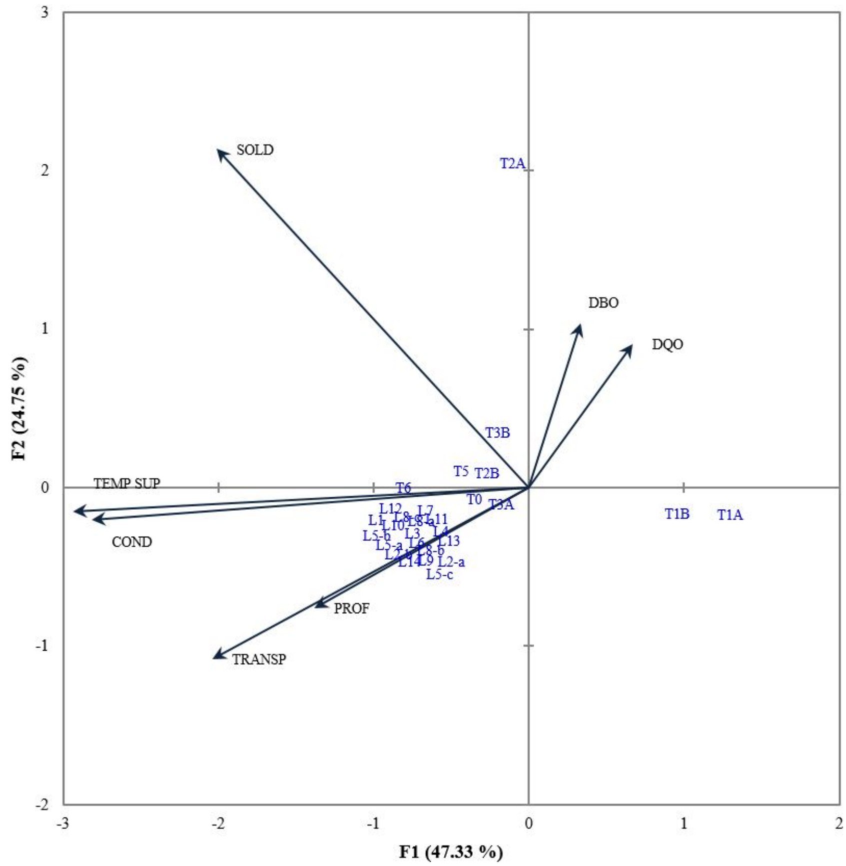

Figure 7. Ordering plan of the sampling areas in relation to the physical-chemical variables of the water, generated by a canonical analysis of correspondences, with data of the three sampling periods: the sites are codified in blue color (L = sites in the lagoon; T = sites in the river).

3.6 Main ecological considerations

It can be mentioned that during 2011-2012 (8-9 years after the spill) there is a mesotrophic state in the Papallacta lagoon and its tributaries, this is determined due to the presence of several bioindicator groups like *Navicula, Nitzschia* and *Oscillatoria*, which indicate that there is moderate organic load concentration, but they do not determine high eutrophication. This current condition may be due to different human causes, such as agrochemical discharges, detergents, and possible oil spill residues of 2003.

It is also important to note that no genus of phytoplankton found has a strict dependence on some determined abiotic variable; rather, they depend simultaneously on several, corroborating what is proposed by (Yin, Zheng y Song, 2011).

The presence and abundance of phytoplankton genera would be determined by various ecosystem processes (Reynolds, 2006), which implies some seasonal variation or not of the abiotic variables. For example, in the rainy season, the lowest abundances of phytoplankton were recorded in most genera, except in *Melosira, Hantzschia, Navicula, Nitzschia* and *Synedra*, which have a relatively constant presence in the three seasons, both in the river and the lagoon.

The presence of phytoplankton groups in the photic area of the lagoon and especially in the rivers indicate that there are good conditions for the development of primary production, even with the disturbances to which the study area has been exposed.

3.7 Considerations about the abiotic variables

Although small changes in the abiotic variables analyzed do not lead to an important variation in the presence and abundance of phytoplankton, it is considered that the existence of major variations would cause more modification in the structure of the local phytoplankton community.

For example, the temperature is decisive for the reproduction of the planktonic organisms, because it influences directly on their physiology and the physico-chemical of the aquatic environment (González-Dávila, 1995; Aznar Jiménez, 2000; Bahnasawy, Khidr y Dheina, 2011); In this sense, it should be mentioned that in Papallacta during the dry season the highest values of water temperature were recorded (6-10 °C) as well as the higher wealth and abundance of organisms; so it is very probable that this variable is determinant in this and other Andean lagoons (Olguín *et al*., 2004; Manjare, Vhanalakar y Muley, 2010).

However, other variables may also have influence on planktonic organisms, especially because the temperature correlates (positively or negatively) with factors such as pH, suspended solids, oxygen concentration and conductivity (Aznar Jiménez, 2000; Anukool y Shivani, 2011); conductivity presented in Papallacta lower values during the rainy season (between 80 μS and 400 μS) in relation to the dry and transitional times in which values were recorded between 120 μS and 800 μS. These elevated conductivity values are unusual in most water sources in the Paramo ecosystems. In Papallacta, however, there is a supply of volcanic hot springs that are discharged into the affluent rivers of the lagoon, which would explain such values.

A similar pattern is observed with suspended solids, which during the rainy season show low values, coinciding with an increase in turbidity during this season; in addition, the passage of natural light reaches a lower depth (0,5 - 0,9 m), unlike the dry and transitional period, in which the transparency values reached higher depth (1-5 m). This higher or lower passage of light in the water column of the lagoon turns out to be another important factor that directly affects the behavior of the organisms, being vital for photosynthesis, as mentioned by Reynolds (2006); Belinger y Sigee (2010).

This incidence of light, which depends on turbidity and solids in suspension, can be determinant on the richness and abundance of the phytoplankton genera, because in dry season and transition (with low turbidity values and more light passage) were recorded higher richness and abundance of phytoplankton in relation to the rainy season, in which lower values were recorded (with high turbidity and less transparency).

Dissolved oxygen values were relatively constant in the three seasons, except for a few sites during the rainy season. The pH remained between seven and nine; the variations within this range do not directly influence a particular organism of phytoplankton. For DBO and DQO high values are recorded during the rainy season, The DBO is especially notable since these high values coincide with the low abundance of phytoplankton, which are responsible for decomposing the organic matter that represents this variable.

Total nitrogen values are relatively low in all campaigns (0 to 3 mg/L), this is a limiting growth component for some groups of phytoplankton (Collos y Berges, 2011); cyanobacteria, for example, are important nitrogen fixatives and their presence in the lagoon and sampled rivers is limited, which can be linked to the availability of nitrogen.

The increase of the water level in the rainy season certainly affects different abiotic variables because the concentrations of suspended solids and low conductivity are diluted, which are usually high due to the influence of the thermal water of the area, which provide significant amounts of sulphur salts especially in the dry and transition periods. Suspended solids were also affected by this dilution (values between 30 mg/L and 240 mg/L in the rainy season, in relation to 70 mg/L and 560 mg/L in thedry and transitional seasons). Also, due to the flows and the typical wind of the rainy season there is a removal of solids from the edges, distributed homogeneously over the entire surface of the lagoon, increasing the turbidity and limiting the passage of light.

3.8 Relation of the phytoplankton genera and the season

The mesotrophic state of the lake system in general, as mentioned above, is based on the presence and abundance of certain phytoplankton genera. For example, there are five genera of diatoms in all seasons sampled, at the same time the most abundant in both the lagoon and the river are: *Melosira, Hantzschia, Navicula, Nitzschia* and *Synedra*. In addition, other genera are also recurrent but with lower abundance values: *Cymbella, Oscillatoria, Microcystis* and *Ankistrodesmus*.

Also, it should be mentioned that the cyanobacteria and green algae described are common in water that have organic contamination and some as Ankistrodesmus can even cause contamination after their presence; considering this group as a natural pollutant capable of affecting the oxygen concentration (Belinger y Sigee, 2010; Likens, 2010).

In general, the results indicate that the ecosystem studied meets the necessary conditions to the existence of types and forms of diverse phytoplankton life, even after the oil spill of 2003, allowing in turn to develop other organisms of higher trophic levels (zooplankton, aquatic macro-invertebrates, amphibians, fish).

4 Conclusions

Due to the nature of the phytoplankton that is suspended in the water column, its dependence on the streams to move and its metabolism; these are considered organisms capable of absorbing heavy metals relatively quickly. This phenomenon may have occurred in Papallacta: a partial passive absorption by the phytoplankton of some dissolved hydrocarbons by exchanging ions directly into the cell wall.

Possibly the phytoplankton in Papallacta absorbed some hydrocarbons during the first days after the spill, the immediate repercussions may have been a rapid decrease of these organisms in the affected areas and changes in the metabolism.

However, when the crude oil went towards the bottom of the lagoon, the phytoplankton community would have recovered quite well and continued a regular development on the surface (up to five to six meters deep), having even come to obtain for 2012 a phytoplankton quality similar to that reported by Kannan (1979), prior to the oil spill.This is corroborated because several genera found in 1979, such as emphSynedra and *Melosira*, were already present in 2011 showing certain abundance; others like *Pinnularia* and *Nitzschia*, also described in that study, are still present. *Fragilaria* and *Amphora* are two genera found in 1979 and in the current research were not observed, so it is possible that they have disappeared as a result of the spill. Since the crude oil went to the bottom of the lagoon, there might be localized pollution by TPHs (total oil hydrocarbons). The same tendency can be observed in the affluent rivers, because the crude, due to the streams was deposited in the lagoon, which could help the riparian ecosystem recover faster (self-purification), towards 2011 there was practically no presence of crude there (at all points of the river TPH are between 0.3 mg/L to 0.26 mg/l).

In the case of local rivers, since there are no studies of phytoplankton communities prior to the spill, it is not possible to affirm which genera were present or their composition or dynamics decades ago; however, it could be speculated on a similar trend in the past on the composition and abundance of phytoplankton in affluent rivers: a recovery in recent years. This assertion is based on the fact that as the river feeds the lagoon, much of the lake phytoplankton arrives from its tributaries; and, although both ecosystems have different dynamics and phytoplankton may have different life forms, the same genera are present in both ecosystems.

The above statement is also consolidated due to the polymictic nature of the Papallacta lagoon (does not present thermal stratification for long periods and its water are mixed from the surface to the bottom) and because it is an open lake system (Terneus, 2002; Kannan, 2006; Roldán, 2008).

It should finally be mentioned that the photic area of the lagoon since 2012 has the conditions to shelter life despite the seasonal environmental changes and the oil spill that occurred. However, it would be advisable to monitor this water system every four or five years, and to observe in the long term its successional behavior.

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