Journal of the Geological Survey of Brazil

Evaluation of the scientific value of Lagoa Salgada (Rio de Janeiro, Brazil): characterization as geological heritage, threats and strategies for geoconservation

Douglas Rosa da Silva[1], Kátia Leite Mansur[1], Leonardo Borghi[1]

[1] Universidade Federal do Rio de Janeiro – UFRJ, Instituto de Geociências, Departamento de Geologia, Av. Athos da Silveira Ramos 274 - Cidade Universitária Ilha do Fundão, Rio de Janeiro - RJ - Brasil - CEP. 21.941-916

Abstract

Lagoa Salgada is located in the northern coast of Rio de Janeiro and is of great scientific relevance for its modern stromatolites. This study aimed to map the types of microbialites, identify damage and threats and provide geoconservation suggestions. Microbialite mapping and sampling was authorized by the administrative body of the Lagoa do Açu State Park - PELAG, where the lagoon is partially located. Petrographic analysis was conducted on stromatolite types according to external morphology. Geology and heritage value data were added to the GEOSSIT platform and analysis of ecosystem services and scientific value was performed based on bibliometrics. Three types of stromatolite were distinguished and mapped (large domal, small domal and branched columnar) with two types of microbial mat (colloform and polygonal). These morphologies suggest different hydrodynamic agents in the growth process and regarding the position in the water column. According to GEOSSIT criteria the site stands out as a "Geosite of International Relevance" and of national scientific relevance for education and tourism, serving as a model for studies on preterit environments. Ecosystem services provided by its Geodiversity, are: (a) Regulation: atmospheric processes related to photosynthesis performed by bacteria during the carbon cycle, fixing carbonates in the biostructures; (b) Support: provision of a habitat established by the seasonal hyper-salinity of the environment; (c) Provision: presence of ichnofossils and considered an environment analogous to the Pre-Salt rock reservoir; (d) Culture: environmental quality of the landscape; geotourism through a Geological Pathways Project panel; historical significance (Roteiro dos Sete Capitães); inspiration for poems and legend; and a location for didactic excursions; and (e) Knowledge: history of the evolution of life on Earth; the first Holocene stromatolites in Brazil; study of sea-level variation; and the possibility of generating jobs in Geoparks. Regarding the scientific value, 32 citations were found in the bibliography among complete articles in periodicals, theses, dissertations, monographs and book chapters. Damage and threats to which the stromatolites are subjected were identified. GEOSSIT recommends medium-term protection. Anthropic remobilization of the biostructures, agricultural use, proximity to the Açu Port Complex and non-inclusion of the lagoon's northern portion in the PELAG area, despite being the only area with branched stromatolites, can be highlighted as damage and threats. Promotion through lectures, booklets, field classes, and maintenance of the Geological Pathways Panel aimed at the local population and visitors is necessary. Scientific knowledge should be incorporated into management of the Geosite to achieve Geoconservation.

Article Information

Publication type: Research paper
Submitted: 30 May 2018
Accepted: 4 July 2018
Online pub. 16 July 2018
Editor(s): E.L. Klein

Keywords:
Modern stromatolites,
Assessment of geoheritage,
Relevance of natural heritage,
Bibliometrics,
Scientific value of geodiversity

*Corresponding author
Kátia Leite Mansur
E-mail address:
katia@geologia.ufrj.br

1. Introduction

The microbialite communities were the first evidence of macroscopic life on Earth and dominated the biosphere for around three billion years, being responsible for transformation of the Earth's atmosphere, biosphere, hydrosphere and lithosphere from the Archean to the Proterozoic (Fairchild et al. 2015). Microbialites are organosedimentary deposits formed by the interaction between microbial communities and detrital or chemically precipitated sediments, lithified or otherwise. Depending on the internal structure they are denominated as stromatolites, thrombolites, oncolites, spherulites or cryptic (Burne and Moore 1987).

Stromatolites are laminated benthic microbial deposits. The term was proposed by Kalkowsky, in 1908, with the meaning of rocks arranged in layers (Riding 1991; 2000). They are known on all continents, including Antarctica, and in the entire geologic time scale. Holocene occurrences, albeit rare, have been observed in Australia, the Gulf of Mexico, the Bahamas, the Persian Gulf, India and Brazil, among others (Hofmann 1973; Srivastava 2002).

The known Holocene occurrences of stromatolites in Brazil are located in the state of Rio de Janeiro, especially the biostructures present in hypersaline coastal lagoons, such as Pitanguinha, Vermelha, Pernambuco and Salgada, besides wetlands like Espinho and Pau Fincado. All the occurrences are located in the Araruama lagoon system, except Lagoa Salgada, which is found close to the mouth of the Paraíba do Sul River. Visibility of these sites has increased in recent years, especially after the discovery of oil in the carbonate reservoirs of the Pre-Salt layer in marginal basins, due to the similarity between the rocky materials (Estrella et al. 2009).

https://doi.org/10.29396/jgsb.2018.v1.n2.2
ISSN: 2595-1939

Thus, as it harbours one of the only recent occurrences of stromatolites in Brazil, besides microbial mats, thrombolites and oncolites, the importance of Lagoa Salgada is undeniable (Srivastava 2002; Silva e Silva et al. 2007b; Iespa et al. 2012). Lagoa Salgada is a site published by SIGEP – the Brazilian Commission of Geological and Paleobiological Sites *(Comissão Brasileira de Sítios Geológicos e Paleobiológicos)*.

The first mention of the lagoon in the historical literature is on January 1st, 1634, when it received the name Lagoa do Salgado, for its "saltpetered" water, as found in the script reporting the voyage of recognition and possession of the territory from Macaé to Baixada Campista by Portuguese officials known as "Os Sete Capitães" (The Seven Captains) (Gabriel and Luz 2012). Thus, its official denomination is Lagoa do Salgado, which is actually the name by which it is known by the local inhabitants.

Holocene stromatolites of Lagoa Salgada were the first of this age described in Brazil (Srivastava 2002). It is located in the northern coast of the state of Rio de Janeiro (41°00'30'' W and 21°54'10'' S), close to Cabo de São Tomé, between the municipalities of Campos dos Goytacazes and São João da Barra (Figure 1). It is inserted into the emerged portion of the Campos Basin, in the context of the coastal plain of the Paraíba do Sul river delta, its formation being associated with sea-level fluctuations in the Quaternary (Martin et al.1993; Winter et al. 2007).

FIGURE 1 - Map with of the location of Lagoa Salgada.

2. Characterization of Lagoa Salgada

The lagoon area can vary during periods of drought or flooding; Lamego et al. (2016) calculated, based on the analysis of aerial photographs and satellite images dated between 1964 and 2015, that the area covered by water of Lagoa Salgada varied from a minimum of 0.94 km^2, in September 2003, up to a maximum measurement of 3.65 km^2, in April 2010.

According to Iespa et al. (2012) and Birgel et al. (2015), Lagoa Salgada presented hyper-saline conditions during its evolution, due to marine influence in its formation in accordance with high levels of evaporation and low rainfall, as a result of the semi-arid climate and its shallow depth.

Measurements of Electrical Conductivity (EC) values of the lagoon water, monitored in recent years (Mansur and Tavares 2015), have registered numbers over 200 mS/cm^2 (above the

detection limit of the instrument) in February 2015, signifying high levels of hypersalinity. On the other hand, the lowest values were presented in August 2014, reaching EC = 33.1 mS/cm^2, characterizing brackish water. It is worth highlighting that the values obtained for sea water in the region reach an average of 50 mS/cm^2. In May 2015 a value approximating to that of the seawater was measured in the lagoon (54.4 mS/cm^2). These values demonstrate that freshwater enters into the Lagoa Salgada system through a channel connecting it to the Lagoa do Açu.

In general, the pH of the lagoon is alkaline (Mansur and Tavares 2015), with values being measured between 7.7 in February 2015, coinciding with the highest measured hypersalinity, and a maximum of 11.5, in December 2014, when the EC reached 100.2 mS/cm^2.

Currently, the region surrounding Lagoa Salgada is occupied by family agriculture, which uses agro-toxins in land management, and by the industrial installations of the Açu Port complex. These activities also coexist with the Lagoa do Açu State Park (Parque Estadual da Lagoa do Açu) (Figure 2), which protects part of the surrounding area and approximately half of the Lagoa Salgada.

The present article intends to discuss the scientific value of Lagoa Salgada, the threats to which it is subject and the strategies to be adopted to ensure its Geoconservation. It is worth mentioning that it is one of the most relevant geological sites of the proposal for the Geopark Cliffs and Lagoons of Rio de Janeiro (Geoparque Costões e Lagunas do Rio de Janeiro) (Mansur et al. 2012)

3. Theoretical Context

Geodiversity is of great value and provides services to ecosystems (Gray 2004; Gray 2013). Gray (2013) propose that Geodiversity is associated with a type of value, known as intrinsic value, that is, Geodiversity possesses a value for what it is and not for its use. Intrinsic value is more difficult to describe since it involves ethical and philosophical dimensions of the relationship between society and nature. Geodiversity may provide services to the ecosystem and supply benefits to human beings, and, as such, it should be conserved. The same author expands on this theme, and, based on the discussions that have been carried out since the creation of the United Nations Millennium Ecosystem Assessment Program (http://www.millenniumassessment.org/en/About.aspx#2), indicates the following ecosystem services for Geodiversity: (a) Regulation; (b) Support; (c) Provision; (d) Culture; and (e) Knowledge. These services were divided into 25 benefits.

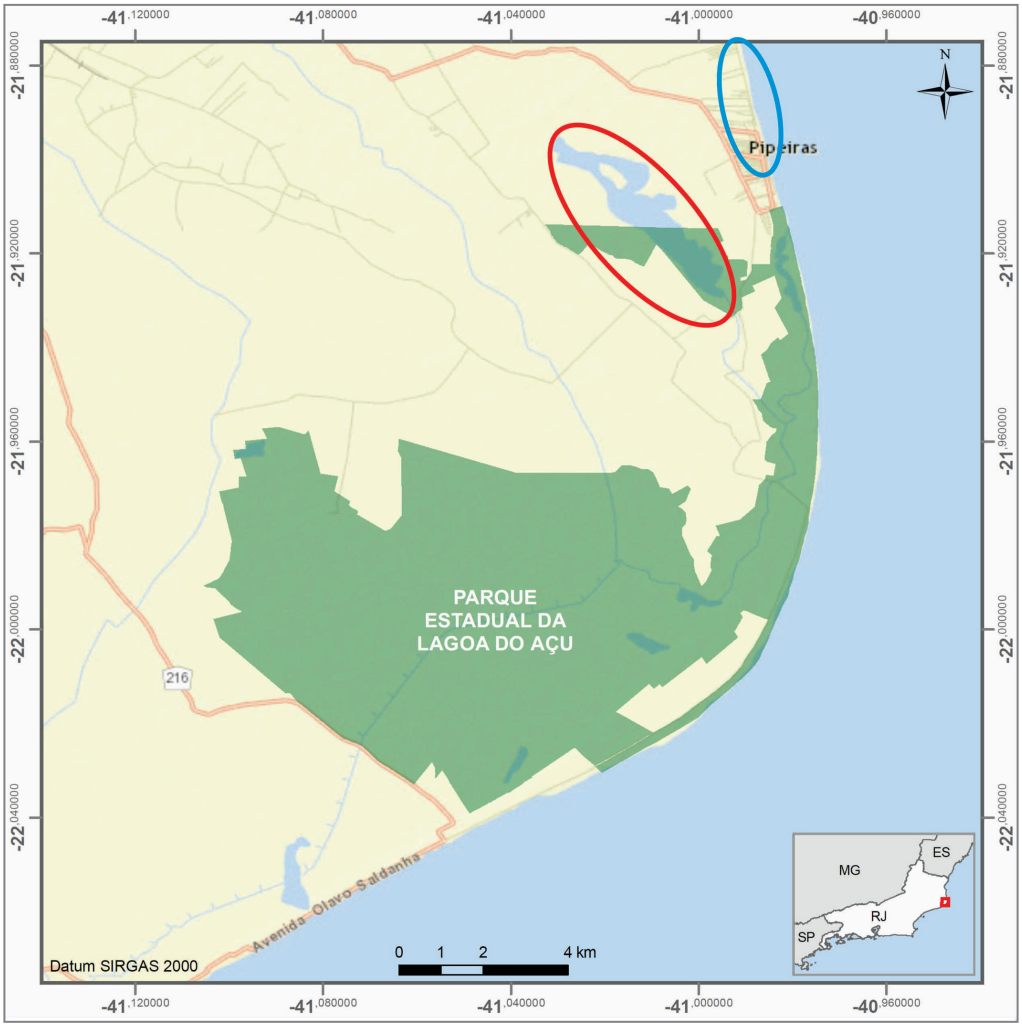

FIGURE 2 - Map with the location of the Lagoa do Açu State Park. Area encircled in red - Lagoa Salgada partially protected. Area encircled in blue – part of the area of the Açu Port. (http://www.inea.rj.gov.br/cs/groups/public/documents/document/zwew/mdi2/~edisp/inea0026977.pdf).

After a wide ranging theoretical review, Brilha (2016) discussed the concept of Geological Heritage, proposing differentiated names for its occurrence in situ (Geosites) and ex situ (Elements of Geological Heritage). For this author, what should determine the necessity for Geoconservation actions is the existence of values (scientific, educational and touristic) attributed to the Geodiversity. However, for the definition of Geological Heritage it is assumed that the scientific value, identified by specialists, is what enables the establishment of this status (Brilha 2018).

For Brilha (2016) and Brilha (2018) the understanding of what scientific value/potential is results from an analysis that takes into account the following criteria: (a) Representativeness; (b) Integrity; (c) Rarity; and (d) Scientific Knowledge.

The places that meet these specific criteria may be nominated as Geological Heritage and, should therefore be the object of Geoconservation to preserve their singular characteristics.

Over the years, diverse quantification methods have been used to value sites of geological interest. To that end, CPRM – the Geological Survey of Brazil developed the GEOSSIT online platform (http://www.cprm.gov.br/geossit/) to promote the inventory and quantification of the value of Brazilian sites.

4. Material and Methods

Scientific publications, monographs, dissertations and theses based on the study of Lagoa Salgada were researched on the sites of periodicals and the CAPES database of dissertations and theses. The results were listed and separated by type of publication. The objective of this research was to establish a connection with the parameters of Representativeness, Rarity and Scientific Knowledge, as established by Brilha (2016) for the indication of scientific value of sites.

An inventory of the Geodiversity present at the site of Lagoa Salgada was carried out through fieldwork definition of the different types of microbialite present. A georeferenced map was developed with the distribution of the various types found. Mapping was based on criteria of macroscopic description and petrographic analysis on manufactured thin sections or those existing in the collection of the Laboratory of Sedimentary Geology of UFRJ - LAGESED (Laboratório de Geologia Sedimentar da Universidade Federal do Rio de Janeiro). This result also enabled the proposition of an evolutionary model based on environments described in the literature for the formation of the types of mapped microbialites. It should be mentioned that the attributes of a place of geological interest are only known and recognized through scientific study. The mapping also sought to characterize the conservation of the site in regard to its integrity. As part of Lagoa Salgada is contained within the Lagoa do Açu State Park, authorization was obtained from the State Institute for the Environment - INEA (Instituto Estadual do Ambiente) - in order to carry out the research.

Information on Lagoa Salgada was added to GEOSSIT to become part of the Brazilian inventory and to carry out quantitative assessment of its scientific, touristic and educational value, besides assessing threats to its integrity. Situations were also identified in which GEOSSIT was not totally suitable for the type of site being studied.

The principal factors that could threaten the integrity of the rare ecosystem were identified during fieldwork, as well as its potential for educative use. This survey also had the objective of proposing protective measures for Lagoa Salgada.

5. Results and Discussion

5.1. Regarding ecosystem services

All five ecosystem services to Geodiversity attributed by Gray (2013) can be identified at Lagoa Salgada, as per the list of services and respective benefits identified in Table 1.

TABLE 1 - Ecosystem services and respective benefits attributed to Geodiversity identified at Lagoa Salgada.

Services	Benefits
Regulation	Atmospheric processes related to the Carbon Cycle, fixing carbonates in the biostructures.
Support	Provision of a specific habitat established through seasonal hypersalinity of the environment.
Provision	Presence of ichnofossils and for being considered an environment analogous to the Pre-Salt rock-reservoir
Culture	(a) Environmental quality in the form of landscape; (b) Geotourism enabled by local implantation of a panel from the Geological Pathways Project (Projeto Caminhos Geológicos); (c) Historical significance (route of the Seven Captains (Sete Capitães)); (d) Inspiration for poetry and legend; and (e) Frequently visited location for didactic excursions.
Knowledge	(a) History of the evolution of life on Earth; (b) The first Holocene stromatolites described in Brazil; (c) Study of variations in sea level; and (d) Possibility of generating jobs in Geoparks.

5.2. Regarding scientific value of the site

A total of 32 citations of studies carried out on Lagoa Salgada were found (Figure 3), these being:

i. Three complete papers in international journals (Coimbra et al. 2000; Lundberg et al. 2009; Birgel et al. 2015);

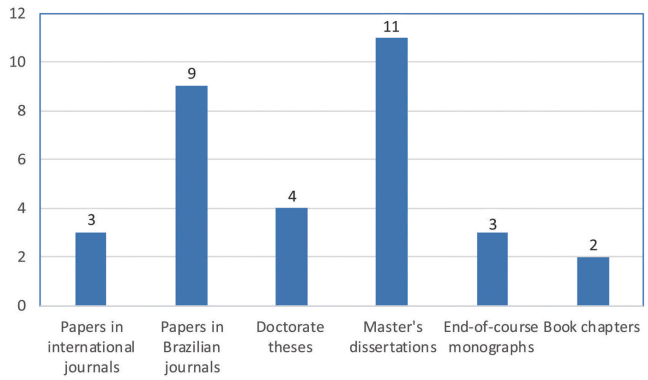

FIGURE 3 - Studies carried out with Lagoa Salgada as the principal theme.

ii. Nine complete papers in Brazilian journals (Silva e Silva et al. 2005; Senra et al. 2006; Silva e Silva et al. 2007a; Silva e Silva et al. 2007b; Silva e Silva et al. 2008; Iespa et al. 2012; Silva e Silva et al. 2013; Toledo et al. 2009);

iii. Four doctorate theses (Silva e Silva 2002; Iespa 2010; Bahniuk 2013; Archilha 2015);

iv. Eleven master's dissertations (Lemos 1996; Toledo 1998; Papaterra 2010; Tudesco 2011; Servidoni 2012; Costa 2013; Blanco 2014; Callefo 2014; Pacheco 2014; Silva 2015; Silva 2018);

v. Three end-of-course monographs (Cataldo 2011; Dias 2014; Yuji 2014); and

vi. Two book chapters (Srivastava 2010; Fairchild et al. 2015).

5.3. Regarding the mapping of microbialite occurrences

Three types of stromatolites and two types of microbial mat were identified on outcrops, these being distinguished by the external growth morphology. Macroscopic description of the samples is presented as follows:

a) Large Domal Stromatolite: morphologically present as dome shapes, rounded heads or mounds (Figure 4), capable of reaching heights of over 30 centimetres and diameters greater than 40 centimetres. They are piled up by local producers, forming fences between properties, or are buried.

FIGURE 4 - Exposure of large domal stromatolites. A) Stromatolite in life position and, in the background, piled rounded heads; B) Rounded heads piled up to form fences; C) Aerial view of buried stromatolites (Adapted from Silva 2018).

b) Small Domal Stromatolite: present as dome shapes, rounded heads or mounds (Figure 5), in general, less than 8 centimetres in height, but may reach a little over 20 centimetres. Less than 25 centimetres in width, except for when ramified, forming a stromatolite composed of two or more heaps. They are generally found buried in life position. Some remobilized structures can also be observed.

c) Branched Columnar Stromatolite: shows a shape of isolated and/or ramified columns (Figure 6) and are, in general, from 12 to 16 centimetres in height with varying widths, from centimetres, when isolated and within the same reef knoll, to bodies of metric dimensions, found in lateral growth, forming slabs (Figure 6). It is important to remember that these biostructures can present as ramified or as isolated columns, hence, the use of the term “columnar / branched”. In general, the slabs formed by this type of stromatolite are found in life position and are better preserved than the other biostructures.

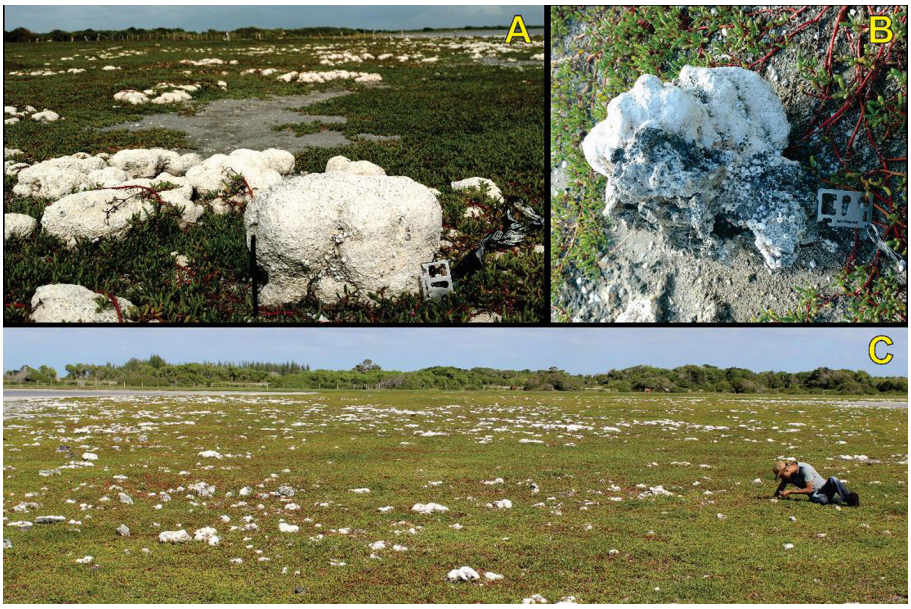

FIGURE 5 - Exposure of small domal stromatolites. A) Outcropping biostructure in life position; B) Remobilized stromatolite; C) Region where the principal stromatolites of this type outcrops (Adapted from Silva 2018).

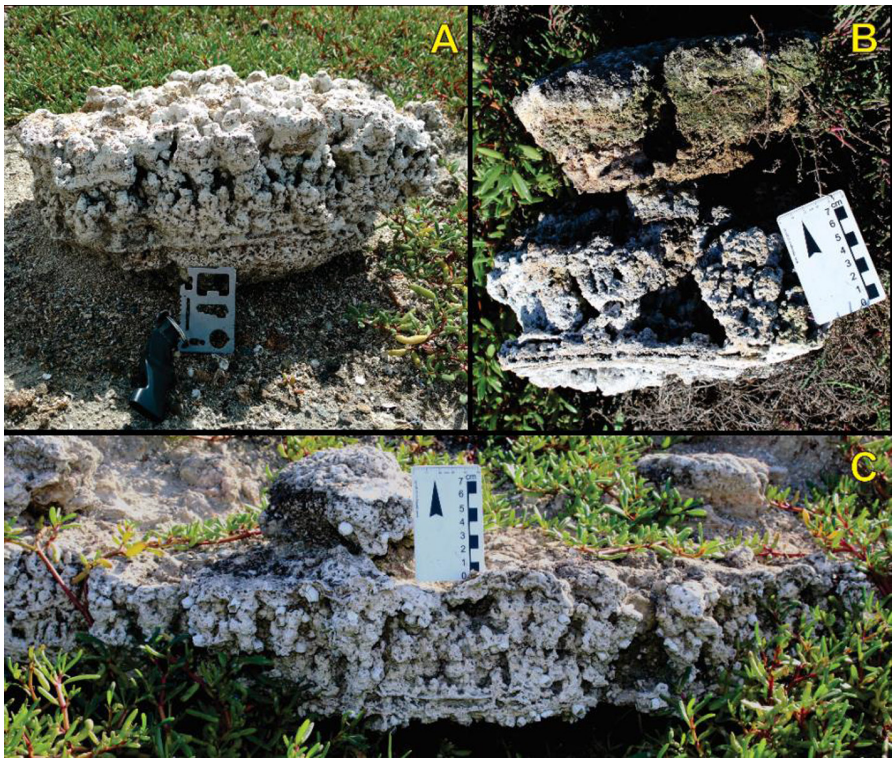

FIGURE 6 - Exposure of columnar branched stromatolites. A) Outcropping biostructure in life position; B) Remobilized stromatolites; C) Biostructure arranged in slabs (Adapted from Silva 2018).

d) Colloform Mats: display rounded botryoidal shapes *(Figure 7)*, forming laminated monticules of positive relief and wrinkled features in the absence of water (Figure 7). In general, they present a size of up to 15 cm thick and 5 to 20 cm wide and long.

e) Polygonal Mat: when submersed, they show polygonal shapes with rectilinear edges, limited by crevices (Figure 8-A), when exposed they present as wrinkled (Figure 8 and 9). They are a few centimetres thick (~3cm) with diameter varying, in general, from 10 to 30 cm, although possibly displaying larger shapes.

The best points or areas for the occurrence of the structures at the edges and in the interior of the lagoon were selected based on the mapping (Figure 10). It is important to remember that the mapped locations were those subject to observation.

Given the occurrences of each type of biostructure, a positioning and formation proposal was developed, considering the physical-chemical, hydrodynamic and sedimentary environmental modifications and the variation in sea level over time (Figure 11).

Figure 11 suggests that the morphology of the biostructures is directly related to their position in the water column, whereby the type of growth is conditioned by the action of hydrodynamic agents and direct connection to the sea (Grotzinger 1989; Serebryakov and Semikhatov 1974; Andres and Reid 2006).

Physical-chemical modifications occur as a result of closure of the lagoon and the high temperatures related to the semi-arid climate of the region. This favoured evaporation and salt precipitation (Birgel et al. 2015). Ages proposed for the different time intervals were based on Castro et al. (2014).

FIGURE 7 - Colloform mat, demonstrating positive relief, observed in the southern portion of Lagoa Salgada. A) Region with colloform mat outcrops. B) Detail of image A. C) Colloform mat view from above / of the top (Adapted from Silva 2018).

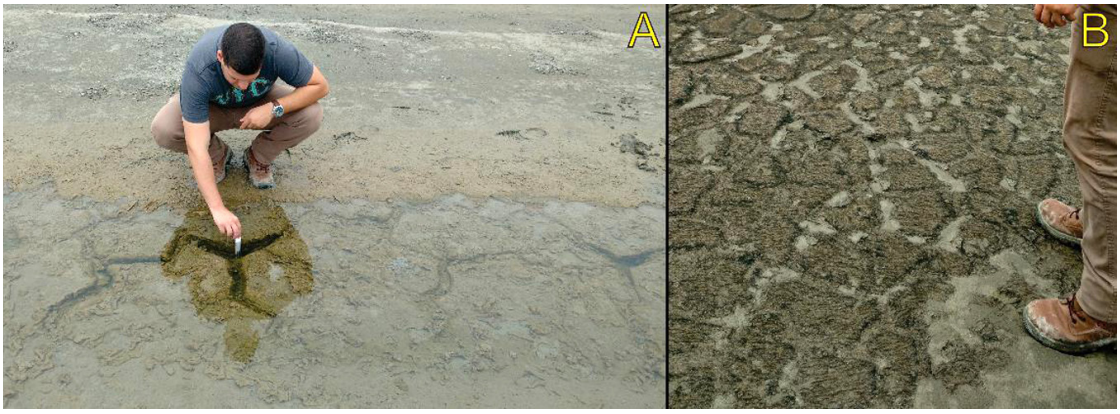

FIGURE 8 - Polygonal mat observed in the southern section of Lagoa Salgada. A) Polygonal mat still submersed, demonstrating fullness and rectilinear edges. B) Recently exposed polygonal mats, close to the outcrop in image A (Adapted from Silva 2018).

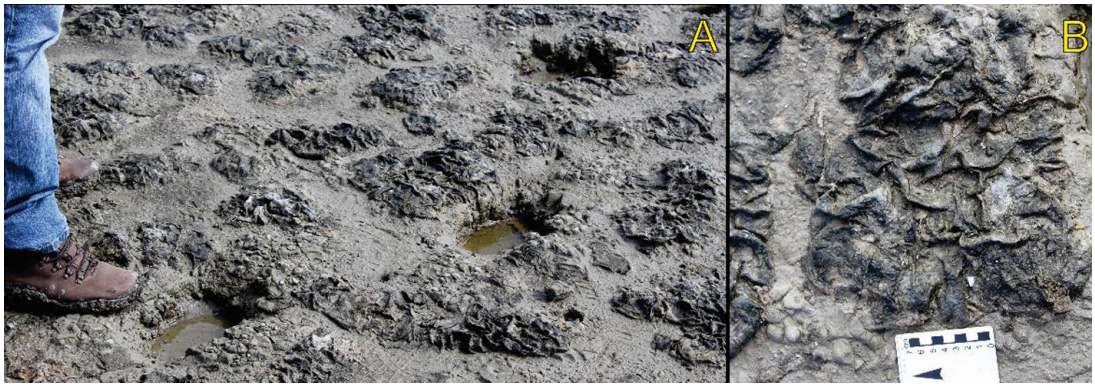

FIGURE 9 - Polygonal mat observed in the northern part of Lagoa Salgada. A) Recently exposed polygonal mat, demonstrating wrinkled shapes. B) Detail from image A, view from above (Adapted from Silva 2018).

FIGURE 10 - Map of the location of the microbialites of Lagoa Salgada, separated by microbial mats, types of stromatolite and their regions of occurrence (Adapted from Silva 2018).

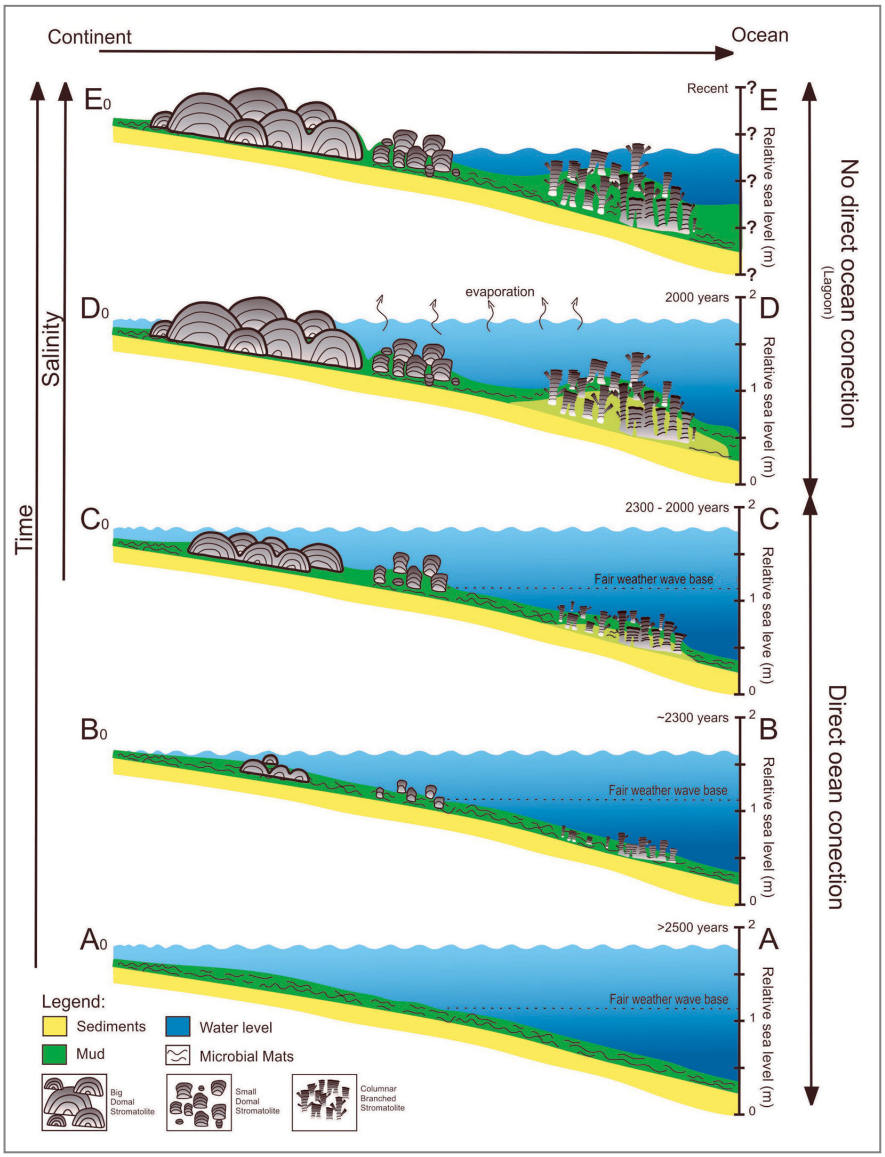

FIGURE 11 - Evolutionary model for stromatolites of Lagoa Salgada, demonstrating growth of the biostructures and environmental and chemical modifications over time (Adapted from Silva 2018).

5.4. Valuation of the geological site

Data from Lagoa Salgada was inserted into the GEOSSIT platform of CPRM, which is aimed at the inventory, qualification and quantitative assessment of Geosites and Geodiversity Sites, using the methodology proposed by Brilha (2016) and Garcia-Cortés and Carcavilla Urqui (2009).

The results indicate Lagoa Salgada as a "Geosite of International Relevance". The maximum number of points per criterion is 400. The values attributed to each item on the register were 350 points for scientific value; 315 for educative value; and 260 for touristic value. Regarding the risk of degradation, the lagoon presents a medium index of 205 points.

It is important to highlight that some assessment parameters of the GEOSSIT platform do not provide the best definition for the case of Lagoa Salgada, as a "Local-type" field. In this case there is no appropriate attribute to frame this site within the parameter. However, Lagoa Salgada is considered a model for the formation of stromatolites, including in comparison to those of the Proterozoic (Birgel et al. 2015).

Therefore, it was classified as follows: "The place of interest is recognized as holostratotype or a lithodemic unit in the stratigraphic lexis of Brazil and Amazônia Legal or similar documents, or is a source of holotype, neotype or lectotype registered in scientific publications, according to the code (ICZN, ICBN or ICN) in force at the time of description and registered on the Paleo Database of CPRM or similar databases, or is an IMA site of reference", this being the best option among those offered on the platform. In this case, the adoption of characterization of the scientific value of Geosites was suggested to CPRM, as per that indicated by Brilha (2016): (A) Representativeness: capacity of a Geosite to illustrate geological elements or processes (related to geological structures, when applicable); and (B) Key location: importance of the Geosite as a reference or model for stratigraphy, palaeontology, minerology, etc.

Lagoa Salgada is, therefore, characterized as an extremely rare world model, but is not considered section-type, as used in formal stratigraphy. It is a key location capable of illustrating geological processes (Brilha 2016).

5.5. Threats

Regarding the recommendation supplied by the GEOSSIT platform that the lagoon is threatened in the “medium term”, it is necessary to indicate the various problems observed in the area, where all the types of stromatolite characterized present remobilized specimens. The biostructures with the highest level of damage are the greater domal stromatolites, with no outcropping elements still in life position. The ramified columnar stromatolite has few specimens in life position, which, in general, are those arranged in slabs. This problem is due to the use of the lagoon as a space for pasture, whereby the microbialites are trampled by the animals and torn from their original position. Also, in the absence of other materials for the construction of fences, the stromatolites have been used to this end.

Moreover, plantations and cultivations of leguminous plants and vegetables, with extensive use of agro-toxins, can be found nearby Lagoa Salgada. The hydrogeological study of the Açu Port (LLX Açu Operações Portuárias S/A 2011) identifies values higher than the acceptable standard for human consumption, according to CONAMA Resolution N° 396/2008 for surface and sub terrain water, for Al, As, B, Cu, Fe, Mn and Pb. These anomalous values require further investigation.

Another important negative impact is the anthropic action interfering in the exchange of water with Lagoa do Açu, the physical-chemical characteristics of which are different to those of Lagoa Salgada. Alteration of the natural conditions enables an exchange of nutrients and organisms, besides alterations in pH, salinity and height of the water column, among others.

However, only part of Lagoa Salgada is located inside the Lagoa do Açu State Park. No scientific reason was indicated by the government organizations to explain the decision to protect only the southern part of the lagoon. The proximity of the Porto do Açu Complex, which is a priority for the authorities for economic reasons, is the only possible motive for its northern section being without legal protection (Figure 12).

It should be mentioned that all the occurrences of columnar / ramified stromatolites occur outside the Conservation Unit.

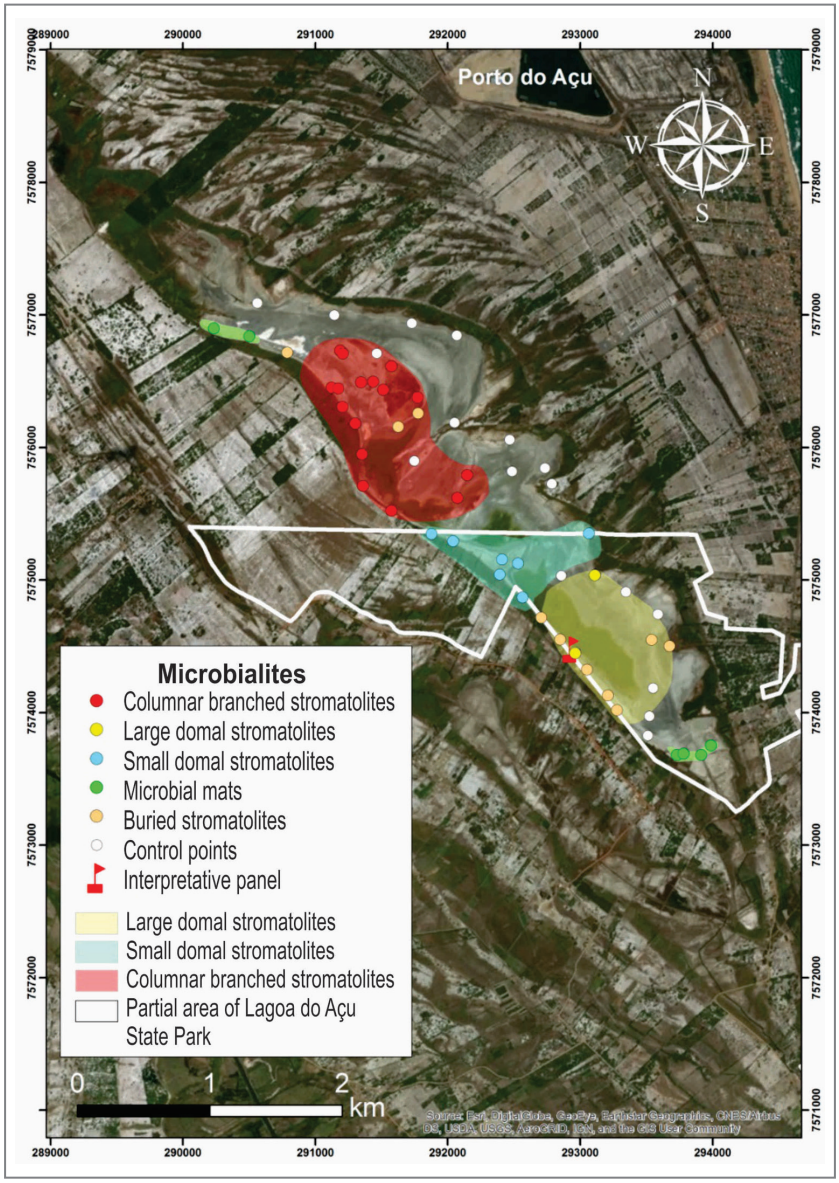

FIGURE 12 - Map demonstrating the location of microbialites of Lagoa Salgada and the area of the Lagoa do Açu State Park (Adapted from Silva 2018).

6. Conclusions

Lagoa Salgada is a site of significant national and international importance for the occurrence of biostructures. All five ecosystem services cited by Gray (2013) were reported, these being regulation, provision, support, culture and knowledge. It is a Geosite considered part of the Rio de Janeiro Coasts and Lagoons Geopark project (Geoparque Costões e Lagunas do Rio de Janeiro).

In the calculation of scientific value, it can be highlighted that a total of 32 publications on Lagoa Salgada were identified among publications in national and international periodicals, theses, dissertations, monographs and book chapters.

Mapping of the occurrences of microbialites enabled identification and characterization of three outcropping stromatolite morphologies and two types of microbial mat.

These attributes were important for the valuation of the geological site, leading to classification of the stromatolites of Lagoa Salgada as a "Geosite of International Relevance". It was also possible to classify the threats to which it is subject. The recommendation of the GEOSSIT platform is that the threats are of "medium term". There is a necessity for remediation / mitigation of the various impacts observed in the area, especially the anthropic remobilization of the biostructures, use of the area for pasture and the non-inclusion of the northern section of the lagoon in the area of the Lagoa do Açu State Park, which makes preservation and legal conservation of these biostructures difficult.

Considering that promotion / popularization of science is essential in the process of Geoconservation, it is indicated that there is a necessity to produce promotional material in the form of lectures, books, booklets, field classes and maintenance of the Geological Pathways Panel, among others, aimed at the local population with particular focus on local schools, tourists and other visitors.

Acknowledgements

We are grateful to CNPq for the scholarship granted to the master's research of the first author and the reviewers for the suggestions for improvement to the text.

References

Andres M.S., Reid, P.R. 2006. Growth morphologies of modern marine stromatolites: a case study from Highborne Cay, Bahamas. Sedimentary Geology, 185, 319-328. https://doi.org/10.1016/j.sedgeo.2005.12.020.

Archilha N.L. 2015. Quantificação de parâmetros geométricos do sistema poroso por tomografia de raios x e análise da influência em propriedades físicas de rochas carbonática. Tese de Doutorado, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, 122 p.

Bahniuk A.M.R. 2013. Coupling organic and inorganic methods to study growth and diagenesis of modern microbial carbonates, Rio de Janeiro State, Brazil: implications for interpreting ancient microbialite facies development. PhD Thesis, ETH Zurich, 161 p.

Blanco A.M. 2014. Processos organo-sedimentares da Lagoa Salgada (RJ, BRASIL) durante os ultimos 7000 anos A.P: implicações paleoambientais. Dissertação de Mestrado, Programa de Pós-Graduação Geociências, Universidade Federal Fluminense, 79 p.

Birgel D., Meister P., Lundberg R., Horath T.D., Bontognali T.R.R., Bahniuk A.M., Rezende C.E., Vasconcelos C., Mckenzie J.A. 2015. Methanogenesis produces strong ^{13}C enrichment in stromatolites of Lagoa Salgada, Brazil: a modern analogue for Palaeo-/Neoproterozoic stromatolites? Geobiology, 13, 245-266. https://doi.org/10.1111/gbi.12130.

Brilha J. 2016. Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage, 8(2), 119- 134. https://doi.org/10.1007/s12371-014-0139-3.

Brilha J. 2018. Geoheritage: inventories and evaluation. In: Reynard E., Brilha J. (eds.) Geoheritage: assessment, protection, and management. Elsevier, p. 69-82. https://doi.org/10.1016/B978-0-12-809531-7.00004-6.

Burne R.V., Moore L.S. 1987. Microbialite: organosedimentary deposits of benthic microbial communities. Palaios, 2, 241-254.

Callefo F. 2014. Análise tafonômica e paleoecológica de estruturas associadas a comunidades microbianas holocênicas e permianas. Dissertação de Mestrado, Programa de Pós-Graduação, Universidade Estadual de Campinas, 207 p.

Castro J.W.A., Suguio K., Seoane J.C.S., Cunha A.M., Dias F.F. 2014. Sea-level fluctuations and coastal evolution in the state of Rio de Janeiro, southeastern Brazil. Anais da Academia Brasileira de Ciências, 86 (2), 671-683. http://dx.doi.org/10.1590/0001-3765201420140007.

Cataldo R.A. 2011. Análise dos estromatólitos e sedimentos associados – Lagoa Salgada/RJ. Trabalho de Conclusão de Curso, Instituto de Geociências, Universidade Estadual de Campinas, 49 p.

Coimbra M.M., Silva C.G., Barbosa C.F., Ken A.M. 2000. Radiocarbon measurements of stromatolite heads and crusts at the Salgada Lagoon, Rio de Janeiro state, Brazil. Nuclear Instruments and Methods in Physics Research, 172, 592-596.

Costa M.B. 2013. Uso e cobertura do solo do Parque Estadual do Açu. Dissertação de Mestrado. Programa de Pós-Graduação em Engenharia Ambiental, Instituto Federal de Educação, Ciência e Tecnologia Fluminense, 64 p.

Dias L.O.P. 2014. Fácies sedimentares e evolução paleoambiental da Lagoa Salgada (litoral norte do Rio de Janeiro). Trabalho Final de Curso, Instituto de Geociências, Universidade Federal do Rio de Janeiro, 62p.

Estrella G.O., Azevedo R.L.M., Formigli Filho J.M. 2009. Pré-Sal: conhecimento, estratégia e oportunidades. In: Velloso J.P.R. (ed.) Teatro mágico da cultura, crise global e oportunidades do Brasil. Editora José Olympio, p. 67-78.

Fairchild T.R., Rohn R., Dias-Brito D. 2015. Microbialitos do Brasil do Pré-Cambriano ao recente: um atlas. Rio Claro: UNESP-IGCE-UNESPetro, 2.

Gabriel A.H.D., Luz M. 2012. Roteiro dos sete capitães: documentos e ensaios. Rio de Janeiro, Funemac Livros, 152 p.

Garcia-Cortés A., Carcavilla Urqui L. 2009. Documento metodológico para la elaboración del inventario español de lugares de interés geológico (IELIG), Espanha, Instituto Geológico y Minero de Espanã, 61 p.

Gray M. 2004. Geodiversity: valuing and conserving abiotic nature. Chichester: John Wiley & Sons. 434 p.

Gray M. 2013. Geodiversity: valuing and conserving abiotic nature. Chichester: John Wiley & Sons. 2nd Edition, 508 p.

Grotzinger J.P. 1989. Facies and evolution of Precambrian carbonate depositional systems: emergence of the modern platform archetype. In: Crevello P., Sarg R., Read J.F., Wilson J.L. (eds.) Controls on carbonate platforms and basin development. SEPM, Tulsa, 44, 79-109.

Hofmann H.J. 1973. Stromatolites: characteristics and utility. Earth-Science, 9(4), 339-373.

Iespa A.A.C. 2010. O plexo estromatólito–trombólito–oncoide, Lagoa Salgada, RJ, Brasil. Tese de Doutorado, Programa de Pós-graduação em Geologia, Universidade Federal do Rio de Janeiro, 157 p.

Iespa A.A.C., Damazio-Iespa C. M., Borghi L. 2012. Evolução paleoambiental da Lagoa Salgada utilizando microbialitos, com ênfase em microfácies carbonáticas. Geociências, 31(3), 371-380.

Lamego V.E., Mansur K.L., Silva Júnior G.C., Rosa D.S. 2016. Análise de alguns parâmetros físico-químicos da água, estudos de variação do espelho d'água e avaliação de possível contaminação da Lagoa Salgada, Rio de Janeiro. In: Congresso Brasileiro de Geologia, 48, Porto Alegre.

Lemos R.M.T. 1996. Estudo das fácies deposicionais e das estruturas estromatolíticas da lagoa Salgada - Rio de Janeiro. Dissertação de Mestrado, Programa de Pós-Graduação, Universidade Federal Fluminense, Niterói, 113 p.

LLX Açu Operações Portuárias S/A. 2011. Estudo de impacto ambiental na implatanção e operações das infraestruturas do Distrito Industrial de São João da Barra. CD-ROM.

Lundberg R., Bontognali, T., Mckenzie, J.A., Vasconcelos C. 2009. Modern stromatolites from Lagoa Salgada, Brazil: role of methanogens in carbonate precipitation. Geochimica et Cosmochimica Acta, 73(13), A800. https://dooi.org/10.1016/j.gca.2009.05.010.

Mansur K.L., Guedes E., Alves M.G., Pressi L.F., Costa JR. N., Pessanha A., Nascimento L.H., Nascimento V., Vasconcelos G. 2012. Geoparque Costões e Lagunas do Estado do Rio de Janeiro (RJ). In: Schobbenhaus C., Silva R. C. Geoparques do Brasil: propostas. CPRM, p. 687-745.

Mansur K.L., Tavares C. 2015. Roteiro da excursão de campo da disciplina Geologia Geral na Universidade Federal do Rio de Janeiro - UFRJ. In: Ensinogeo, Campos do Jordão, p. 658-662.

Martin L., Suguio K.E., Flexor J.M. 1993. As flutuações de nível do mar durante o Quaternário Superior e a evolução geológica de deltas brasileiros. Geociências, 15,186.

Pacheco R.C. 2014. Avaliação da interação fisico-química de componentes de petróleo com estromatólitos da Lagoa Salgada, RJ. Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia de Reservatório e de Exploração, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, 111 p.

Papaterra G.E.Z. 2010. Pré-sal: conceituação geológica sobre uma nova fronteira exploratória no brasil. Dissertação de Mestrado, Programa de Pós-Graduação em Geologia, Universidade Federal do Rio de Janeiro, 94 p.

Riding R. 1991. Classification of microbial carbonates. In: Riding R. (ed.) Calcareous Algae and Stromatolites. Springer-Verlag, p. 21-51.

Riding R. 2000. Microbial carbonates: the geological record of calcified bacterial-algal mats and biofilms. Sedimentology, 47, 179-214.

Serebryakov S.N., Semikhatov M.A. 1974. Riphean and recente stromatolites: a comparison. American Journal of Science, 274, 556-574.

Senra M.C.E., Silva e Silva L.H., Conde J.N. 2006. Microbioerosion on shells of Heleobia australis (Gastropoda; Rissooidea) from Lagoa Salgada, Rio de Janeiro State, Brazil. Anuário do Instituto de Geociências, 29, 199-209.

Servidoni A.P.S. 2012. Análise de porosidade e o potencial como rocha reservatório em estromatólito do recente da Lagoa Salgada, litoral fluminense – RJ. Dissertação de Mestrado, Programa de Pós-Graduação em Geologia, Universidade Federal do Paraná, 141 p.

Silva D.R. 2018. Mapeamento e caracterização dos estromatólitos presentes na Lagoa Salgada: passo estratégico para sua Geoconservação. Dissertação de Mestrado, Programa de Pós-Graduação em Geologia, Universidade Federal do Rio de Janeiro, 129 p.

Silva W.G.A.L. 2015. Análise do espaço poroso para simulação numérica do escoamento de fluidos em estromatólito utilizando microtomografia computadorizada de raios X. Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia Civil, Universidade Federal do Rio de Janeiro, 225 p.

Silva e Silva L. H. 2002. Contribuição ao conhecimento da composição microbiana e química das estruturas estromatolíticas da lagoa Salgada, Quaternário do Rio de Janeiro, Brasil. Tese de Doutorado, Programa de Pós-Graduação em Geologia, Universidade Federal do Rio de Janeiro, 176 p.

Silva e Silva L.H., Iespa A.A.C., Damazio-Iespa C. M., Carvalhal S.B.V., Alves S.A.P. 2005. Confronto entre estruturas estromatolíticas domais (composição cianobacteriana) das lagoas Pernambuco e Salgada, Brasil. Revista de Geologia, Fortaleza, 18(2), 159-165.

Silva e Silva L. H., Iespa A. A. C., Damazio-Iespa C. M. 2007a. Considerações sobre Estromatólito do Tipo Domal da Lagoa Salgada, Estado do Rio de Janeiro, Brasil. Anuário do Instituto de Geociências, UFRJ, 30(1), 50-57.

Silva e Silva L.H., Iespa A.A.C., Damazio-Iespa C. M. 2008. Composição dos Estromatólitos Estratiformes da Lagoa Salgada, Rio de Janeiro, Brasil. Anuário do Instituto de Geociências, 31(2), 42-49.

Silva e Silva L.H., Alves S.A.P.M.N., Magina F.C., Gomes S.B.V.C. 2013. Composição cianobacteriana e química dos estromatólitos da Lagoa Salgada, Neógeno do estado do Rio de Janeiro, Brasil. Revista do Instituto de Geociências - USP, 13(1), 95-106.

Silva e Silva L.H., Srivastava N.K., Damazio-Iespa C.M. 2007b. Evidência de oncóides recentes da lagoa Salgada, norte do estado do Rio de Janeiro, sudeste brasileiro. Revista Universidade Guarulhos, 6(1), 201-206.

Srivastava N.K. 2002. Lagoa Salgada, RJ: estromatólitos recentes. In: Schobbenhaus C., Campos D.A., Queiroz E.T., Winge M., Berbert-Born M. (eds.) Sítios geológicos e paleontológicos do Brasil. DNPM, CPRM, SIGEP, p 203-209.

Srivastava N.K. 2010. Estromatólito. In: Carvalho I.S. (ed.) Paleontologia: conceitos e métodos. 3 ed. Editora Interciências, p. 229-250.

Toledo M.B. 1998. Evolução ambiental da Lagoa Salgada, sudeste do Brasil, com base em estudos palinológicos. Dissertação de Mestrado, Programa de Pós-Graduação em Geologia e Geofísica Marinha, Universidade Federal Fluminense, 29 p.

Toledo M.B., Barth O.M., Silva C.G., Barros M.A. 2009. Testing multivariate analysis in paleoenvironmental reconstructions using pollen records from Lagoa Salgada, NE Rio de Janeiro State, Brazil. Anais da Academia Brasileira de Ciências, 81(4), 757-768.

Tudesco C.C. 2011. A Lagoa Salgada e a ação antrópica em sua faixa marginal de proteção, região norte do estado do Rio de Janeiro. Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia Ambiental, Instituto Federal de Educação, Ciência e Tecnologia Fluminense, 102 p.

Winter W.R., Jahnert R.J., França A.B. 2007. Bacia de Campos. In: Milani E., Rangel H.D., Bueno G.V., Stica J.M., Winter W.R., Caixeta J.M., Pessoa Neto O.C. (eds.) Cartas estratigráficas, Boletim Geociências da Petrobras, 15(2), 511-529.

Yuji F.D.H. 2014. Avaliação do volume representativo elementar (REV) em estromatólito de Lagoa Salgada. Trabalho Final de Curso, Instituto de Geociências, Universidade Federal do Rio de Janeiro, 53 p.