Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

How can global climate change influence the geographic distribution of the eucalyptus yellow beetle? Modeling and prediction for Brazil

Como mudanças climáticas globais podem influenciar na distribuição geográfica do besouro amarelo do eucalipto? Modelagem e predição para o Brasil

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Abstract

Popularly known as the yellow eucalyptus beetle, *Costalimaita ferruginea* (Fabricius, 1801) (Coleoptera: Chrysomelidae), in the adult phase it feeds on the leaves of the myrtaceae, leaving them laced, a fact that impairs the productivity of plantations. Therefore, this work aims to model the potential distribution of the beetle in climate change scenarios for Brazil. The biotic data were collected through a review of the literature and entomological collections, totaling 88 georeferenced points of occurrence of the insect in the country. The abiotic data (19 biovariables, precipitation and minimum, average and maximum temperature) in the Wordcllim database, represent the periods: current (1970-2000), middle (2041-2060), and final (2061-2080) of the century, with representation in two projections of climatic anomalies (RCP 4.5 and RCP 8.5). To determine the most important variables for the models, the Jackknife test was performed in the Maxent software, which resulted in five biovariables, namely: annual precipitation (35.2%), temperature seasonality (15.2%), annual temperature variation (13.7%), seasonality of precipitation (8.7%) and an average temperature of the coldest quarter (7.4%). Subsequently, the Openmodeller software was used and five algorithms were tested to determine which model represents the prediction of areas of suitability for the occurrence of the insect. The algorithm that best represented the appropriate areas was the Envelope Score (AUC = 0.808), corroborating the occurrence data collected. The prediction shows that the Pampa biome, in the RCP8.5 scenario for the period between 2061-2080, will become fully suitable for the occurrence of this defoliator beetle, unlike the Amazon, which presents retraction in areas suitable for the occurrence of the beetle for the same period. In this sense, commercial eucalyptus plantations implemented in climatologically suitable areas for the occurrence of this insect must be monitored periodically.

Keywords: climatic suitability, *Costalimaita ferruginea*, environmental modeling, forest pests, defoliators insects.

Resumo

Conhecido popularmente como, o besouro-amarelo do eucalipto, *Costalimaita ferrugínea* (Fabricius, 1801) (Coleoptera: Chrysomelidae), na fase adulta alimenta-se das folhas da mirtácea deixando-as rendilhadas, fato este que prejudica a produtividade dos plantios. Sendo assim, este trabalho tem como objetivo modelar a distribuição potencial do besouro em cenários de mudanças climáticas para o Brasil. Os dados bióticos foram levantados através de revisão de literatura e de coleções entomológicas, totalizando 88 pontos georreferenciados de ocorrência do inseto no país. Os dados abióticos (19 biovariáveis, precipitação e temperatura mínima, média e máxima) no banco de dados Wordlclim, representando os períodos: atual (1970-2000), meio (2041-2060) e final (2061-2080) do século, com representação em duas projeções de anomalias climáticas (RCP 4.5 e RCP 8.5). De modo a determinar as variáveis mais importantes para os modelos, foi realizado o teste *Jackknife* no software *Maxent*, o qual resultou em cinco biovariáveis, sendo elas: precipitação anual (35.2%), sazonalidade da temperatura (15.2%), variação anual de temperatura (13.7%), sazonalidade de precipitação (8.7%) e temperatura média do trimestre mais frio (7.4%). Posteriormente, utilizou-se o software Openmodeller e testados cinco algoritmos, para determinar qual modelo representa a predição de áreas de adequabilidade para a ocorrência do inseto. O algoritmo que melhor representou as áreas adequadas foi o Envelope Score (AUC = 0.808), corroborando com os dados de ocorrência levantados. A predição mostra que o bioma Pampa, no cenário RCP8.5 para o período entre 2061-2080 se tornará totalmente adequado à ocorrência desse besouro desfolhador, ao contrário da Amazônia, que apresenta retração nas áreas adequadas à

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Received: June 18, 2022 – Accepted: November 6, 2022

ocorrência do besouro para o mesmo período. Nesse sentido, plantios comerciais de eucalipto implementados em áreas climatologicamente adequadas à ocorrência desse inseto devem ser monitoradas periodicamente.

Palavras-chave: climatic suitability, *Costalimaita ferruginea*, environmental modeling, forest pests, defoliators insects.

1. Introduction

Brazil stands out worldwide as the second largest pulp producer (IBÁ, 2021) due to the 7.47 million hectares of Eucalyptus (Myrtaceae) plantations out of a total 9.55 million hectares of planted trees forests in the country. This huge forestry massive provides wood that is destined, among other industrial uses, for vegetal coal production for the steel industry, wood panels and lumber, being the South American country the leader in forestry productivity, with an average increment of 36.8 m^3/ha of wood each year (IBÁ, 2021). In the search of a low carb emission and socioenvironmentally sustainable economy, the forestry based sector in the country becomes attractive due to its important ecological role in ensuring wood production from planted trees, reducing pressure over native forests (Farinha e Silva et al., 2016).

Brazilian agribusiness suffers annual losses in the order of US$ 12 billion caused by insects considered pests (Rangel, 2015). The damage caused by these insects to the Brazilian economy may increase in the future since most of the insects considered prejudicial to the agribusiness are poikilothermics (Biber-Freudenberger et al., 2016). By this means, due to the influence of climate factors in the spreading and suitability of the insects, areas that are currently not considered favorable to the occurrence of pests, may, in the future, become appropriated to the development and establishment of these insects as much as increase the propitious time period for their occurrence (Pinkard et al., 2011).

Costalimaita ferruginea (Fabricius, 1801) (Coleoptera: Chrysomelidae) is an important eucalyptus defoliating pest. In its adult phase attacks eucalyptus plants of all ages, including seedlings in hatcheries (Pires et al., 2013) and in its worm phase is developed in the soil feeding from grassy roots (Máfia et al., 2014). Characteristically, by feeding, the adult laces the leaves, which affects the growth in height and decreases the photosynthetic capability of the trees, influencing the final wood production or even causing the death of the plants (Mendes, 2004). When adult this insect is between 5.0 and 6.5 mm long and presents rusty-yellow color, which makes it popularly known as the “yellow beetle of eucalyptus” (Máfia et al., 2014).

The occurrence of this coleopteran was reported in many Brazilian states (Dias et al., 2018), also in other South America countries (Medina and Pinzón-Florián, 2011), however, some information about its occurrence is not yet published, being its occurrence only verified by the deposit of specimens in museums and schooling institutions entomological collections.

Many evidences suggest that the average global temperature will increase by 2-4ºC by the end of the century (Intergovernmental Panel on Climate Change – IPCC, 2014), then it is assumed that favorable areas to the development of the yellow beetle of eucalyptus in the country will suffer alteration in the future. For these conclusions, modeling has been used to determine the potential geographic distribution of pest insects and also predicts the further expansion or retraction of this geographic distribution of pest insects under different scenarios of global climate changes (Queiroz et al., 2018; Whitehead, 2011). Although, studies related to the geographic distribution of the Coleopterons and climate changes are still insufficient, especially when comparing the number of studies to the number of species already identified in the same order (Andrew et al., 2013). Relations between insects and clime help to understand how elements of the ecological branch and abiotic factors may influence the geographic distribution of these insects (Pinkard et al., 2017). So could global climate changes influence in the suitability of favorable areas to the occurrence of *C. ferruginea* in the future? To verify this possible influence, the objective of the present work was modeling the geographic distribution of the yellow beetle of eucalyptus for two scenarios of global climate changes in order to predict the potentially favorable area to its occurrence, today and in the future.

2. Material and Methods

2.1. Occurrence of Costalimaita ferruginea

The occurrence data of *C. ferruginea* were obtained through literature revision in journals, using the scientific database of the websites Scielo, Science Direct and CAPES portal of journals, as much as consulting entomological collections of natural history museums and schooling institutions. The database of the Global Biodiversity Information Facility - GBIF (2018) was also consulted. Data with equal location or inconsistency in the given information, like absence of specific location description, mentioning only the state of occurrence, were discarded as recommended by Queiroz et al. (2018). To determine the geographic coordinates of the points without their description, the software Google Earth (Google Inc., 2009) was used.

Of the biotic data collected, only 88 points were used to perform To run the models and realize the external validation test. Thus, the occurrences that fall in the same square were not used, as it would cause a prediction error.

2.2. Climate data

The climate variables minimum, maximum and avarage temperature, as much as precipitation and bioclimatic variables (bio) used, were obtained in the website WorldClim version 1.2 (Hijmans et al., 2005) database, on the 4th IPCC Report. Nineteen bioclimatic variables (Table 1) were obtained for the current, mid (2041 – 2060) and final (2061 -2080) 21st century periods. The future analysis was realized for two GEE emission scenarios, according

Table 1. Available bioclimatic variables and contribution rate of variables used for modeling *Costalimaita ferruginea* (Fabricius, 1801) (Coleoptera: Chrysomelidae).

Code (Bio)	Variables	Contribution (%)*
1	Annual mean temperature	2.2
2	Mean diurnal range (mean of monthly (max temp - min temp))	0.7
3	Isothermality (100*mean diurnal range/annual temperature range) or (bio_2/bio_7*100)	0.3
4	Temperature seasonality (standard deviation *100)	35.2
5	Max temperature of warmest month	4.0
6	Min temperature of coldest month	0
7	Temperature annual range (bio_5-bio_6)	13.7
8	Mean temperature of wettest quarter	0.9
9	Mean temperature of driest quarter	1.0
10	Mean temperature of warmest quarter	1.2
11	Mean temperature of coldest quarter	7.4
12	Annual precipitation	15.2
13	Precipitation of wettest month	1.3
14	Precipitation of driest month	1.0
15	Precipitation seasonality (coefficient of variation)	8.7
16	Precipitation of wettest quarter	1.1
17	Precipitation of driest quarter	1.0
18	Precipitation of warmest quarter	1.9
19	Precipitation of coldest quarter	3.2

*Result of the Maxent program. Source: WorldClim (2022).

to the Intergovernmental Panel on Climate Change - IPCC (2014), considering the Representative Concentration Pathways (RCP) (W/m^2) RCP4.5 as the best scenario and the RCP8.5 as the worst scenario for the analyzed periods in the future, of model HadGEM2. The resolution of the used layers was 2.5 min (Giannini et al., 2012), with cut only for the climate change scenario in Brazil

The bioclimatic variables were organized in space by using the software QGis (QGIS Development Team, 2018) and through the software Maxent (versão 3.1; Phillips et al., 2017). Due to the correlation between the variables the test Jackknife was realized to determine the most important variables for the models (Queiroz et al., 2018; Dalapicolla, 2016), being them: annual precipitation (bio12), temperature seasonality (bio 4), temperature annual range (bio7), precipitation seasonality (bio 15) and the mean temperature of coldest (bio 11), each one with respectively, 35.2%, 15.2%, 13.7%, 8.7%, 7.4% of contribution in the determination of the favorable areas to the occurrence of *C. ferruginea* (Table 1). The variables of biggest contribution were used for both scenarios, the current and future.

2.3. Modeling

The software OpenModelller (Souza Muñoz et al., 2011) was operated to test five different algorithms used to model the geographic distribution. Bioclim, Envelope score, Environmental distance, Niche-mosaic and Climate Space Model were evaluated according to the Area Under the Curve (AUC) in order to determine which algorithmic best represents the geographic distribution of *C. ferruginea*. For each algorithm were realized five replications, being in each replication 80% of the points used to run the models and 20% to the external validation test (Queiroz et al., 2018; Dalapicolla, 2016; Giannini et al., 2012). The final result of the averages obtained after the replications determined which algorithm was the best for the analyzed insect.

The maps generated by the algorithms were converted into a "raster" format with the intention of transforming the obtained maps in categorical numbers varying from 0 to1, being from 0 to 0.30 = low probability of occurrence of the beetle, 0.31 to 0.60 = moderate probability and 0.61 to 1.00 = high probability of occurrence. The maps containing the probability gradients were discussed according to the six phiytogeographic domains in the country (Amazônia, Mata Atlântica, Cerrado, Caatinga, Pantanal and Pampa).

3. Results

Out of the 88 occurrence points analyzed, 28 are located in the Atlantic Forest, 22 in Amazônia, 21 in Cerrado, 9 in the Pampa, 6 in Caatinga and 2 in Pantanal (Figure 1). Based on the occurrence points and climate data used, the algorithm Envelope Score (AUC = 0.808) presented the best prediction of the most propitious areas to the occurrence of the yellow beetle of eucalyptus, being better than randomly.

For future scenarios, the period of 2041-2060 presented the biggest area with high probability of occurrence of the beetle (Figure 2), related to the current potential geographic distribution of the beetle in the country (Figure 1). For the scenario RCP4.5, an expansion of favorable habitats to the occurrence of the yellow beetle of eucalyptus in the biomes Caatinga and Pampa can be observed, being the south and northeast regions the ones that presented biggest increase in areas with moderate and high probability of occurrence of the beetle. The Amazon biome also demonstrated increase in areas with moderate probability. To the most pessimist scenario (RCP8.5), Amazônia presented diminution in the area with moderate probability of occurrence, making the Atlantic Forest and Caatinga the most propitious to the dispersion of this insect. The regions south and southeast of Brazil presented from moderate to high probability of occurrence.

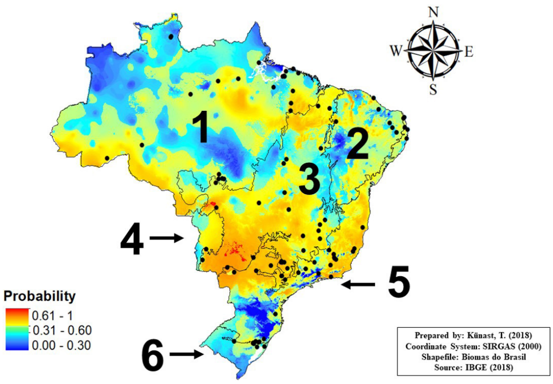

Figure 1. Current potential geographic distribution of Costalimaita ferruginea determined by the algorithm Envelope Score (AUC = 0.808). The numbers 1 to 5 represent the Brazilian biomes, being 1 = Amazônia, 2 = Caatinga, 3 = Cerrado, 4 = Pantanal, 5 = Mata Atlântica e 6 = Pampa.

In the period of 2061-2080 (Figure 3), the algorithm predicts that in the Amazon biome there is going to be a retraction in the areas with high probability, transforming this region, almost in its totality, unfavorable to the occurrence of the specie in the scenario RCP8.5. The increase of unfavorable areas also occur in Cerrado for the same scenario. Pantanal does not present areas with high probability of occurrence, being the biome with least number of suitable areas for the beetle. Caatinga will also suffer decrease in suitable areas in the scenario RCP8.5 for the period 2061-2080, related to the other periods and scenarios studied, including the current one.

4. Discussion

The attack of the yellow beetle of eucalyptus causes diminution of the average annual increment by wood hectare, jeopardizing the production chain of industries which need this source. Mendes (2004) demonstrated that in attacks to eucalyptus in wich ¾ or more of the cope is destroyed, the reduction of the volume of total wood produced was as high as 43,61% related to non-attacked trees with age of 84 months.

The predictions for the current potential geographic distribution of *C. ferruginea* are in conformance with the

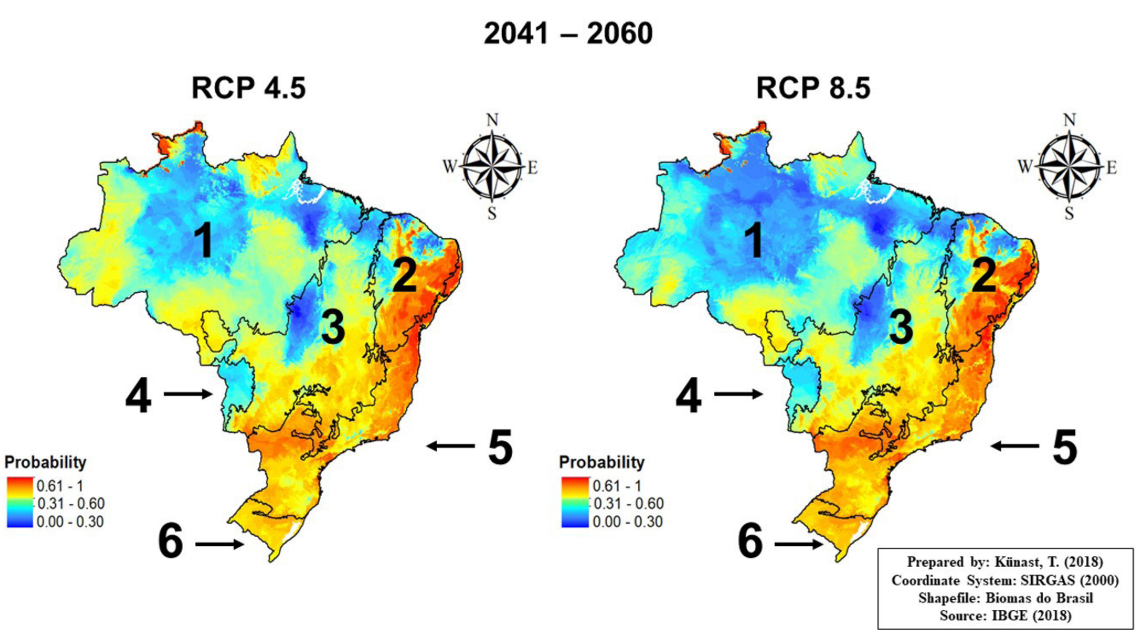

Figure 2. Predicting of potential areas to the occurrence of Costalimaita ferruginea in the period of 2041-2060, in two climate change scenarios, Representative Concentration Pathways (RCP) 4.5 e 8.5 (W/m^2), using the algorithm Envelope Score (AUC = 0.808). The numbers 1 to 5 represent the Brazilian biomes, being 1 = Amazônia, 2 = Caatinga, 3 = Cerrado, 4 = Pantanal, 5 = Mata Atlântica e 6 = Pampa.

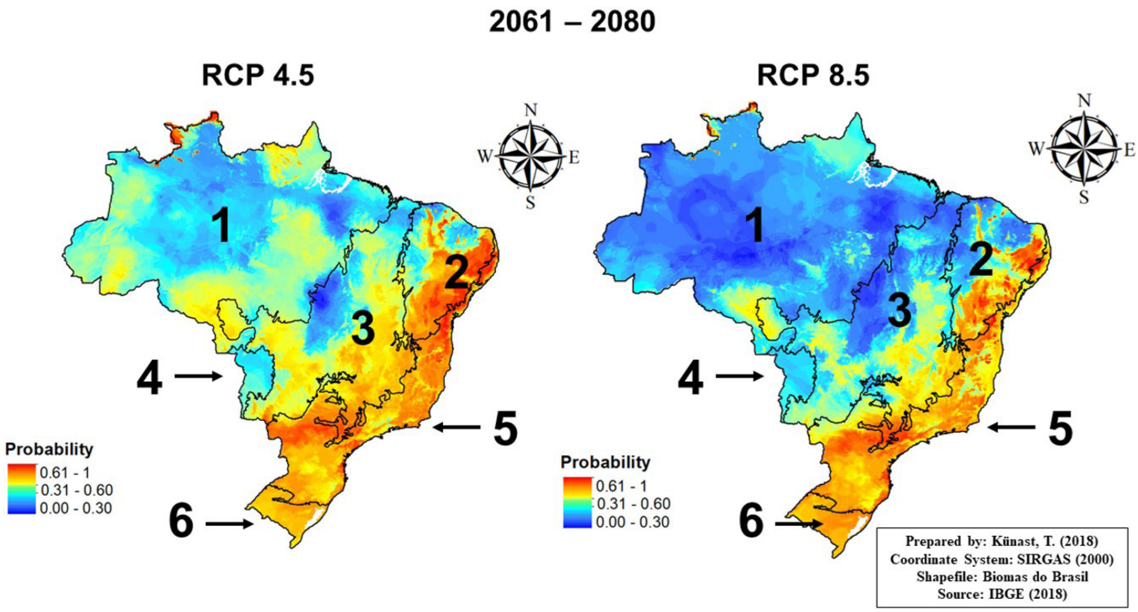

Figure 3. Predicting of potential areas to the occurrence of *Costalimaita ferruginea* in the period of 2061-2080, in two climate change scenarios, Representative Concentration Pathways (RCP) 4.5 e 8.5 (W/m²), using the algorithm Envelope Score (AUC = 0.808). The numbers 1 to 5 represent the Brazilian biomes, being 1 = Amazônia, 2 = Caatinga, 3 = Cerrado, 4 = Pantanal, 5 = Mata Atlântica e 6 = Pampa.

occurrence data raised. The Atlantic Forest and Cerrado, categorized as being the domains with the biggest number of occurrence reports, presented the biggest area with high susceptibility of favorable habitats to the occurrence of the specie for the current period. The results of the modeling showed that the favorable areas to the occurrence of this chrysomelidae may be affect by reasonability of temperature, as much as precipitation, however, in low proportions. Climate factors also influenced in the expansion of favorable areas to other chrysomelidae considered as crops pests (Wang et al., 2017).

The increase of favorable areas to the occurrence of this insect in coast regions, for the period of 2061-2080, in the Atlantic Forest and part of Caatinga can be explained by the fact that these areas be the most urbanized in the country, consequently are going through periods of extreme temperature and precipitation changes (Intergovernmental Panel on Climate Change – IPCC, 2014; Painel Brasileiro de Mudanças Climáticas – PBMC, 2013). Peaks in temperature influenced in the suitability of a place to the occurrence of *C. ferruginea*, since that annual temperature variation (bio7) represents the variation between the highest temperature in the hottest trimester (bio5) and the lowest temperature in the coldest trimester (bio6) (Hijmans et al., 2005).

Pires et al. (2014) related that there was an increase in the population of this chrysomelidae in eucalyptus plantations in the region of Guiricema, Minas Gerais, in periods before the raining period in the region. Since the precipitation can affect the suitability of the environment to the occurrence of *C. ferruginea*, the retraction of the favorable areas to its occurrence in Amazônia in the period of 2061-2080, in the two considered scenarios, may be explained by the fact that this biome, in the scenario of climate changes, will probably suffer with drier periods and with higher incidence of fires (IPCC, 2014). In the Amazon southeast, the dry season will last longer, increase of 5 to 6ºC will be observed and a reduction of more than 40% in precipitation is projected for the final of the century (PBMC, 2013). In Dom Eliseu, Pará, region part of the Amazon biome, eucalyptus plantations were observed being attacked by this beetle in the raining period of the year, well defined between the months of December and March, to this region (Lunz and Azevedo, 2011). The authors still state that a possible occurrence in this period was due to the fact that, with higher hydric offer, the plants issued sprouts and young leaves, favoring the attack of this coleopteran.

Species distributed in warmer regions, especially in tropical regions, like the yellow beetle of eucalyptus, are the most propitious ones to feel the effects of the minimum temperatures in the coldest periods (Watling et al., 2013). The probable increase of precipitation in the south of the country, especially in the Pampa, increase in the average of temperature and reduction of frosting periods and also of cold days (PBMC, 2013) will make that these areas become climatologically suitable to the occurrence of *C. ferruginea* in the period of 2061-2080 in both scenarios tested. The states of Rio Grande do Sul and Paraná, represent, respectively, 6 and 5% of all eucalyptus planted area in Brazil, being the fifth and sixth biggest eucalyptus producers in the country (IBÁ, 2021).

Modeling in species distribution has been widely used to understand how the clime and its global alterations may influence in the suitability of a region to the occurrence of pest insects (Queiroz et al., 2018; Ning et al., 2017). The algorithm that presented the best result (AUC = 0.808), being its predicting better than randomly, was the Envelope score, that uses climate variables to predict climatologically favorable areas to the developing of a determined specie (Watling et al., 2013). Associations between insects and environmental clime conditions are common, being the insects living in natural habitats or plantations, however, outbreaks may occur, many times are driven by favorable climate conditions (Pinkard et al., 2017). For chrysomelidae, warmer temperatures may affect the number of generations by year and diminish mortality, whatsoever heating waves may have the opposite effect, increasing the mortality (Pinkard et al., 2017).

Not only the clime influences the distribution and abundance of pests, the local conditions, like nutrients availability, soil humidity, as much as the susceptibility of the hosting plant, like its defense mechanisms and recovering capacity can also influence in the impact that insects cause in forestry plantations (Pinkard et al., 2017). The fields borders were the most critical points in the damage study of *C. ferruginea* in eucalyptus plantations in Espirito Santo, as established by Máfia et al. (2014), probably due to the fact that limiting areas constituted by grassy species being more attractive to the initial development of chrysomelidae (Pinkard et al., 2017). In a study about the yellow beetle of eucalyptus in the state of Acre in 2013, Santos et al. (2016) state that younger leaves and the apical region were the preferred by the insect, probably due to physicalchemical characteristics of the eucalyptus leaves.

Global climate changes may influence in the productivity of forestry plantations (Keenan, 2017). The alterations, however, are uncertain, since there is still the necessity of studies that demonstrate the answer of vegetal species and animal ones to the climate changes. Plasticity in insects, like diapause for example, may be a determinant factor on its adaptation to the clime variations not favorable to its development (Sgró et al., 2016). For Australia, Keenan (2017) demonstrated that native insect's species in tropical regions of the country may be dispersed faster, however the increase in emission of greenhouse effect gases, like the increase of carbonic gas in the atmosphere, may potentially increase the productivity of planted forests in areas with better soils.

Adaptation, diminution in the emission of greenhouse effect gases and understanding of how these clime alterations may affect the life cycle, the distribution and severity of attacks from pest insects are primordial to slow down the damage caused by global climate changes in agriculture. The diversification in commercial plantations of eucalyptus also becomes an alternative of adaptation, since homogenous massive plantations in monoculture cultivars may favor the occurrence and attack of pest insects (Máfia et al., 2014). Modeling studies of geographic distribution help in the planning and execution of integrated management projects of pests as well, which demand better diffusion. Eucalyptus commercial plantations in suitable areas to the establishment of *C. ferruginea* as demonstrated in the study must be monitored with double attention in the analyzed periods, especially those ones close to pastures.

Acknowledgements

To the Coordination of Superior Level Staff Improvement (CAPES) for the assistance with the scholarship. We also thanks to every curator of the entomological collections consulted, as much to the prof. Dr. Rodolfo Molinário de Souza for the information shared.

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