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ORIGINAL PAPER

Identification and Quantification of Bioaerosols in a Tropical Coastal Region: Cartagena de Indias, Colombia

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Abstract
Bioaerosols are particles of living or dead biological material released into the atmosphere from the biosphere that play a vital role in ecosystem dynamics, and they affect agriculture, climate and human health. Scientific data about concentrations and identification of fungal spores, airborne bacteria, pollen and other primary biological particles are insufficient, especially in coastal regions. Therefore, the objective of this study was to identify and quantify fungi and bacteria concentrations on one beach of Cartagena de Indias, Colombia. Over a period of 4 months, 300 fungi and bacteria samples were collected using a cascade impactor. The results show that the fungal concentration was 176 ± 44 CFU/m^3, and *Aspergillus sp.* was the most common fungus in the air. In comparison, the bacterial concentration was 146 ± 38 CFU/m^3, with a higher presence of *Staphylococcus aureus*. It was found that some bioaerosols were pathogenic, and others had bioremediation potential. In addition, this study addresses the relevance of meteorological factors in controlling the fungi and bacteria concentrations finding a significant linear correlation between wind speed and bioaerosol concentrations, explained by a strong land–sea breeze circulation in tropical areas.

Keywords Fungi · Bacteria · Biological aerosols · Beach · Tropic

1 Introduction

Bioaerosols, also known as primary biological aerosols (PBAs), are particles of biological origin and large molecules that transport living or dead microorganisms (e.g., viruses, fungi, bacteria, pollen and metabolic products). Bioaerosols range in size from 0.1 to 100 µm (Hurtado et al. 2014), and their emission sources can be humans, animals, water and plants (Heo et al. 2014).

Bioaerosols represent approximately 30% of the aerosols in urban and rural air (Fröhlich-Nowoisky et al. 2016), and they play a significant role in the hydrological cycle of the planet; thus, they influence the global climate. In marine environments, bioaerosols contribute substantially to the ice nuclei abundance and cloud condensation nuclei (Fröhlich-Nowoisky et al. 2016; Heo et al. 2014; Sun and Ariya 2006). PBAs are central elements of ecosystems because they can be units of reproduction for plants and microorganisms, and therefore, biological aerosols affect agriculture and human health (Fröhlich-Nowoisky et al. 2016). Researchers have suggested that bioaerosols can be etiological agents related to respiratory diseases, such as asthma and rhinitis, and in particular, bacteria transported in bioaerosols are connected to pneumonia, tuberculosis and brucellosis (Heo et al. 2014).

Currently, the identity, diversity and abundance of several types of bioaerosols are not well known, and there is insufficient information about their spatial and temporal distribution (Fröhlich-Nowoisky et al. 2016). This lack of knowledge stems from absence of studies that examine the concentrations and identity of microorganisms in the air. Overall, studies are primarily focused on determining bioaerosol concentrations in indoor environments, such as hospitals and buildings (Maldonado-Vega et al. 2014; Norhidayah et al. 2013), or in outdoor environments,

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such as cities (García-Mena et al. 2016), landfills (Agarwal et al. 2016; Vélez-Pereira et al. 2010) or composting facilities (O'Connor et al. 2015; Wéry 2014). However, there have been few studies conducted in coastal regions (Hurtado et al. 2014; Li et al. 2011), particularly in areas close to the equator line. This location has unique meteorological conditions, such as high solar radiation, salinity and humidity due to the closeness to the ocean; these conditions imply a hostile atmosphere that affects the viability of PBAs. Simultaneously, these conditions become special environments to identify microorganisms that can be used in bioremediation processes due to their capacity to resist adverse conditions. Identification of bioaerosols can guide to recognize possible emission sources which can be helpful to design effective control measurements.

Identifying and quantifying bioaerosols in coastal regions have a significant impact on tourism legislation and regulation. In the framework of sustainable development, tourism beaches have to protect their natural resources and promote an adequate environment for stakeholder groups. Most of the environment tourism regulation considers water quality standards but they do not include air quality standards related to bioaerosols to protect the health of tourist. Therefore, monitoring bioaerosols in coastal regions can contribute not only in a technical level such as bioremediation processes and emission sources recognition, but also it can provide useful data to reinforce tourist legislation. In this regard, the objective of the present study was to identify and quantify fungi and bacteria concentrations present on one beach of Cartagena de Indias, Colombia, a city declared a World Historical Heritage site. The analysis included a multiple linear regression model to assess the relationship between meteorological conditions and microorganism concentrations. This is the first bioaerosol study developed in Cartagena de Indias.

2 Methodology

This section describes the place selected to carry out the measurement campaign, the equipment and laboratory tests conducted to identify and quantify fungi and bacteria bioaerosols. Likewise, the statistical tools used to associate bioaerosol concentrations and meteorological variables are explained.

2.1 Measurement Site

Cartagena de Indias is a city located on the northern coast of Colombia on the Caribbean Sea, and it is the most important tourist destination in the country. Due to its geographical location, the city has two climate periods and one transition period. The dry period covers the months between December and April, and the wet period spans from August to November. Finally, the transition period begins in May and finishes in July (CIOH 2017).

Blas del Teso beach was selected to carry out the measurement campaign. This beach is located in the northern part of Cartagena de Indias (10°27′N, 75°30′W), and it is close (approx. 180 m) to one of the city's main access roads, as can be observed in Fig. 1. A hydraulic structure is located approx. 650 m from the beach and is responsible to stabilize tides and connect and oxygenate the swamp. Blas del Teso is located in one of the city's hotel sectors; hence, it is frequently visited by tourists, and the number of visitors increases on weekends. Due to these circumstances, it is possible to find tourism services that make use of jet skis off

Fig. 1 Measurement site for the bioaerosol campaign in Cartagena de Indias, Colombia. Modified from Google maps

the beach, and the presence of vehicles is allowed. Furthermore, this beach has enough land space (more than 200 m) without any construction that can interfere in the monitoring of bioaerosol and meteorological variables.

2.2 Monitoring Campaign

A two-stage viable Andersen cascade impactor was set up during the measurement campaign. The device is factory designed in two stages selecting respirable and non-respirable particles. The first stage collected particles with diameters equal to or greater than 7 µm, and the second stage collected particles with a diameter between 0.6 µm and 1.1 µm, corresponding to sizes that can get into the pulmonary alveolus (the two-stage impactor has the first and sixth stage of a six-stage cascade impactor). The impactor was installed, using a tripod, at 1.5 m height, which corresponds to the typical human breathing height. The sampling device was located halfway between the seashore and the main avenue close to the Blas del Teso beach (see Fig. 1). To minimize the risk of sample contamination, masks were used while the monitoring was conducted. The flow rate was 28.3 L/min and samples were collected in the morning from 9:00 to 10:00 h and in the afternoon from 14:00 to 15:00 h.

Prior to the measurement period, a pre-sampling test was conducted to identify the appropriate time to collect the samples, according to the following criteria: (1) the time was sufficient to identify the growth of microorganisms in the laboratory; and (2) there was no overlap of microorganisms in the Petri dishes that interfered with their identification. We found the optimal sampling time for bacteria and fungi was 10 min and 5 min, respectively, during April–July of 2017. Each sample was performed in triplicate, and a total of 300 samples were collected, including 156 for fungi and 144 for bacteria. The difference between the number of fungi and bacteria samples was because in 2 days bacteria samples could not be collected. Meteorological variables (solar radiation, wind speed, wind direction, temperature, and humidity) were monitored in situ with a portable meteorological station followed WMO (2008) recommendations. Meteorological data were recorded each 5 min and later averaged during the sampling period.

Prior to each sampling, the impactor was sterilized, and Petri dishes were prepared with culture media. Luria-Bertani (LB) and Sabouraud Agar were used as growth media for bacteria and fungi, respectively, and for bacteria, the LB agar was prepared according to the procedure defined in Acevedo et al. (2016).

2.3 Quantification and Identification of Bioaerosols

The traditional culture methods (TCM) are reliable procedures for microorganism identification, widely used in the field of bioaerosols (Coccia et al. 2010; Flores et al. 2007; Olaya and Perez 2006; Wang et al. 2015). These methods use microscopy and biochemical tests to identify genus and specie of airborne microorganisms. The TCM can only detect culturable and viable bioaerosols that have been previously reported in the literature. Therefore, the use of TCM is recommended when there is a low diversity of PBAs that avoid the overlap of several species on the Petri dishes, and when the purpose of the study does not include the identification of new species. For these reasons, molecular methods, which identify a specific DNA sequence, are also applied for bioaerosols identification (Yoo et al. 2017).

In this study, the TCM were applied. Bacteria samples were incubated at 37 °C for a period of 48 h, and then, we proceeded to quantify colony forming units (CFU) per m^3 of air. Subsequently, each colony was separated by the streak plate method. The Gram stain technique was applied to classify bacteria making use of a microscope (Olympus BX41) and applying the taxonomic key suggested by Vos et al. (2009) and Koneman (2008). Genus and species were determined by catalase and oxidase biochemical tests and the identification test BBL Crystal™ Kit ID (Mohammed et al. 2011; Moll et al. 1996).

Fungal samples were grown for 5 days at ambient temperature (25 °C), and then, each colony was quantified in CFU per m^3 of air. A macroscopic identification was made to determine the fungi genus using morphological and physiological specifications based on color, texture, structure and shape that were compared to the Koneman (2008) classification. Methylene blue staining was applied to identify specific parts of the fungi such as hyphae, conidiophores and ascospores under a microscope. These structures were compared to Vos et al. (2009) for their final identification.

2.4 Statistical Analysis of Samples

To compare fungi and bacteria results, 95% confidence intervals were calculated for the overall samples. Comparisons were applied between the morning and afternoon, collected during the week and weekend, and for particle size (stage one and stage two).

Due to each measurement of bioaerosol concentrations and meteorological variables are normally distributed and they are independent one of each other, Pearson correlation coefficient (r) was calculated to measure the linear correlation between meteorological variables and bioaerosol concentrations. Furthermore, a multiple regression linear model (MRLM) was implemented to identify the influence of meteorological parameters in bioaerosol concentrations. MRLM was applied in three scenarios of time, including (1) the total monitoring campaign, (2) morning and (3) afternoon. This model was evaluated through use of a determination

coefficient (R^2). The statistical analysis was conducted using R software version 3.3.3.

3 Results

3.1 Fungi and Bacteria Concentrations

The average concentration of fungi and bacteria was 176 ± 44 CFU/m^3 and 146 ± 38 CFU/m^3, respectively, during the 4 months of sampling. This result indicates, with 95% confidence, that fungal and bacterial average concentrations are not significantly different. However, when bioaerosols concentrations are disaggregated by weekend and weekdays and the morning and the afternoon, it is possible to observe a difference between fungi and bacteria concentration related with diverse emission sources and the influence of meteorological conditions (see Sect. 3.3). Due to these mixed effects the overall fungi and bacteria concentrations are not statistically different. Table 1 shows studies that have previously reported the concentration of bioaerosols in coastal regions; a literature search found very few studies conducted in these types of areas. It is observed that concentrations found in this study are lower than concentrations reported in Mexico and China. These studies also used a cascade impactor to collected bioaerosol samples, then concentration differences are not associated to collection method. The sampling period was longer in Mexico and China respect to our study, it can be the cause of the concentration differences. On the other hand, concentrations report in our study are greater than concentrations report in Venezuela, in this case they use passive air settle plate monitoring that can be the cause of the difference.

Currently, there is no outdoor air quality standard for bioaerosols. INSHT (1996) indicates that it is not possible to have exposure limits because (1) bioaerosols are a complex set of multiple dead and/or living microorganisms, (2) the degree of affection of bioaerosols on humans depends on each person's susceptibility factors, and (3) measured concentrations of culturable and viable bioaerosols depend on the sampling method. However, there is an indoor air quality standard for non-industrial environments published by the European Commission (Wanner et al. 1993); they classify fungal concentration levels from very low (< 50 CFU/m^3) to very high (> 2000 CFU/m^3). Our results are within the intermediate level (100–500 CFU/m^3), closer to the lower limit.

When bioaerosol concentrations were compared between weekdays and the weekend, it was found that the average fungal concentration for the weekend was higher (219 ± 63 CFU/m^3) than for weekdays (85 ± 33 CFU/m^3). This result can be explained because there are more tourists on the beach during weekends, leading an increase in private and recreational vehicles; in other words, there are more bioaerosol emission sources. On the other hand, the average bacteria concentration did not show a statistical difference between the weekend (125 ± 43 CFU/m^3) and weekdays (194 ± 79 CFU/m^3). This difference between fungi and bacteria concentration might confirm that probably the main emission source of bacteria is not related with human activities on this coastal region. The literature reports (Cunliffe et al. 2013; Marks et al. 2001; Zhang et al. 2017) that bursting bubbles can eject bioaerosols into the air of the sea surface microlayer and in combination with the air masses, bacteria can be transported over long distances. This could be one of the major sources of bacteria on Blas del Teso beach considering that the predominant wind direction came always from the sea, during the sampling period.

The average fungal concentration was higher in the morning (268 ± 81 CFU/m^3) than in the afternoon (88 ± 26 CFU/m^3). However, bacteria concentrations are not significantly different in the morning (130 ± 36 CFU/m^3) and (169 ± 80 CFU/m^3) in the afternoon. These differences can be influenced by local meteorological phenomena which impact the bioaerosols viability. Section 3.3 explains and explores the relationships between meteorological parameters and bioaerosols concentrations, analyzing the typical meteorology in tropical coastal regions.

Figure 2 shows daily fungal and bacterial concentrations during the period of sampling. The figure shows that during the first days of April and June, fungal concentrations increased in the mornings, particularly in stage two, which means particle sizes between 0.6 µm and 1.1 µm. These

Table 1 Bacteria and fungi concentrations reported in coastal regions

City, Country	Year	Microorganism	Range or arithmetic average (CFU/m^3)	Reference
Tijuana, Mexico	2010–2013	Bacteria	340	Hurtado et al. (2014)
Puerto de la Vela, Venezuela	2013	Bacteria	69	Araujo et al. (2013)
		Fungi	5	
Qingdao, China	2009–2010	Bacteria	63–815	Li et al. (2011)
		Fungi	33–664	
Cartagena de Indias, Colombia	2017	Bacteria	146 ± 38	This study
		Fungi	176 ± 44	

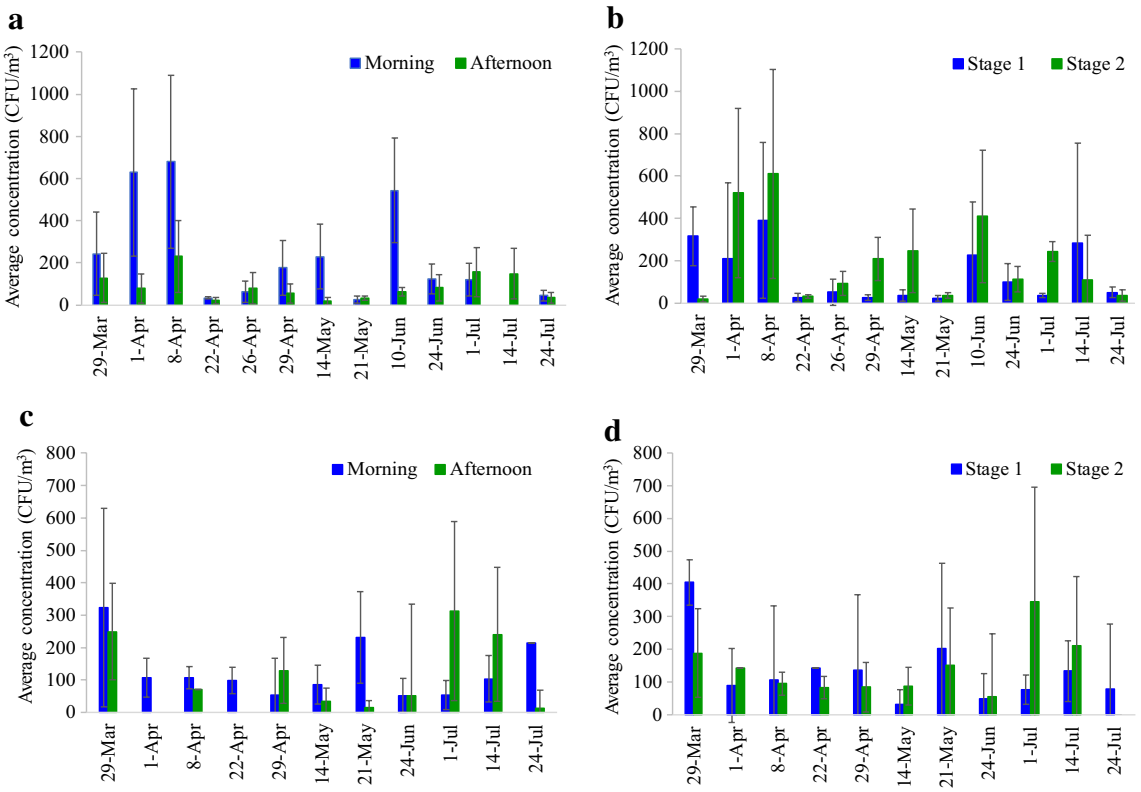

Fig. 2 Daily average concentrations of bioaerosols at Blas el Teso beach in Cartagena de Indias. **a** Fungi concentrations classified by time, **b** fungi concentrations classified by size particle, **c** bacteria concentrations classified by time, and **d** bacteria concentrations classified by size particle. Bars represent a 90% confidence interval

dates correspond to holy week and summer vacations, when there is an increase in the number of visitors. This tendency is not clearly identified in bacteria concentrations.

On average, the stage two collected higher fungi concentrations (122 ± 40 CFU/m^3) than the stage one (50 ± 23 CFU/m^3) in the afternoon. Similar results were found in bacteria concentrations (250 ± 147 CFU/m^3 stage two and 83 ± 63 CFU/m^3 stage one). These results indicate that during the afternoon the bioaerosol diameters are lower than in the morning, probably because high wind speed created a force that unattached fungi and bacteria of inert particles. One implication of this founding is that tourists are more exposed to fine particles during the afternoon compared to the morning, which go deeper in the respiratory system reaching the alveolar duct.

3.2 Fungi and Bacteria Identification

We found a total of 9 fungal species and 15 bacterial species. Figure 3 shows the microscopic identification of fungi and bacteria. Figure 4a presents the fungi and bacteria frequency of occurrence during the monitoring campaign. *Aspergillus sp.* was the most frequent fungus (32%), followed by *Mucor sp.* (29%) and *Aspergillus flavus* (23%). The presence of the *Aspergillus* genus was expected because it is ubiquitous, and in particular, the *flavus* species has been found in tropical countries (Hedayati et al. 2007). Araujo et al. (2013) reported that *A. flavus* is a common species found in air and water with possible bioremediation properties and Hedayati et al. (2007) mentioned that if this species is inhaled, it is located mainly in the upper respiratory system.

On the other hand, *Mucor* spores have the characteristics of high capacity for humidity absorption and adherence to surfaces, and they are usually found in moist environments (Morin-Sardin et al. 2017). Hence, their presence is expected in an environment such as Blas del Teso beach because this location has a relative humidity greater than 70%. *Mucor sp.* was the genus most common with a frequency of occurrence in the afternoon of 35% and similar proportions in stage one and two (27% and 30%, respectively). We also found other species such as *Aspergillus fumigatus,* which is an etiologic agent of invasive aspergillosis (Araujo et al. 2013). INSHT (1996) classifies biological agents in terms of infection risk into four groups, the fourth group being the most dangerous. Included within group two is *Penicillium* sp., which is considered a pathologic agent that can cause illnesses in humans. This fungus was found at the Blas del Teso beach.

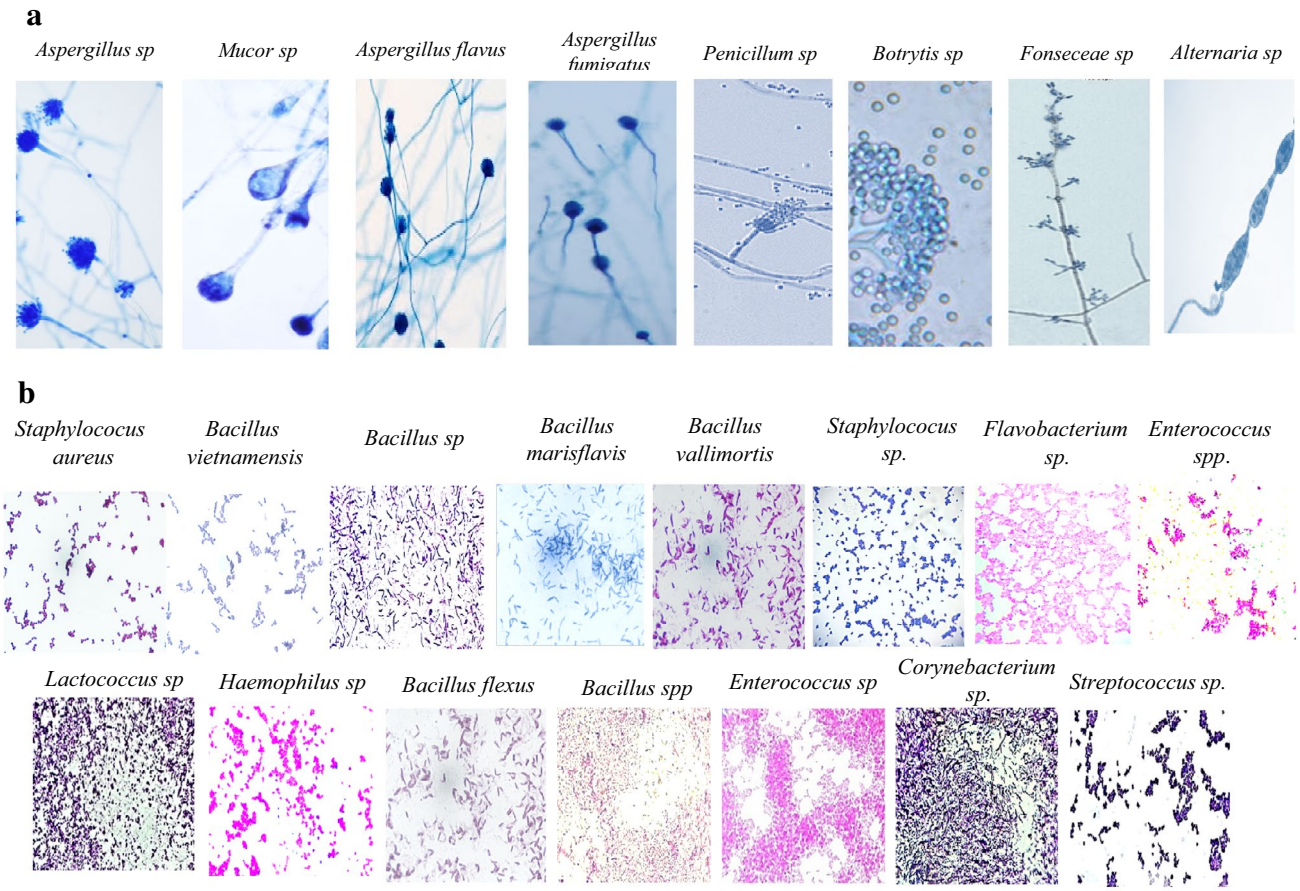

Fig. 3 Identification of fungi (**a**) and bacteria (**b**) found in the air at Blas el Teso beach in Cartagena de Indias

Six types of fungi genus were found, where 83% corresponded to Ascomycota (AC) and 17% to Basidiomycota (BC). According to the map presented by Fröhlich-Nowoisky et al. (2012), the proportion of AC and BC coincides with data reported for marine environments, in particular, in polar ocean samplings (Antarctica) where the AC and BC proportion were 85% and 15%, respectively.

INSHT (1996) states that a high frequency of Gram-negative bacteria is an indicator of a possible source of pollution; however, for the case of Cartagena beach, 85% of the bacterial species were Gram-positive bacteria. The high percentage of Gram-positive bacteria is because they have a cell wall of peptidoglycan that makes them more resistant to hostile environments such as desiccation and solar radiation. These results are consistent with data reported by Araujo et al. (2013) and Hurtado et al. (2014) from beaches in Venezuela and Mexico, respectively. Figure 4a depicts the most frequent bacteria genus, i.e., *Staphylococcus,* which belongs to microorganisms that are common in the air where there is human activity. At Blas del Teso beach, *Staphylococcus aureus* was the most frequent bacterial species (24%). This bacterium is an opportunistic pathogen with a particle size between 0.5 µm and 1.5 µm. Figure 4c shows that this bacterium was mainly captured in particle sizes equal to or higher than 7 µm. Thus, *S. aureus* is attached to bigger particles to disperse in the air. Dash et al. (2013) mentioned that *Staphylococcus aureus* is one of the few bacteria used for bioremediation of heavy metals and can be genetically modified to increase its bioremediation potential.

Bacillus vietnamensis presented a high frequency of occurrence (24%) during the afternoon in comparison with the morning (3%). This bacterium has been isolated in other marine environments, and its origin is probably fish (Noguchi et al. 2004). *Bacillus flexus* is a moderate halophilic bacterium, and it was the third-most common bacterium, as shown in Fig. 4a. This bacterium has a huge capacity to synthesize enzymes that degrade extracellular biopolymers and antibiotics. *B. flexus* also presents tolerance to a large variety of pollutants and different extreme environmental factors (Trivedi et al. 2011). Figure 4c shows that *B. flexus* was captured in stage two, which indicates particle sizes between 0.6 µm and 1.1 µm. This result is expected because bacilli usually have diameters between 0.4 µm and 0.8 µm (Acevedo et al. 2016). This is consistent with higher

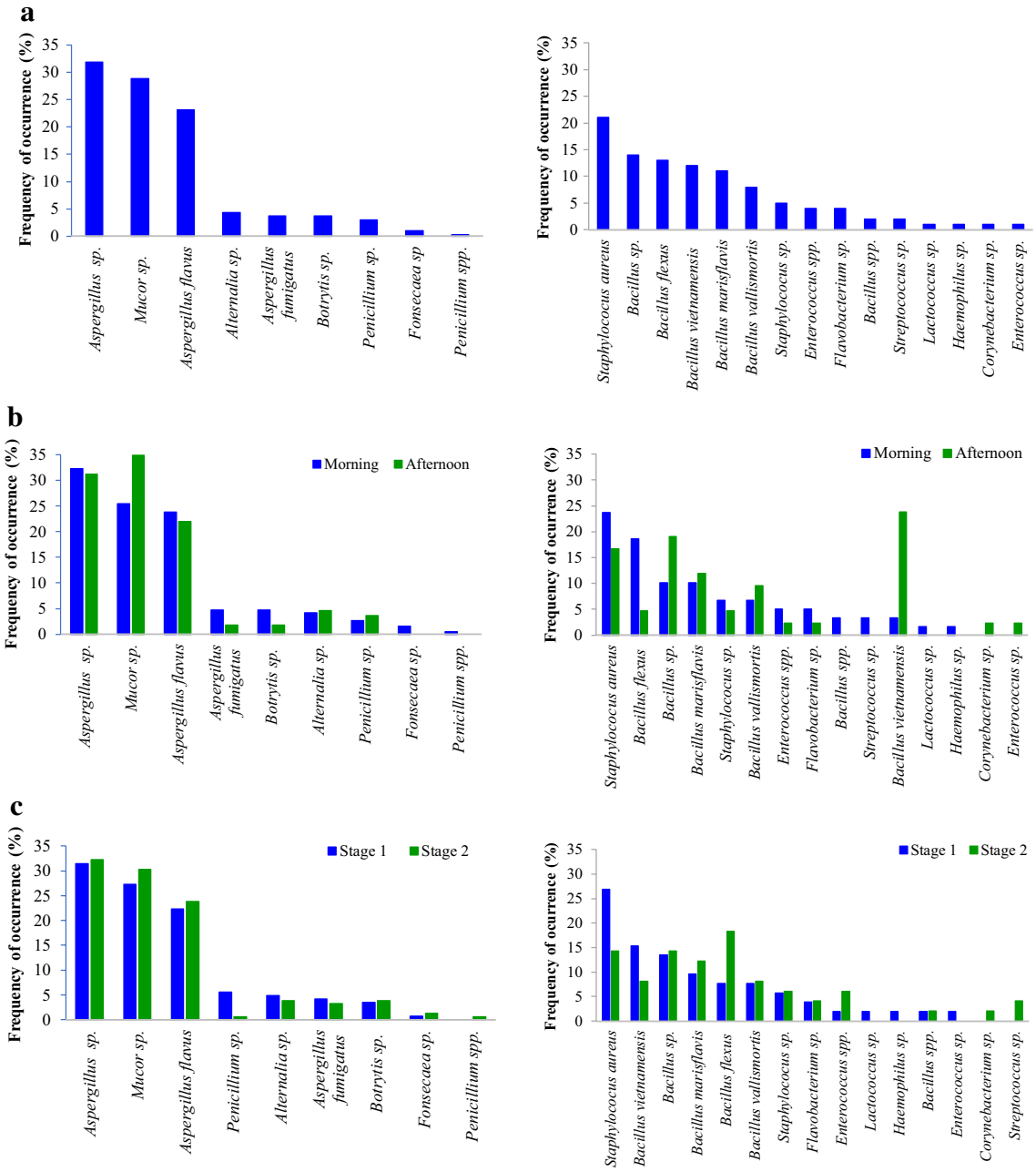

Fig. 4 Identification of fungi (left) and bacteria (right) found in the air at Blas el Teso beach in Cartagena de Indias. **a** General frequency of occurrence. **b** Species found by morning and afternoon frequency of occurrence. **c** Species found by size particle frequency of occurrence

bacteria concentrations presented in stage two in the afternoon (250 ± 147 CFU/m^3) compared to concentrations in stage one (83 ± 63 CFU/m^3) and the presence in high frequency of *Bacillus vietnamensis* confirms the hypothesis that sea is a significant emission source of bacteria.

Figure 4b shows that it is more common to find bacilli during the afternoon, while there is a greater presence of cocci in the morning; however, the present data do not explain this phenomenon. According to Acevedo et al. (2016), in Blas del Teso soil the morphology of the bacteria are commonly vibrios; however, this type of bacterium was not found in the air samples. Therefore, it can be inferred that most likely the suspension of beach sand is not the main source of airborne bacteria.

3.3 Evaluation of Meteorological Conditions and Bioaerosols Concentrations

During the sampling period, the beach temperature had a slight variation between 28 °C and 30 °C, and this same

behavior was observed for relative humidity, with a variation between 70% and 80%. There was an average wind speed of 2.1 ± 0.5 m/s in the morning and an average wind speed of 5.6 ± 0.9 m/s in the afternoon. In terms of wind direction, the prevalent direction was north northwest (NNW) in the morning and north (N) in the afternoon. Winds never came from the south or the east.

The Pearson correlation coefficient (r) showed a low linear correlation ($r < 0.6$ and $r > -0.6$) among meteorological variables and between fungi and bacteria concentration and meteorological variables. Higher fungi concentrations in the morning coincided with lower wind speed ($r = -0.3$) and lower fungi concentrations are related to higher wind speed in the afternoon ($r = -0.3$). These differences are explained by the general wind patterns in coastal areas which are influenced by local land and sea breezes. Srinivas et al. (2006) indicated that thermal internal boundary layer and land–sea breeze circulation are the two most important phenomena influencing the diffusion and pollution plume direction in coastal regions. In particular, Zhong et al. (2016) identified that in mid-latitudes coastal areas concentration of bioaerosols are regulated by synoptic weather and land–sea breeze circulation. In tropical regions, land and sea breezes are more frequent than in higher latitudes due to the weak Coriolis force and strong radiative heating and convection. The heating difference between land and sea water creates a pressure gradient that defines the air motion over land and sea (Srinivas et al. 2006). Sea breeze is caused by the temperature gradient between hot land and cool sea surface promoting a pressure gradient that produces an air flow from the ocean to the land. Miller et al. (2003) mentioned that sea breeze's behavior may persist at any time during the day or night.

In this study, during the sampling period the predominant wind direction was N (0°). At the measurement site, this direction coincides with the seashore zone. This might indicate that see breeze was the predominant meteorological phenomenon in the Blas del Teso beach, which is consistent with the significant linear correlation between fungi concentrations and wind direction ($r = -0.8$). Since the temperature difference between sea and land increases during the day, a stronger wind speed is recorded in the afternoon. As a consequence, fungi concentrations decrease because the bioaerosol is diluted. This effect has also been reported in other coastal regions (Jones and Harrison 2004; Zhong et al. 2016). In addition, during the afternoon the convective mixing layer depth increases which contributes to the decreasing in bioaerosol concentrations. Considering that temperature, relative humidity and wind direction did not present significant changes during the sampling period, we concluded that probably wind speed is the main meteorological factor affecting the fungi concentrations on this coastal region.

An inverse relation between wind speed and bacteria concentration was found in the morning ($r = -0.6$) and in the afternoon ($r = -0.2$). Similarly, bacteria concentration presented a negative correlation with wind direction ($r = -0.4$). Thus, bacteria concentrations decrease when wind came from the sea with a high speed (sea breeze). However, bacteria concentrations did not present significant changes during the morning and the afternoon (Fig. 2b). This can be explained because unlike fungi, airborne bacteria are less resistant to extreme weather. Tang (2009) mentioned that around 24 °C decrease the airborne bacterial survival. In Blas del Teso beach, the temperature during the monitoring period was always over 24 °C, both in the morning and in the afternoon. As a consequence, bacteria viability is probably reduced because high temperatures would lead to the inactivation and denaturation of proteins (Slonczewski et al. 2009). On the other hand, Theunissen et al. (1993) reported that Gram-positive bacteria are more likely to survive under higher relative humidity. In contrast, Tang (2009) referred diverse studies where Gram-positive bacteria viability decrease with high and intermediate relative humidity levels. They concluded that even within the same structural classification the bacteria response to temperature and relative humidity might change. Therefore, it is expected that bacteria concentration, unlike fungi concentration, be affected by a combination of meteorological parameters.

A multiple linear regression model was conducted to identify the impact of meteorological variables on bioaerosol concentrations. Equation 1 presents the model, where C_{it} (CFU/m^3) is the concentration of a microorganism j (fungi or bacteria) during a period of time t, D is wind direction (°), T is temperature (°C), H is relative humidity (%), R is solar radiation (W/m^2), V is wind speed (m/s), β_0 is the intercept, and β_s are coefficients that pair with each meteorological variable.

$$C_{it} = \beta_0 + \beta_1 D + \beta_2 T + \beta_3 H + \beta_4 R + \beta_5 V. \quad (1)$$

Table 2 shows the coefficients for each regression model and its corresponding determination coefficient (R^2). We observed that R^2 was lower than 0.55 when all of the meteorological data were included, meaning that meteorological variables are not the unique factors that explain bioaerosol concentrations, as it is expected because bioaerosol concentrations also depend on the emission sources. Nevertheless, when the meteorological data were divided into the morning and afternoon, R^2 was higher than 0.75 for bacterial concentration. This confirms the hypothesis that bacteria concentrations are influenced by a combination of meteorological factors beyond only one parameter. In addition, this result indicates that the bioaerosol monitoring requires more than one sample per day in coastal regions considering that the changes of meteorological conditions have an important impact on their concentrations. With the multiple linear regression models, it

Table 2 Coefficient values and R^2 of the multiple linear regression model

Period of time	Bioaerosol	Beta values						R^2
		β_0	β_1	β_2	β_3	β_4	β_5	
All samples	Bacteria	1329.90	−0.24	−43.19	2.17	−0.04	−12.47	0.35
	Fungi	3932.94	−0.74	−91.20	−12.15	0.15	−43.01	0.53
Morning	Bacteria	−54.27	−0.04	−26.15	12.06	0.18	−56.62	0.77
	Fungi	3305.76	−1.08	−97.95	−1.91	0.06	52.74	0.69
Afternoon	Bacteria	11,741.05	−2.91	−404.6	−9.46	0.30	155.17	0.98
	Fungi	3543.45	−0.65	−86.35	−12.82	0.12	5.73	0.62

is possible to infer the weight of each meteorological factor on the bioaerosol concentrations; however, additional sampling periods throughout the year are necessary to clearly stablish these relations.

4 Conclusions

A monitoring bioaerosol campaign was developed at Blas del Teso beach, Cartagena de Indias, Colombia. It was found that fungal and bacterial concentrations were in typical ranges reported in other marine environments and bacteriological diversity was higher than fungal diversity. Microorganisms with a high frequency of occurrence were the fungus *Aspergillus sp.* and the bacterium *Staphylococcus aereus.* Pathogenic microorganisms were detected in the air, and other microorganisms presented bioremediation potential.

Sea breeze was the meteorological condition that explained the relations found between wind direction, wind speed and bioaerosol concentrations. During the sampling period, an increase in fungal concentration was observed as the presence of tourists increased and when there was an average wind speed of 2.1 m/s. Bacteria concentrations also be influenced by the sea breeze but human activity seemed not to be the main emission source. According to the bacteria identification and the wind direction we infer that ocean is the main emission source of bacteria.

According to bioaerosol concentrations found in this study and comparing them to concentrations report in others beaches, Blas del Teso beach has an adequate air quality, in terms of bioaerosols, for tourism activities. A bioaerosol monitoring network is recommended to get a complete data about periods where high concentrations can affect the health of tourists and collected information can be useful to identify possible emission sources that require controls to avoid pathogenic microorganisms in the air.

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