v. 2, n. 3, 2022

Journal of
Agricultural
Sciences
Research

TERRITORIAL ZONING OF BRAZILIAN AREAS FAVORABLE TO *Anastrepha curvicauda* (DIPTERA: TEPHRITIDAE) IN PAPAYA CROP

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Abstract: *Anastrepha curvicauda* (Diptera: Tephritidae) (syn. *Toxotrypana curvicauda*) is one of the main fruit flies of papaya crop abroad. The insect is an absent quarantine pest (AQP) in Brazil. However, due to its great potential to attack the fruit crop, with economic and social impacts, and because it is present in areas of Venezuela and Colombia, the insect was prioritized among the 20 AQPs for prospective research. The use of ecological niche modeling and geoprocessing techniques, considering respectively the algorithm Genetic Algorithm for Rule-set Production (GARP) in OpenModeller platform and ArcGIS, has contributed to obtaining georeferenced information on national municipal areas favorable to the occurrence of insect pests. Information from technical-scientific literature and from national and international databases was used. This work presents the territorial zoning of Brazilian areas favorable to *A. curvicauda* in papaya crop, considering ecological niche modeling in GARP, ArcGIS and information from international/national databases on papaya crop, municipalities and climatic factors (GBIF, SIDRA/IBGE, BDMEP/INMET). Suitable areas for the insect were identified in all geographic regions of the country, predominantly in municipalities of the Southeastern, Northeastern, and Southern regions. Suitable microregions of the states were also identified, allowing the observation of their respective municipal concentrations presenting this favorability. The federation units that showed greater municipal favorabilities for the occurrences of this AQP in papaya were Bahia, Minas Gerais, São Paulo, Rio Grande do Sul, Paraná, and Espírito Santo. The results contribute to national phytosanitary defense strategies aimed at preventing the entry of this absent quarantine pest in Brazil.

Keywords: Fruit fly, GIS, Open Modeller, absent quarantine pest, crop protection.

INTRODUCTION

The papaya fruit fly *Anastrepha curvicauda* (Gerstaecker, 1860) (syn. *Toxotrypana curvicauda*) (Diptera: Tephritidae) is considered one of the main pests of papaya crop abroad (ALUJA et al., 2000; NORRBOM et al., 2018). Currently, the insect is present in North America (Florida Peninsula, Southern Texas, and Mexico), Central America and the Caribbean, and South America (CABI, 2021; AUSTRALIA.PLANT HEALTH, 2021; MARTINEZ & BURBANO, 2006; BOSCÁN & GODOY, 1998). The presence of the papaya fruit fly in South America occurs in areas of Venezuela and Colombia. *Anastrepha curvicauda* was presented by the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA) as an absent quarantine pest (AQP) in the Normative Instruction number 39, of October 1st, 2018 (BRASIL.MAPA, 2018) and prioritized by Embrapa and the Department of Plant Health - Secretary of Agricultural Defense/MAPA (DSV-SDA/MAPA) among the 20 most important AQPs for prospective research (FIDELIS et al., 2018). In this context, information that contributes to prospecting the zoning of areas in the country favorable to the establishment of *A. curvicauda* is an important instrument to guide monitoring and other preventive control strategies for the entry of this pest into the country. The use of ecological niche modeling techniques for insect pest (SANTANA, 2009) based on the Genetic Algorithm for Rule-set Production (GARP) algorithm (SCACHETTI-PEREIRA, 2002), available at the OpenModeller platform (SOUZA et al., 2011; CRIA, 2021), has enabled the identification of areas favorable to the maintenance of populations of insect-pest species of agricultural importance (JACOMO et al., 2020, 2021). The determination of these places are carried out from the identification of areas already affected by the insect pest. This information can be prospected in technical-scientific literature and/or databases, such as that made available by the international network Global Biodiversity Information Facility (GBIF) (GBIF, 2021). GARP model input data makes use of a survey of previous information that, later, is incorporated into an information plan of the Geographic Information System (GIS), representing the geographic points of occurrence records of the species in focus. Other representative plans of climatic factors capable of guaranteeing the capacities for survival, development, and generation of offspring will be also considered. The papaya crop, the main host of *A. curvicauda*, is of great economic importance for Brazil. The country is the second world producer of this crop and the crop areas are present throughout the national territory, with the highest productions recorded in the Northeastern (54.9%) and Southeastern (40.3%) regions (EMBRAPA. CNPMF, 2021; ATLASBIG, 2021). In 2019, the largest national producers were the states of Espírito Santo, Bahia, Ceará, Rio Grande do Norte, and Minas Gerais, with the states of Ceará, Espírito Santo, Mato Grosso do Sul, Bahia, and Rio Grande do Norte standing out as those with higher revenue (EMBRAPA. CNPMF, 2021). For this reason, it is equally important to follow up the evolution of the area planted with this crop, in order to identify places potentially favorable to a greater availability of preferential food for *A. curvicauda* in the country. Jacomo et al. (2021) provided the worldwide ecological niche estimate for *A. curvicauda* by GARP modeling in OpenModeller. In this work, the occurrence points of *A. curvicauda* were obtained from those available on the GBIF platform and, afterwards updated according to data available at Cabi website (Cabi, 2021). It also considered information on precipitation, temperatures (maximum, average, and minimum), obtained from WorldClim2 (FICK; HIJMANS, 2017), as well as relative humidity obtained from Willett et al. (2017; 2018); both replaced for Brazilian territory by its national average data, from those retrieved from the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology (INMET) considering the period from 1961 to 2018 (INMET, 2020). Jacomo et al. (2021) also presented Brazilian areas with the presence of papaya crops. However, they did not provide the zoning of areas favorable to the insect in Brazil for this crop, which could be enabled by a new crossing in GIS ArcGIS; as has been done for other quarantine and exotic insect pests of economic importance (MINGOTI et al, 2017, 2018; PESSOA et al., 2016, 2019). This work presents the zoning of areas favorable to the development of *Anastrepha curvicauda* (Diptera: Tephritidae) considering the estimate of the ecological niche of this insect in Brazil, obtained using the GARP algorithm in the OpenModeller platform, and the presence of papaya crop in the country.

MATERIAL AND METHODS

The estimate of the ecological niche of *A. curvicauda* in Brazil by GARP modeling in OpenModeller was obtained from the section of the national territorial borders carried out from the estimate of the insect's world niche, provided by the same algorithm on the same platform by Jacomo et al. (2021). Thus, the occurrence points of *A. curvicauda* were obtained from those available on the GBIF platform and updated according to Cabi (2021). It also considered information on precipitation, temperatures (maximum, average, and minimum) obtained from WorldClim2, as well as on relative humidity obtained from Willett et al. (2017; 2018), which were replaced by representative average data of the Brazilian territory obtained from those retrieved from the Meteorological Database for Teaching and Research (BDMEP) of the

National Institute of Meteorology (INMET) considering the period from 1961 to 2018 (INMET, 2020). For the generation of data in the Brazilian territory, files in text type format followed by standardization and conversion to point type geodatabase in ArcGIS application were used. Subsequently, interpolations were performed using the simple cokriging method, considering a grid of points of 100 km apart as an auxiliary variable and monthly average temperatures, obtained considering the period from 1950 to 1990 by Álvares et al. (2013). The processing was performed in GIS ESRI ArcGIS v.10.7, adopting the WGS 84 Reference System in geographic coordinates with a pixel equal to 10 min. or 0.1667°.

Municipal data for areas with papaya crop were obtained from retrieved information from Jacomo et al. (2021) via the IBGE Automatic Recovery System (SIDRA/IBGE), in the Municipal Agricultural Survey for the year 2017 and in the Agricultural Census of 2017; both from the Brazilian Institute of Geography and Statistics (IBGE). Subsequently, the data were standardized using Microsoft Excel spreadsheets and joined to each municipality of the shapefile of the country's municipal grid of 2018 (IBGE, 2018). The results were presented in ecological niche classes of *A. curvicauda* in Brazil, identifying the places with papaya crop, through the ESRI ArcGIS v.10.7 GIS, adopting SIRGAS 2000 Reference System and Polyconic Projection System (IBGE, 2019). The areas identified at the intersection of ecological niche areas of the insect pest with those of occurrence of papaya crop were hatched to enable visual identification on the map generated for the zoning of areas favorable for the insect in this crop. These areas were identified and made available in a Microsoft spreadsheet, allowing the identification of municipalities, microregions and states apt to the occurrence and establishment of the pest in the country.

TERRITORIAL ZONING OF BRAZILIAN AREAS FAVORABLE TO *Anastrepha curvicauda* IN PAPAYA CROPS AND ARISING DISCUSSIONS

The zoning of Brazilian areas favorable to *Anastrepha curvicauda* was obtained considering the estimation of its ecological niche by GARP algorithm in the OpenModeller platform and the presence of papaya crop in the country (**Figure 1**).

Areas favorable to the occurrence of *A. curvicauda* were observed close to the Brazilian borders with neighboring countries, mostly with Bolivia, Guyana, French Guiana, Peru, Suriname, and Venezuela; although they are also present in smaller border areas, or in sparse areas, observed close to Colombia, Paraguay, and Argentina. It is worth noting that the insect is present in areas of Venezuela and Colombia; therefore, the border areas indicated in this zoning must have intensified monitoring.

The federation units with the highest number of municipalities favorable to the development of *A. curvicauda* in papaya crop were Bahia (68 municipalities), Minas Gerais (50 municipalities), São Paulo (48 municipalities), Rio Grande do Sul (42 municipalities), and Paraná (32 municipalities) (**Table 1**). However, the highest concentrations of municipalities with favorable conditions by state microregions were different: in the state of Bahia they were concentrated in 13 microregions, in the state of Paraná they were concentrated in nine microregions, and in the state of Rio Grande do Sul in six (**Table 1**). In this context, this concentration of municipalities in a smaller number of microregions can be an indicator of the impact that could occur in the event of a future occurrence of the pest, given that the states of Bahia and Ceará are big national papaya producers.

However, when observing the number

Areas favorable to *Anastrepha curvicauda* according to ecological niche by GARP algorithm and the presence of areas planted with papaya crop

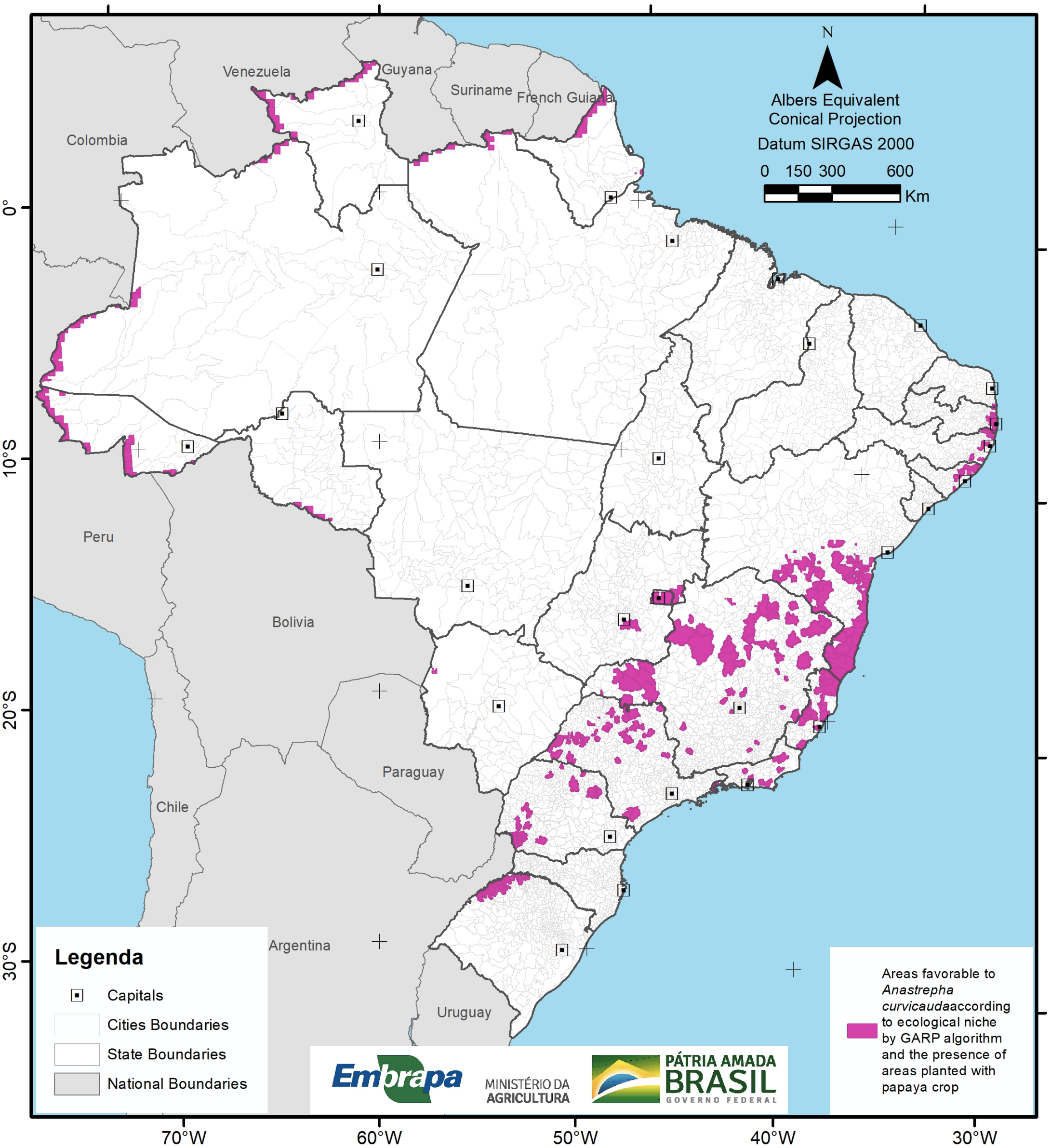

Figure 1. Zoning of Brazilian areas favorable to *Anastrepha curvicauda* obtained according to the estimate of the insect's ecological niche by GARP algorithm and the presence of areas planted with papaya crop.

States	Cities	Micro-regions
Acre	14	5
Alagoas	13	3
Amazonas	4	3
Amapá	2	2
Bahia	68	13
Distrito Federal	1	1
Espírito Santo	25	9
Goiás	3	2
Minas Gerais	50	29
Mato Grosso do Sul	1	1
Pará	3	2
Paraíba	14	5
Pernambuco	13	5
Paraná	32	9
Rio de Janeiro	8	8
Rio Grande do Norte	3	1
Rondônia	3	2
Roraima	5	3
Rio Grande do Sul	42	6
São Paulo	48	19
TOTAL	**352**	**128**

Table 1. Numbers of municipalities and microregions by federation unit favorable to the development of *Anastrepha curvicauda* in papaya.

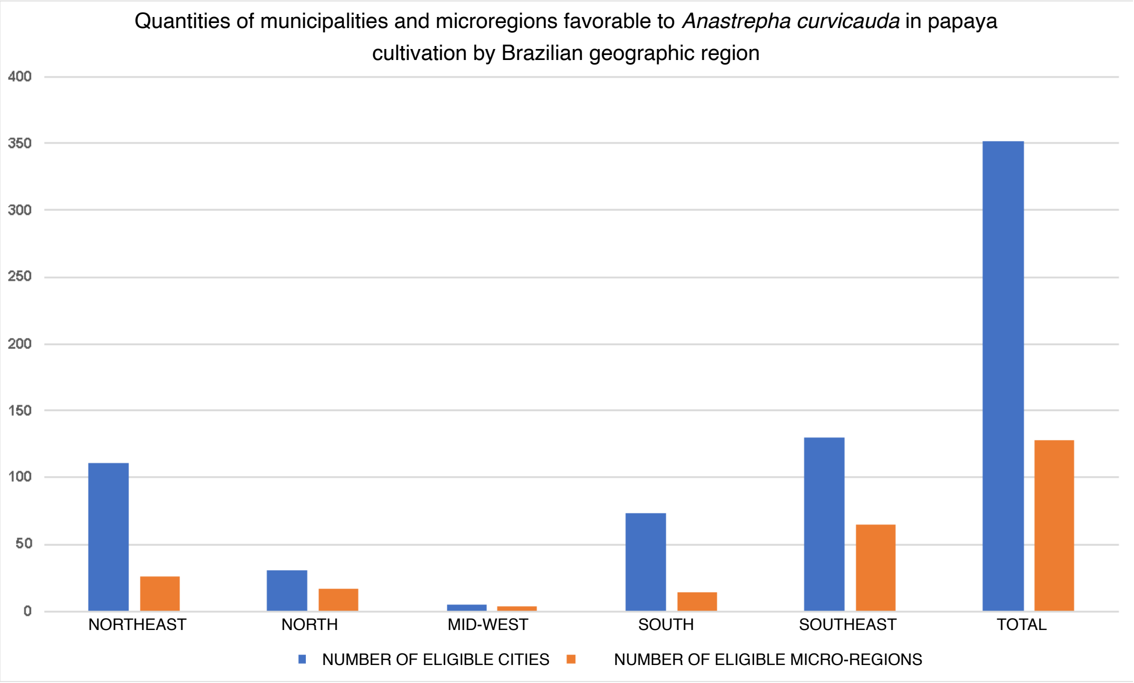

Figure 2. Quantities of municipalities and microregions suitable for *Anastrepha curvicauda* in papaya cultivation by Brazilian geographic region.

of municipalities per state microregion belonging to each Brazilian geographic region, the Southeastern, Northeastern, and Southern regions were more favorable to *A. curvicauda*, with emphasis on the Southeastern region (**Figure 2**). In the Southeastern region, the aptitude for the occurrence of the pest in papaya crops was observed in 131 municipalities in 65 microregions, predominantly in the states of Minas Gerais and São Paulo. In Minas Gerais, 50 municipalities of 28 microregions, namely Aimorés (1), Alfenas (1), Almenara (2), Araçuaí (1), Belo Horizonte (1), Bocaiúva (1), Capelinha (2), Caratinga (1), Curvelo (2), Frutal (2), Governador Valadares (1), Ituiutaba (1), Janaúba (6), Januária (1), Juiz de Fora (1), Montes Claros (3), Pará de Minas (1), Paracatu (3), Passos (1), Peçanha (1), Pedra Azul (1), Pirapora (3), Salinas (2), Sete Lagoas (3), Teófilo Otoni (1), Ubá (1), Uberaba (1), Uberlândia (4), and Unaí (1), were identified as suitable for the insect pest. In turn, São Paulo presented 48 municipalities distributed in 19 microregions, namely Adamantina (10), Araçatuba (1), Araraquara (2), Assis (1), Auriflama (1), Barretos (1), Bauru (1), Birigui (3), Capão Bonito (1), Catanduva (1), Dracena (3), Franca (1), Jaboticabal (4), Novo Horizonte (1), Pirassununga (1), Presidente Prudente (7), Registro (1), Ribeirão Preto (2), and São José do Rio Preto (6). The predisposition of 25 municipalities of nine microregions was also observed (namely, Afonso Cláudio (2), Colatina (1), Itapemirim (2), Linhares (4), Montanha (4), Nova Venécia (3), Santa Teresa (4), São Mateus (4), and Vitória (1)) in the state of Espírito Santo to the occurrence of *A. curvicauda* in papaya; which also requires attention, given that this state is the largest national producer of this fruit, with the highest yield of the crop. In the state of Rio de Janeiro, this aptitude was observed in eight municipalities of the microregions of Baía da Ilha Grande (1), Campos dos Goytacazes (1), Lagos (1), Macacu-Caceribu (1), Macaé (1), Rio de Janeiro (1), Santo Antônio de Pádua (1), and Vassouras (1). In the Northeastern region, aptitudes were observed in 111 municipalities of 27 regions, predominantly highlighting the aptitude of the state of Bahia; as previously mentioned. In this state, the favorabilities for the occurrence of the insect pest were observed in the microregions of Brumado (5), Feira de Santana (1), Guanambi (6), Ilhéus-Itabuna (13), Itaberaba (2), Itapetinga (1), Jequié (7), Livramento do Brumado (3), Porto Seguro (17), Santo Antônio de Jesus (1), Seabra (2), Valença (7), and Vitória da Conquista (3). In the state of Alagoas, the suitable microregions were Litoral Norte Alagoano (4), Mata Alagoana (7), and São Miguel dos Campos (2). In the same region, the state of Pernambuco showed aptitude for *A. curvicauda* in papaya in 13 municipalities, distributed in the following microregions of the state: Itamaracá (1), Mata Meridional Pernambucana (2), Mata Setentrional Pernambucana (6), Recife (1), and Vitória de Santo Antão (3). Aptitude was also observed for the state of Rio Grande do Norte, but only for three municipalities of the Litoral Sul microregion. In the Northern region, aptitudes were highlighted in 31 municipalities distributed in 17 microregions, mainly in the state of Acre, with 14 municipalities of five microregions (namely, Brasiléia (3), Cruzeiro do Sul (5), Rio Branco (1), Sena Madureira (3), and Tarauacá (2)). In the state of Amazonas the aptitudes were concentrated in 4 municipalities belonging to the microregions of Alto Solimões (3) and Rio Negro (1), while in the state of Amapá they were observed in the microregions of Macapá (1) and Oiapoque (1)). In the same region, the state of Pará also showed favorability to the occurrence of *A. curvicauda* in papaya, with 14 suitable municipalities distributed in five microregions, namely Guarabira (1), João Pessoa (3), Litoral Norte (4), Litoral

Sul (4), and Sapé (2). The states of Rondônia and Roraima also showed aptitudes for three municipalities (belonging to the microregions of Cacoal (1) and Guajará-Mirim (2)) and in five municipalities distributed in the microregions of Boa Vista (3), Caracaraí (1), and Nordeste de Roraima (1), respectively. In the Southern region of the country, the aptitudes were observed for 74 municipalities, concentrated in 15 microregions. Only the states of Rio Grande do Sul and Paraná showed favorabilities for occurrences of the insect pest in papaya, in 42 and 32 municipalities, respectively. However, these municipalities were concentrated in a few microregions. Six microregions were identified for the Rio Grande do Sul State (namely, Cerro largo (5), Frederico Westphalen (9), Ijuí (1), Santa Rosa (13), Santo Ângelo (4), and Três Passos (10); highlighting the microregions of Santa Rosa, Três Passos, and Frederico Westphalen), while for Paraná nine microregions were identified (namely, Astorga (2), Capanema(8), Cascavel (7), Cornélio Procópio (1), Francisco Beltrão (5), Ibaiti (6), Londrina (1), Pato Branco (1), and Wenceslau Braz (1); mainly concentrated in the microregions of Capanema, Cascavel, Ibaiti, and Francisco Beltrão). In the Midwest region, the aptitudes for the insect were observed only in five municipalities of four microregions. Favorabilities were also identified for the Federal District (Brasília), Goiás State and Mato Grosso do Sul State; mainly in Goiás State, where suitable areas were noticed in three municipalities of two microregions (namely, Entorno de Brasília (1) and Goiânia (2)). Favorability observed for the state of Mato Grosso do Sul was noticed in a single municipality of the Baixo Pantanal microregion.

FINAL COMMENTS

The zoning of Brazilian areas favorable to *Anastrepha curvicauda* in papaya crop was performed considering the estimate of the ecological niche of this insect by the GARP/OpenModeller algorithm and the presence of papaya crop in the country. From this zoning, areas suitable for *Anastrepha curvicauda* in papaya crop in all geographic regions of the country were identified, being 131 municipalities of 65 favorable microregions in the Southeastern region, 111 municipalities of 27 microregions in the Northeastern region, 74 municipalities of 15 microregions in the Southern region, 31 municipalities of 17 microregions in the Northern region, and 5 municipalities from 4 microregions in the Midwestern region. The federation units that exhibited a greater municipal favorabilities to the occurrences of AQP *A. curvicauda* were Bahia (68 municipalities), Minas Gerais (50 municipalities), São Paulo (48 municipalities), Rio Grande do Sul (42 municipalities), Paraná (32 municipalities), and Espírito Santo (25 municipalities). Favorable areas were observed close to the national borders with neighboring countries, most of them close to French Guiana, Suriname, Guyana, Venezuela, Peru, and Bolivia; although they are also present in a smaller or sparse border area observed close to Colombia, Paraguay, and Argentina. Therefore, it is recommended to intensify the monitoring in the areas indicated by this zoning, mainly those close to Venezuela and Colombia.

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