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Impact of global warming on the distribution of *Anastrepha grandis* (Diptera: Tephritidae) in Brazil

Impacto potencial do aquecimento global sobre a distribuição de **Anastrepha grandis** *(Diptera: Tephritidae) no Brasil*

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ABSTRACT: *Anastrepha grandis* is one of the main pests related to Cucurbitaceae in South and Central America. This study discusses the impact of temperature increase on the number of generations of *A. grandis*, whose distribution could be aggravated due to temperature increase. Climatic variations were analyzed for reference scenarios obtained from 1961–1990 and of A2 and B1 climatic change scenarios of the Intergovernmental Panel on Climate Change, in which a less pessimistic scenario (B1) and a more pessimistic scenario (A2) were found. In relation to the reference scenarios, in colder seasons, the southern and southeastern regions are inadequate for the development of *A. grandis*, presenting one generation at most. In other regions of Brazil, where temperatures are higher throughout the year, the number of generations is at least two, and there is no variation from one climatic season to another. When analyzing the temperature increase, in a more pessimistic scenario (A2), there is a considerable variation in the number of generations, if we take into account three future climate scenarios in which *A. grandis* practically doubles the number of generations. In relation to a less pessimistic scenario (B1), there is a smaller variation in the number of generations, mainly in the southern region of the country. This variation is more accentuated in southeastern Brazil due to the temperature increase, in which the pest's number of generations doubles even in colder seasons.

KEYWORDS: abiotic factors; Cucurbitaceae; climatic changes; quarantine pest.

RESUMO: *Anastrepha grandis* é uma das principais pragas relacionadas à Cucurbitaceae nas Américas do Sul e Central. O presente trabalho teve como objetivo conhecer o impacto do aumento da temperatura no número de gerações de *A. grandis*, cuja distribuição poderá ser agravada devido ao aumento da temperatura. Essas variações climatológicas foram analisadas para cenários de referência obtidos de 1961–1990 e nos cenários de mudanças climáticas A2 e B1 do Painel Intergovernamental de Mudanças Climáticas, onde encontramos um cenário menos pessimista (B1) e um mais pessimista (A2). Em relação ao período de referência é possível observar que, nas estações mais frias, as regiões Sul e Sudeste mostram-se inadequadas para o desenvolvimento de *A. grandis*, apresentando no máximo uma geração, enquanto nas estações mais quentes o inseto pode chegar a duas gerações. Nas demais regiões do país, onde as temperaturas apresentam-se mais elevadas durante todo o ano, o número de gerações é de no mínimo duas e não há variação de uma estação climática para outra. Quando analisado o aumento da temperatura, em um cenário mais pessimista (A2), é possível observar uma variação considerável no número de gerações nos três cenários climáticos futuros, podendo *A. grandis* dobrar o número de gerações. Em relação a um cenário menos pessimista (B1), é evidente uma variação menor no número de gerações, principalmente na região Sul do país, enquanto que na região Sudeste essa variação já é mais acentuada devido ao aumento da temperatura, podendo dobrar o número de gerações mesmo nas estações mais frias.

PALAVRAS-CHAVE: fatores abióticos; cucurbitáceas; mudanças climáticas; praga quarentenária.

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INTRODUCTION

The current phytosanitary scenario of Brazilian agriculture may be altered by anthropogenic climate change, influencing the importance of pests and diseases of cultivated plants. The analysis of the possible effects of climate change on the phytosanitary problems of commercial crops is key for the adoption of measures to mitigate damages (GHINI, 2005).

For insects in general, climate variables, especially air temperature, are important as they favor changes mainly in dispersal, development, and reproduction rates (WREGE et al., 2017). Temperature, humidity, and light are the abiotic factors that most affect fruit flies (GARCIA, 2009). Therefore, any changes in one of these components have a direct impact on the populations of insects.

Climate change affects insect species differently and should be studied in depth (KRÜGER et al., 2017). Some bioclimatic studies on fruit flies have been conducted to predict areas where pest species survive and reproduce (MESSENGER; FLITTERS, 1954). However, few studies investigate the impact of climate change on the development of agricultural pests under Brazilian conditions, mainly fruit flies.

The species *Anastrepha fraterculus* (Wiedmann, 1830), *Anastrepha obliqua* (Macquart), *Anastrepha sororcula* (Zucchi, 1979), *A. grandis*, and *Ceratitis capitata* (Wiedmann) are listed by the protection agencies of various countries as quarantine species (NASCIMENTO et al., 1993). In Brazil, the genera *Ceratitis* and *Anastrepha* are the most economically important, where the former is represented by only one species, *Ceratitis capitata*, while the latter is represented by 112 species (ZUCCHI, 2008). Both genera are responsible for considerable losses due to the frugivorous habit of their larvae, which cause damages to the fruit's mesocarp that make it unfit for consumption (DUARTE; MALAVASI, 2000). The importance of an insect species may vary depending on the host, region, or time of year within the same country (ZUCCHI, 2008).

Among the species of fruit flies with quarantine restrictions, we highlight *A. grandis*, whose main host are the Cucurbitaceae fruits, and is present in the southern, southeastern and central-western regions of Brazil. This species has oligophagous and multivoltine habits and is considered a quarantine pest of importance by cucurbit-importing countries (GARCIA, 2009). To export cucurbit fruits to countries that are free of this pest, countries where *A. grandis* is present must produce in pest free areas (PFA) or areas with the implementation of the integrated system for pest risk management (SPRM), which are programs recognized by official bodies (BOLZAN et al., 2016).

In southern Brazil, changes in the minimum air temperature have already been detected by studies of climate behavior in recent decades, as well as by time series analysis of climate data from state agricultural research institutions. Overall, the minimum temperature increase observed at various weather stations over the past 50 years has been of approximately 1.5°C, varying according to location. An increase in the maximum temperature has also been detected, but to a lesser extent, about 0.5°C (RICCE et al., 2008; STEINMETZ et al., 2005).

Studies on insect population distribution indicate that rising temperatures may aggravate losses for crops. In this study, these increases were analyzed in the baseline climate-related scenarios obtained from 1961−1990 (HAMADA et al., 2008) and in the climate change scenarios A2 and B1 of the Intergovernmental Panel on Climate Change (IPCC) addressing the least pessimistic scenario (B1) and the most pessimistic scenario (A2) for the coming decades (MEEHL; STOCKER, 2007). This study investigated the impact of temperature increase on the number of generations of *A. grandis* in Brazil.

MATERIAL AND METHODS

The number of generations in a year was calculated by the total thermal sum existing at each location, dividing it by the thermal constant required for the completion of the insect's life cycle. This calculation was made for all regions of Brazil, using climate data organized by HAMADA et al. (2008), who verified the consistency, errors, and completeness of various climate models, selecting and compiling the best models, which were the models that best represented the reality of each region. The thermal sum was calculated for the base period of 1961−1990 (considered as reference period) and for projections of future climate scenarios until 2100.

The thermal sum was calculated by the difference between the average of the maximum and minimum temperatures and the lower developmental threshold temperature or base temperature (Tb). The Tb represents the limit below which the insect does not develop because it does not find favorable conditions to complete its life cycle. Thus, in winter, the life cycle of the insect lasts longer than in summer, as the temperature often approaches the lower developmental threshold temperature in winter. Maps of the numbers of insect generations in the base period and projections of future scenarios were created by multiple linear regression, where the variable number of generations was correlated with altitude, latitude, and longitude of each location using the numerical model of the insect (MNT) of GTOPO30 (Table 1) (U.S. GEOLOGICAL SURVEY, 1999). The mappings were made in geographic information systems, using the ArcGIS 10 program.

RESULTS AND DISCUSSION

Based on the thermal requirements obtained by BOLZAN et al. (2017) and the climatological norm of 1961–1990 (reference period), *A. grandis* can have one or two generations per year, possibly varying depending on region and climate season throughout the year (Tables 2 and 3) (Fig. 1). Comparing this baseline scenario with scenarios B1 (least pessimistic),

Table 1. Equations used to forecast the number of generations of *Anastrepha grandis* regarding altitude, latitude, and longitude for the reference period and future scenarios in different seasons.

Scenario	Year season	Regression equation	R^2
Reference period			
Reference period	Spring	2,476+0.018*latitude+0.0015*longitude-0.0002*altitude	0.68
Reference period	Summer	2,364+0.006*latitude+0.0014*longitude-0.0003*altitude	0.60
Reference period	Fall	2,478+0.025*latitude+0.0016*longitude-0.0003*altitude	0.76
Reference period	Winter	2,445+0.034*latitude+0.0006*longitude-0.0002*altitude	0.79
Future scenarios with climate changes A2 and B1 (2011-2040)			
2011–2040 (A2)	Spring	2,476+0.018*latitude+0.0015*longitude-0.0002*altitude	0.68
2011–2040 (A2)	Summer	2,363+0.006*latitude+0.0014*longitude-0.0003*altitude	0.60
2011–2040 (A2)	Fall	2,480+0.026*latitude+0.0016*longitude-0.0003*altitude	0.80
2011–2040 (A2)	Winter	2,445+0.034*latitude-0.0006*longitude-0.0002*altitude	0.79
2011–2040 (B1)	Spring	2,562+0.017*latitude+0.0019*longitude-0.0002*altitude	0.67
2011–2040 (B1)	Summer	2,440+0.006*latitude+0.0007*longitude-0.0003*altitude	0.63
2011–2040 (B1)	Fall	2,523+0.025*latitude+0.0006*longitude-0.0002*altitude	0.75
2011–2040 (B1)	Winter	2,451+0.033*latitude-0.0009*longitude-0.0002*altitude	0.79
Future scenarios with climate changes A2 and B1 (2041-2070)			
2041–2070 (A2)	Spring	2,561+0.016*latitude+0.0007*longitude-0.0002*altitude	0.68
2041–2070 (A2)	Summer	2,485+0.006*latitude+0.0004*longitude-0.0002*altitude	0.65
2041–2070 (A2)	Fall	2,596+0.024*latitude+0.0008*longitude-0.0002*altitude	0.75
2041–2070 (A2)	Winter	2,472+0.032*latitude-0.0015*longitude-0.0002*altitude	0.79
2041–2070 (B1)	Spring	2,547+0.016*latitude+0.0012*longitude-0.0002*altitude	0.68
2041–2070 (B1)	Summer	2,449+0.006*latitude+0.0004*longitude-0.0003*altitude	0.64
2041–2070 (B1)	Fall	2,564+0.025*latitude+0.0008*longitude-0.0002*altitude	0.76
2041–2070 (B1)	Winter	2,453+0.032*latitude-0.0011*longitude-0.0002*altitude	0.79
Future scenarios with climate changes A2 and B1 (2071-2100)			
2071–2100 (A2)	Spring	2,552+0.015*latitude+0.0007*longitude-0.0002*altitude	0.68
2071–2100 (A2)	Summer	2,502+0.006*latitude+0.0003*longitude-0.0002*altitude	0.66
2071–2100 (A2)	Fall	2,609+0.022*latitude+0.0012*longitude-0.0002*altitude	0.75
2071–2100 (A2)	Winter	2,493+0.032*latitude-0.0009*longitude-0.0001*altitude	0.78
2071–2100 (B1)	Spring	2,561+0.016*latitude+0.0008*longitude-0.0002*altitude	0.68
2071–2100 (B1)	Summer	2,485+0.006*latitude+0.0004*longitude-0.0002*altitude	0.66
2071–2100 (B1)	Fall	2,587+0.045*latitude+0.0007*longitude-0.0002*altitude	0.76
2071–2100 (B1)	Winter	2,465+0.032*latitude-0.0016*longitude-0.0002*altitude	0.80

A2 (most pessimistic) with high GHG emissions (Fig. 2), and with low GHG emissions (Fig. 3), there is an increase in the number generations, especially in the colder seasons of the year, as temperatures tend to increase over the years.

The best development of *A. grandis* occurs in warmer regions, usually with lower altitudes. In higher altitude zones, where temperatures are lower, dissemination is slower (Fig. 1). Taking this definition into account, the most pessimistic scenario A2 is characterized by the maintenance of GHG emission standards observed in recent decades, which would imply higher atmospheric concentrations. On the other hand, scenario B1 would have lower GHG emissions, or a least pessimistic scenario, with a tendency towards stabilization of GHG emissions and concentration at the end of this century, at about 550 ppm (NAKIĆENOVIĆ et al., 2000).

The South American cucurbit fly, as well as all flies belonging to the genera *Anastrepha*, *Ceratitis* and *Dacus*, are multivoltine with more than one generation a year, without diapause, and distributed in tropical regions (BATEMAN, 1972; GARCIA, 2009). Although development in alternative hosts is reduced, insects can survive unfavorable seasons and later, in a next generation, attack their preferred hosts.

Table 2. Locations with *Anastrepha grandis*, pest free area, risk mitigation system area and number of generations, reference period, and projections for the most pessimistic scenario (A2), in different seasons in Brazil.

State	Location	Status	No. of generations (Reference period)				No. of generations 2011–2040 (A2)				No. of generations 2041–2070 (A2)				No. of generations 2071–2100 (A2)			
			Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
RN	Mossoró	PFA-MF	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.3	2.2	2.2	2.2	2.4	2.2
RN	Assu	PFA-MF	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.3	2.2	2.2	2.2	2.4	2.2
RN	Macau	SPRM	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.3	2.2	2.2	2.2	2.4	2.2
RN	Jandaíra	SPRM	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.3	2.2	2.2	2.2	2.4	2.2
CE	Jaguaruana	PFA-MF	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.4	2.2	2.2	2.4	2.4	2.2
BA	Curaçá	Occurrence	2.0	2.0	2.0	1.8	2.0	2.0	1.7	1.7	1.9	1.9	1.9	1.9	1.8	1.8	2.2	2.2
MT	Rondonópolis	Occurrence	2.0	2.0	1.7	1.5	1.7	2.0	1.7	1.9	1.8	1.8	2.0	2.0	1.6	1.6	2.2	2.2
GO	Goianésia	SPRM	2.0	2.0	1.9	1.6	1.9	2.0	1.9	1.9	2.1	1.8	1.8	2.1	1.8	1.9	2.1	2.1
RJ	Nova Iguaçu	Occurrence	2.0	2.0	1.6	1.3	1.6	1.9	1.6	1.9	1.8	1.6	1.8	2.1	1.6	1.6	2.0	2.0
RJ	Seropédica	Occurrence	2.0	2.0	1.6	1.3	1.6	1.9	1.6	1.9	1.8	1.6	1.8	2.1	1.6	1.6	2.0	2.0
SP	Presid. Prudente	Occurrence	1.7	1.7	1.4	1.4	1.5	1.7	1.4	1.6	1.7	1.6	1.8	1.9	1.6	1.6	1.9	1.8
SP	Mesópolis	SPRM	1.7	1.7	1.4	1.4	1.5	1.7	1.4	1.6	1.7	1.6	1.8	1.9	1.6	1.6	1.9	1.8
SP	Urânia	SPRM	1.7	1.7	1.4	1.4	1.5	1.7	1.4	1.6	1.7	1.6	1.8	1.9	1.6	1.6	1.9	1.8
SP	Presid. Bernardes	SPRM	1.7	1.7	1.4	1.4	1.5	1.7	1.4	1.6	1.7	1.6	1.8	1.9	1.6	1.6	1.9	1.8
SP	Paranapuã	SPRM	1.7	1.7	1.4	1.4	1.5	1.7	1.4	1.6	1.7	1.6	1.8	1.9	1.6	1.6	1.9	1.8
PR	Maringá	Occurrence	1.6	1.6	1.2	1.1	1.3	1.7	1.4	1.4	1.6	1.7	1.8	1.6	1.5	1.5	1.8	1.8
PR	Stª Isabel do Ivaí	SPRM	1.6	1.6	1.2	1.1	1.3	1.7	1.4	1.4	1.6	1.7	1.8	1.6	1.5	1.5	1.8	1.8
SC	Lages	Occurrence	1.4	1.4	1.2	1.1	1.2	1.4	1.2	1.4	1.4	1.3	1.6	1.8	1.4	1.4	1.8	1.8
RS	Montenegro	Occurrence	1.6	2.0	1.2	1.1	1.2	1.4	1.5	1.9	1.4	1.3	1.7	1.9	1.4	1.4	1.8	1.8
RS	Bagé	SPRM	1.4	1.7	1.2	1.1	1.2	1.4	1.1	1.7	1.4	1.3	1.6	1.8	1.4	1.4	1.8	1.8

SPRM: system for pest risk management; PFA-FF: pest free area-fruit flies.

At present, considering the average, *A. grandis* can have two generations per year in the most development-friendly regions of northeastern and southeastern Brazil (Fig. 2). This number may be higher with increasing temperatures, rising from one to nearly two generations per year in colder, higher altitude regions, and at most three generations per year in warmer, lower altitude regions. This means doubling the number of generations compared to the reference period. For future projections, in scenario B1, there is an increase of only one generation per year, either in the warmer, lower altitude regions, or in the colder, higher altitude regions (Fig. 3).

Research on pest management techniques and actions to mitigate the effects of climate change is strategic, seeking at least to maintain the insect population at current levels and thus avoiding further contamination of the environment by use of pesticides, as well as their effect on plant toxicity. Thus, zoning based on climatic factors that influence insect development allows the definition of ecologically favorable and/or unfavorable environments for its development (BAKER et al., 2000). Climate change can also affect insects indirectly, induced by other factors, namely, interaction with another species (competition, predation, and parasitism) or interaction with host plants for herbivorous insects. Global warming can

Table 3. Sites with occurrence of *Anastrepha grandis*, pest free area, risk mitigation system area, and number of generations, reference period and projections for the least pessimistic scenario (B1), in different seasons in Brazil.

State	Location	Status	No. of generations (Reference period)				No. of generations 2011–2040 (A2)				No. of generations 2041–2070 (A2)				No. of generations 2071–2100 (A2)			
			Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
RN	Mossoró	PFA-MF	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.2	2.1	2.1	2.4	2.4	2.4	2.2	2.4	2.2
RN	Assu	PFA-MF	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.2	2.1	2.1	2.4	2.4	2.4	2.2	2.4	2.2
RN	Macau	SPRM	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.2	2.1	2.1	2.4	2.4	2.4	2.2	2.4	2.2
RN	Jandaíra	SPRM	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.2	2.1	2.1	2.4	2.4	2.4	2.2	2.4	2.2
CE	Jaguaruana	PFA-MF	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.2	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.4
BA	Curaçá	Occurrence	2.0	2.0	2.0	1.8	2.2	1.7	1.9	1.9	1.8	1.8	2.1	1.9	1.8	1.8	2.2	2.2
MT	Rondonópolis	Occurrence	2.0	2.0	1.7	1.5	2.2	1.6	1.8	1.8	1.6	1.5	1.8	1.9	1.7	1.7	2.2	2.0
GO	Goianésia	SPRM	2.0	2.0	1.9	1.6	2.2	1.9	1.9	1.9	1.8	1.8	2.0	2.0	1.9	1.9	2.0	2.0
RJ	Nova Iguaçu	Occurrence	2.0	2.0	1.6	1.3	2.2	1.6	1.8	2.0	1.5	1.5	1.7	1.7	1.7	1.5	1.7	1.7
RJ	Seropédica	Occurrence	2.0	2.0	1.6	1.3	2.2	1.6	1.8	2.0	1.5	1.5	1.7	1.7	1.7	1.5	1.7	1.7
SP	Presid. Prudente	Occurrence	1.7	1.7	1.4	1.4	2.2	1.6	1.8	1.8	1.6	1.6	1.7	1.8	1.6	1.6	1.7	1.9
SP	Mesópolis	SPRM	1.7	1.7	1.4	1.4	22	1.6	1.8	1.8	1.6	1.6	1.7	1.8	1.6	1.6	1.7	1.9
SP	Urânia	SPRM	1.7	1.7	1.4	1.4	2.2	1.6	1.8	1.8	1.6	1.6	1.7	1.8	1.6	1.6	1.7	1.9
SP	Presid. Bernardes	SPRM	1.7	1.7	1.4	1.4	2.2	1.6	1.8	1.8	1.6	1.6	1.7	1.8	1.6	1.6	1.7	1.9
SP	Paranapuã	SPRM	1.7	1.7	1.4	1.4	2.2	1.6	1.8	1.8	1.6	1.6	1.7	1.8	1.6	1.6	1.7	1.9
PR	Maringá	Occurrence	1.6	1.6	1.2	1.1	2.2	1.2	1.5	1.5	1.3	1.3	1.6	1.6	1.4	1.4	1.6	1.6
PR	Stª Isabel do Ivaí	SPRM	1.6	1.6	1.2	1.1	2.2	1.2	1.5	1.5	1.3	1.3	1.6	1.6	1.4	1.4	1.6	1.6
SC	Lages	Occurrence	1.4	1.4	1.2	1.1	2.2	1.1	1.5	1.5	1.3	1.3	1.6	1.6	1.4	1.3	1.6	1.6
RS	Montenegro	Occurrence	1.6	2.0	1.2	1.1	2.2	1.1	1.5	1.8	1.5	1.3	1.7	1.7	1.4	1.3	1.7	1.7
RS	Bagé	SPRM	1.4	1.7	1.2	1.1	2.2	1.1	1,5	1.8	1.3	1.3	1.6	1.7	1.4	1.3	1.6	1.7

SPRM: system for pest risk management; PFA-FF: pest free area-fruit flies.

affect the structure of existing communities because individual responses will inevitably alter interactions between insect species and lead to changes in the composition of natural communities (MENÉNDEZ, 2007).

Temperature, precipitation, humidity, and other climatic parameters affect several insect biological activities (rates of development, reproduction, distribution, migration, and adaptation). In addition, indirect effects may occur through the influence of climate on host plants, natural enemies, and interspecific interactions with other insects. Thus, climate change resulting from increased GHG emissions in the atmosphere could have a significant impact on the development, distribution, and population density of natural insect pests (PORTER et al., 1991).

Considering areas free of *A. grandis*, in the states of Ceará and Rio Grande do Norte, the environmental conditions and vegetation type of the semi-arid do not favor the permanence of high population densities of fruit flies throughout the year, and the number of flies caught during the driest months of the year is very limited (ARAÚJO et al., 2000).

Future projections were based on the needs of *A. grandis* regarding environmental factors (temperature and relative humidity). Based on the analysis of these factors, future climatic conditions are favorable to the development of this pest. SANTOS (2008) described that *A. fraterculus* and *C. capitata* could adapt to the temperature increase predicted for 2080. However, in the case of frugivorous species, it is also necessary to consider that the natural conditions favorable to maintaining their host plants are crucial to the survival of fruit flies, regardless of the intrinsic biological characteristics of these insects, as well as the effect of the natural conditions on their natural enemies (KRÜGER et al., 2017).

CONCLUSIONS

- Projections for 2041 to 2070 point to a tendency of increase in air temperature, thus favoring the spread of *A. grandis* population, with an increase in the number of generations that occur in a year.
- At present, the number of *A. grandis* generations can be higher with increasing temperatures, from one to nearly two generations a year in colder regions and up to three generations a year in warmer regions.
- Future projections point to an increase of one generation per year in both warmer and colder regions.

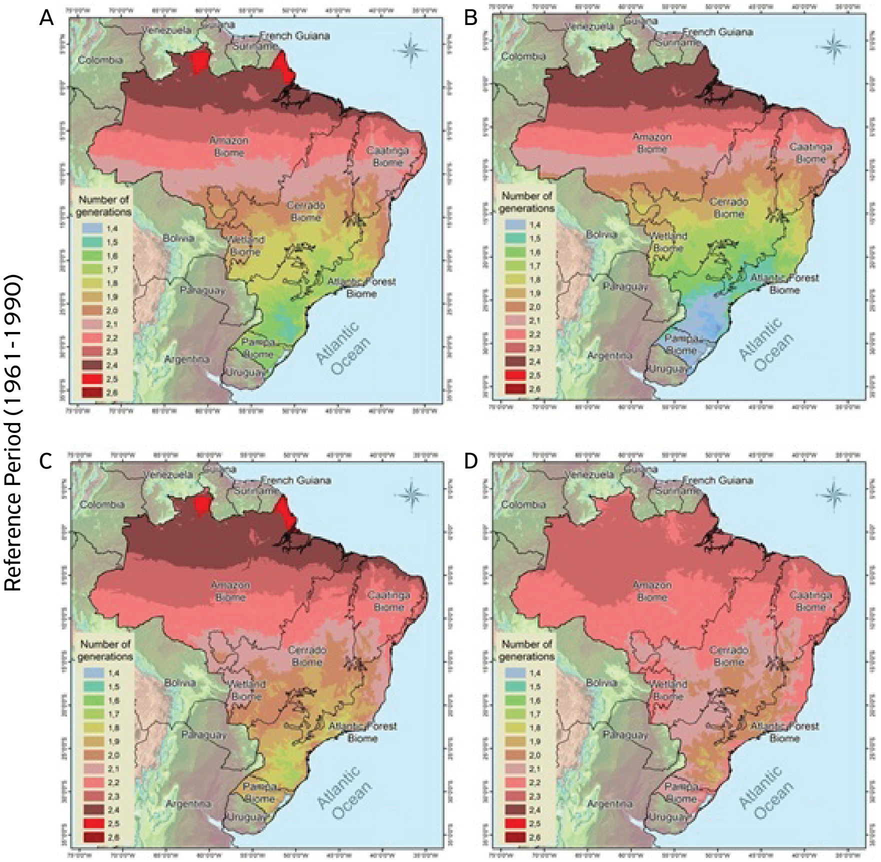
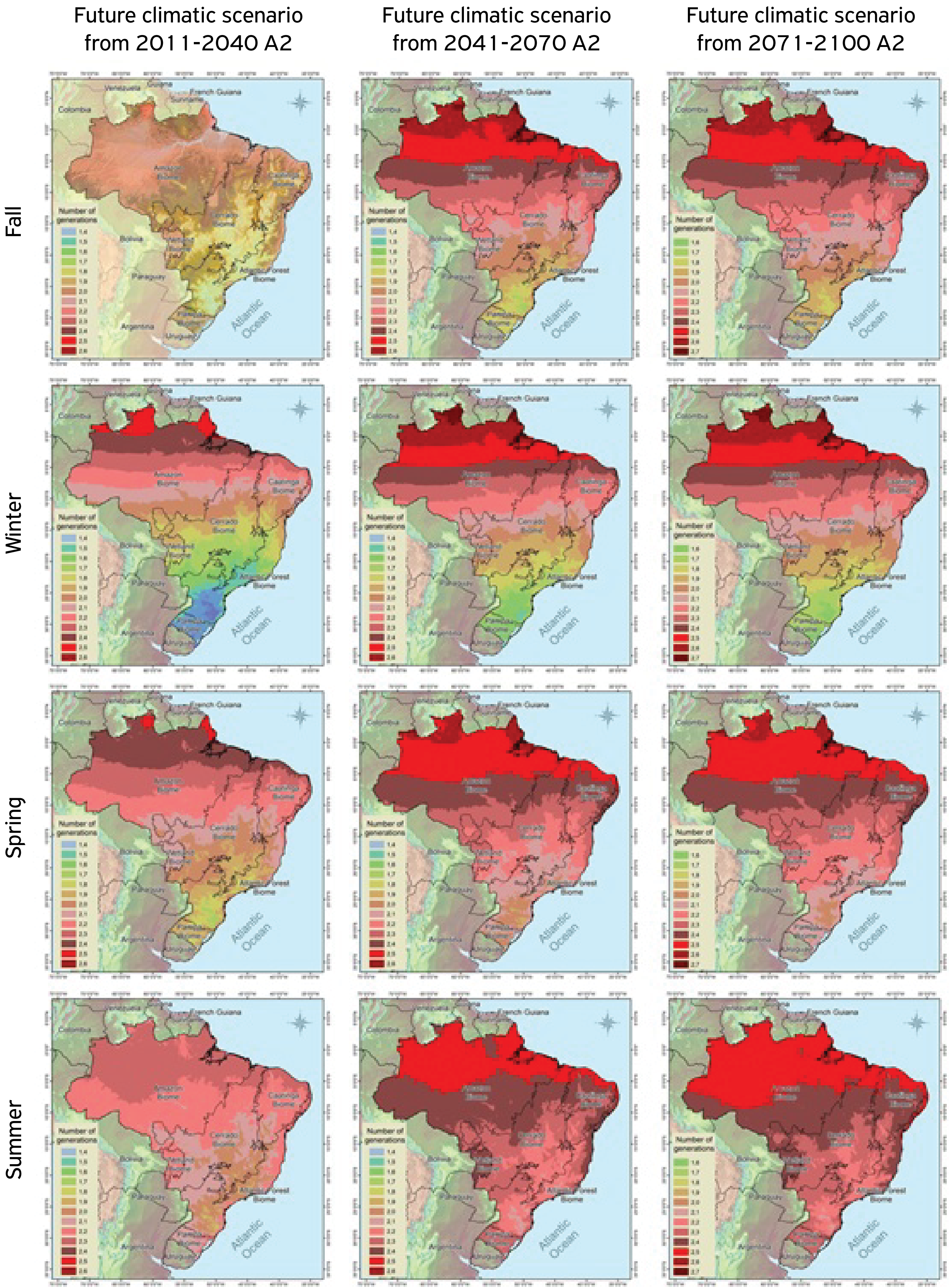


Figure 1. Climatic maps of Brazil, reference period 1961-1990, where (A) fall, (B) winter, (C) spring, and (D) summer.



Future climatic scenario from 2011-2040 A2

Future climatic scenario from 2041-2070 A2

Future climatic scenario from 2071-2100 A2

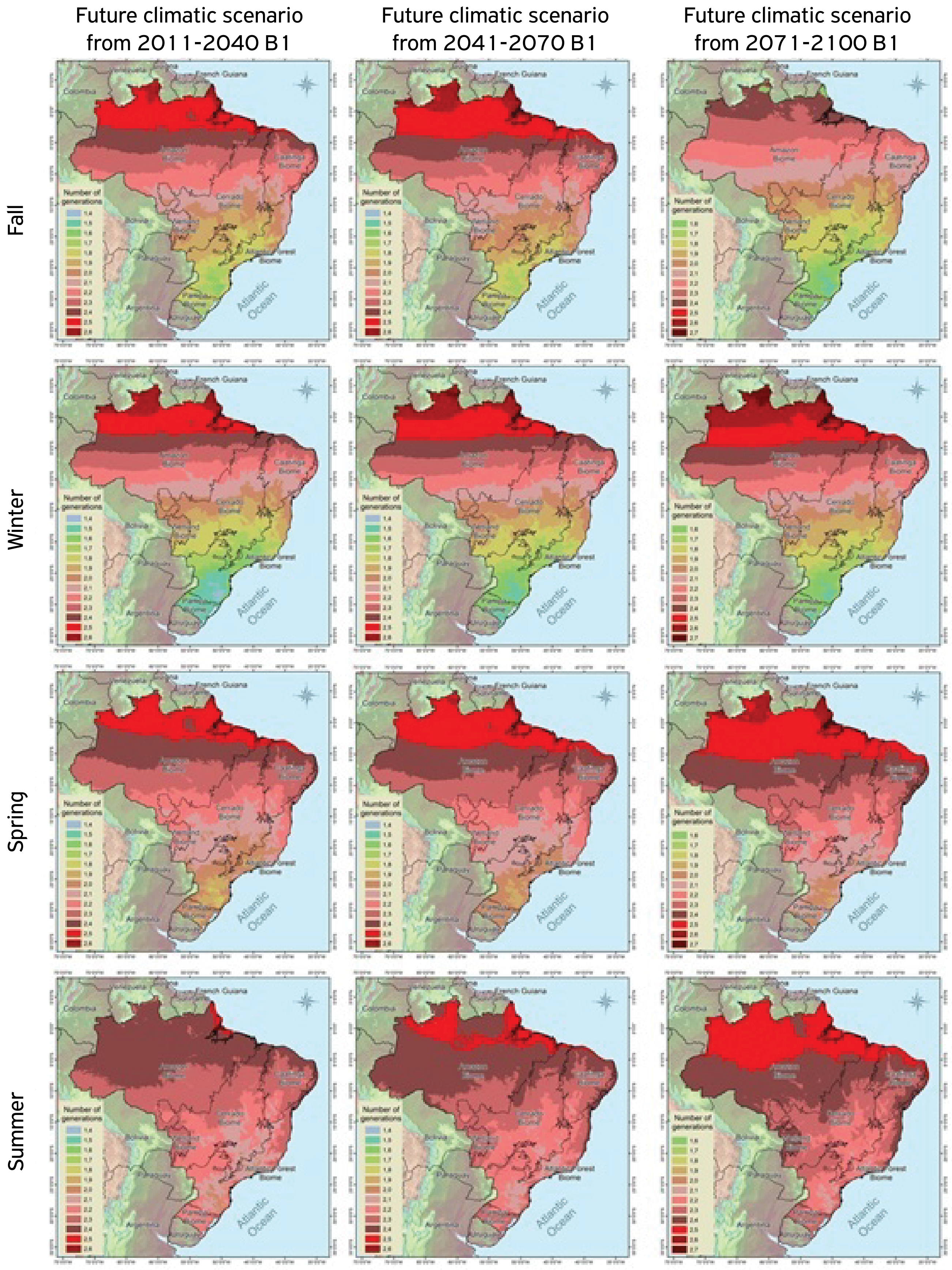
Fall

Winter

Spring

Summer

Figure 2. Generations of *Anastrepha grandis* per year in Brazil in different year seasons, in the most pessimistic climate change scenario (A2), in projections for 2011–2040, 2041–2070 and 2071–2100.



Future climatic scenario from 2011-2040 B1

Future climatic scenario from 2041-2070 B1

Future climatic scenario from 2071-2100 B1

Figure 3. Generations of *Anastrepha grandis* per year in Brazil in different year seasons, in the least pessimistic climate change scenario (B1), in projections for 2011–2040, 2041–2070 and 2071–2100.

- In the northeastern region of Brazil, where areas free of *A. grandis* are located, populations of fruit fly are considerably smaller than in the coastal regions, mainly due to the climatic conditions and vegetation type of the semiarid region, which do not favor high densities of the pest throughout the year.

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