



Challenges and Opportunities for *in situ* Maintenance of the Native Brazilian Cotton *Gossypium mustelinum* Miers

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The native Brazilian cotton *Gossypium mustelinum* has never been planted. It is tetraploid and may cross with cultivated cotton. Endemic to Northeast Brazil, it was known only to grow in semi-arid areas, but expeditions in 2011, 2016, and 2018 localized plants in preservation areas on the coast of Northeast Brazil (in the States of Paraíba and Pernambuco), as predicted before by niche simulations. New climatic modeling shows that new populations can still be found in the Pernambuco semi-arid area, despite the lack of herbarium and germplasm bank information. Historical data show that the preserved populations are in regions where sympatry has not occurred in the last 47 years. Gene flow is unlikely to be a threat, and communication may foster significantly in *in situ* preservation.

Keywords: cotton, riparian vegetation, pioneer species, preservation area, climatic modeling

INTRODUCTION

Brazil is the center of origin of *Gossypium mustelinum* (*G. mustelinum*), one of the five allotetraploid species of the genus. The species is endemic to Brazil, restricted to the Northeast region of the country, where semi-arid conditions predominate. There is no evidence, not even archeological, of domestication and use of *G. mustelinum*. It is sexually compatible with cultivated cotton species; therefore, it can be used in cotton breeding and is an important genetic resource (Pereira et al., 2012).

To our knowledge, the first written report about native Brazilian cotton was made by Accioli Bettencourt (1798), who describes the presence of two wild cotton trees, one of brown fiber, probably *G. mustelinum*, and the other of white fiber on the margins of the Contas River, where Brazilian native cotton was later localized (Menezes et al., 2014a). The first scientific report of *G. mustelinum* was made by Gardner in 1838, who collected seeds and other plant materials in the municipality of Crato, state of Ceará (CE), whose exsiccatæ were described by Watt (1907). Besides the materials collected by Gardner, Watt refers to another specimen collected in Colombia, by Hutton, in 1853 in La Paila, which he believed to be *G. mustelinum* but, as there has never been any other report of the species there, it may be a case of incorrect botanical classification. A new description was made only in 1916, by Edward Green, an American agronomist who was the superintendent of the Governmental Cotton Service of Brazil, in 1913, on a hill in the municipality of Caicó, State of Rio Grande do Norte (RN; Green, 1916). Four exsiccatæ of *G. mustelinum* have

been deposited by J.M. Fernandes at the Kew Royal Botanical Garden, attributed to the municipality of Coroatá, State of Maranhão, where there was, at that time, an important experimental station (Serviço do Algodoeiro); therefore it is possible that these exsiccatae are derived from seeds brought from Caicó by Green and planted in Coroatá. There have been no other reports of native Brazilian cotton there. Only at the end of the 1960s was the Caicó site rediscovered by researchers of the Agronomic Institute of Campinas (Neves et al., 1968). They considered it a new species and named it *Gossypium chacoensis* (Neves et al., 1968), today considered a synonym of *G. mustelinum*. Other populations were reported by Pickersgill et al. (1975).

Conservation and gene flow have been discussed since 2005, when transgenic cotton was commercially released in Brazil, to answer questions regarding the biosafety of the cultivation of genetically modified cotton, fostering efforts to locate and characterize native and naturalized species. Dozens of expeditions and experiments were undertaken, resulting in the identification of many new populations (Barroso et al., 2010; Alves et al., 2013; Menezes et al., 2014a), as well as new information regarding the species' reproductive aspects (Pereira et al., 2012; Menezes et al., 2014b) and possible interactions with cultivated cotton plants (Alves et al., 2008; Menezes et al., 2014b). Advances were significant, providing important increases in knowledge about the species.

The present paper recounts the discovery of new Brazilian native cotton populations on the coast, estimates the potential geographical distribution, and discusses the impact of sympatry between wild and crop species on *in situ* conservation.

METHODS

Identification of New Populations

The last three expeditions to localize the native Brazilian cotton were made in 2011, traveling to the States of Paraíba (PB), Pernambuco (PE), and Alagoas (AL), followed by one expedition in 2016 to Bahia (BA) PB and PE), and 2018 (PE and PB only). These expeditions were motivated by information regarding the existence of wild cotton plants in the coastal region. From each population, passport data were collected, and *in situ* characterization was made. This characterization included geographic and environmental data, and possible risks to which the populations could be submitted.

The native cotton is neither planted nor used for any purposes, such as spinning or any other use (medicinal, ornamental), based on the expeditions in 2011, 2016, and 2018, and also previous visits to BA (Barroso et al., 2010; Alves et al., 2013; Menezes et al., 2014b), summing hundreds of interviews with people living near the collection sites.

Climatic Modeling

Climatic modeling was used in order to identify regions suitable for the existence of *G. mustelinum*. This was created using the software openModeller Desktop (v.1.1.0; Souza Muñoz et al., 2011). First, an exploratory analysis was conducted, using 13

different algorithms [artificial neural networks, Bioclim, climate space model, ecological-niche factor analysis (ENFA), envelope score, environmental distance, four different GARP models, maximum entropy, niche mosaic, and simultaneous multiple volume (SMV)] in all of them using 19 WorldClim Bioclimatic variables for WorldClim version 2 (Fick and Hijmans, 2017), in arc 30 seconds resolution. The geological coordinates of the populations located by Embrapa were used as modeling inputs. To those, non-redundant data from SpeciesLink (Centro de Referência e Informação Ambiental (CRIA), 2011) were added, these data were identified in two herbaria, from the Universidade Federal de Pernambuco¹ and the Universidade Federal do Recôncavo da Bahia².

In order to accomplish the modeling, 80% of the populations were used to train the models and 20% to validate them. The models that presented the best results (with area under the curve over 0.7) were SMV, GARP best subset (desktop implementation), environmental distance, envelope score, and Bioclim. A consensus model was obtained by averaging, pixel by pixel, the probability of each individual model. The results were used to make maps with the software QGIS v.3.4.12.

Historical and Current Location of Cotton Crops Sympatric With *Gossypium mustelinum*

All the historical data, produced since 1974 of the harvested area of herbaceous cotton (*Gossypium hirsutum* var. *latifolium*) and of mocó cotton (*G. hirsutum* var. *marie galante*) in each municipality of Brazil were obtained using the Produção Agrícola Municipal (Municipal Agricultural Production) and PAM³ databases.

The data on the harvested area of both species were added up year by year, and divided by the surface area of each municipality, in order to obtain the proportion of municipal area to the area where cotton was grown in each year in the historical series. The number of years in which at least 10 hectares of cotton were planted in each municipality was also determined. The data were spatialized using the software QGIS v.3.4.12, in order to make temporal-spatial evaluations possible.

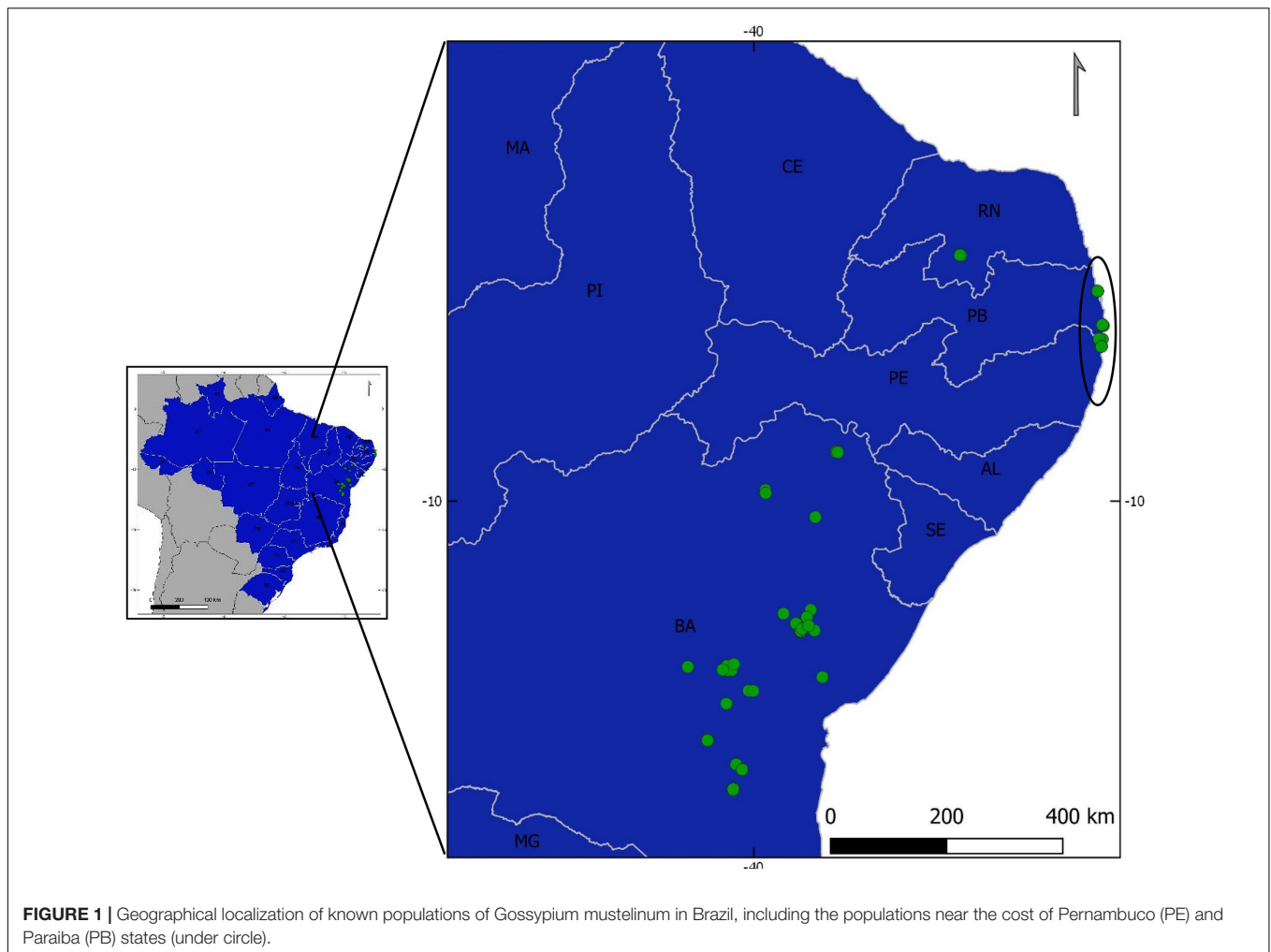
RESULTS

New populations of *G. mustelinum* were found near the coast of the States of PB and PE, as shown in **Figure 1**. In the State of PB, populations were identified in the municipalities of Lucena and Pitimbu. In Lucena, a new population was found near the ruins of the Bonsucesso Church, listed by the Historical and Artistic Heritage Institute of the State of PB. At least 40 *G. mustelinum* plants were located in the church's courtyard, as well as many young plants in the road that gives access to it, and in the way to the Miriri river and beach. In an area of around four hectares, hundreds of plants seemed to be present. Local vegetation was

¹<https://www.ufpe.br/dri>

²<https://www.ufrb.edu.br/porta/international>

³IBGE, <https://sidra.ibge.gov.br/pesquisa/pam/tabelas>



well preserved and satellite images confirmed that little change was made to the local vegetation in the last 10 years.

In Pitimbu, a population was identified, beginning in the margins of the PB-008 road and ending near Praia Bela beach. Most of the individuals were in heavily anthropized areas, being explored by agriculture or real estate expansion, although it is an environmental preservation area, under sustainable management (Área de Preservação Ambiental de Tambaba). Some were found near the borders and interior of forest remnants, suggesting that there should be more plants in areas destined for conservation, rural private properties, and publicly protected areas.

In the State of PE, populations were also found in the municipalities of Goiana and Itamaracá. In Goiana, plants were located in three different places: the first, beginning in the margins of the PE-49 road, between the Tejucopaco and the São Lourenço regions, and in a forest remnant to the north of the road; the second was about 750 m away from the first, south of the previously mentioned road, in a recently urbanized area; the third was on the Carne de Vaca beach. The beach is under an environmental protected area (Área de Preservação Ambiental Santa Cruz) where sustainable use is allowed. During the 2016 expedition, the plants were found to have been slashed and burned and the area had become a coconut plantation. Parts of

old native cotton plants remained near the beach, and tens of adult plants were observed in the surrounding mangrove. The plants were found between 100 and 300 m away from the shore.

The second municipality where plants were located was Itamaracá, an island on the north portion of the Pernambuco coast. Most of the plants were located in a place called Pontal da Ilha, in a vacant lot, very close to the sea. In 2016, we observed that the plants had been burned, but resisted (**Figure 2**). A group of plants was also found in a forest remnant, in the beginning of a mangrove. The only known population in RN, Caicó, with 11 individuals (Barroso et al., 2010) was no longer there in 2015, possibly due to a longer drought. Seeds collected from these plants have been planted and maintained by Embrapa. Despite the incursions made, no other plants were located in AL or RN.

Ecological-niche simulation showed that the areas with the highest probability of occurrence of the species included regions along the coast from the states of RN to Sergipe (SE), as shown in **Figure 3**. It included part of the interior of the states of CE, RN, PB, almost the entire state of PE, the coast of SE, a long strip that extends from north to south of BA, and small portions of the state of Minas Gerais (MG) and Espírito Santo (ES).

Sympatry between remaining native Brazilian cotton populations and the cultivated species has not been found



FIGURE 2 | Native cotton plant that has been burned, near the beach Pontal da Ilha, Itamaracá, Pernambuco, Brazil.

since 1974. A glance at the maps could suggest that the presence of a single Caicó extinct population, with just 11 plants, in the interior of RN, shown in **Figure 4**, was an

exception, but no cultivation was reported or seemed to be practiced nearby.

DISCUSSION

The discovery of the species in coastal regions expands the known range of the species. They had been predicted by former ecological-niche simulations, and realized with the previously known population. The extreme points where *Gossypium mustelinum* has been found on the coast are separated by about 100 km in a straight line. The character of pioneer species of *G. mustelinum* is seen when it occurs in greater numbers in places that have undergone recent anthropization, either by the removal of natural vegetation or by the action of fire. It was more evident at the Contas river, in Bahia, during a 2009 visit after recent deforestation by the river bank where lots of young native cotton plants were seen, which may be due to the ability to regrow from the roots, observed also in plants conducted *ex situ*.

Brazilian Amerindians first cultivated cotton, spun its fiber, and wove it to produce nets and other objects. The history of cotton cultivation and use in Brazil predates European colonization, according to one of three documents produced

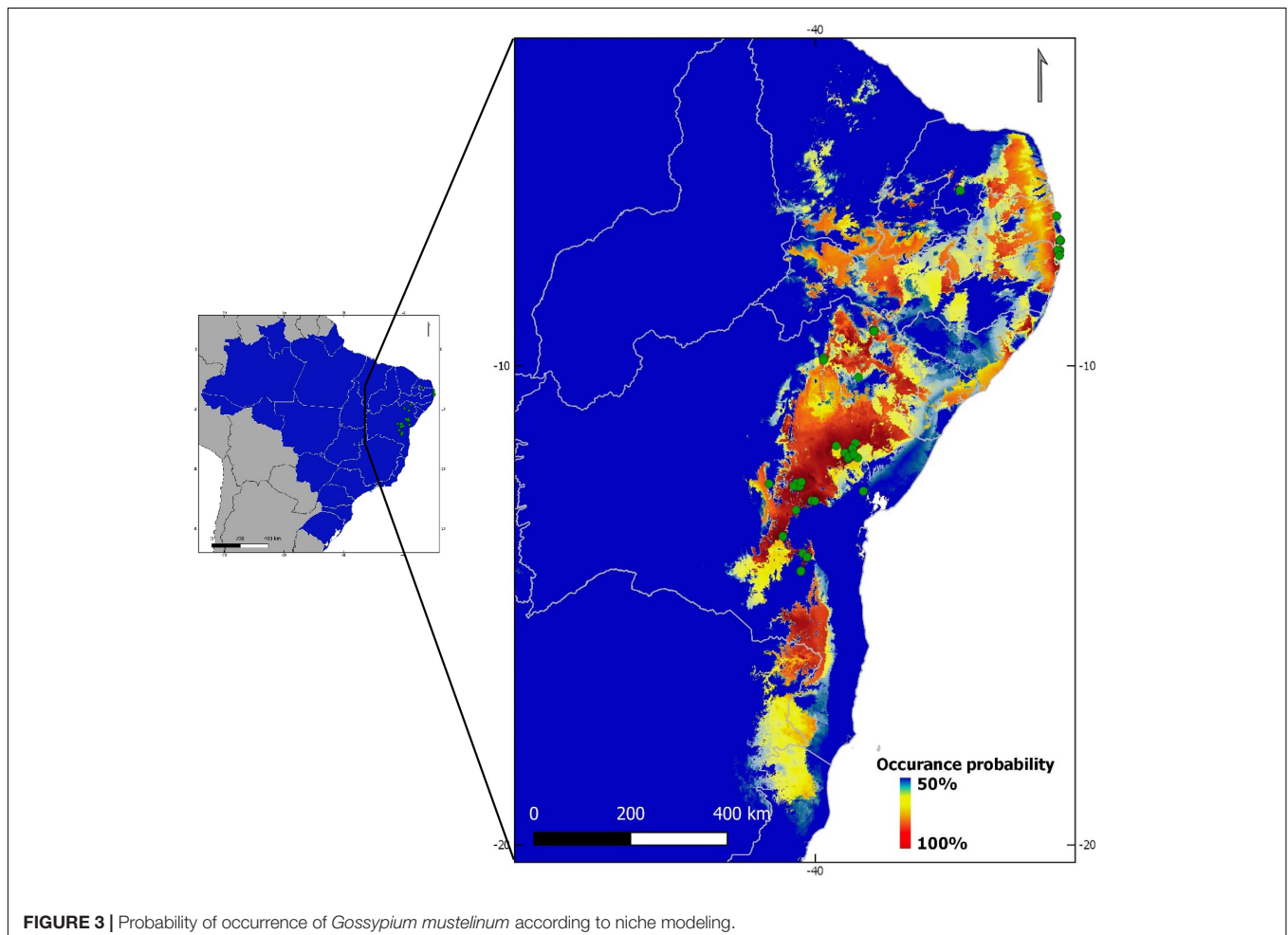
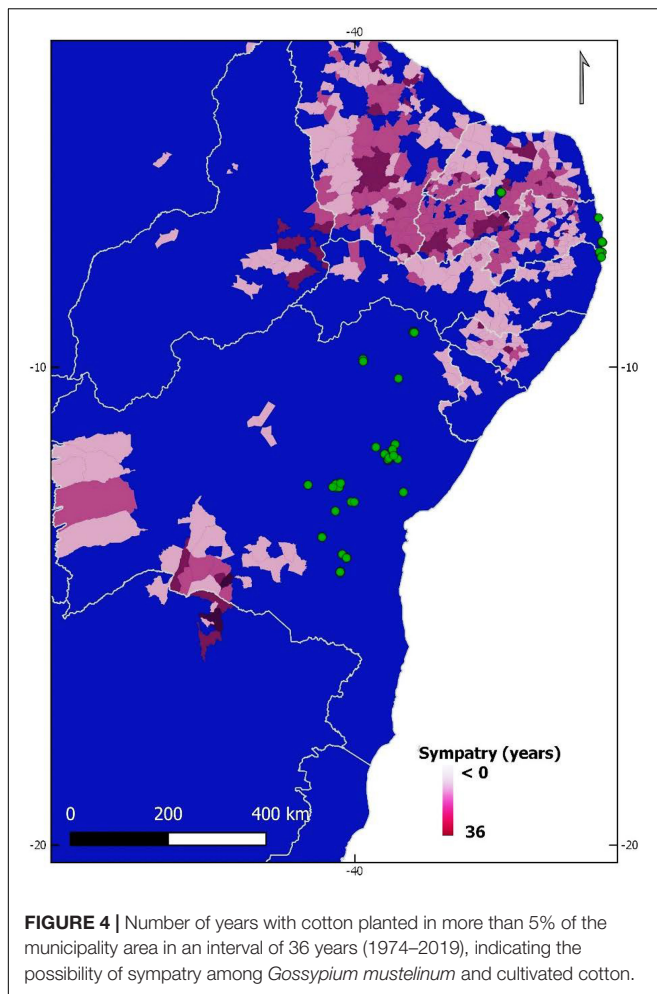


FIGURE 3 | Probability of occurrence of *Gossypium mustelinum* according to niche modeling.



by the Portuguese when they arrived on Brazilian territory in 1500, “Relação do Piloto Anônimo” (Accioli Bettencourt, 1798), where cotton cultivation and sleeping on hammocks were described. The cotton species cultivated at the time was *Gossypium barbadense*, native to the coast of Peru and Ecuador. The species would have been brought to the Amazon basin by human migratory movements and spread throughout Brazil very early on (Giband et al., 2010). Cotton was cultivated wherever farming was practiced, including the Northeast region of the country, such as BA, Itamaracá Island, and PE (Sousa, 1927; Prado, 1945; Mello and Albuquerque, 1997).

When the country was divided into hereditary captaincies (1534), exportation to Europe was reported. Cotton farming expanded in Brazil between the end of the 18th century and the beginning of the 19th century, when demands increased due to the Industrial Revolution. The main producers were also located in the Brazilian Northeast region, mainly in the States of Maranhão and PE (to which the production was transported to the current States of PB, AL, and RN). Production declined due to competition with US cotton. In the 19th century, the cotton mocó, *G. hirsutum* var. *marie galante*, gradually replaced *G. barbadense* in the interior of Northeast Brazil. It was widely

cultivated in the semi-arid region of the Northeast until the 1980s, when socioeconomic and phytosanitary issues caused its decline and almost disappearance as an economic activity (Menezes et al., 2010, 2017). A smaller area of upland cotton (*G. hirsutum* var. *latifolium*) was also cultivated in the coastal area of the region, which is wetter.

The absence of marked sympatry between the native and cultivated cotton during the last 47 years may explain why hybrids are not frequently found, and gene flow is not so important for the conservation of the species, as it seems to be in Mexico (Wegier et al., 2011). Pollen competition acts as a prezygotic barrier reducing fecundation of the native Brazilian cotton by upland cotton, therefore diminishing gene flow impact (Pereira et al., 2012).

The only hybrids found during these expeditions were among *G. mustelinum* and *G. barbadense* (Alves et al., 2008; Menezes et al., 2015). The plants of *G. barbadense* were present as dooryard plants in the vicinity of some native cotton plants.

There were reports of brownish fiber among cultivated mocó fields during the period when it was widely cultivated, before 1980s, and it is possible that native Brazilian cotton plants had been eventually destroyed as a source of pollen which could cause contamination of the fiber color.

In some of the regions marked as probable occurrence points by niche simulation, there were no known populations of the species, notably Alagoas, where scarce native vegetation remains, and previous expeditions did not find any plants. New expeditions can verify reports of occurrence in other coastal towns in the states of PE, RN, and AL. There is no more information available in herbaria or germplasm banks. Almost the entire inland region has semi-arid climatic conditions. In these locations the species is almost always found in places with a greater abundance of water, such as in riparian forests of intermittent streams and near floodplains. On the coast, the plants were not in the vicinity of more durable water sources. This is probably due to the higher rainfall present in coastal regions.

The species has never been found in places where other more aggressive pioneer species are present, notably castor bean (*Ricinus communis*), prosopis (*Prosopis juliflora*), and leucena (*Leucaena leucocephala*), exotic species that are much more competitive.

Native Brazilian cotton is very susceptible to pests, such as nematodes, bacteria, and viruses that infest the cultivated cotton (Menezes et al., 2014b), therefore it is possible that the proximity to cotton cropping prejudices the native species more due to pest transmission than due to gene flow. The exotic pink bollworm (*Pectinophora gossypiella*), introduced with cotton cultivation, is the main phytosanitary concern, based on *in situ* observations. Mocó cotton has been the main cultivated cotton type in this region, which boll-weevil (*Anthonomus grandis*) reached during the 1980s, and its cultivation sharply declined (Menezes et al., 2010). The destruction of some native cotton plants might have been an efficient measure to reduce the population of this pest.

The plants newly found within conservation and touristic areas open opportunities for conservation, since out of them governmental efforts to supervise native plant conservation are not yet established. Within conservation areas, even when

sustainable use is allowed, civil construction has to be requested and analyzed, and any concession may involve conservation of native trees. It is also possible to maintain them as ornamental plants.

Brazilian law 12.727/2012, known as the Brazilian Forest Code, establishes that private farms must preserve native vegetation, with the proportion of protected area depending on farm size, and that riparian vegetation must be preserved, to variable extents. Those that are not preserved must be restored. *G. mustelinum* is highly indicated for use in the regions where its natural distribution is predicted, since those regions aggregate climate and soil conditions ideal for the species. Seedling production may be emphasized aiming either at the replacement of natural vegetation or even animal feeding, since it is palatable and consumed by cattle and sheep.

Ex situ, some plants of the species are conserved by Embrapa, in greenhouses, and seeds are conserved in negative temperatures. *In situ* conservation is being fostered by contacting both conservation area managers and municipalities.

DATA AVAILABILITY STATEMENT

Georeferencing data on native Brazilian cotton is available at <http://alelobag.cenargen.embrapa.br/AleloConsultas/Home/index.do>

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AUTHOR CONTRIBUTIONS

NC prepared geographical data. PB and LH realized the expeditions and wrote and discussed the manuscript. PB reviewed the species history and made the maps. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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