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First record of *Navicula pelagica* (Bacillariophyta) in the South Atlantic Ocean: the intriguing occurrence of a sea-ice-dwelling species in a tropical estuary

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Abstract. Despite the wide distribution of species of the genus *Navicula* in the most diverse habitats around the globe, *Navicula pelagica* Cleve (Bacillariophyceae) is reported almost exclusively as one of the main components of the diatom biota of Arctic sea-ice. The present study is the first record of *N. pelagica* in the South Atlantic Ocean (Brazil) and demonstrates an ecological niche model of the species. The analyzed specimens were rectangular, with rounded angles in pleural view, the pervalvar axis measured 7.9-9.5µm and the apical axis 22-25µm, an evident central nucleus and two comma-shaped chloroplasts, one on each side of the nucleus, were observed. The specimens formed chains of 35 cells, on average, arranged in the typical pattern of rotation about the chain axis relative to their neighboring cell. The applied ecological niche model indicated that the Brazilian coast has low environmental suitability (~12%) for the development of *N. pelagica*. Our hypothesis is that its occurrence in this tropical environment was due to transport and discharge of ballast water. Further studies are needed with the objective of monitoring this species in the Camamu Bay, considering that even ecosystems that are only minimally suitable for non-indigenous species are potentially vulnerable to invasion.

Key words: Ballast water, Camamu Bay, Diatoms, Ecological niche modeling

Resumen: Primer registro de *Navicula pelagica* (Bacillariophyta) en el Océano Atlántico Sur: la intrigante ocurrencia de uma especie que habita hielo marino en un estuario tropical. A pesar de la amplia distribución del género *Navicula* en los diversos ambientes a nivel global, *Navicula pelagica* (Bacillariophyceae) se conoce casi exclusivamente como un componente importante de la biota diatomológica de los glaciares. En este trabajo, se documenta el primer registro de esta especie en el Atlántico Sur, incluyendo el modelo de nicho ecológico de la especie. Los especímenes observados fueron rectangulares, con ángulos redondeados en vista pleural, el eje pervalvar mide 7,9-9,5µm y el eje apical 22-25µm, con un núcleo central evidente y dos cloroplastos en forma de coma, uno a cada lado del núcleo. Los especímenes formaron cadenas con un promedio de 35 células, dispuestas con el patrón típico de rotación alrededor del eje de la cadena en relación con su célula vecina. El modelo indicó que la costa brasileña tiene una idoneidad ambiental baja (~12%) para la supervivencia de *N. pelagica*. Nuestra hipótesis es que su ocurrencia en este ambiente tropical está relacionada al transporte vía agua de lastre. Sin embargo, enfatizamos la importancia de nuevos estudios con el objetivo de investigar el establecimiento de las especies en la Bahía de Camamu, considerando que todas las localidades que presentan condiciones ambientales mínimas para la ocurrencia de especies no nativas representan áreas potencialmente vulnerables a la invasión.

Palabras clave: Agua de lastre, Bahía de Camamu, Diatomeas, Modelado de nichos ecológicos

Introduction

Diatoms are the principal components of microphytoplankton in coastal environments (Garbary 2001, Rochelle-Newall *et al.* 2011) and are widely geographic distribution, due to their euryhaline habit (Tilstone *et al.* 2000). The genus *Navicula* includes a large variety of freshwater and marine species, which typically colonize benthic habitats but are common in pelagic environments. This genus also includes some species with restricted distributions, such as *Navicula pelagica* Cleve, a very common species in the sea ice biota, occurring almost exclusively in meltwater in the Arctic sea (Ikeyal *et al.* 2001, von Quillfeldt *et al.* 2003, Werner *et al.* 2007, Tamelander *et al.* 2009, Szymanski & Gradinger 2016). *Navicula pelagica* is a chain-forming diatom whose main characteristic is the spiral rotation pattern in which the cells occur well-spaced around the length of the central axis of the chain (Syvertsen 1984). The chain-forming strategy, in general, favors increased buoyancy (Gherardi *et al.* 2016). This strategy provides the maintenance of the cells in the surface layer of the water column during thawing periods, besides being an important factor for the dispersion of the species. Furthermore, most chain-forming diatoms control chain length as a strategy to minimize grazing pressure (Bergkvist *et al.* 2012).

Introduction of non-indigenous marine species to different biogeographic regions is an important consequence of globalization (Zaiko *et al.* 2018). Some barriers to species dispersal may be ruptured by human action, especially regarding ballast water which is the predominant mode of distribution of marine species to novel habitats (Ruiz *et al.* 1997, Naylor *et al.* 2001). It is estimated that more than 10,000 species are transported in this manner through the world's oceans, each day (Carlton & Geller 1993, Ruiz *et al.* 2000). An example of the breaking-down of dispersal barriers of a microalga occurred in *Coscinodiscus wailesii* Gran et Angst, which was initially restricted to the southwest Pacific, but was introduced in coastal regions of Europe and the United States via ballast water (Laing & Gollasch 2002) where it became established and forms blooms that cause damage to activities fish farming. At the Brazilian coast, C. wailesii was recorded for the first time in Paranaguá Bay (Valente-Moreira 1987), and after this, it was recorded at the coast of Rio de Janeiro, São Paulo (Tenenbaum *et al.* 2004), and Bahia (Affe *et al.* 2018a), indicating the expansion of the geographic distribution of this species.

In general, only a small fraction of introduced species succeed develop in novel environments and significantly affect the invaded ecosystems (Ruiz *et al.* 1997); however, it is difficult to differ accurately between native and introduced taxa because of the currently limited knowledge of the true distribution of the species and due to a large number of species that have not been described so far (Garbary 2001, Gómez 2008). In this sense, ecological niche modeling has been widely used as a tool to predict areas of environmental suitability of species (Peterson 2003, Elith & Leathwick 2009), and it helps delimit the geographical distribution and identify the factors that influence their occurrence (Franklin 2009). In this study, we present the first record of *N. pelagica* in the South Atlantic Ocean, considering the hypothesis that it was introduced in this tropical environment via ballast water transport, we applied an ecological niche model, with the objective of verifying environmental suitability for the eventual establishment of the *N. pelagica* in Camamu Bay.

Material and methods

Samples were collected at four sites (P1 to P4), on January 20 and 21, 2015 in Camamu Bay (13°40.2' to 14°12.6' S and 038°55.8' to 039°9.6' W) (Fig. 1). The regional climate is hot and humid, with a mean annual temperature of 25 °C and high rainfall of 2,400 to 2,600 mm year^{-1} (CRA 2007). Water temperature and salinity were measured *in situ* using a multiprobe meter (Hanna HI 9829) and water transparency was assessed using a Secchi disk. Water samples of 5 L were collected using a Van Dorn bottle for analysis of dissolved inorganic nutrients (nitrite, nitrate, ammonium, phosphate, and silicate) and were filtered immediately after collection, using a vacuum pump and glass fiber filters (Whatman GF/F, 0.7 µm pore size, Sigma-Aldrich). Aliquots of 250 mL of the filtrate of each sample were stored frozen until until spectrophotometric analyses were carried out (Grasshoff *et al.* 1983).

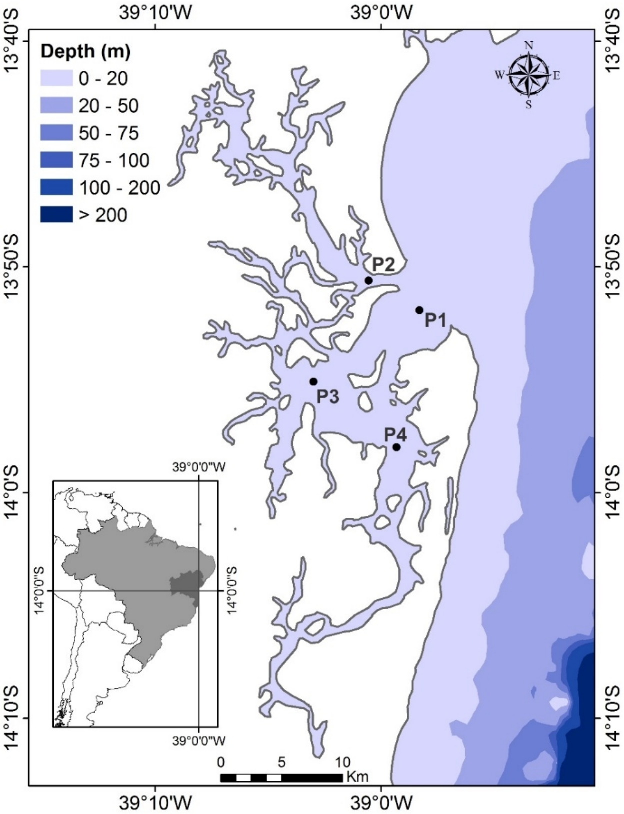

Figure 1 - Map showing the location of the samples sites (P1-P4) with occurrences of *Navicula pelagica* Cleve in the Camamu Bay, Brazil.

To the phytoplankton analysis, samples of 1 L (12 total samples) were collected at the subsurface (at a depth of about 0.5 m) using a Van Dorn bottle and phytoplankton net hauls with a mesh of 20 µm (250 mL) and stored in dark polyethylene bottles, fixed with 1% lugol. The specimens were observed on slides under a microscope (Olympus® trinocular CX31RTS5) equipped with a digital camera (QImaging GO-3, QImaging) and with the image capture software QCapture Pro (QImaging). Taxonomic identification was performed according to Hasle & Syvertsen (1996) and Throndsen *et al.* (2007). To determine the cell densities (cells L^{-1}) of the species, the Utermöhl method (1958) was employed using sedimentation chambers of 50 or 100 mL, counting the entire bottom of the chamber, under an inverted microscope (Motic AE 2000).

For ecological niche modeling, 160 records of the occurrence of *Navicula pelagica* Cleve were obtained from the Global Biodiversity Information Facility (GBIF) <https://www.discoverlife.org/mp/20m?kind=Navicula+pelagica> and through a bibliographic review (Appendix 1). Their occurrence records in Camamu Bay was not considered in the model. Environmental data were obtained from the Bio-Oracle database (Tyberghein *et al.* 2012, Assis *et al.* 2017) with a resolution of 5.0 arcmin (about 10 km). A geographic filter was used to reduce spatial autocorrelation, and only points with a minimum distance of 10 km were considered. Only variables with a correlation lower than 0.8 were selected (i.e., pH, salinity, silicate, sea surface temperature range, and sea-surface temperature minimum).

Modeling was performed using R software (R Core Team 2018), using the Model-R interface (Sánchez-Tapia *et al.* 2018). To evaluate the statistical performance of the calibrated models, a k-fold partitioning method with three partitions was used (Fielding & Bell 1997). Model performance was assessed using the True Skill Statistic (TSS) (Allouche *et al.* 2006) as threshold-dependent indices, and the Area Under Curve (AUC) was used as a threshold-independent evaluation (Liu *et al.* 2011). The threshold was the value that maximized the sum of sensitivity and specificity that produced the most accurate predictions (Jiménez-Valverde & Lobo 2007). The algorithms Bioclim, Maxent, RandomForest (RF), Boosted Regression Tree (BRT) and Support Vector Machines (SVM) were used; subsequently, a consensus model (ensemble) was developed, comprising the mean values from of the models of all applied algorithms with TSS > 0.7.

Results and discussion

The samples were collected during a period of occasional rainfall of, in total, 93 mm over the 30 days before sampling in Camamu Bay. The mean water temperature was 29.5 °C, mean salinity was 32, mean transparency was 2.6 m, and low concentrations of dissolved inorganic nutrients were observed (Table I).

The analyzed specimens (approximately 300 cells) were rectangular, with rounded angles in pleural view, the pervalvar axis measured 7.9-9.5 µm, and the apical axis measured 22-25 µm; the cells showed an evident central nucleus and two comma-shaped chloroplasts, one on each side of the nucleus (Fig. 2). Chains of about 35 cells each were observed, showing typical spiral rotation (Fig. 2). Using phase contrast optics, delicate hyaline seta-like extensions were observed emerging from the mucilage between cells in some specimens (Fig. 2). These characteristics are in line with the description of the species by Syvertsen (1984): “the cells of

Table I Abiotic variables (minimum-maximum and mean ± standard deviation) of water collumn, and cell densities of *Navicula pelagica* Cleve at the samples collected at four sites in Camamu Bay, Brazil.

Variables	Samples sites			
	P1	**P2**	**P3**	**P4**
pH	7.85-8.26 (8.23 ± 0.11)	7.75-8.46 (8.16 ± 0.37)	8.1-8.41 (8.24 ± 0.15)	8.26-8.35 (8.30 ± 0.45)
Temperature (°C)	28.41-29.58 (29.1 ± 0.38)	29.79-29.92 (29.87 ± 0.07)	29.84-30.19 (29.8 ± 0.17)	29.78-30.23 (30.07 ± 0.25)
Salinity	30.2-34.39 (32.68 ± 1.63)	30.41-31.5 (30.91 ± 0.54)	30.1-31.06 (30.65 ± 0.49)	30.27-31.68 (30.7 ± 0.79)
Transparency (m)	3.0-3.2 (3.12 ± 0.10)	2.0-2.5 (2.16 ± 0.28)	1.3-1.7 (1.46 ± 0.21)	1.3-2.3 (1.9 ± 0.52)
Nitrite (µM)	0.52-0.57 (0.53 ± 0.02)	0.51-0.52 (0.51 ± 0.005)	0.51-0.52 (0.52 ± 0.005)	0.51-0.52 (0.51 ± 0.005)
Nitrate (µM)	0.79-1.01 (0.84 ± 0.02)	0.70-0.88 (0.76 ± 0.10)	0.65-0.88 (0.77 ± 0.11)	0.74-0.92 (0.85±0.09)
Silicate (µM)	0.79-1.96 (1.06 ± 0.47)	1.30-2.59 (1.73 ± 0.74)	1.93-2.99 (2.27 ± 0.62)	1.43-1.87 (1.61 ± 0.23)
Phosphate (µM)	0.41-0.43 (0.42 ± 0.01)	0.40-0.41 (0.40 ± 0.005)	0.42-0.45 (0.43 ± 0.015)	0.41-0.42 (0.41 ± 0.005)
Density (cells L^{-1})	$1.38x10^2$-$7.16x10^2$ ($4.74 \pm 3.0\ x10^2$)	$3.91x10^2$-$3.86x10^2$ ($3.57 \pm 0.54\ x10^2$)	$2.76x10^1$-$1.38x10^2$ ($2.09 \pm 0.69\ x10^2$)	$2.49x10^2$-$2.76x1^2$ ($2.47 \pm 0.30\ x10^2$)

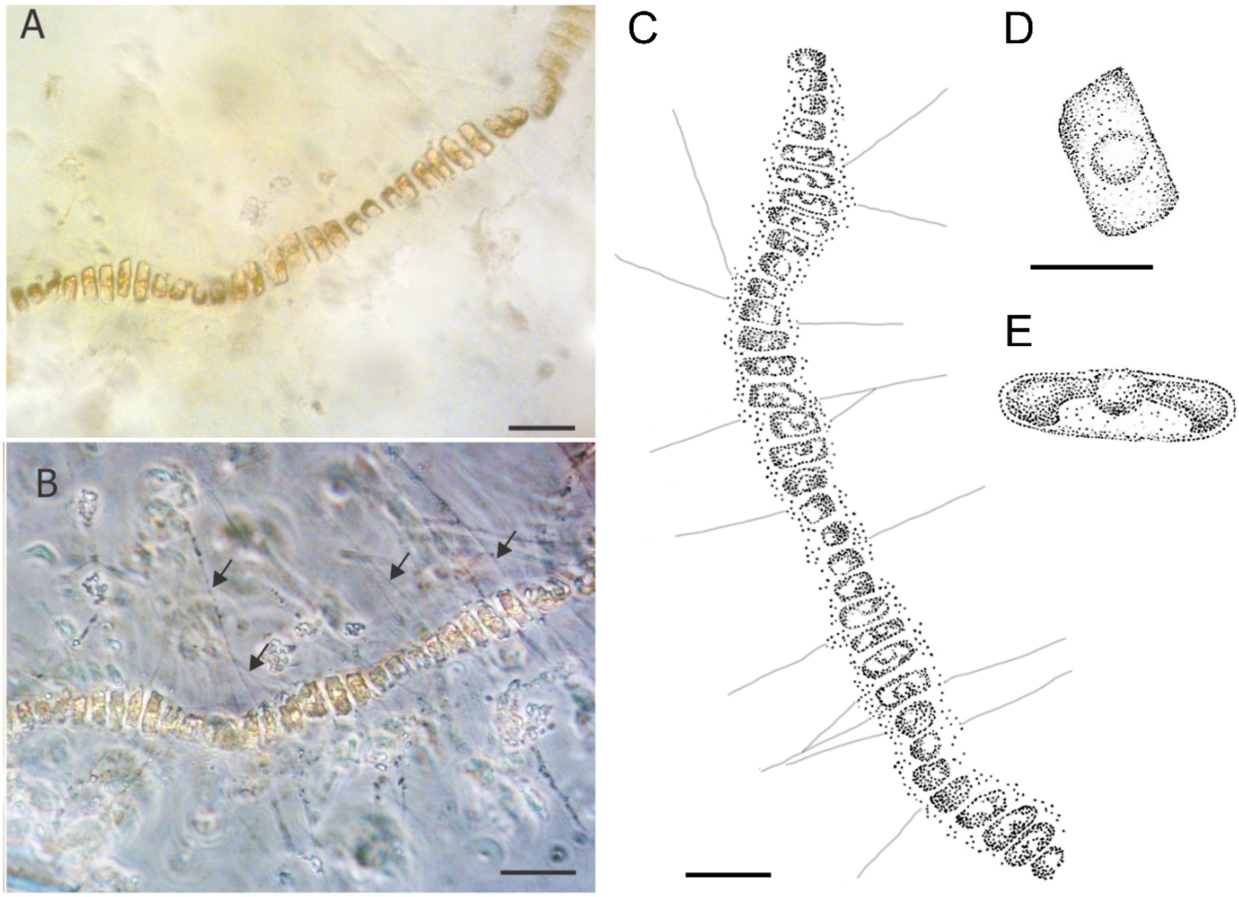

Figure 2. General aspect of *Navicula pelagica* Cleve: (A) Chains of about 35 cells, showing typical spiral rotation pattern, observed in light microscopy; (B) 'setae' (indicated by the black arrows) observed in phase contrast microscopy; (C) Schematic representation of chain organization pattern of the specimens observed in the Camamu Bay, (D) detail of evident central nucleus, and (C) two comma-shaped chloroplasts, one on each side of the nucleus. Scale bar = 40 µm.

Navicula pelagica Cleve are attached in long chains, sometimes of more than 50 cells each, by mucilage from which emerge seta-like structures that make the chains superficially similar to *Chaetoceros*. However, differing mainly by the arrangement of the cells in the chains, which are rotated about 50° on the colony axis relative to the neighboring cell in *N. pelagica*."

Cell density ranged from 1.38 x 10^2 to 7.16 x 10^2 (mean = 3.21 x 10^2; standard deviation = ±1.86 x 10^2) cells L^{-1} (Table I). As expected, the average cell density of *Navicula pelagica* Cleve recorded in Camamu Bay was lower than that in meltwater from Arctic sea where this species may be dominant (Michel *et al.* 1993, Norrman & Andersson 1994) and is commonly associated with other diatoms during the early-spring blooms (Wiktor & Szymelfenig 2002, Różańska *et al.* 2009). The low concentrations of dissolved nutrients in the bay was likely not favorable to sustain high densities of this species, considering that higher concentrations of nutrients are typically associated with greater diatom abundance, including *N. pelagica* (Lara *et al.* 1994, Norrman & Andersson 1994). The highest densities recorded so far were 0.1 × 10^3 to 11 × 10^3 cells L^{-1} in Resolute Bay, Canada (Riedel *et al.* 2003), and 0.2 × 10^3 cells L^{-1} in the Norwegian Arctic (Assmy *et al.* 2013). In melting water of sea ice in Canada, *N. pelagica* accounted for up to 14% of the total phytoplankton abundance in Hudson Bay (Michel *et al.* 1988) and 3-39% in the Amundsen Gulf (Poulin *et al.* 2011).

The generated models showed very good performance (AUC: mean = 0.967 ± 0.039 standard deviation; TSS mean = 0.884 ± 0.089 standard deviation), indicating a high accuracy (see Allouche *et al.* 2006). Areas with the highest environmental suitability were located in the north temperate zone (higher than approximately 23.5° N) and at the Arctic Circle (higher than 66° 33′ 44″ N), as well as in the south of Latin America, particularly in the vicinity of the Falkland Islands, whose temperate zone conditions are environmentally close the conditions of the native habitat of the *Navicula pelagica* Cleve of the Arctic sea. Furthermore, some areas with low environmental suitability were observed in tropical regions, being the largest extensions in South America, both at the Pacific coast and at the Atlantic coast. Environmental suitability at the Brazilian coast for the development of *N. pelagica* was approximately 12% (Fig. 3). However, we emphasize that even sites with a minimum environmental suitability for non-indigenous species may be vulnerable to invasion.

Despite this intriguing first occurrence in tropical waters of the Atlantic, other records of *Navicula pelagica* Cleve in tropical and subtropical regions were reported previously from the Bay of Bengal (Paul *et al.* 2007), from Port Blair, India (Sahu *et al.* 2014), and from the Mexican Pacific (Cordero & Mendieta 2006, Licea *et al.* 2016). These are the only records in which the species did not occur associated with meltwater temperatures, where low concentrations of dissolved inorganic nutrients were also recorded, such as in Camamu Bay. However, *N. pelagica* is only mentioned on checklists of phytoplankton communities of these areas, there is no discussion about its occurrence in systems with higher water temperatures, such as tropical environments (> 20 ° C), and only with these data it is not possible to conclude on potential expansion of its distribution geographical area. Considering the global network of sea traffic (see Kaluza *et al.* 2010) and oil and gas platforms on the continental shelf adjacent to Camamu Bay which receive shipped goods from different parts of the world (ANP 2005), it may be assumed that *N. pelagica* was accidentally introduced into the bay via ballast water, as ballast water-exchange is a potential source of introduction of novel species (Burkholder *et al.* 2007). It is also worth mentioning that a metagenomic study of cyanobacteria in Camamu Bay showed a community dominated by a *Synechococcus* lineage typically found in polar/subpolar waters (Affe *et al.* 2018b).

Introduction of non-indigenous species may have different impacts on estuarine systems, affecting negatively their functioning, and may compromise the structure and composition of the phytoplankton community (Simberloff 2005, Silva *et al.* 2012). Unfortunately, we did not have success with SEM analyzes, which prevented a more detailed study of the frustules. However, the morphological patterns of the examined specimens in the present study, strongly suggest that we found *N. pelagica*. Further studies are needed to investigate the occurrence of *N. pelagica* in Camamu Bay. We highlighted the importance of local monitoring, including analysis of ballast water of ships arriving at the oil and gas platforms on the continental shelf adjacent to the bay. Moreover, we suggest to collect live specimens for culturing under laboratory conditions and to experimentally study the species' ecology regarding temperature variation.

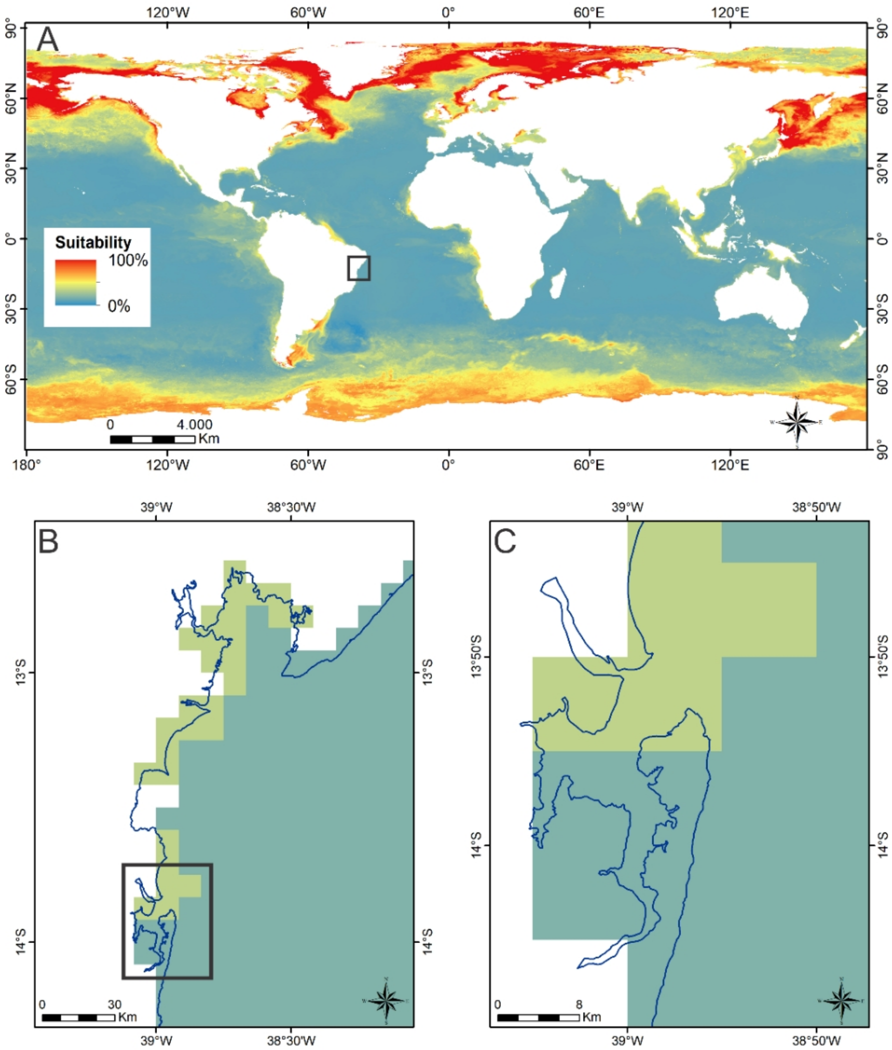

Figure 3. Map of ecological niche model of *Navicula pelagica* Cleve (A) in the world; (B) in the Bahia State coast and (C) in the Camamu Bay, Brazil.

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First record of *Navicula pelagica* (Bacillariophyta) in the South Atlantic Ocean: the intriguing occurrence of a sea-ice-dwelling species in a tropical estuary

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ELECTRONIC SUPPLEMETARY MATERIAL

Appendix 1 - Check list of *Navicula pelagica* Cleve occurrence records used for ecological niche modeling

Species	Longitude	Latitude	Source
Navicula pelagica	1.51449	50.7627	GBIF*
Navicula pelagica	-123.65	69.815	GBIF*
Navicula pelagica	31.8172	74.8093	GBIF*
Navicula pelagica	33.405	66.31	GBIF*
Navicula pelagica	33.2383	66.2783	GBIF*
Navicula pelagica	32.99	76.02	GBIF*
Navicula pelagica	-4.54	88.29	GBIF*
Navicula pelagica	33.6617	66.3283	GBIF*
Navicula pelagica	-2.031	88.919	GBIF*
Navicula pelagica	32.404	75.6329	GBIF*
Navicula pelagica	32.9254	76.5361	GBIF*
Navicula pelagica	32.6974	76.0447	GBIF*
Navicula pelagica	32.76	75.47	GBIF*
Navicula pelagica	32.5517	75.125	GBIF*
Navicula pelagica	32.1933	74.4667	GBIF*
Navicula pelagica	32.485	66.8783	GBIF*
Navicula pelagica	154.29	87.9	GBIF*
Navicula pelagica	34.9967	66.2017	GBIF*
Navicula pelagica	33.52	66.32	GBIF*
Navicula pelagica	32.1475	74.7958	GBIF*
Navicula pelagica	32.2573	75.427	GBIF*

Species	Longitude	Latitude	Source
Navicula pelagica	26.007	82.057	GBIF*
Navicula pelagica	19.5	69.49	GBIF*
Navicula pelagica	33.4158	66.6817	GBIF*
Navicula pelagica	19.0012	69.3667	GBIF*
Navicula pelagica	31.6705	74.6034	GBIF*
Navicula pelagica	32.4583	74.8017	GBIF*
Navicula pelagica	18.21	69.3	GBIF*
Navicula pelagica	3.787	88.566	GBIF*
Navicula pelagica	33.3167	66.3033	GBIF*
Navicula pelagica	34.3617	66.415	GBIF*
Navicula pelagica	-0.355	88.507	GBIF*
Navicula pelagica	34.5067	66.4783	GBIF*
Navicula pelagica	-2.03	88.92	GBIF*
Navicula pelagica	-9.496	88.2	GBIF*
Navicula pelagica	35.6883	66.105	GBIF*
Navicula pelagica	31.9683	74.1392	GBIF*
Navicula pelagica	33.6617	66.3283	GBIF*
Navicula pelagica	33.3167	66.3033	GBIF*
Navicula pelagica	33.2383	66.2783	GBIF*
Navicula pelagica	-9.496	88.2	GBIF*
Navicula pelagica	-4.54	88.29	GBIF*
Navicula pelagica	-0.355	88.507	GBIF*
Navicula pelagica	3.787	88.566	GBIF*
Navicula pelagica	-2.031	88.919	GBIF*
Navicula pelagica	-2.03	88.92	GBIF*
Navicula pelagica	154.29	87.9	GBIF*
Navicula pelagica	26.007	82.057	GBIF*
Navicula pelagica	34.9967	66.2017	GBIF*
Navicula pelagica	35.6883	66.105	GBIF*
Navicula pelagica	34.3617	66.415	GBIF*
Navicula pelagica	33.4158	66.6817	GBIF*
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Navicula pelagica	32.485	66.8783	GBIF*
Navicula pelagica	34.5067	66.4783	GBIF*
Navicula pelagica	32.4583	74.8017	GBIF*
Navicula pelagica	32.99	76.02	GBIF*
Navicula pelagica	32.76	75.47	GBIF*
Navicula pelagica	32.5517	75.125	GBIF*
Navicula pelagica	32.1475	74.7958	GBIF*
Navicula pelagica	32.1933	74.4667	GBIF*
Navicula pelagica	31.9683	74.1392	GBIF*
Navicula pelagica	19.5	69.49	GBIF*
Navicula pelagica	19.0012	69.3667	GBIF*
Navicula pelagica	18.21	69.3	GBIF*

Species	Longitude	Latitude	Source
Navicula pelagica	32.9254	76.5361	GBIF*
Navicula pelagica	32.6974	76.0447	GBIF*
Navicula pelagica	32.404	75.6329	GBIF*
Navicula pelagica	32.2573	75.427	GBIF*
Navicula pelagica	31.8172	74.8093	GBIF*
Navicula pelagica	31.6705	74.6034	GBIF*
Navicula pelagica	-164	71.42	Discoverlife**
Navicula pelagica	-162	71.4	Discoverlife**
Navicula pelagica	-158.37	71.2	Discoverlife**
Navicula pelagica	-152.333	71.367	Discoverlife**
Navicula pelagica	-150.07	71.17	Discoverlife**
Navicula pelagica	-148.369	70.367	Discoverlife**
Navicula pelagica	-162.803	56.083	Discoverlife**
Navicula pelagica	-163.217	55.645	Discoverlife**
Navicula pelagica	-166.313	54.405	Discoverlife**
Navicula pelagica	-166.95	58.083	Discoverlife**
Navicula pelagica	-167.448	57.398	Discoverlife**
Navicula pelagica	-169.372	54.895	Discoverlife**
Navicula pelagica	-167.125	61.735	Discoverlife**
Navicula pelagica	-169.538	60.675	Discoverlife**
Navicula pelagica	-169.283	58.85	Discoverlife**
Navicula pelagica	-170.863	60.958	Discoverlife**
Navicula pelagica	-172.493	59.85	Discoverlife**
Navicula pelagica	-173.62	57.152	Discoverlife**
Navicula pelagica	-174.078	60.712	Discoverlife**
Navicula pelagica	-173.753	60.253	Discoverlife**
Navicula pelagica	-175.007	59.745	Discoverlife**
Navicula pelagica	-176.297	62.008	Discoverlife**
Navicula pelagica	-177.075	61.907	Discoverlife**
Navicula pelagica	-178.41	60.807	Discoverlife**
Navicula pelagica	-177.745	59.748	Discoverlife**
Navicula pelagica	141.583	42	Discoverlife**
Navicula pelagica	142	41.5	Discoverlife**
Navicula pelagica	143.003	41.517	Discoverlife**
Navicula pelagica	144	42.5	Discoverlife**
Navicula pelagica	143.983	42	Discoverlife**
Navicula pelagica	144	41.5	Discoverlife**
Navicula pelagica	145	41.5	Discoverlife**
Navicula pelagica	146	41.5	Discoverlife**
Navicula pelagica	147	41.5	Discoverlife**
Navicula pelagica	143.833	40.55	Discoverlife**
Navicula pelagica	144	40	Discoverlife**
Navicula pelagica	144	39.333	Discoverlife**
Navicula pelagica	144	38.667	Discoverlife**

Species	Longitude	Latitude	Source
Navicula pelagica	144	37.333	Discoverlife**
Navicula pelagica	144	36.65	Discoverlife**
Navicula pelagica	85.993	81.83	Discoverlife**
Navicula pelagica	79.67	73.45	Discoverlife**
Navicula pelagica	78.175	75.611	Discoverlife**
Navicula pelagica	76.53	73.75	Discoverlife**
Navicula pelagica	75.73	73.82	Discoverlife**
Navicula pelagica	73.87	73.83	Discoverlife**
Navicula pelagica	70.45	73.78	Discoverlife**
Navicula pelagica	68.43	73.17	Discoverlife**
Navicula pelagica	67.08	71.92	Discoverlife**
Navicula pelagica	66.3	72.87	Discoverlife**
Navicula pelagica	65.2	71.07	Discoverlife**
Navicula pelagica	63.38	70.6	Discoverlife**
Navicula pelagica	64.865	81.38	Discoverlife**
Navicula pelagica	60.17	69	Discoverlife**
Navicula pelagica	58.47	70.57	Discoverlife**
Navicula pelagica	58	69	Discoverlife**
Navicula pelagica	57.4	70.13	Discoverlife**
Navicula pelagica	54.93	69.95	Discoverlife**
Navicula pelagica	54.12	70.2	Discoverlife**
Navicula pelagica	53.52	70.12	Discoverlife**
Navicula pelagica	51.8	70.03	Discoverlife**
Navicula pelagica	49.52	69.82	Discoverlife**
Navicula pelagica	47.53	69.58	Discoverlife**
Navicula pelagica	44.18	69.15	Discoverlife**
Navicula pelagica	52.73	74.08	Discoverlife**
Navicula pelagica	50.28	73.75	Discoverlife**
Navicula pelagica	48.68	73.48	Discoverlife**
Navicula pelagica	47.03	73	Discoverlife**
Navicula pelagica	45.7	72.7	Discoverlife**
Navicula pelagica	43.932	73.32	Discoverlife**
Navicula pelagica	40.987	69.918	Discoverlife**
Navicula pelagica	39.67	72	Discoverlife**
Navicula pelagica	38.669	68.651	Discoverlife**
Navicula pelagica	36.08	69.118	Discoverlife**
Navicula pelagica	35.5	70.267	Discoverlife**
Navicula pelagica	34.42	69.301	Discoverlife**
Navicula pelagica	33.5	69.5	Discoverlife**
Navicula pelagica	21	82.5	Assmy *et al.* (2013)
Navicula pelagica	15.26667	76.91667	Wiktor & Wojciechowska (2005)
Navicula pelagica	-53.4833	69.23333	Dünweber *et al.* (2010)
Navicula pelagica	30	80	Hegseth Sundfjord (2008)

Species	Longitude	Latitude	Source
Navicula pelagica	22.48333	64.08333	lkavalko & Thomsen (1997)
Navicula pelagica	143.9698	44.11925	Mcminn *et al.* (2008)
Navicula pelagica	144.9805	44.06553	Michel *et al.* (1993)
Navicula pelagica	-126.433	70.06667	Morata *et al.* (2011)
Navicula pelagica	19.78333	63.51667	Norrman & Andersson (1999)
Navicula pelagica	-167.867	67.66667	von Quillfeldt *et al.* (2003)
Navicula pelagica	97	75.21667	Riedel *et al.* (2003)
Navicula pelagica	-126.433	70.06667	Rozanska *et al.* (2009)

*<www.gbif.org>
** < https://www.discoverlife.org/mp/20m?kind=Navicula+pelagica>