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Zoning Map of Favorable Areas for the Major Occurrence of *Thaumastocoris peregrinus* in Brazil

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Abstract: Native of Australia, *Thaumastocoris peregrinus* (*Eucalyptus* bronze bug) is a *Eucalyptus* insect pest which was firstly detected in Brazil in June 2008. Some studies have shown favorable areas for *T. peregrinus* population outbreaks in Brazil, based on georeferenced-crossing information using geographical information system (GIS). Despite that, it is crucial to both enhance the precision of methods used on georeferenced crossings and update information, in order to enable greater precision toward the identification of propitious areas for the occurrence of the insect. The objective of this study was to identify areas with favorable conditions to occurrence of *Thaumastocoris peregrinus* in Brazil, in at least one month in the year, based on national information of this insect-pest. Favorable conditions to the occurrence of the insect, the average climatic data from weather stations (2009-2018) and *Eucalyptus* crop areas in 2018 were considered. This information was used in GIS to obtain a zoning map indicating the favorable areas to the insect in at least one month in the year. The georeferenced-crossing technique used considered both spatial interpolation by Cokriging methods and by Inverse Distance Weighted (IDW). Results indicated the presence of propitious outbreaks for *T. peregrinus* occurring in differentiated months in the Southern, Southeastern, Midwestern and Northeastern geographic regions of the country, with lowest monthly aptitude noticed for the Northern region. Different sequential periods of favorability for occurrences from very high to medium intensities were identified.

Key words: *Eucalyptus*, bronze bug, forest, geostatistical, spatial analysis.

1. Introduction

The Brazilian forestry planted areas reached 9.0 million ha in 2019, concentrated mostly in forests planted with *Eucalyptus* (6.97 million ha) and Pinus (1.64 million ha) [1]. *Eucalyptus* sp., endemic to Australia, was introduced in Brazil in the 19th century and nowadays has widely grown to produce raw material for the multiple industrial uses (charcoal, cellulose pulp, paper, wood panels, laminate flooring, solid wood products, essential oils, among others) [1-3]. In 2019, the main export trades of Brazilian forest chain production were registered toward the five continents, being predominant to Asia (38%), Europe (23%), and North America (21%) [1]. The country has kept its first place in the worldwide rank of cellulose pulp exportation since 2017 [1]. The production of *Eucalyptus* forests could be limited by abiotic and biotic factors in the environment.

Eucalyptus species planted are increasingly threatened by exotic insect pests, which are becoming established. Among these pests, *Thaumastocoris peregrinus* Carpintero & Dellapé (Hemiptera: Thaumastocoridae), also known as *Eucalyptus* bronze bug is an exotic sap-sucking insect firstly recorded in Brazil in June of 2008 [4-6]. This pest causes browning of leaves and dryness of canopy, followed by falling of leaves and canopy thinning [4, 5]. Depending on climate factors, the development of the insect can reach several generations along the year, promoting occurrence of high population densities (outbreaks), which intensify damages, that can lead to

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the reduction of leaf area (due to falling leaves) to host-plant death [7-19].

Analyses of monitoring data of *T. peregrinus* in Brazilian *Eucalyptus* planted forests, conducted by Embrapa Environment in the scope of actions of the Cooperative Project of Forest Protection Program of Institute of Research and Forestry Studies (PROTEF/IPEF), determined the maximum and minimum temperatures and relative humidity most propitious to promote outbreaks on *T. peregrinus* population availability [20, 21]. This information enabled the application of geoprocessing techniques for obtaining information of areas subject to a greater occurrence of *T. peregrinus* in Brazil, making use of data from climatic factors (National Institute of Meteorology, INMET), from *Eucalyptus* producer cities (Brazilian Institute of Geography and Statistic, IBGE), and from spatially digitalized mesh of the Brazilian cities (IBGE) in geographic information system ArcGIS [20, 21]. The zoning maps provided contribute to monitoring in field. As more currently information became available updates on mapped areas for *T. peregrinus* were provided [22, 23].

The use of GIS techniques has been noticed for different plants species and insect pests. As examples, it could be mentioned, the review presented by Reddy [24], Hochmair *et al*. [25], Prado *et al.* [26] and Dminić *et al*. [27].

More accurate methods of georeferenced crossing, including those using spatial interpolations such as Inverse Distance Weighted (IDW) or kriging, are enabling more precise maps [28, 29]. However, the concomitant use of these both spatial interpolation techniques on geostatistical approaches can enhance the precision and accuracy in maps applied for integrated pest management strategies. Siqueira *et al*. [30] have already presented the use of this technique for presenting monthly mappings of favorable areas for *T. peregrinus*, which considered averages of a wide climatic range (1961-2018). Nevertheless, due to the relatively recent occurrence of *T. peregrinus* in Brazil and the influence of climate change recorded mainly in contemporary years, an assessment of the trend of insect outbreak aptitudes also considering a shorter climatic period is necessary.

The main objective of this work is to identify areas with favorable conditions to occurrence of *Thaumastocoris peregrinus* in Brazil, in at least one month in the year, based on national information of this insect-pest.

2. Material and Methods

Monthly temperatures and humidity data from 2009 to 2018 were obtained from Meteorological Databank for Education and Research (BDMEP) of the INMET. Microsoft Excel (version 2013) was used to standardize data and to enable average and standard deviations (SD) of temperatures (maximum (T_{max}) and minimum (T_{min})) and of relative humidity (RH), separately by month.

Geodatabase ArcMap (version 10.7.1) files of temperatures and relative humidity were provided. Interpolations were done by cokriging method (simple type) for the average, using an auxiliary point-grid with points 100 km apart, containing monthly average temperatures obtained by Álvares *et al*. [31].

The IDW method was used for the SD, considering power factor of two. Then, T_{max} ± SD, T_{min} ± SD and RH ± SD were calculated for each monthly and yearly average. A reclassification was made based on climatic variables that express greater favorability for the great occurrence of population (outbreaks) of *T. peregrinus*, which was represented by T_{min} from 15 to 18 °C, T_{max} from 27 to 31 °C and RH from 70 to 80% [20, 21]. The reclassification products were converted into polygons in order to reach the shapefiles of each variable considered for each month.

Data of *Eucalyptus* forest areas by city in 2018 were obtained from IBGE's System of Automatic Recovery (SIDRA) of the IBGE, which were then adjusted in Microsoft Excel spreadsheet to ensure the union of these attributes to each feature of city present on the shapefiles of Brazilian city mesh of 2018 [32].

Geographic-crossings were performed for each month in which the suitable areas for the occurrence of *T. peregrinus* by Brazilian geographic regions were then obtained and quantified (in km^2).

The greatest favorable area for each Brazilian geographical region was later identified. Excel was used to calculate the percentage of favorable area for each month within the same region, in relation to its greatest respective favorable area identified. Afterwards, shades of gray were assigned to each percentage range, relative to the intensity of favorable area for the occurrence in the same region, as follows: (a) "very low" (gray 10%): 0.0 to 20%; (b) "low" (gray 30%): 20.1% to 40%; (c) "mean" (gray 50%): 40.1% to 60%; (d) "high" (gray 70%): 60.1% to 80%; and (e) "very high" (black): 80.1% to 100%.

3. Results and Discussion

The map obtained for *Eucalyptus* areas in Brazil in 2018 was presented (Fig. 1).

The zoning map of favorable areas for occurrence of *T. peregrinus* outbreaks in Brazil in at least one month in a year was presented (Fig. 2), enabling the determination and quantification (in km^2) of the monthly favorable areas for *T. peregrinus* for each Brazilian geographical region, as well as, their color of intensities in accordance with the shades of gray established (Table 1).

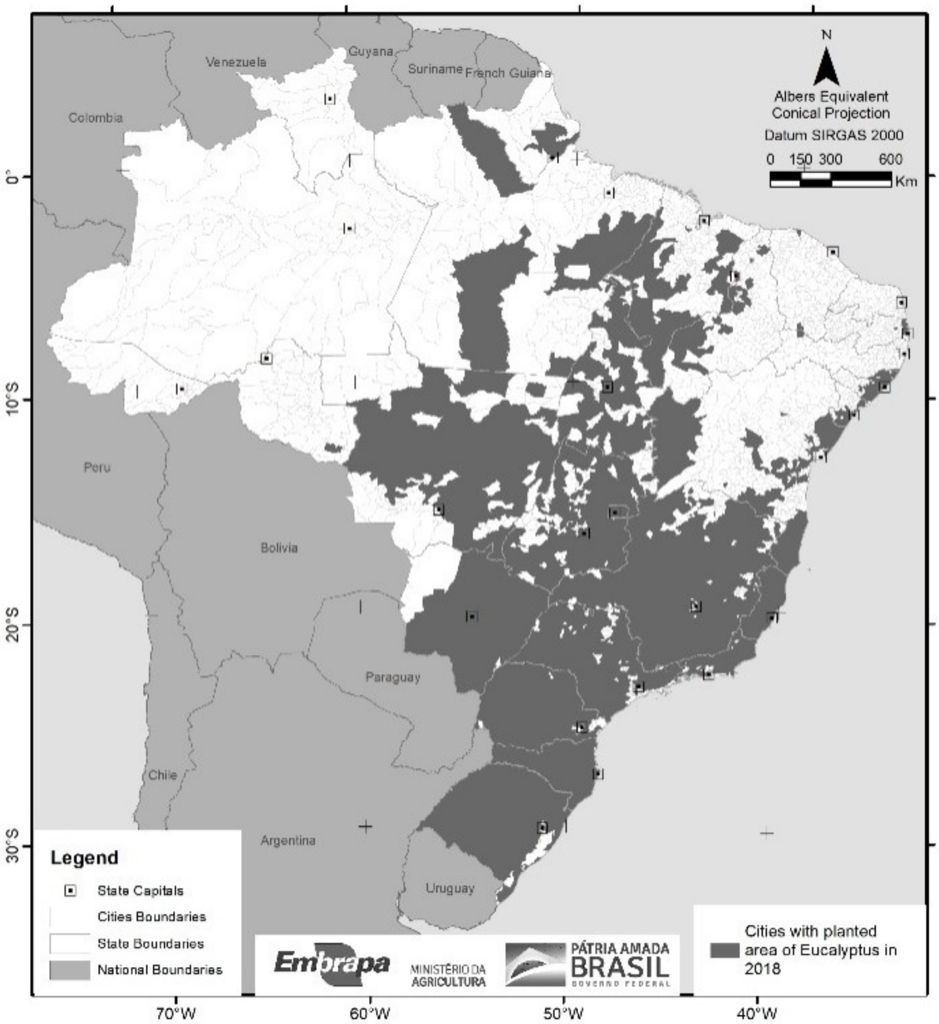

Fig. 1 Map of *Eucalyptus* sp. areas in Brazil based on IBGE.

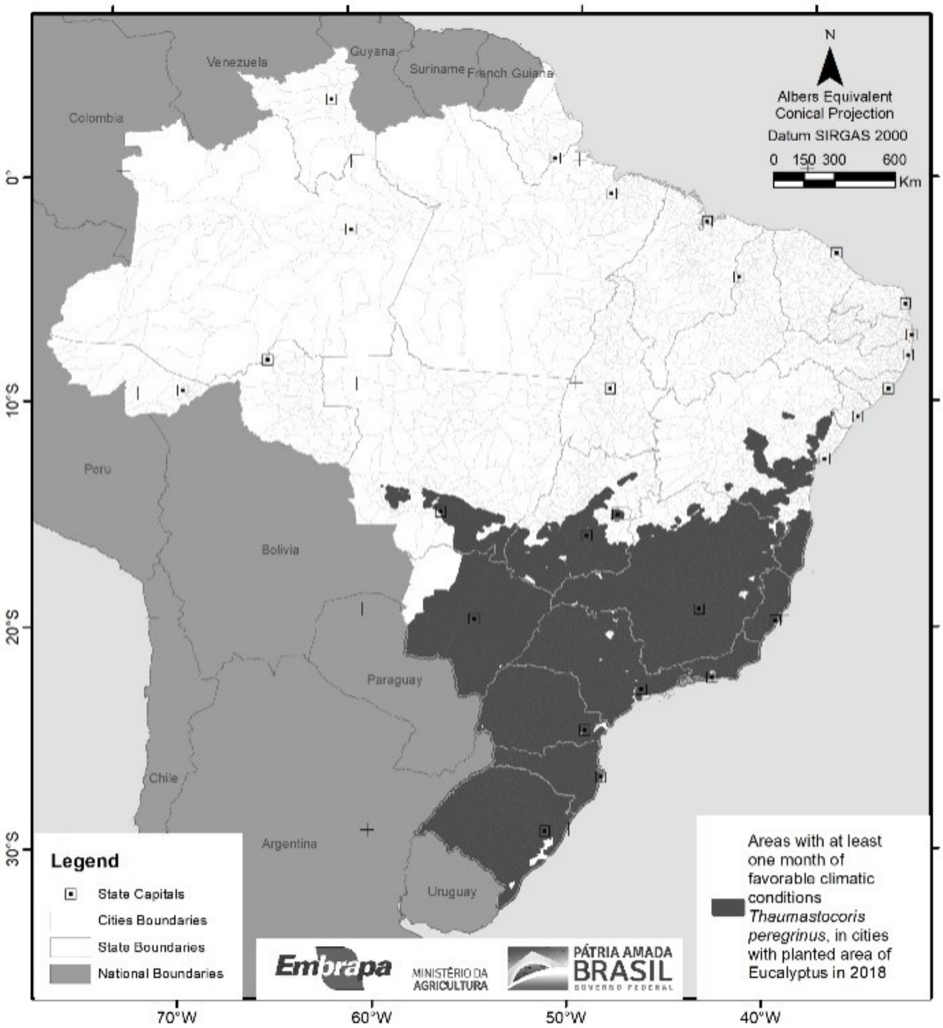

Fig. 2 Zoning map of favorable areas for occurrence of *Thaumastocoris peregrinus* outbreaks in Brazil in at least one month in a year.

The *Northern* region (N) presented no favorability for a greater occurrence of populational outbreaks of *T. peregrinus* (Table 1). However, Saliba *et al.* [18] cited four cities in Pará State (PA), close to the border of Maranhão State (MA) which presented, in 2015 and in 2016, considerable number of individuals (438 and 920 for each year monitored, respectively). The same authors mentioned that probably those invasions in the PA came from MA. No other records of occurrence in *Eucalyptus* plantation areas in the Northern region were found, corroborating the present work, which resulted in "very low" favorability to outbreaks in the Northern region.

The main favorable periods for outbreaks in the *Northeastern* region were observed from *May* to *June* and in *August*. Lima *et al.* [8] mentioned the occurrence of *T. peregrinus* in two cities of the Bahia State (BA) in *January* (2010), as well as in another city in the same state in *December* (2011). In the Maranhão State (MA), Governo do Maranhão-SAGRIMA [14] informed the occurrence of "high level" of *T. peregrinus* populations in *May* (2014) in one city, which is close to the border areas of Pará State, in the same area already mentioned under the presence of *T. peregrinus* in 2015 and 2016. Ribeiro *et al.* [16] also mentioned one city of the Sergipe State (SE) with the presence of the insect in 2015.

Table 1 Shades of gray according to the percentage of the intensity of favorable area for the *Thaumastocoris peregrinus* outbreaks by Brazilian geographical region (S = Southern; SE = Southeastern; MW = Midwestern; NE = Northeastern, and N = Northern).

Month/region	S	SE	MW	NE	N
January	High	Very low	Very low	Very low	Very low
February	Very low	Very low	Very low	Very low	Very low
March	Very high	Low	Very low	Very low	Very low
April	Medium	Very high	Low	Very low	Very low
May	Very low	High	Very high	High	Very low
June	Very low	Medium	High	Very high	Very low
July	Very low	Very low	Very low	Very low	Very low
August	Very low	Low	Very low	Very high	Very low
September	Low	Medium	Low	Very low	Very low
October	Low	Very high	Very low	Very low	Very low
November	Very high	High	Very low	Very low	Very low
December	Very high	Low	Very low	Very low	Very low
Legend:	Very low: 0.0-20%	Low: 20.1%-40%	Medium: 40.1%-60%	High: 60.1%-80%;	Very high: 80.1%-100%.

In the *Midwestern* region, favorability from *May* to *June* was noticed, although "low" levels were also observed for *April* and *September* (Table 1). Wilcken *et al*. [5] reported occurrences in two cities in Mato Grosso do Sul State (MS) in *October* (2009), and Pereira *et al*. [11] registered immature and adult phases in very low populations in three cities in Goiás State (GO) in *November* (2011), which corroborating the findings of the present work.

The main aptitude for outbreaks of *T. peregrinus* was observed in the *Southeastern* region from *September* to *November* and from *April* to *June*, despite also being registered in "low" level for *March* and *December* (Table 1). Wilcken *et al*. [5] mentioned that the insect was introduced in Jaguariúna city in São Paulo State in *June* (2008), probably due to the proximity to Campinas's airport and of highways. The same authors, cited by Saliba *et al*. [18], mentioned the presence of *T. peregrinus* in 74 cities in the same state in *October* (2009), which was here classified as "very high" favorability. Serafim *et al.* [10] also reported increase of occurrence in monitored areas in SP, in 2009, from *August* (2009), which was here identified as "low" favorability for the Southeastern region. The same authors observed outbreaks in the following months, *September* and *October* (2009), both classified here as "medium" and "very high". High occurrences were also highlighted by Serafim *et al.* [10] in *November* with a decrease in *December*, here classified as "high" and "low", respectively. In 2010, Serafim *et al*. [10] mentioned the presence of the insect in *May* and an increase in population in *June*, until reaching peaks in *August*. High population levels were also observed in *September* and *October*, as well as in *December*, although in lower numbers. Still in SP, Machado *et al*. [19] reported the presence of the insect in *December* (2016) in one city. Considering the outbreaks in Minas Gerais State (MG), Wilcken *et al*. [5] reported occurrence of *T. peregrinus* in two cities in *December* (2008), whose favorability was here identified for the Southeastern region as "low". Sartori *et al.* [17] reported presence of *T. peregrinus* in MG in "low" levels in *August* and *September* (2014), which enhanced significantly in *October* and reached peaks in *November*, with a decrease in population observed from *December* (2014), corroborating with the findings of the present work (Table 1). Machado *et al.* [19] also reported the occurrence of *T. peregrinus* in *December* (2016) in one city and in *January* (2017) in another one, in the same state. Still in MG, Fortan *et al*. [33] reported the presence of *T. peregrinus* in different *Eucalyptus* clones in other city, where the insect population became higher after the first week of *August* (2020) reaching the highest levels (peaks) in the third week of *August* and maintaining the high number of individuals in *September* and in part of *October* (2020). Wilcken *et al.* [5] also reported *T. peregrinus* in *July* (2009) in a single city present in Espírito Santo State (ES) and in another one in the state of Rio de Janeiro (RJ).

Variation in the intensity levels was pointed out for the *Southern* Region, where the main aptitude for "high" population levels of the insect was observed from *November* to *January* and from *March* to *April*, although also observed in "low" levels in *September* and *October* (Table 1). This result corroborates the works of Wilcken *et al*. [5], who mentioned that the introduction of *T. peregrinus* in state of Rio Grande do Sul (RS) was noticed in *May* (2008) in one city and, afterward, in nine cities in *January* (2009). *Thaumastocoris peregrinus* was also registered in monitoring (*March* to *October* 2019) from *April* (2009) in the 13 cities located in the south of RS [6, 18]. Monitoring conducted by Garlet [7] has noticed gradual enhancement of high level of outbreaks in another city in RS, from *September* (2008) to *January* (2009), which probably promoted the later greatest peak of outbreak observed by the author occurring in *February* (2009) and maintaining a decrease in outbreak values, but still high, in the subsequent months (mainly *March* and *April*); which corroborated the findings here observed. Still in the RS, Machado *et al.* [19] reported the insect in Santa Maria city in *December* (2016). In the state of Santa Catarina (SC), Savaris *et al*. [6] also reported outbreaks observed in four cities of the western region of the state in *April* (2009), while Machado *et al.* [19] had mentioned that an outbreak happened in one city of this same region in *February* (2017). In Paraná State (PR), Barboza *et al.* [9] reported that the first sign of the presence of *T. peregrinus* occurred in an urban area of one city in *June* (2009), but also mentioned the presence of different immature phases (eggs and nymphs) together with adults. Considering the low temperatures during autumn/winter period in PR, and the influence of this temperature on the developmental time (36.37 days at 18 °C) of nymphs [34], as well as the time (approximately 6 days) required for the eggs to hatch at 17-22 °C [35], the nymphs observed in *June* probably came from adults arriving in the state in the previous two months (*April*), which was here reported as having "medium" favorability for the Southern region. Wilcken *et al*. [5] also had mentioned the presence of the insect in PR in one city in *October* (2009), corroborating the "low" tendency here observed. Lorencetti *et al.* [15] also reported the presence of *T. peregrinus* in 2012 in PR.

The results obtained updated the information previously provided [20-23, 30]. Higher temperatures and longer periods of droughts along with lower relative humidity observed in more recent years, mainly in the Southeastern and in Southern regions, may have contributed to the non-favorability for outbreaks of the insect in *July*. These outbreaks were presented by Pessoa *et al*. [23] as having "high" favorability in ES, with "medium" in Mato Grosso do Sul (MS), with "low" in Mato Grosso (MT) and RJ, and in "very low" in BA, MG, Rondônia (RO), SP and Tocantins (TO). Siqueira *et al*. [30] reported no favorability for the insect in July. It should also be mentioned that Pessoa *et al*. [23] used national climate data from 1961 to 2014, while Siqueira *et al*. [30] from 1961 to 2018, and the present work from 2009 to 2018, which is more representative for recent periods.

The spatial interpolators considering both cokriging method and IDW enabled a decrease in the greater influence of distant points in the determination of the calculated interpolation values. Thus, the method enhanced the accuracy of information plans in GIS, such those considered in the present work for $T_{\max}$, $T_{\min}$ and RH; previously applied [30].

4. Conclusion

Potential outbreaks of *Thaumastocoris peregrinus* were identified for all Brazilian geographic regions. Results indicated the presence of propitious outbreaks for *T. peregrinus* occurring in differentiated months in the Southern, Southeastern, Midwestern and Northeastern geographic regions of the country.

Different sequential periods of favorability for occurrences from "very high" to "medium" intensities were identified, where a "very low" aptitude was observed for the Northern region, while the highest levels ("very high" and "high") were observed for the Southern and the Southeastern regions. Based on the results obtained, a "very low" aptitude for outbreaks of *T. peregrinus* was identified for all regions occurring in July.

The presented zoning map of favorable areas for occurrence of *T. peregrinus* outbreaks in Brazil in at least one month in a year can subsidize the integrated pest management plans for the insect.

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