Potential impact of the global climate changes on the spatial distribution of areas of risk for the occurrence of eucalyptus rust in Brazil

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ABSTRACT

Moraes, W.B.; Jesus Junior, W.C.; Cecílio; R.A., Mafia, R.G.; Moraes, W.B.; Cosmi, F.C.; Valadares Junior. R. **Potential impact of the global climate changes on the spatial distribution of areas of risk for the occurrence of eucalyptus rust in Brazil** *Summa Phytopathologica,* v.40, n.2, p.114-122, 2014.

Rust, caused by *Puccinia psidii*, is one of the most important diseases affecting eucalyptus in Brazil. This pathogen causes disease in mini-clonal garden and in young plants in the field, especially in leaves and juvenile shoots. Favorable climate conditions for infection by this pathogen in eucalyptus include temperature between 18 and 25 ºC, together with at least 6-hour leaf wetness periods, for 5 to 7 consecutive days. Considering the interaction between the environment and the pathogen, this study aimed to evaluate the potential impact of global climate changes on the spatial distribution of areas of risk for the occurrence of eucalyptus rust in Brazil. Thus, monthly maps of the areas of risk for the occurrence of this disease were elaborated, considering the current climate conditions, based on a historic series between 1961 and 1990, and the future scenarios A2 and B2, predicted by IPCC. The climate conditions were classified into three categories, according to the potential risk for the disease occurrence, considering temperature (T) and air relative humidity (RH): i) high risk ($18 \leq T \leq 25$ ºC and RH $\geq 90\%$); ii) medium risk ($18 \leq T \leq 25$ ºC and RH $< 90\%$; T$<$ 18 or T $>$ 25 ºC and RH $\geq 90\%$); and iii) low risk (T $<$ 18 or T $>$ 25 ºC and RH $< 90\%$). Data about the future climate scenarios were supplied by GCM Change Fields. In this study, the simulation model Hadley Centers for Climate Prediction and Research (HadCm3) was adopted, using the software Idrisi 32. The obtained results led to the conclusion that there will be a reduction in the area favorable to eucalyptus rust occurrence, and such a reduction will be gradual for the decades of 2020, 2050 and 2080 but more marked in scenario A2 than in B2. However, it is important to point out that extensive areas will still be favorable to the disease development, especially in the coldest months of the year, i.e., June and July. Therefore, the zoning of areas and periods of higher occurrence risk, considering the global climate changes, becomes important knowledge for the elaboration of predicting models and an alert for the integrated management of this disease.

Additional keywords: *Eucalyptus, Puccinia psidii*, predicting and alert system, global climate changes.

RESUMO

Moraes, W.B.; Jesus Junior, W.C.; Cecílio; R.A., Mafia, R.G.; Moraes, W.B.; Cosmi, F.C.; Valadares Junior. R. **Impacto potencial das mudanças climáticas globais na distribuição espacial de áreas de risco para ocorrência da ferrugem do eucalipto no Brasil.** *Summa Phytopathologica,* v.40, n.2, p.114-122, 2014.

A ferrugem, causada pelo fungo *Pucciniapsidii*, constitui em uma das principais doenças do eucalipto no Brasil. O patógeno causa doença em minijardim clonal e em plantas novas no campo, principalmente em folhas e em brotações juvenis. As condições climáticas favoráveis para infecção deste patógeno em eucalipto incluem temperatura entre 18 a25 °C, com períodos de pelo menos 6 horas de molhamento foliar, por 5 a 7 dias consecutivos. Considerando a interação entre ambiente e patógeno, o presente trabalho objetivou avaliar o impacto potencial das mudanças climáticas globais sobre a distribuição espacial de áreas de risco para ocorrência da ferrugem do eucalipto, no Brasil. Para isso, elaboraram-se mapas mensais das áreas de risco para ocorrência da doença, considerando as condições climáticas atuais, com base em uma série histórica entre 1961 e 1990 e, os cenários futuros A2 e B2, previstos pelo IPCC. As condições climáticas foram classificadas em três categorias, de acordo com o risco potencial de ocorrência da doença, considerando a temperatura (T) e umidade relativa do ar (UR): i) alto risco ($18 \leq T \leq 25$ ºC e UR $\geq 90\%$); ii) médio risco ($18 \leq T \leq 25$ ºC e UR $< 90\%$; T$<$ 18 ou T $>$ 25 ºC e UR $\geq 90\%$); e iii) baixo risco (T $<$ 18 ou T $>$ 25 ºC e UR $< 90\%$). Os dados sobre os cenários climáticos futuros foram fornecidos pelo GCM Change Fields. Empregou-se neste trabalho o modelo de simulação Hadley Centre for Climate Prediction and Research (HadCm3), utilizando o software Idrisi 32. Com base nos resultados obtidos foi possível concluir que haverá redução da área favorável para ocorrência da ferrugem do eucalipto, sendo que esta redução será gradativa para as décadas de 2020, 2050 e 2080, sendo mais acentuada no cenário A2 que no B2. Entretanto, é importante ressaltar que extensas áreas ainda continuarão favoráveis ao desenvolvimento da doença, principalmente nos meses mais frios do ano, ou seja, junho e julho. Sendo assim, o zoneamento das áreas e épocas de maior risco de ocorrência, considerando as mudanças climáticas globais, tornam-se importantes conhecimentos para elaboração de modelos de previsão e de alerta para o manejo integrado da doença.

Palavras-chave adicionais: *Eucalyptus, Puccinia psidii*, sistema de previsão e alerta, mudanças climáticas globais.

The Brazilian Forest Sector has undergone an accelerated development, which can be evidenced by the manufacturing potential and by the extension and establishment of new productive units in different regions, including the previous growth of forest bases, specially eucalyptus. According to (1), the investments made by the pulp and paper sector alone were approximately US$12 billions in the last 10 years. The already implanted or started projects represent an increase of around 10 million $m^3.year^{-1}$ in wood consumption. There was also an increase in the eucalyptus planted area between 2006 and 2012, which, at the end of 2013, accounted for up to 5,100,000 ha of planted area.

Rust caused by the fungus *Puccinia psidii* is nowadays one of the most important diseases affecting eucalyptus crop. Average air temperature varying between 18 and 25°C, associated with overnight leaf watering (night dew or drizzle during periods longer than 6 hours for 5 to 7 consecutive days), and existence of young members (new leaves and terminal buds) promote infection. The fungus infects the young leaves of new plants or shoots after the cutting/pruning of trees. Besides eucalyptus, the pathogen can infect other species that belong to the Myrtaceae and to the Heteropyxidaceae family (2, 3, 19).

Climate conditions can influence the host plant's development and sensitivity, the pathogen's multiplication, survival and activities, and the interaction between them (5, 12, 13, 16, 23, 25, 28). Consideringthe most important consequences of climate change on plant diseases, it is worth mentioning that it has potential effects on damage, geographical distribution, efficiency of control methods and interactions among the plant, the pathogen and other microorganisms (4, 10, 11, 12, 23, 24).

The prognostication on global climate change (GCC) has opened several discussions in different sectors of the society, especially about the studies of its causes and the projection of its consequences (18). According to the projections of the Intergovernmental Panel on Climate Change (22), it is believed that until the end of the XXI century, the expected warming average will be around 1.8 to 4.0 °C. GCC has generated a serious threat to the Brazilian phytosanitary scenario because it can promote significant changes in the occurrence and in the intensity of this disease in plants. Analyses of those effects are extremely necessary for the adoption of measures, with the aim of avoiding future losses. Nowadays, protecting the territorial forest bases, according to the phytosanitary point of view and considering the climate changes, constitutes one of the most important integrating strategic challenges between improvement and forest management.

Therefore, the present study aimed to evaluate the possible impacts of GCC on the spatial distribution of areas of risk for the occurrence of eucalyptus rust in Brazil.

MATERIAL AND METHODS

Climate Database

Spatial distribution maps of areas showing different levels of favorability for eucalyptus rust development were elaborated by applying monthly data of the average temperature and relative air humidity obtained in the Climate Research Unit (CRU) of the University of East Anglia, England (27). Such data refer to the historical average of those variables in the period between 1961 and 1990, available as matrix format (grid), with cells of 10' X 10' latitude and longitude.

As regards the future projections of temperature and relative air humidity, we applied the forecast obtained from the IPCC (Intergovernmental Panel on Climate Change), made based on the model developed by Hadley Centre for Climate Prediction and Research (HadCm3). The utilized future scenarios were A2 and B2, centered in the decades of 2020 (periods between 2010 and 2039), 2050 (periods between 2040 and 2069) and 2080 (periods between 2070 and 2099) (22). Scenario A2 describes a very heterogeneous world where regionalization is dominant, while scenario B2 describes a future heterogeneous world where regionalization is dominant; in addition B2 describes a world where local solutions for the economical, social and environmental sustainability are emphasized. Therefore, scenario A2 previews more substantial climate changes because of the greater release of greenhouse gases, compared to scenario B2 (21).

Modeling and elaboration of risk maps

The Geographical Information System (GIS) Idrisi 32® was used in the elaboration of maps. On account of the spatial resolution of the model provided by IPCC (HadCM3: 3.75° X 2.5°), the data had to be resampled by using the tool resampled (Idrisi 32®) to reach the final spatial resolution of 10' X 10' latitude and longitude. For every month, a map was created with the data of temperature and relative air humidity, considering the current climate situation and the forecasts for the decades of 2020, 2050 and 2080, in scenarios A2 and B2.

The maps of average temperature and relative air humidity for the current period and the future scenarios A2 and B2 (2020, 2050, and 2080) were used to elaborate monthly maps of the distribution of areas of risk for the disease occurrence by applying defined classes based on the epidemiologic data about the effects of temperature and relative air humidity on the development of rust in eucalyptus (Table 1) (3, 14, 15, 29).

Calculation of the percentage of areas within the risk class

GIS software Idrisi 32® was employed to calculate the percentage of areas within the risk class. Based on the monthly maps of the distribution of areas of risk for the disease occurrence and utilizing the tool Gys Analysis – Database Query – AREA (Idrisi 32®), the areas for each risk class were obtained as acres, which were then transformed into percentage. For every month, percentage values were generated for each class of risk, considering the current climate conditions and the forecasts for the decades of 2020, 2050 and 2080, in scenarios A2 and B2.

Table 1. Classes of favorability for eucalyptus rust (*Puccinia psidii*) development defined as a function of temperature and relative humidity intervals.

Favorability Classes	Risk	Description	Temperature intervals (ºC)	Relative humidity intervals (%)
1	High	Favorable	18 to 25	≥ 90
2	Medium	Relatively Favorable	18 to 25	< 90
2	Medium	Relatively Favorable	< 18 or > 25	≥ 90
3	Low	Unfavorable	< 18 or > 25	< 90

RESULTS

We obtained 96 maps (Figures 1 to 4) containing the potential spatial distribution of the areas of risk for the occurrence of rust, in a monthly scale, for the current and the future (2020, 2050 and 2080) climate conditions in the two studied scenarios. For the future scenarios, in general, the maps showed that the areas favorable to rust development in the country will be reduced, compared to the current climate, either for scenario A2 (Figures 1 and 2) or for scenario B2 (Figures 3 and 4). That reduction is projected both for the most favorable period of the disease, from April to August, in scenarios A2 and B2, respectively, and for the least favorable period, from September to March, in scenarios A2 and B2, respectively.

In general, there was a greater reduction in the disease area for scenario A2, compared to B2, according to the simulations based on the HadCM3 model (Table 2). Scenario A2 previews a greater reduction in humidity than scenario B2, resulting in less favorable conditions for eucalyptus rust. Furthermore, the reduction in the area favorable to the disease is gradual for the three studied decades and the two scenarios, which means that every decade the favorable area is reduced. For example, in the period considered current, from April to August, the area favorable to eucalyptus rust corresponds, on average, to 35.77% of the national territory and, from September to March, to 27.53%. For scenario A2, the average area will be 26.53% and 18.27% in 2020, 21.01% and 12.06% in 2050, and 15.81% and 8.52% in 2080, respectively.

The intervals used in this study to characterize classes of favorability to eucalyptus rust were adequate because the maps obtained by considering the current climate were in agreement with data available in the literature (3, 14, 15, 28, 29), in which favorable conditions to the disease development were presence of running water (humidity over 90%), darkness, and temperatures between 18 and 25°C, allowing the germination of uridiniospores on the leaf surface. In Brazil, those favorable environmental conditions occur mostly from April to August, the period when rust has been more intense (29). However, favorable periods for the infection may vary from year to year according to the geographical area.

DISCUSSION

In general, based on the results of the present study, there were a reduction in the percentage of areas classified at high risk for eucalyptus rust occurrence (class 1) and an increase in areas at medium and low risk (classes 2 and 3) (Table 2), considering scenarios A2 (Figures 1 and 2) and B2 (Figures 3 and 4). However, in scenario A2, where a greater reduction in the average relative air humidity and a greater increase in the average temperature were expected, there was a greater potential reduction in the disease occurrence, which means that less areas in the territory were affected by the disease included in class 1. Other authors have also shown changes in the geographical distribution of classes of favorability to other pathological systems in future projections, for example, phytopathogens in Finland (9), studies of the effect of the climate changes on phytopathogenic nematodes (*Xiphinema* and *Longidorus*) in Europe (6), occurrence of *Phytophthora cinnamomi* Rands in oak (*Quercus* spp.) in the European continent (7) and (8), and black-sigatoka of banana (17) and (24).

As regards spatial distribution, it is important to point out that extensive areas, especially in the states of Bahia, Espírito Santo, Minas Gerais, São Paulo and the states in the south of Brazil, where the majority of eucalyptus crops are concentrated (1), even considering the expected global warming, are still favorable to the disease development, especially in winter months, which should result in the need of adopting control measures such as: evasion, moving the sprouts during the unfavorable time for the disease, planting resistant clones in the most favorable areas, allowing the rationalization of all the maneuver strategies since all of them were implemented in the adequate moment, considering each component of the disease triangle (pathogen, host and environment).

The methodology adopted for these studies allowed us to evaluate the potential effect of the climate changes on the current and future conditions by mapping the risk areas, considering the time and the space, which was used in previous studies about the interactions between climate changes and plant disease (16, 17, 20, 23, 24, 26). It is important to stress that this type of analysis had as basis only the climate conditions for the disease development, and it did not take into consideration the evolution of either the pathogen or the host, which will probably occur over the years.

The coldest months (April, May, June, July and August) are considered more favorable to the development of the disease in the current climate conditions and remain favorable to future projections. On the other hand, months showing higher temperatures (November, December and January) will be, every time, less favorable to eucalyptus rust because of the increase in temperature and the decrease in relative humidity. The data presented in this study showed that class 2 (medium risk) of favorability tends to become higher depending on the decrease in the relative humidity which can increase the incubation period and the latent period (the smallest number of cycles of the pathogen per year). Nevertheless, the disease will have great importance mostly in the main eucalyptus producing states.

Considering the potential effect of MCG on the eucalyptus crop, even with the previewed climate changes in the two scenarios (A2 and B2) and in the three periods (2020, 2050 and 2080), we suppose that the crop will not suffer significant alterations since the extent of eucalyptus growth is inserted in the changing values. What may occur is that some areas will become more suitable for cultivation than others, a fact that can lead to the advent or to the better development of some new areas for planting.

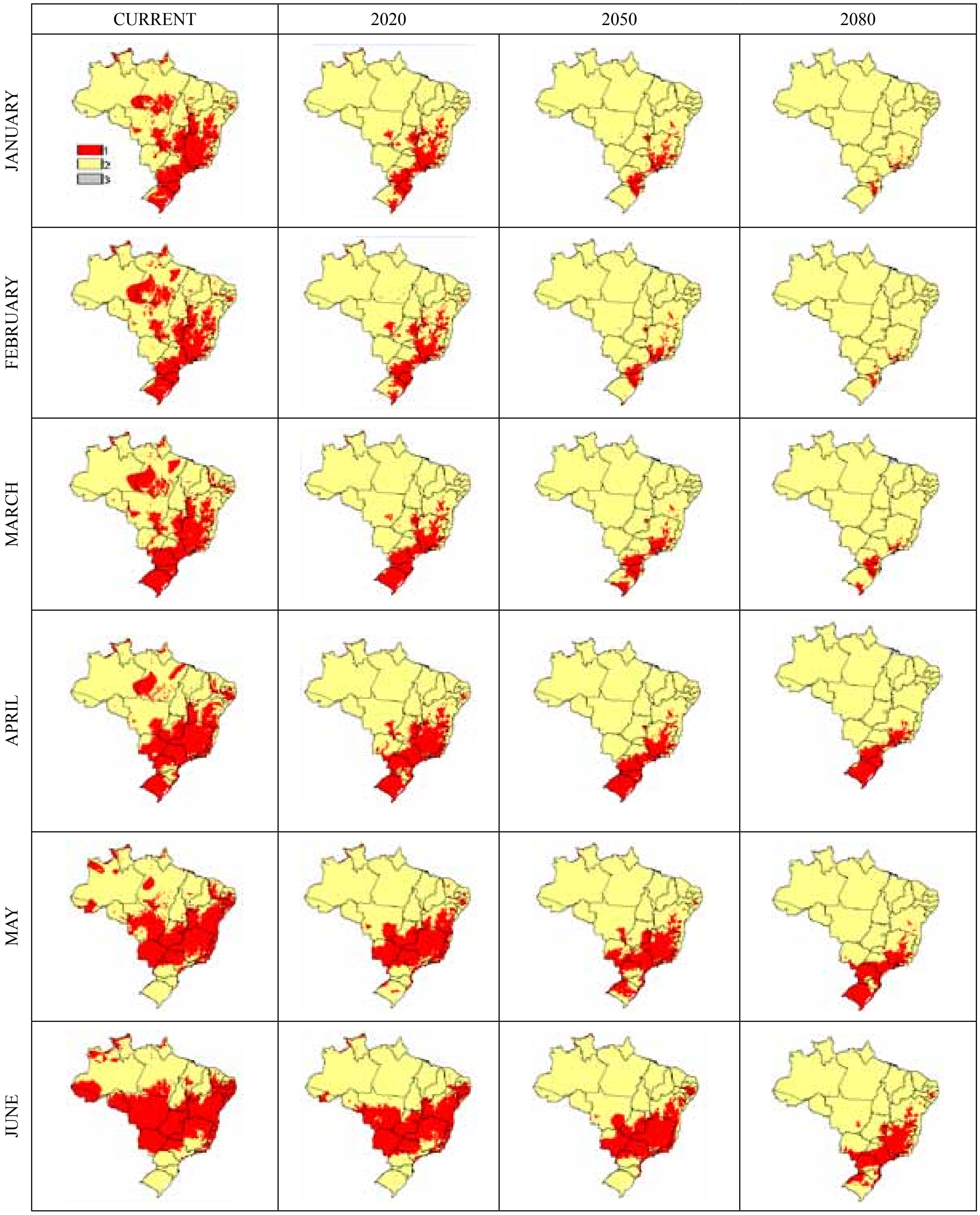
CONCLUSIONS

The adopted methodology was efficient for mapping the risk of occurrence of eucalyptus rust, considering the spatial and temporal distribution.

Based on the previewed scenarios for the climate changes, we strongly expect a reduction in the percentage of the favorable areas and an increase in the areas at medium risk for the occurrence of eucalyptus rust.

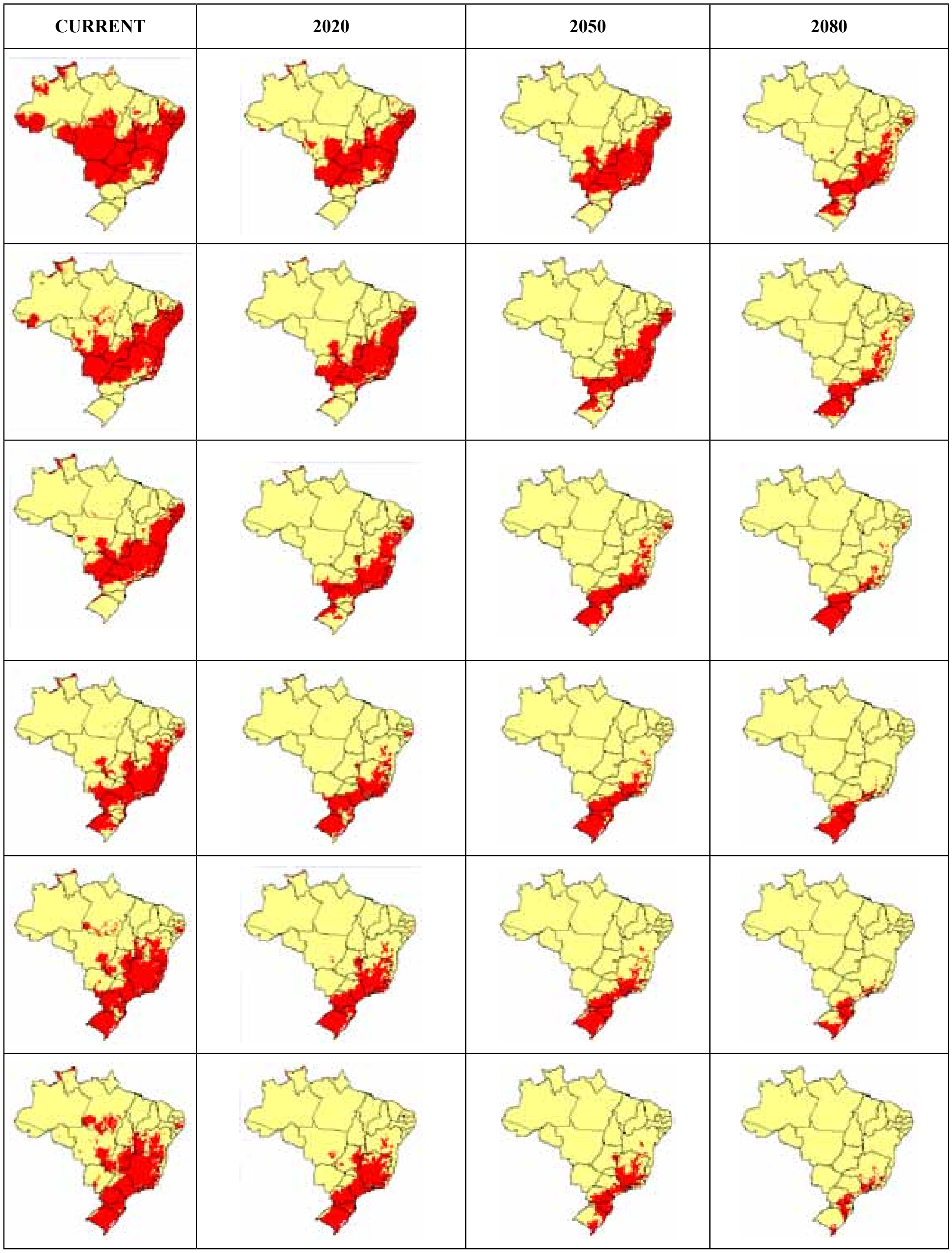
The areas showing greater forest activities with eucalyptus, even undergoing global warming which tends to be unfavorable to the disease occurrence, will still be favorable to rust epidemics.

The acquired knowledge, associated with the development of models for the disease prevision, can form important tools in the integrate management of the eucalyptus rust.



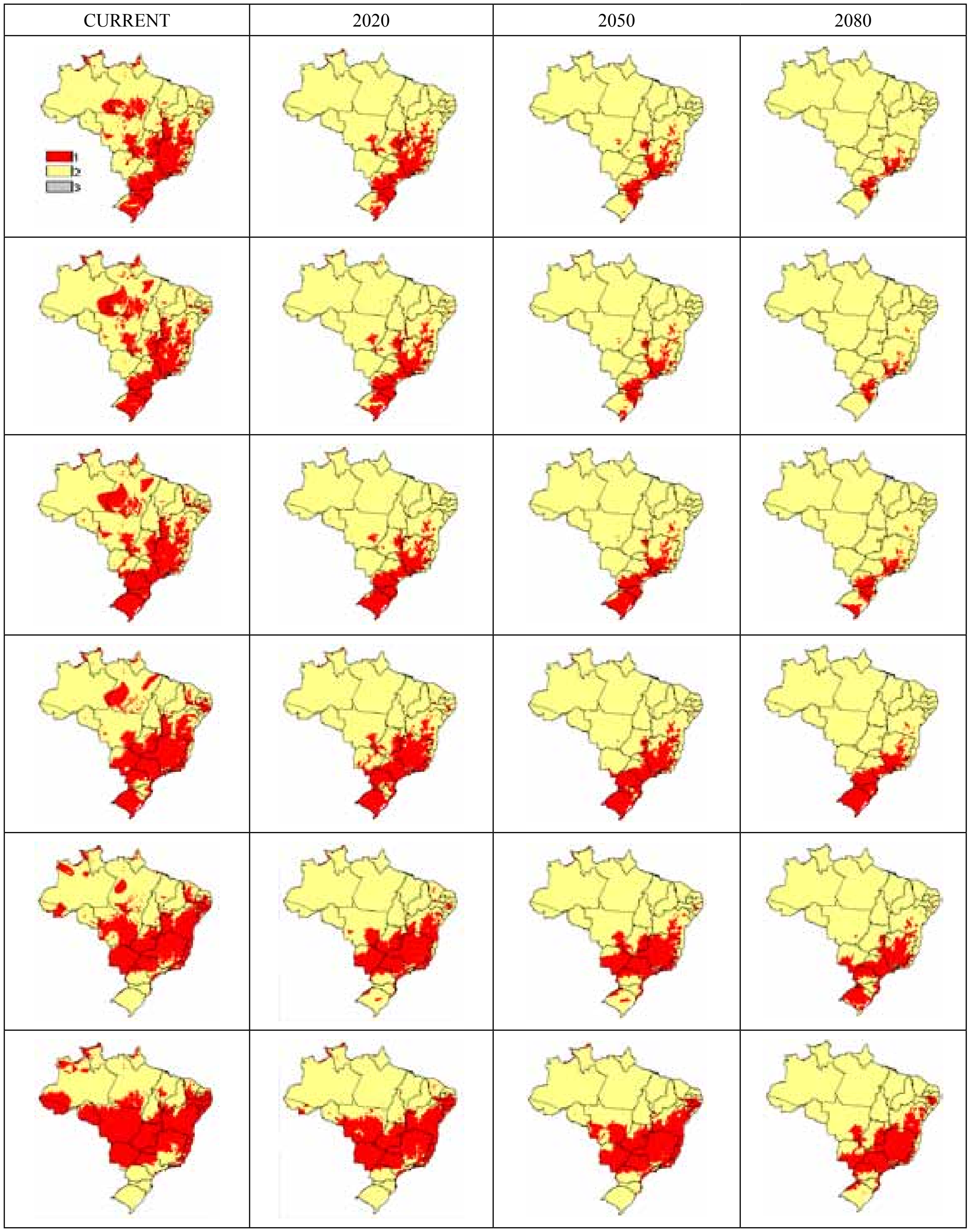
1-High, 2- Medium, 3- Low

Figure 1. Distribution of risk areas for the occurrence of eucalyptus rust, considering the months of January to June, in the current period (average from 1961 to 1990) and in the future (2020, 2050 and 2080) for scenario A2.



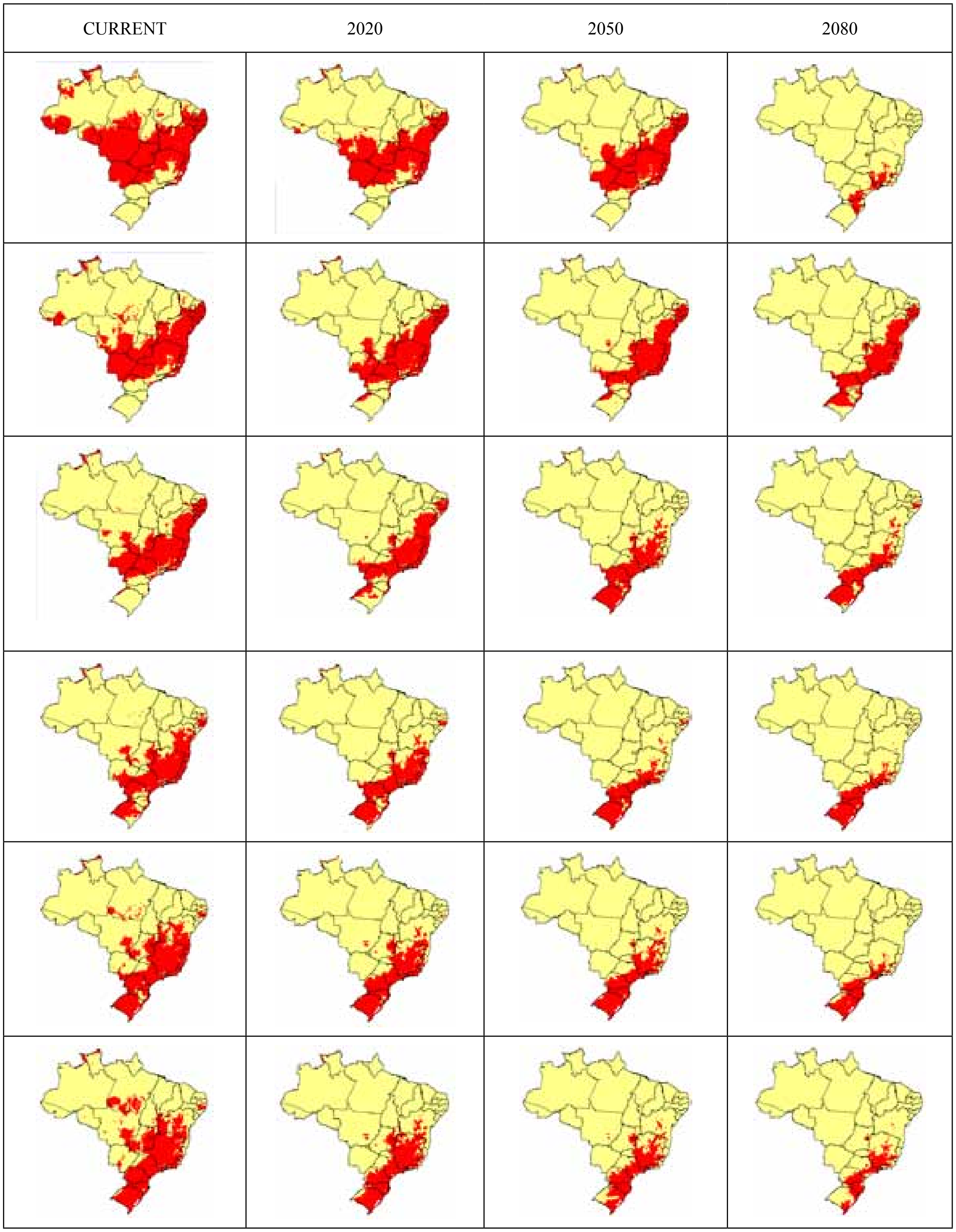
1- High, 2- Medium, 3- Low

Figure 2. Distribution of risk areas for the occurrence of eucalyptus rust considering the months of July to December, in the current period (average from 1961 to 1990) and in the future (2020, 2050 and 2080) for scenario A2.



1- High, 2- Medium, 3- Low

Figure 3. Distribution of risk areas for the occurrence of eucalyptus rust, considering the months of January to June, in the current period (average from 1961 to 1990) and in the future (2020, 2050 and 2080) for scenario B2.



1- High, 2- Medium, 3- Low

Figure 4. Distribution of risk areas for the occurrence of eucalyptus rust, considering the months of July to December, in the current period (average from 1961 to 1990) and in the future (2020, 2050 and 2080) for scenario B2.

Table 2. Brazilian area (%) occupied by classes of favorability for rust eucalyptus considering every month in the current date, in 2020, in 2050 and in 2080 (scenarios A2 and B2), situations predicted by HadCm3 climate change model.

Months	Risk Class	Current	Scenarios Previewed by IPCC					
			A2			B2		
			2020	2050	2080	2020	2050	2080
JAN	High	26.03	14.13	7.46	4.71	16.47	9.42	6.40
	Medium	73.97	85.87	92.54	95.29	83.53	90.58	93.60
	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEB	High	28.48	15.82	7.73	4.68	16.81	10.94	6.13
	Medium	71.52	84.15	92.23	95.20	83.19	89.06	93.78
	Low	0.00	0.03	0.03	0.12	0.00	0.00	0.09
MAR	High	32.61	20.25	12.55	8.46	20.21	15.92	11.87
	Medium	67.39	79.75	87.29	91.26	79.76	84.03	87.87
	Low	0.00	0.00	0.16	0.27	0.03	0.05	0.26
APR	High	34.66	27.22	20.06	16.05	26.45	23.15	19.09
	Médium	65.34	72.73	79.81	83.67	73.49	76.81	80.71
	Low	0.00	0.05	0.13	0.28	0.05	0.04	0.21
MAY	High	35.20	26.18	21.10	17.20	25.46	21.34	19.06
	Medium	64.80	73.76	78.56	82.26	74.48	78.36	80.54
	Low	0.00	0.06	0.35	0.54	0.06	0.30	0.41
JUN	High	39.25	29.58	22.20	16.26	29.86	26.85	20.66
	Medium	60.75	70.14	77.46	83.16	69.84	72.87	78.96
	Low	0.00	0.28	0.34	0.58	0.30	0.28	0.39
JUL	High	39.17	26.24	22.65	16.26	28.20	25.06	21.41
	Medium	60.83	73.57	77.05	83.31	71.69	74.73	78.27
	Low	0.00	0.19	0.30	0.43	0.11	0.20	0.32
AUG	High	30.59	23.44	19.05	13.30	24.75	19.39	19.23
	Medium	69.41	76.54	80.73	86.42	75.22	80.47	80.55
	Low	0.00	0.02	0.22	0.28	0.03	0.13	0.22
SEP	High	25.50	19.42	15.54	13.15	20.49	23.15	14.61
	Medium	74.50	80.58	84.46	86.77	79.51	76.85	85.39
	Low	0.00	0.00	0.00	0.09	0.00	0.00	0.00
OCT	High	25.32	19.13	16.36	12.58	21.59	17.46	14.57
	Medium	74.68	80.87	83.64	87.42	78.41	82.54	85.43
	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOV	High	28.03	20.35	14.34	10.07	19.97	16.53	12.28
	Medium	71.97	79.65	85.66	89.93	80.03	83.47	87.72
	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DEC	High	26.73	18.77	10.41	6.02	18.80	14.07	8.81
	Medium	73.27	81.23	89.59	93.98	81.20	85.93	91.19
	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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