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Diatom Morphology in Light of a Changing Climate: A Focus on Aulacoseira crenulata

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DIATOM MORPHOLOGY IN LIGHT OF A CHANGING CLIMATE: A FOCUS ON *AULACOSEIRA CRENULATA*

by

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DIATOM MORPHOLOGY IN LIGHT OF A CHANGING CLIMATE: A FOCUS ON *AULACOSEIRA CRENULATA*

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ABSTRACT: Fossilized diatoms are arguably the most vital proxy record utilized in paleolimnology. Diatoms are unicellular microalgae that are the basis of countless food webs, are invaluable bioindicators, and generate nearly a quarter of global net primary productivity. Diatoms are affected by a variety of environmental factors but there is relatively little research on how environmental conditions impact diatom valve morphology, and in particular whether there is a correlation between incoming light and diatom pore morphology. This report focuses on the Amazon lowland lake Garzacocha, and analyzes the relationship between light levels and the corresponding size of *Aulacoseira crenulata* pores. We hypothesize that if pore size of *Aulacoseira crenulata* was larger than the overall average pore size of 0.632 μm, sunlight was at lower levels. If pore size of *Aulacoseira crenulata* was smaller than 0.632 μm, sunlight was at higher levels. Our results suggest an indirect relationship between light availability and pore size of *Aulacoseira crenulata*. Future research on this relationship is needed, and efforts to identify the existence of this relationship in other diatom communities and geographic locations is suggested.

Keywords: Amazon lowlands, Aulacoseira crenulata, Aulacoseira granulata, Aulacoseira italica, diatom morphology, Ecuador, Garzacocha, paleoclimatology, paleolimnology, solar activity, sunspots

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INTRODUCTION

Paleoclimatology & Paleolimnology

Researching and reconstructing past climate conditions enhances our understanding of present climate and ensures accuracy for future climate projections. This research is referred to collectively as paleoclimatology. Proxy records, such as fossilized plankton, pollen, ice cores, tree rings, and sediment geochemistry are the foundation of paleoclimatology ("Paleoclimatology Datasets"). Analyzing proxy data provides insight to variability in biogeochemical cycles and aids in understanding historic conditions, such as sea or lake levels or atmospheric carbon dioxide concentrations. This knowledge is especially valuable in placing our current climate conditions in a broader context and is indispensable when creating emission regulations, planning for coastal communities, and focusing research efforts in hotspots, like coral reefs. Without climate reconstruction, there would be no knowledge of how Earth looked two thousand years ago or how Earth might look in six hundred years.

Specific disciplines exist within paleoclimatology and focus on the aforementioned proxy records. Paleolimnology is one such discipline and is the study of lake history and change within lake systems (Cohen 2003). Paleolimnology provides insight to long-term ecological conditions, timing of pollutant introductions, shifts in climate, and much more (Cohen 2003; Smol & Stoermer 2010). Arguably the most important approach to lake analyzation begins with sediment deposition (Cohen 2003). This is largely due to the lifespan of sediments; even if a lake system evaporates and disappears over time, the lake sediments remain to tell the history of the system (Cohen 2003).

The most widely-used method of obtaining sediments from lakes is sediment coring (Cohen 2003). Taking a sediment core allows for first-hand data collection. Sediment cores are also used in marine studies and

provide insight in the same disciplines as freshwater sediment cores, such as climate change patterns and

pollutant levels (Rothwell & Rack 2006). However, lakes are especially useful in measuring past environmental

fluctuations because they accumulate sediments relatively rapidly compared to oceans (Cohen 2003). Due to

their smaller size, lakes also respond more quickly to these external changes than oceans (Cohen 2003). The

combination of relatively rapid deposition and measurable shorter-term variations in lake systems makes

paleolimnology an indispensable avenue for collecting paleoclimate data.

Diatom taxonomy, ecology, and morphology

A vital component in sediment core samples are diatoms, unicellular organisms that are responsible for

much more than meets the eye. Many researchers toute diatoms as the most crucial proxy in paleolimnology,

and diatoms are among the most widely-used bioindicators (Cohen 2003; Pajunen et al. 2020; Smol & Stoermer

2010). Diatoms are members of the heterokont algae group and belong to the class Bacillariophyceae (Sims et

al. 2006). Diatoms evolved around 190-200 million years ago and have since become widely specialized and

incredibly diverse (Smol & Stoermer 2010). It is estimated that there are more than 10,000-100,000 species of

diatoms, although this estimate will likely change with future research (Mann & Droop 1996). Diatoms are

categorized into two distinct orders, the Centrales and the Pennales (Sims et al. 2006). The Centrales,

commonly called the centrics, are characterized by having valves form in radial orientation around a point,

rather than along a plane as in the Pennales (Sims et al. 2006; Smol & Stoermer 2010).

Diatoms are not only indispensable to paleolimnological studies but also to ecosystems in which they

reside (Smol & Stoermer 2010). Diatoms proliferate in nearly all aquatic habitats, and some species of diatoms

even live in or on moist soils, plants, and animals (Patrick 1978; Smol & Stoermer 2010). Diatoms are common

in aquatic systems of variable flow rates and volumes and have adapted to wide nutrient, pH, salinity, and

temperature gradients (Patrick 1978; Sims et al. 2006; Smol & Stoermer 2010). Globally, diatoms are highly

influential autotrophs and are responsible for around 20% of net primary productivity worldwide (Mann & Droop 1996). Diatoms are indispensable in providing both food and oxygen to aquatic food webs (Patrick 1978). Organisms such as fish, snails, oysters, and micro-crustaceans depend on the presence and abundance of diatoms for food (Patrick 1978).

Diatoms consist of two siliceous valves that are fused together, and pores dot the surfaces of these valves. These valves are held together by multiple siliceous bands, and together the valves and bands create what is known as a 'frustule' (Sims et al. 2006; Smol & Stoermer 2010). The siliceous nature of the cell walls allows for preservation in sediments, and this preservation is what makes diatoms so beneficial to paleolimnology (Smol & Stoermer 2010). The pores on the cell walls of diatoms vary in arrangement patterns, and can be vertically positioned or can follow a semi-diagonal pattern across the length of the valve. The arrangement of pores is speculated to influence their purpose (Losic et al. 2006). These pores, sometimes referred to as areolae, are openings that enable interactions and exchanges between the diatom and the surrounding aquatic habitat (Smol & Stoermer). Diatom pores also serve to sort alien particles, exclude bacteria and viruses, regulate nutrient intake, and possibly influence communication (Losic et al. 2006).

Study preamble

This study aims to evaluate the relationship between freshwater diatom pores and environmental conditions, specifically light levels. *Aulacoseira*, included in the order Centrales, is the genus chosen for this study (Sims et al. 2006). *Aulacoseira* was chosen because it was consistently abundant throughout multiple depths in the sediments of the study site selected for analysis (Garzacocha, Ecuador), which ensured the genus as a good indicator of change. The presence of *Aulacoseira* in Garzacocha was also documented in a study from 1985, in which *Aulacoseira granulata* (*A. granulata*), composed 50-99% of the entire Bacillariophyta community in Garzacocha (Colinvaux et al. 1985).

Previous studies have documented a relationship between pore size in *Aulacoseira* and light availability. *Aulacoseira* species with small pores were abundant in high light levels, and *Aulacoseira* species with large pores were abundant in low light levels (Kilham et al. 1986). Kilham and colleagues also suggested the possibility of pore size divergence within a population of a single species if members of the same species were exposed to variable light levels during growth stages (Kilham et al. 1986).

Another study globally analyzed the patterns between *A. granulata* and light abundance (Carbajo et al.) and suggested that temperature and geographic location did not alter *A. granulata* pore size, but that light availability did (Carbajo et al.). Carbajo and colleagues found that *A. granulata* had an inverse relationship between pore size and light levels, and they suggested that this relationship existed to protect the cell from UV radiation (Carbajo et al.).

In this research, I analyzed diatom pore size in the sediments of Garzacocha, a freshwater lake in the eastern Amazon lowlands of Ecuador (Figure 1). Garzacocha literally means heron lake, with "cocha" translating to "lake" from the Quechua language (Frost 1998). In Garzacocha, *Aulacoseira* species were most abundant in the photic zone along the lake perimeter, and a surface sediment sample taken at a depth of 2 meters was dominated by *Aulacoseira* species, including *Aulacoseira ambigua, Aulacoseira crenulata, Aulacoseira granulata var. angustissima*, and *Aulacoseira herzogii*. After analyzing the abundance of each species and the quality of pore preservation, *Aulacoseira crenulata (A. crenulata)* was chosen as the study species for this thesis. There are differing views on whether or not *A. crenulata* is synonymous with *Aulacoseira italica* or if it should be recognized as its own species (Crawford et al. 2011). For the purposes of this study, *A. crenulata* will be considered an independent species. It was hypothesized that if pore size of *A. crenulata* was higher than the calculated average pore size for the entire core, then light availability was

inferred to be lower. If pore size of *A. crenulata* was smaller than the calculated average, light availability was inferred to be higher.

This study provides necessary insight on the relatively undocumented relationship between light availability and diatom pore size. To my knowledge, *A. crenulata* has not been studied previously in this context. Additionally, research on *A.crenulata* is limited in comparison with other members of the *Aulacoseira* genus. Similarly, there has not been prior research dedicated to only the diatom communities of Garzacocha. This project will hopefully inspire future research on *A. crenulata*, Garzacocha, and how diatom morphology is affected by light availability.

METHODS

Site description

The Amazon lowlands of Ecuador lie east of the Andes and are located close to the equator (Miller et al. 1984; Steinitz-Kannan et al. 1983). In this region many lakes are oxbows and are formed by riverine processes, including Garzacocha (Miller et al. 1984). Garzacocha (N 0.583° latitude, E 76.333° longitude) has an area of 0.28 km^2 (Colinvaux et al. 1985). Its relatively small size suggests that it may be a good recorder of past environmental perturbations, as it will respond faster and more drastically to changes than larger lakes (Cohen 2003). This is especially useful for our particular study, as the core depth provided a time range of ~210 years BP/1740 AD (Table 1), a relatively brief analysis of time in paleolimnology.
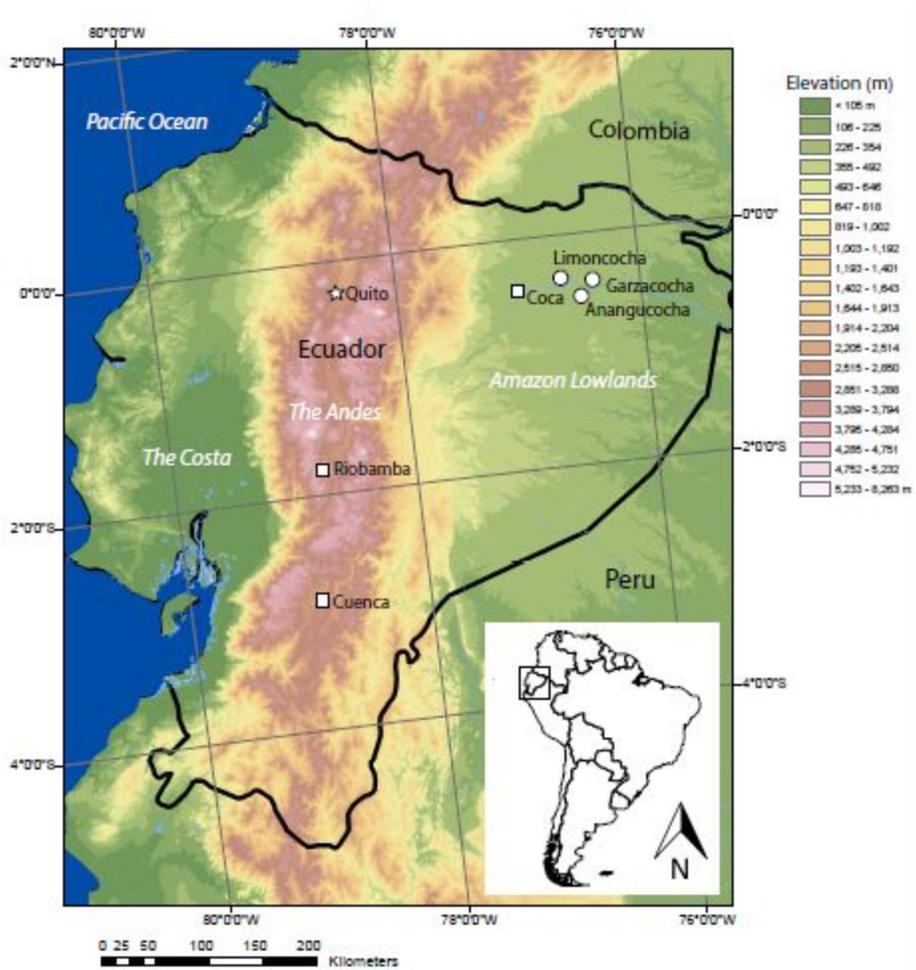
Figure 1: Location of Garzacocha in relation to Ecuadorian landscapes. All cities are indicated by squares apart from Quito, the capital city of Ecuador, which is distinguished with a star. Lakes are indicated by circles. The lakes Anañgucocha and Limoncocha are included on this map to provide context for theories described in this thesis. Adapted from Luethje 2020.

Garzacocha, like other small tropical lakes in Ecuador, is considered to be oligomictic, meaning it mixes very rarely (Steinitz-Kannan et al. 1983). Garzacocha is also identified as an Amazonian blackwater lake. Amazonian blackwater systems appear brown or red-brown in colour, which is partially resultant from high levels of dissolved organic matter (Frost 1998). Garzacocha lies at an elevation of 300 meters, and limnological analyses from several decades ago indicated an alkalinity of 0.40 meq, surface temperature of 26.1°C, and maximum depth of 2.3 meters (Miller et al. 1984). Another study from the same period reported a pH of 7.4, a

surface temperature of 28° C, a secchi depth of 75 cm (indicating light penetrated 75 cm from the lake surface), and silica values of 21.10 Si^{4-} mgl^{-1} (Colinvaux et al. 1985). These values are fairly similar to measurements made as part of this study in July 2017, in which there was a water depth of 2.0 meters, surface temperature of 31°C, secchi depth of 80 cm, and total nitrogen of 0.581 mg/L (indicating Garzacocha is a lower nutrient lake). In addition, diatom communities at Garzacocha consisted mainly of planktic species, such as *A. granulata*, *A. granulata* var *angustissima*, *Discostella stelligera*, *Fragilaria tenera,* as well as benthic members of the genus *Eunotia*.

Field work methodology

Field work for the samples used in this study was carried out in July 2017. Temperature and conductivity were measured with a YSI microprobe. Secchi transparency, a measurement of water clarity, was obtained using a Secchi disc. A water sample was taken from the lake surface to characterize the modern lake chemistry. This sample was stored in a 20 ml plastic bottle and was sent to the University of Nebraska-Lincoln Water Sciences Lab to test for major cations, anions, and nutrient concentrations. Sediment samples were collected using a UWITEC gravity corer near the center of Garzacocha. The length of the sediment core was 51 centimeters, with the first centimeter being the mud-water interface. The sediment was removed from the corer in the field, sectioned into one centimeter thick samples, and transported to the University of Nebraska-Lincoln Earth and Atmospheric Sciences Paleolimnology Lab for analysis.

Laboratory methodology

Sediment samples were kept in individual, resealable bags and were stored in a laboratory refrigerator. To begin the process of converting the sediment samples to slides for diatom analysis, the sediment was weighed to ~0.1 grams wet weight in vials (51 vials total) and then freeze dried. After drying, the new dry weight was recorded. Next, a combination of 20 ml H_2O_2 (hydrogen peroxide) and 20 ml distilled water were

added to each individual vial to remove organic matter from each sample (Battarbee et al., 2001; Blanco et al., 2008; Smol & Stoermer 2010). The vials were left to react in this mixture for several days. Once the organic matter was removed, the samples were mounted on slides. To begin this mounting process, slides were labelled for each depth, and a cover slip was placed on each slide. Diatoms were then suspended in the diluted water by shaking the vials. A 1 ml pipette was used to obtain the suspended sample, and 0.5 ml of the sample was placed on the corresponding cover slip. The cover slip and slide were then placed on a countertop hot plate to expedite the drying process (Smol and Stoermer 2010).

Once the diatom samples were dry, the hot plate in the fume hood was heated to ~130 °C. A Naphrax mounting medium with toluene was used to permanently mount the coverslip onto the slide (De Olivera 1992; Smol and Stoermer 2010). The Naphrax was spread onto the side of the cover slip that contained the diatom sample and then covered in a thin layer of Naphrax. The cover slip was then placed diatom and Naphrax side down onto the slide, and the Naphrax was heated until it was no longer rapidly bubbling, which took approximately 15 minutes. This entire process was repeated for each individual slide. The slides were then left to properly cool and were stored in a well-labeled slide box for future analysis. In this way, 51 slides were created and represented depths from 1 to 51 centimeters.

Data collection and analysis

After properly mounting all 51 slides, the next step was to decide which diatom species would be used for the study. The main requirement for identifying a suitable species to analyze changes in pore size through time was to find a species that was abundant throughout multiple depths of the core, with at least ~30 individuals per slide to ensure a suitable population size for statistical analysis . The number of individuals was based on the Central Limit Theorem, which indicates a sample size of 30 is representative of a normally distributed population ("The Role of Probability 2016).

It was hypothesized that *Aulacoseira* would be a suitable study genus, as previous analyses by lab members indicated high numbers of *Aulacoseira* throughout Garzacocha core samples, and because prior studies (Kilham et al. 1986) had focused on this genus. After reviewing the slides using a Zeiss microscope, *A. crenulata* was chosen as the study species for this research. *A. crenulata* declined in numbers after 37 cm, and the slides below that depth were not used in this study. Slide 34 was omitted, as there were insufficient numbers of *A. crenulata* in the depth sample. *A. crenulata* was the most constant species throughout the core sequence, even though it was absent in deeper sediment samples. Thus, *A. crenulata* was determined to be the best bioindicator for this study.

The next step in data collection was to use a microscope camera to photograph at least 30 individual *A. crenulata* in each slide. To limit repeated photographing of the same diatom valve, each slide was viewed methodically in vertical lines. Once photos had been taken, I measured the pores on both the top and bottom valves of *A. crenulata*. On each individual *A. crenulata*, I made at least 10 pore measurements for each valve, resulting in at least 20 pore measurements per frustule. Given the natural variability of diatom morphology, this number of measurements was occasionally slightly lower, but this was rare and avoided. Measurements of pore diameter in micrometers were taken using measurement software through the camera application. After measurements were catalogued, the photos were saved into organized folders for future access and reference. This process was similar to that used by Carbajo and colleagues, however our study utilized electronic images, whereas the Carbajo et al. study measured pores on printed photographs (Carbajo et al.).

Measuring 30 frustules in each slide yielded approximately 600 pore measurements for each depth. Mean pore size was first calculated for each individual frustule. This resulted in one average pore size for all 30 frustules. These 30 average pore sizes were then used to calculate total average pore size for each sample depth. This process was repeated for all 36 slides. These 36 data points were then plotted against core depth (cm) in

order to visualize whether or not there were trends in *A. crenulata* pore sizes, and if there were, whether or not light availability to the lake correlated with these trends.

RESULTS

Several trends are apparent in the data. Average pore size remained fairly consistent from depths of ~9 cm to 37 cm, varying around the mean pore size of 0.632 μm, with the exception of several outliers (15, 21, 24, 32 cm) (Figure 2). From 8 -1 cm, there was a clear decrease in average pore size, except for the peak at 4 cm.
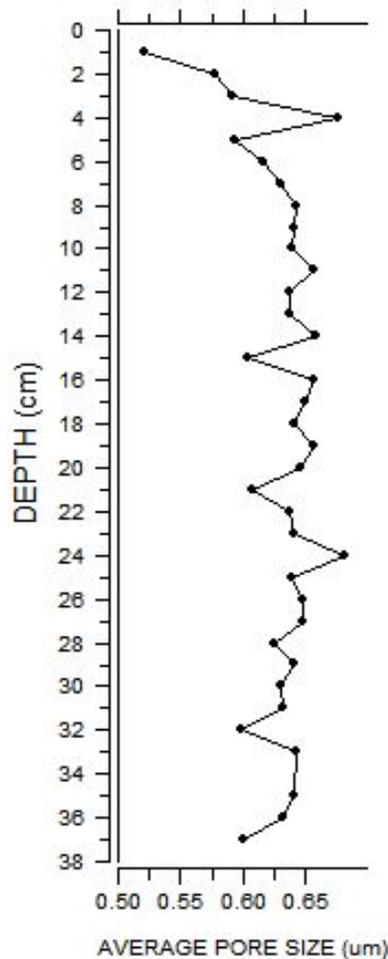

Figure 2: Graph displaying the relationship between depth (cm) and average pore size (μm) in *A. crenulata..*

To approximate age associated with lake depth in the absence of direct radiometric dating, several

Amazonian fossilized pollen records nearby Garzacocha were cross referenced with the lake sediment data from

this study. These included: (1) Añangucocha, where 112-118 cm was dated at 830 +/- 160 calibrated years BP

(Frost 1988); (2) Limoncocha, where 160-173 cm was dated at 755 +/- 135 calibrated years BP (Colinvaux et al.

1985). All three lakes occur adjacent to Rio Napo and were thought to have been formed by flooding events,

which alter the landscape and create new bodies of water (Frost 1988; Colinvaux et al. 1985). The lakes in this

area likely originated around the same time due to the same flooding event of Rio Napo, or at least are affected

by the same flooding events (Figure 1). Due to the similarities in origin and limnological characteristics, I

judged Añangucocha and Limoncocha to be reasonable analogs for Garzacocha. To estimate the age of our

sediment samples (depth of 37 cm), the following calculations were completed.

Amazon basin lake	Average depth (cm)	Average age (cal. yr. BP)	Average age (yr. AD)
Anañgucocha	115	830	1120
Limoncocha	166.5	755	1195
Garzacocha	37	210	1740

Table 1: Age approximation for Garzacocha based on surrounding Amazon basin lakes. Includes both calibrated years BP and years AD. Approximations for Garzacocha ages can be found below this table.

To estimate sediment age at 37 cm in Garzacocha, I used two separate methods to ensure accurate

results. Years are reported in both calibrated years BP (before 1950) and years AD so as to appeal to a wider

audience. **Method 1**: I calculated the mean sediment accumulation rate (cm/yr) for Anañgucocha (115 cm/830

yr) and Limoncocha (166.5 cm/755 yr). This yielded a rate of 0.1386 cm/cal. yr. BP for Anañgucocha and 0.2205 cm/cal. yr. BP for Limoncocha. I averaged the two sediment accumulation rates to obtain one rate of 0.1796, which I then applied to Garzacocha. This method yielded an age of 206 cal. yr. BP / 1743 yr. AD for Garzacocha at 37 cm. **Method 2:** I applied the calculated sediment accumulation rates for Anañgucocha and Limoncocha from Method 1 separately to Garzacocha. The result of Anañgucocha and Garzacocha was 267 cal. yr. BP and the result of Limoncocha and Garzacocha was 167.8 cal. yr. BP. I then found the mean of these two years, which was 217.4 cal. yr. BP / 1733 yr. AD.

Given that both methods of age estimations for Garzacocha were comparable, it was determined that the sample depth of 37 cm is indicative of ~210 calibrated years BP / 1740 years AD. Using these same methods would also suggest that the change in average *A. crenulata* pore size begins ~44.5 calibrated years BP. However, sedimentation rates alter with time in lakes, even if they are geographically close. The sedimentation rate of Garzacocha was not analyzed in this study but should be considered in future analysis of the relationship between sunlight and pore sizes. The current age approximation is still deemed to be reasonable , but it is merely an estimation.

DISCUSSION

Trends in A. crenulata pore size

Previous studies have noted that freshwater *A. granulata* colonies with large pore sizes occur with higher frequency in regions of low light (Kilham et al. 1986), which suggests that historic mixing and nutrient conditions could be hypothesized based on *A. granulata* morphology (Kilham et al. 1986). Our research suggests that *A. crenulata* pore size does vary with depth, which suggests the morphology of *A. crenulata* is being altered as a result of an environmental control.

A shift from larger to smaller pore size in *A. crenulata* is clearly visible in our data set. This could be due to a change in turbidity of Garzacocha, or a fluctuation in nutrients. Garzacocha is not a eutrophic lake, and given the relatively low nutrient concentrations this hypothesis is rather unlikely. Nutrient alteration could have occurred from variable canopy cover in the surrounding watershed, as *A. crenulata* prefers benthic nearshore regions of the lake. Canopy cover could be altered by urbanization, although human encroachment is somewhat limited near Garzacocha.

I hypothesized that the touristic lodge La Selva, the closest development to Garzacocha, and the tourism the lodge promotes might have influenced lake chemistry and biology. La Selva is on the bank of Garzacocha and advertises the eco-consciousness of their business ("Ecuadorian Amazon Rainforest Jungle Lodge"). Even so, tourism and development can have unintended impacts on ecosystems (Cohen 1978). I thought if La Selva caused an influx of algal biomass there would be a decrease in light availability in Garzacocha. However, I found that the trend towards smaller pore sizes in *A. crenulata* did not coincide with the creation of La Selva, as the lodge was opened in 2002 (Figure 2). As these hypotheses were not significant, I then approached alternate theories of light availability influencing diatom pore morphology..

Based on the hypothesis that *A. crenulata* pore size reflects light availability, the smaller pore size in the uppermost sediments suggests a reduction in light availability occurred ~44 years BP (Figure 2). I hypothesized that solar activity influenced light availability. Solar activity generally follows 11 year cycles (Hathaway 2015) which are characterized in part by sunspot occurrences (Hathaway 2015; Figure 3, Figure 4). It should be stated that solar activity and sunspots have a relatively minor impact on Earth's climate, but that to some extent there are documented connections between the two (Clette et al. 2014; Hathaway 2015).

Here I show sunspot number (SN) and the group number (GN) as calculated by Clettee et al. (2014), who have studied historic sunspot variation (Figure 3). The sunspot data suggest increased sunspot activity

during the 20th century that somewhat aligns with trends in Garzacocha. In addition, a high documentation of

sunspot occurrences near 1950 could partially suggest a reasoning behind the sharp increase in average *A.*

crenulata pore size in recent years (Figure 4). If the sunspot data and age estimations of Garzacocha can be

regarded with relative confidence, there is a relationship between historic sunspot activity and *A. crenulata* pore

size. Until further studies are completed, this conjecture will serve as a tentative explanation of light availability
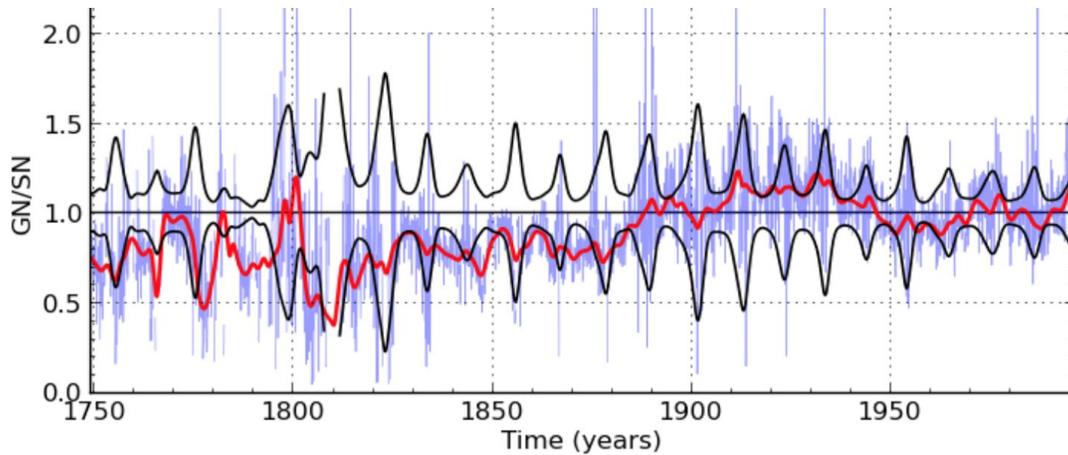
and diatom pore size correlation.

Figure 3: Graph obtained from Clette et al. 2014 in "Revisiting the Sunspot Number: A 400-Year Perspective on the Solar Cycle".
This graph depicts a ratio of the sunspot number (SN) and the group number (GN) in blue (Clette et al. 2014). The red line is a
smoothed version of this SN/GN ratio, and confidence intervals are depicted in black (Clette et al. 2014). The SN/GN ratio
significantly deviates prior to 1880 (Clette et al. 2014). The GN is an adaptation of the SN using supplemental observations and
current knowledge of sunspot occurrence (Clette et al. 2014). Both have been presented, as there are still uncertainties in both the SN
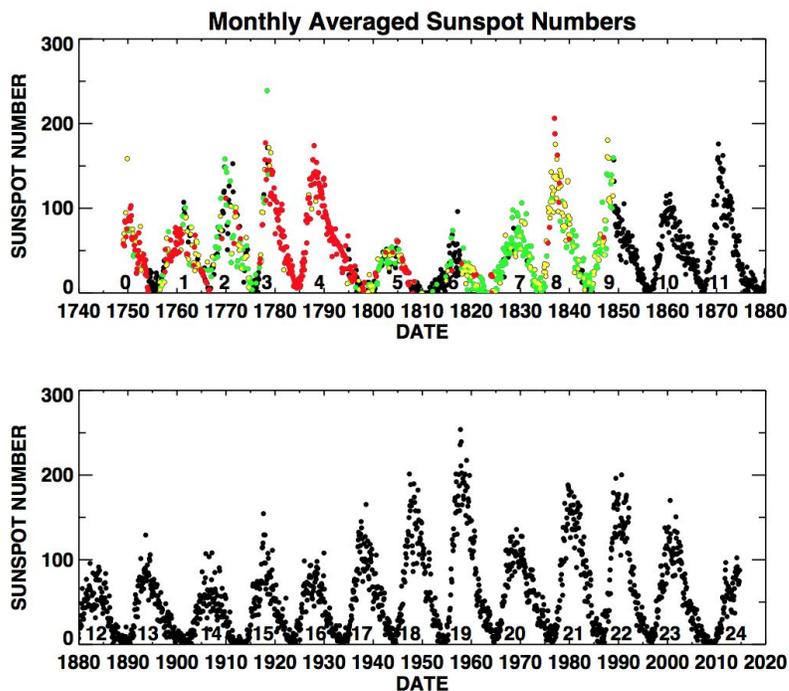and the GN (Clette et al. 2014).

Figure 4: This graph detailing the solar cycle was obtained from Hathaway 2015. Black indicates months that have observation each day, green indicates months that have 1-10 missing days of observation, yellow indicates months that have 11-20 missing days of observation, and red indicates months that have more than 20 missing days of observation (Hathaway 2015). The missing days of observation were acquired from the International daily sunspot numbers and the Group Sunspot Numbers (Hathaway 2015). In contrast, Figure 3 averages sunspot numbers with group numbers. Additionally, Figure 3 uses 50 year increments. When attempting to determine if sunspot numbers affected outliers in our data set, the 10 year incriminate of Figure 4 was especially useful.

The observed absence of *A. crenulata* from 38 -51 cm is indicative of change in the early history of Garzacocha. Variations in alkalinity, organic matter content, and/or dissolved carbon could impact the light available to A. crenulata or impact it directly. I hypothesized that the drastic change in *A. crenulata* abundance could be due to a shift in alkalinity levels or light availability that occurred prior to ~210 calibrated years BP. Using the same approach to age estimation used above, the age of the sediment sample at 51 cm would be ~284 calibrated years BP / ~1666 years AD. This is especially interesting to note, as there is a documented interruption in the sunspot cycle between 1645 AD and 1715 AD (Eddy 1976; Hathaway 2015; Maunder 1890; Figure 5). This interruption is referred to as the Maunder Minimum (Hathaway 2015). Additional research is

suggested to further analyze the possible alignment of the Maunder Minimum and the lack of *A. crenulata*, a photophilic species, as well as to determine other sources of variation in light availability.
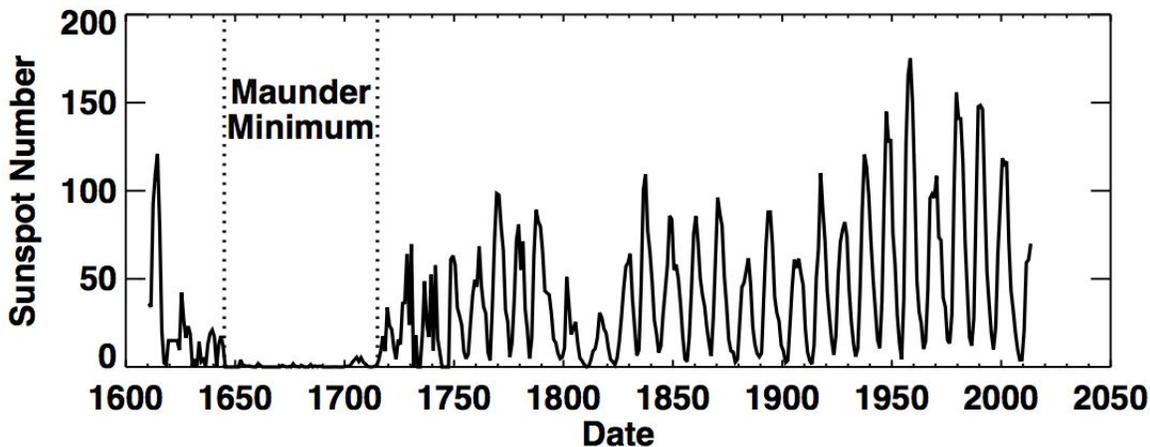

Figure 5: This graph is obtained from Hathaway 2015. The Maunder Minimum offers a possible explanation for the notable absence of *A. crenulata* between depths of 38-51 cm, or ~1738 AD to ~1666 AD.

The possibility of error in our results could stem from misidentification of the study species or incorrect measurements of pore sizes. *Aulacoseira* individuals are highly variable, and, as previously mentioned, the identification of *A. crenulata* is still debated. Misidentification was limited as much as possible by having only one individual identify the species. As for the possibility of incorrect measurements, error was limited by having only one individual measure pores, by using the same program to measure the pores, and by using the same method to record measurements for future analysis. Measurement error was assessed by determining the standard deviation of depth 1-37 cm to be 0.029, thus measurement error was not a concern.

The future of bacillariophyta

The most diverse biomes on earth are tropical rainforests, and yet these biomes are becoming more fragmented and endangered at accelerated rates each year (De Oliveira 1992). Wide gaps of knowledge in biodiversity and quickly dwindling study area in tropical rainforests has heralded an almost frantic age of

research in the Amazon (De Olivera 1992). However, this research is still relatively sparse in comparison to paleolimnological studies at higher latitudes (Escobar et al. 2020). The Amazon lowlands are affected by repeated aquatic variation and stress (Colinvaux et al. 1985). Understanding additional relationships between diatoms and environmental conditions will further our understanding of historic Amazon lowland conditions. Indeed, further research on how environmental conditions affect diatom morphology is vital to the future of paleolimnology (Kilham et al. 1986).

Diatoms are not immune to the endangerment humans inflict upon multicellular organisms of the world. Climate change and anthropogenic impacts influence aquatic ecosystems on a global scale (Pajunen et al. 2020), and there are documentations of local diatom extinction likely due to human activities (Mann & Droop 1996). Additionally, pollutants cause reverberating ecological effects and can alter algal community composition (Patrick 1978). Extinction and community modification not only alters diatom and aquatic ecosystems, but also will alter how we interpret paleolimnological data. There is still much to be discovered about Amazonian diatoms, the history they hold, and their ever unfolding relationship with the environment. Our research will hopefully be one of many future analyses of the correlation between diatom pore size and light availability.

CONCLUSION

Without diatoms, little would be known about the past climatic constraints of ecosystems. Fewer predictions would be made about future environmental changes, and the knowledge of aquatic ecosystems would be rudimentary. Knowing more about how diatoms are impacted by environmental conditions will expand our ability to make future predictions and understand the historic relationship between diatoms and climate. This study suggests the existence of an inverse relationship between sunlight availability and *A.*

crenulata pore size. Future research is suggested for this relationship and for supplemental diatom morphology analysis.

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