1 **Changes in the potential distribution of the guava fruit fly *Anastrepha striata* (Diptera,**

2 **Tephritidae) during the current and possible future climate scenarios in Colombia**

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13 **Short title:** Potential changes in distribution of *Anastrepha striata* in response to climate

14 change

15

16 **Abstract**

17 Climate change has affected the geographical distributions of most species worldwide; in
18 particular, insects of economic importance inhabiting tropical regions have been impacted.
19 Current and future predictions of change in geographic distribution are frequently included
20 in species distribution models (SDMs). The potential spatial distributions of the fruit fly
21 *Anastrepha striata* Schiner (the main species of agricultural importance in guava crops)
22 under current and possible future scenarios in Colombia were modeled, and the establishment
23 risk was assessed for each guava-producing municipality in the country. The SDMs were
24 developed using 221 geographical records in conjunctuin with nine scenopoetic variables.
25 The model for current climate conditions indicated an extensive suitable area for the
26 establishment of *A. striata* in the Andean region, smaller areas in the Caribbean and Pacific,
27 and almost no areas in the Orinoquia and Amazonian regions. A brief discussion regarding
28 the area suitability for the fly is offered. The expansion of the suitable area was observed in
29 all future scenarios; moreover, this effect was more pronounced in the Amazonian region.
30 The Colombian guava-producing municipalities were classified according to the degree of
31 vulnerability to the fly establishment as follows: 42 were high-risk, 16 were intermediate-
32 risk, and 17 were low-risk. The implementation of future integrated management plans must
33 include optimal spatial data and must consider environmental aspects, such as those
34 suggested by the models presented here. Control decisions should aim to mitigate the positive
35 relationship between global warming and the increase in the dispersal area of the fruit fly.
36

37 **Keywords:** climate change, global warming, guava crops, modeling, species distribution

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Introduction

40

41 Climate change is expected to cause shifts in the geographical distribution of species as a

42 result of the rearrangement of climate zones (Beever et al. 2011). Hence, the magnitude of

43 the associated impacts is projected to be higher in some regions than in others. The Latin

44 American and Caribbean region is one of the most vulnerable areas to climate change; most

45 of the species living there are endemic or restricted to a specific tropical ecosystem

46 (CEPAL 2015). Consequently, they are more susceptible to the effects of global warming

47 because of their particular physiology and phenological qualities, which are typically

48 adapted to narrow ecological niches (Sheldon 2019). It is anticipated that poikilothermic

49 organisms such as insects, whose body temperature varies according to surrounding

50 weather, will be strongly influenced by a volatile climate (Régnière et al. 2012).

51 Temperature, precipitation, and other climatic parameters can directly affect the ecological

52 interactions of insect pests; for instance, the increase in heat in the tropics allows species to

53 colonize higher elevations and extend their geographical distributions upslope (Freeman et

54 al. 2018). Indeed, climate warming resulting from increasing levels of greenhouse gases in

55 the Earth's atmosphere could have a significant and highly uncertain impact on the

56 development, distribution, and population density of agricultural insect pests (Lehmann et

57 al. 2020).

58

59 Predictions of geographical distribution changes relating to global warming are frequently

60 included in species distribution models (SDMs) (Guisan and Zimmermann 2000). These

61 models use associations between environmental variables, such as temperature,

62 precipitation and geographical records of species to identify the environmental conditions

63 under which reproductive populations can be established (Peterson et al. 2011); SDMs have

64   multiple applications in conservation, ecology, evolution, epidemiology, and invasive

65   species management studies (Peterson 2006). In an agricultureural context, SDMs allow

66   the assessment of the potential dispersal of exotic and invasive species to crops (Villacide

67   and Corley 2003; Beckler et al. 2005; Campo et al. 2011), while also permitting the

68   implementation of control and eradication programs and monitoring of these biological

69   agents. SDMs can also can assist in the selection of cultivable areas and declaration of

70   phytosanitary problem-free-zones (Anderson and Martínez-Meyer 2004; Parra et al. 2004;

71   Phillips et al. 2006; Aluja and Mangan 2008). The advantages of these models make their

72   use appropriate in making decisions to mitigate the effects of insect pests.

73

74   One of the most common crop-limiting insects is the guava fruit fly *Anastrepha striata*

75   Schiner, 1868 (Diptera, Tephritidae); it endemic species to the Neotropical region, and it is

76   listed as a quarantine species. *A. striata* has been reported to be associated with thirty-seven

77   host plant species in twenty-three genera and seventeen families; most are in Myrtaceae,

78   which is a primary host taxon (Norrbom 2004; Cruz-López et al. 2015). This fruit fly

79   causes substantial agricultural losses, particularly in guava crops, thoroughout the

80   American continent (Castañeda et al. 2010). It is distributed from the southern USA to

81   Brazil (Hernandez-Ortiz and Aluja 1993), with an altitudinal distribution between 15 and

82   2,398 meters of elevation (Martinez and Serna 2005; Castañeda et al. 2010). In Colombia,

83   this fruit fly is common and has been systematically collected (Rodriguez Clavijo et al.

84   2018); its prevalence in this area is typically associated with the hostplant (Gallo-Franco et

85   al. 2017). In particular, the species has been reported on guava crops, turning into a plague

86   with significant negative impacts on fruit production (Insuasty et al. 2007; Martinez-Alava

87   2007; Castañeda et al. 2010). In Colombia, guava is one of the top five species of economic

88   importance and is a significant crop in Colombian agriculture as an essential product of

89   small and intermediate producers (Agronet 2018). The damage caused by *A. striata* can be

90   devastating; total losses of 90% of the crop have been documented recent decades (Núñez

91   et al. 2004). Management plans, including the potential distribution of fruit flies, have been

92   considered in the United States (Sequeira et al. 2001), Europe (Godefroid et al. 2015), and

93   globally for *Anastrepha obliqua* (Fu et al. 2014). In Colombia, integrated pest management

94   against fruit flies has been proposed by governmental institutions (Instituto Colombiano de

95   Agropecuario - ICA); however, none of these initiatives have included potential distribution

96   or spatial distribution modeling (ICA 2016). We aimed to model the potential distribution

97   of *A. striata* and to assess the establishment risk in Colombia under current and possible

98   future climate change scenarios. The resulting maps and concerned data may provide a

99   geographical criteria basis for decision-making in integrated fruit fly management for

100   guava crops.

101

102   **Methods**

103   *Geographical records*

104   Geographic records of *A. striata* were compiled from specimens deposited at following

105   entomological collections: Colección Entomológica de la Universidad de Antioquia,

106   Medellín, Antioquia, Colombia [CEUA], Colección Entomológica de la Universidad

107   Nacional de Colombia, Sede Palmira, Valle del Cauca, Colombia [CEUNP], Colección

108   Taxonómica Nacional Luis María Murillo, ICA Tibaitatá, Mosquera, Cundinamarca,

109   Colombia [CTNI], Colección Entomológica Forestal Universidad Distrital Francisco José

110   de Caldas, Bogotá, Cundinamarca, Colombia [EF-UDFJC], Colección de Insectos del

111   Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Villa de

112   Leyva, Boyacá, Colombia [IAVH], Colección de Insectos del ICA Palmira, Valle del

113   Cauca, Colombia [ICA-P] Colección de Zoología, Instituto de Ciencias Naturales,

114   Universidad Nacional de Colombia, Sede Bogotá, Cundinamarca, Colombia [ICN], Museo

115   Entomológico "Francisco Luis Gallego", and Universidad Nacional de Colombia, Sede

116   Medellín, Antioquia, Colombia [MEFLG]; secondary sources, including articles and

117   databases, are also listed (Supp. Table S1). For an adequate geographical interpretation, we

118   provide a plate with the maps of the administrative boundaries ("Departments", as they are

119   locally known in Colombia), natural regions, digital elevation models, and the location of

120   some geographical features referred to troughout the text (Figure 1).

121

122   *Climatic information*

123   Bioclimatic variables were gathered from the WorldClim 1.4 climate data archive (Hijmans

124   et al. 2005) (Table 1) in the form of 19 bioclimatic data layers, summarizing potentially

125   relevant climate dimensions at a 30 arc-second (~1 km) spatial resolution. The date were

126   derived from monthly precipitation and temperature values, appropriate to the biological

127   requirements of *A. striata* in terms of temperature, precipitation, and seasonal trends, and

128   extreme or limiting environmental factors (Hijmans et al. 2005). Bioclimatic data layers

129   incorporating global climate change were calculated using a general circulation model

130   (GCM) for different scenarios. The MIROC5 Global Climate model was selected to

131   include variation and uncertainty among climate change mathematical simulations (Yañez-

132   Arenas et al. 2016). We considered 2050 and 2070 as future time slices, under two emission

133   scenarios: Representative Concentration Pathways (RCPs) 2.6 and 8.5. They are consistent

134   with a wide range of possible changes in future anthropogenic (i.e., human-caused)

135   greenhouse gas (GHG) emissions, and aim to represent their atmospheric concentrations in

136   different scenarios (Ward et al., 2012). RCP 2.6 assumes that global annual GHG emissions

137   (measured in CO2 equivalents) peak will between 2010 and 2020, with emissions declining

138   substantially after that (Meinshausen et al., 2011). Under RCP 8.5, emissions continue to

139   rise throughout the 21st century (Meinshausen et al. 2011).

140   An essential element in the development of ecological niche models is the hypotheses of

141   areas (M) that have been accessible to the species (Barve et al. 2011). Based on the

142   presence records and the terrestrial ecoregions of the world proposed by the World Wildlife

143   Foundation (Olson et al. 2001), we estimated the area M to calibrate the model. Charted

144   colombian administrative boundaries (Fig. 1) were used as the area for the final projection

145   model. According to the variable contributions calculated by the jackknife analysis and the

146   Pearson correlation coefficients, we determined which variables would be ratained for

147   further evaluations. If two variables had a correlation of $> [0.8]$, the highly contributing

148   variable was preferred over the other (Raghavan et al. 2019). In the current and future

149   models, we used a total of nine bioclimatic variables (Table 1).

150

151   *Model design*

152   The potential distribution model was generated with a maximum entropy algorithm

153   incorporated in MaxEnt v.3.3.3k (Phillips et al. 2006). Partial receiver operating

154   characteristic (pROC) statistics were applied for only the current model to the 50% subset

155   of occurrences left out before model calibration for testing. We chose pROC as a

156   significance test in light of critiques of the appropriateness of traditional ROC approaches

157   (Peterson et al. 2008). This metric was used to test the statistical significance of ecological

158   niche model predictions. A value of 1.0 was equivalent to the performance of a random

159   classifier. These results were based on 100 bootstrap replicates, and statistical significance

160   was assessed by bootstrapping and comparison with a random classifier ratio of 1.0

161   according to the significant sensitivity of this algorithm to particular parameter settings. We

162   conducted a detailed model selection exercise, using the ENMeval R package. This

163   provided an automated method to execute MaxEnt models across a user-specified range of

164   regularization multiplier (RM) values and feature combinations (FCs) (Muscarella et al.

165   2014). We set the RM range from 0.5 to 4.0, with increments of 0.5, and employed three

166   FCs, i.e., linear (L); linear and quadratic (LQ); linear, quadratic and product (LQP); linear,

167   quadratic, product and threshold (LQPT); linear, quadratic, product threshold and hinge

168   (LQPTH), resulting in 45 possible combinations of features and regularization multipliers

169   (Muscarella et al. 2014). The fine-tuned MaxEnt models were made by seeking the lowest

170   delta value of Akaike's information criterion, which was corrected for small sample sizes

171   (AICc) among the candidate models, reflecting both model goodness-of-fit and complexity

172   to provide the most conservative results (Basanta et al. 2019). We selected a model with the

173   lowest delta AICc score, which had a parametrization of regularization multiplier of 2.0 and

174   an LQHP feature combination; it exhibited good predictive performance.

175   A total of ten model replications were implemented through bootstrapping tools. The

176   medians were used through repetitions as a final niche estimation (Altamiranda-Saavedra et

177   al. 2017). All models were converted to binary using a threshold of training omission rate

178   with an error rate of E = 5%. The threshold selection methods were based on lower

179   threshold values, i.e., with a broader distribution of suitable habitat and close to zero errors

180   of omission. To predict variations in the spatial distribution, the expansion and contraction

181   in the dispersion area were estimated through pairwise ranking between the two binary

182   distribution models (current and future distribution models) through the SDMtoolsbox tool

183   in ArcGIS 10.3. Finally, we calculated the range of median values across all models for

184   RCP 2.6 and 8.5, and we considered the estimated variance among models as a measure of

185   uncertainty using ArcGis 10.3 (Peterson et al. 2018). A variance partitioning approach was

186   used to compare the estimates of environmental suitability in the SDM prediction maps on

187   a pixel-by-pixel basis across different maps and to characterize the proportion of variance

188   in the estimates of suitability attributable to individual factors (Diniz-Filho et al. 2009). As

189   supplementary material, all models are available to download in the *.KMZ* format

190   (Supplementary Material 2).

191

192   **Current risk of establishment of *A. striata* in municipalities**

193   A preliminary list of 75 guava producer municipalities was generated by consulting annual

194   reports from the ICA (Instituto Colombiano Agropecuario) Phytosanitary Surveillance and

195   Epidemiology Technical Division (ICA 2020). The area at risk for *A. striata* establishment

196   was measured as the percentage of suitable space in the current potential distribution model

197   by each municipality using ArcGIS 10.3. Consequently, the seventy-five districts were

198   classified in the following way: units with coverage below 33% were considered low

199   vulnerability; those with coverage between 33% and 66% had intermediate vulnerability;

200   and those with coverage above 66% had high vulnerability.

201   **Results**

202   We collected a total of 211 geographical records of *A. striata* at elevations ranging from 6

203   to 3,044 m (Figure 2a); and most were located in the Andean region (Figure. 1A). The

204   percentage contribution of the bionomical variables is shown in Table 1. The final model

205   for current environmental conditions showed an extensive suitable area for *A. striata*

206   establishment, mainly in the Andean region (Figure 1A). There was less establishment risk

207   in the Caribbean (Figure 1D) and Pacific region (Figure 1E), and almost none existent risk

208   in the Orinoquia (Figure 1C) and Amazonian regions (Figure 1D) (Figure 2a). Despite the

209   notable absence of suitable areas in the Amazonia region, the current model (Figure 2a)

210   included the interfluvial areas of the Inírida, Guainía, and Vaupés rivers (Figure 1.

211   Localities d,g); the surroundings jurisdiction of Mitú in Vaupes (Figure 1.26); southwestern

212   Putumayo (Figure 1.20); and the western area of La Paya National Natural Park (Figure 1.

213   locality k) as suitable for *A. striata* establishment. Glaring errors of omission were

214   evidenced in locations such as Leticia in southern Amazonas (Figure 1.1); southwestern

215   Putumayo (Figure 1.20); Orinoquian localities, such as northeastern Vichada (Figure 1.27),

216   and northern Arauca (Figure 1.3); and finally in the Caribbean in central Guajira (Figure

217   1.15). The currently unsuitable areas for the establishment of *A. striata* (Figure 2a) were as

218   follows: in the Caribbean region, a large part of the xerophytic formations in northern

219   Guajira (Figure 1. 15), areas of Salamanca National Park (Figure 1. Locality i), the

220   Depresión Momposina (Figure 1. Locality a), Sierra Nevada de Santa Marta (Figure 1.

221   Locality e) and swamp complexes in eastern Cordoba (Figure 1.12). Areas above the 2,050

222   m elevation along the Andean region were also unsuitable, including all high altitude areas

223   of the Andean paramos complex (Figure 1A); the foothills of western Norte de Santander

224   (Figure 1.19), eastern Boyacá (Figure 1.6) and Cundinamarca (Figure 1.13); and the

225   surrounding areas of El Cañon de Chicamocha (Figure 1. locality b) and Valle de Laboyos

226   in Huila (Figure 1. Locality h). Extensive areas of tropical rainforest (TRF) in the Pacific

227   and the Amazon (Figure 1B, E) were deemed unsuitable, as were the savannas in the

228   Orinoquia region (Figure 1C).

229   *Potential distribution under climate change scenarios*

230   Significant levels of uncertainty in climate change models were found, specially in the

231   Andean region (Figure 3). An increase in the area suitable for *A. striata* establishment was

232   observed in all climate change scenarios (Figure 4a,b,c,d). This result was more

233   pronounced in the most pessimistic greenhouse gas emission scenario (RCP 8.5), for both

234   temporal projections in 2050 and 2070 (Fig. 4B and 4D). According to the analysis of

235   predicted changes in suitable habitat and the associated potential distributions, the greatest

236   extent of the possible area increase for *A. striata* was predicted under the RCP 8.5 scenario

237   by 2050 (Figure. 5b) with an increased area of 520,071 km^2 (Table 2). Remarkably, this

238   expansion was predicted to occur mainly in the Amazonian natural region (Figure 1B),

239   including the departments of Caquetá (Figure 1.8), Amazonas (Figure 1.1), Vaupés (Figure

240   1.26), Guainía (Figure 1.14), and Putumayo (Figure 1.20). On the other hand, RCP 2.6

241   predicted reductions in the area (i.e., contraction area) by 2050, with a potential decrease of

242   more than 52, 808 km^2 (Table 2). This effect was specially distinct in the northern area of

243   the Pacific region, specifically in the Chocó department (Figure 1.11 and 4a).

244

245   *Current risk of establishment of A. striata in municipalities*

246   Forty-eight guava-producing municipalities in Colombia are located in the Andean region

247   (Fig. 1A), 18 in the Caribbean region (Fig. 1D), 8 in the Pacific region (Fig. 1E), and 6 in

248   the Orinoquia region (Fig. 1C) (Figure 2c). Of these municipalities, 56 % were categorized

249   as highly vulnerable to the establishment of *A. striata,* 21 % had intermediate vulnerability,

250   and 23% had low vulnerability (Figure 2c and Table 3).

251

Discussion

253   This study is the first regional (northwest South America) approach tho use ecological

254   niche modeling to assess the potential distribution of a fruit fly species of economic

255   importance under global climate change scenarios. Aditionally, this study is the first to

256   consider the risk of pest establishment according to administrative boundaries to configure

257   regional policies and decision making. The results showed that in Colombia, i) under the

258   current environmental model, the suitable areas for the establishment of *A. striata* were

259   located mainly in the Andean region, with some risk area in the Caribbean region and to a

260   lesser extent in the Pacific, Orinoquia and Amazonian regions. High spatial alignment with

261   geographical records was recently reported by Rodriguez Clavijo et al., (2018). ii) The

262   climate change models showed an increase in suitable areas for the establishment of the *A.*

263   *striata* in response to global warming, and iii) high environmental suitability for the

264   establishment of populations was evidenced in the guava-producing municipalities in

265   Colombia.

266   The retrieved geographical records of *A. striata* were mainly based on two sources: the first

267   came from five departmental initiatives (control programs) (Castañeda et al. 2010) and the

268   second came from sporadic records of specimens deposited in entomological collection.

269   These data demostrated the lack of comprehensive monitoring of fruit fly management and

270   a rigorous systematic phytosanitary surveillance program. Optimal biological data are a

271   crucial aspect for good results in mitigating the effects of the fly, and avoiding duplication

272   of efforts; different Colombian environmental agencies operate under varying policies.

273   Despite these circumstances, the current distribution model coincided with previous

274   information, which showed that guava fruit flies were common in Colombia, as

275   summarized by Rodriguez Clavijo et al., (2018). The distribution of fruit fly species in

276   Colombia is also related to the presence of its primary host plant (Castañeda et al. 2010). *A.*

277   *striata* is associated mainly with Myrtaceae, a family encompassing nearly 180 species in

278   Colombia that is distributed across all vegetation types communities and altitudinal

279   gradients (Parra-0 2014).

280   Additionally, it is commonly found among the most diverse plant families in vegetation

281   surveys, either in the Amazonian region or in the ecotones of Páramo (Parra-0 2014).

282   However, the prevalence of *A. striata* in Colombia may be associated not only with the

283   presence of its host plants but also with favorable environmental conditions or factors that

284   regulate their trophic relationships (Hedström 1991). Our results indicated that *A. striata*

285   currently inhabits a significant portion of the Colombian territory, not only because of the

286   above mentioned factors but also because of its thermal physiological plasticity (Baker et

287   al. 1944) related to the climate along the Andean altitudinal gradient (between 6 to 3,044 m.

288   elevation, ranging from 9.2°C to 23.8°C). Low misture or high or low temperature regimes

289   may pose physiological restrictions for both the fly and its hosts. This fact was evidenced

290   by Stone (1939), who reported high mortality rates in *A. striata* larvae exposed

291   momentarily to temperatures of 40°C. Similarly, Bolzan et al. (2017) reported no

292   embryonic development in regimes above 35°C.

293

294   The most influential variables of *A. striata* occurrence were the temperature and the

295   precipitation-related variables (Table 1); these results aligned with those of Porter et al.,

296   (1991), who reported that these factors significantly affected the distribution of pest insects.

297   The models also indicated absence of the flies in cold localities at high altitudes, such as

298   paramo ecosystems; the paramo is distributed along the top of the Andean ranges (Figure

299   1A) and the upper Sierra Nevada de Santa Marta (Figure 1 locality e). Additionally, very

300   humid regions with high precipitation levels (tropical rainforests) such as the Serrania de

301   Darien (Figure 1 Locality f) and most forested areas of the Pacific (Figure 1E) and

302   Amazonia region (Figure 1B) were identified as having low suitability for the flies. It has

303   been showed that less disturbed ecosystems , such as tropical rainforests, offer fewer host

304   plant species, lower infestation rates, and more ecological complexity, which probably

305   reduces fruit fly pest performance (Hernández-Ortiz and Pérez-Alonso 1993). Eventually,

306   the land use in these areas, which are considered to have high forestry potential, may result

307   the fruit fly introduction (Mena et al. 2015). The area suitable for *A. striata* in the Pacific

308   region was mainly located in northern Chocó (Figure 2a. and Figure 1.11), in extensive

309   areas bordering the Golfo de Uraba (Figure 1. Locality c) and in a small area in the Nariño

310   department (Figure 1.18). The low suitability of habitat in this natural region might be

311   associated with the forest conservation levels and the vocation for the agroforestry industry

312   of the region (De la Hoz 2007). However, the map indicates suitability in the interfluvial

313   area of the Inírida (Figure 1 locality d), Guainía and Vaupés rivers, and the surroundings of

314   the jurisdiction of Mitú (Figure 1 locality g) in the Orinoquia and Amazonian regions. The

315   establishment of *A. striata* must be interpreted cautiously since the precarious conditions of

316   the soils, where it is common to find rocky outcrops and floristic associations of

317   monocotyledons (Hernández-Camacho and Sanchez-Páez 1992), provide unfavorable

318   conditions for *A. striata*'s host plants. However, bionomic and scenopoetic variables not

319   assessed there may positively affect the occurrence of source populations (Peterson et al.

320   2011).

321 The models under climate change scenarios with an increase in temperature ,expanded the

322 geographic area suitably, as evidenced here for *A. striata* in Colombia (Figure 4). This

323 behavioral response may be evidenced in species limited by low temperatures, where the

324 increase in warmth in the occurrence area may shift the geographical range towards cold

325 regions (Fu et al. 2014). Although the presence probability decreased in the Pacific region,

326 it could be the result of climatic effects due to proximity to the coastal zone, where the

327 general climatic conditions are remarkably unstable (Martínez-Ardila et al. 2005). Changes

328 in climatic variables , such as precipitation regimes, can cause contraction in the spatial

329 distribution (Martínez-Freiría et al. 2016). Our results were in agreement with those of Fu

330 et al., (2014), who demostrated that climate change expanded the potential distribution of

331 the fruit fly *Anastrepha obliqua* (Macquart, 1835) towards the poles but decreased the

332 distribution in northwestern Australia and northern sub-Saharan Africa due to climate stress

333 caused by marine climate effects.

334

335 It should be noted that the potential distributions of species depend not only on weather

336 conditions but also on dispersal capacity, host availability, and the effects of ecological

337 relationships (Peterson et al. 2011). The estimation of these aspects is especially critical for

338 species of economic importance (Lira-Noriega et al. 2013). This information is difficult to

339 model with climate change scenarios, and even current biotic interaction data are

340 challenging to include (Peterson et al. 2011). This study faced a poor understanding of the

341 basics bionomic parameters of *A. striata* (Cruz-López et al. 2015) due to insufficient local

342 data to infer ecological and distributional patterns in *A. striata* populations (Canal 2010;

343 Castañeda et al. 2010). The current and future ecological interactions of *A. striata* in

344 Colombia are still enigmatic and lead to additional challenges for integrated management.

345   Nevertheless, we offer an additional tool never before considered in Colombian fruit

346   agriculture. The most significant proportion of potential areas predicted by climate change

347   scenario models for the expansion of *A. striata* occurred in the Amazonian region (Figure

348   4b,d). This result could be related to accelerated deforestation rates, which are caused

349   primarily by the presence of illicit crops and expansion of the agricultural frontier (Vieira

350   2019); these activities could promote *A. striata* establishment (Aluja et al. 2003).

351

352   Due to the economic importance of *A. striata*, knowledge on the autoecology and variables

353   determining its geographic distribution is essential at the local scale (Castañeda et al. 2010);

354   this information provides crucial feedback for implementing effective integrated pest

355   management programs (IPMs (Martínez-Ardila et al. 2005). Our results indicated that

356   under the current environmental and climatic conditions, the *A. striata* distribution is

357   intimately associated with guava crops. The predominance of *A. striata* and guava crop

358   interactions, the high vulnerability of the guava producer municipalities to the potential

359   occurrence of *A. striata*, and its presence in a large area principally on the Andes (Figure

360   2c, Table 3) make it difficult to effectively establish integrated pest management strategies

361   based on a single local initiative. We encourage the use of the offered data here concerning

362   each municipality to configure national policies based on area-wide management (AWM).

363

364   Furthermore, the estimated distributions for *A. striata* according to climate change

365   scenarios for 2050 and 2070 will not modify this outlook and are trending towards

366   expansion. Importantly, the data presented here have established a clear and present risk to

367   the spread of this fly of economic importance, emphasizing that these risks will only

368   worsen in the face of climate change. Action needs to be taken to ensure optimal guava

369   productivity. The Selection and cultivation of cultivars adapted to environments unsuitable

370   for *A. striata*, as well as the selection of fly resistant varieties, present promising

371   opportunities. Alternative approaches employing chemical ecology and trophic relationship

372   studies could represent useful improvements for guava fruit fly management in Colombia.

373   Finally, it would be desirable to establish transnational policies to enhance monitoring of

374   fruit fly pests in areas where eradication techniques, such as low prevalence areas and

375   sterile individulas use, are unlikely.

376

385

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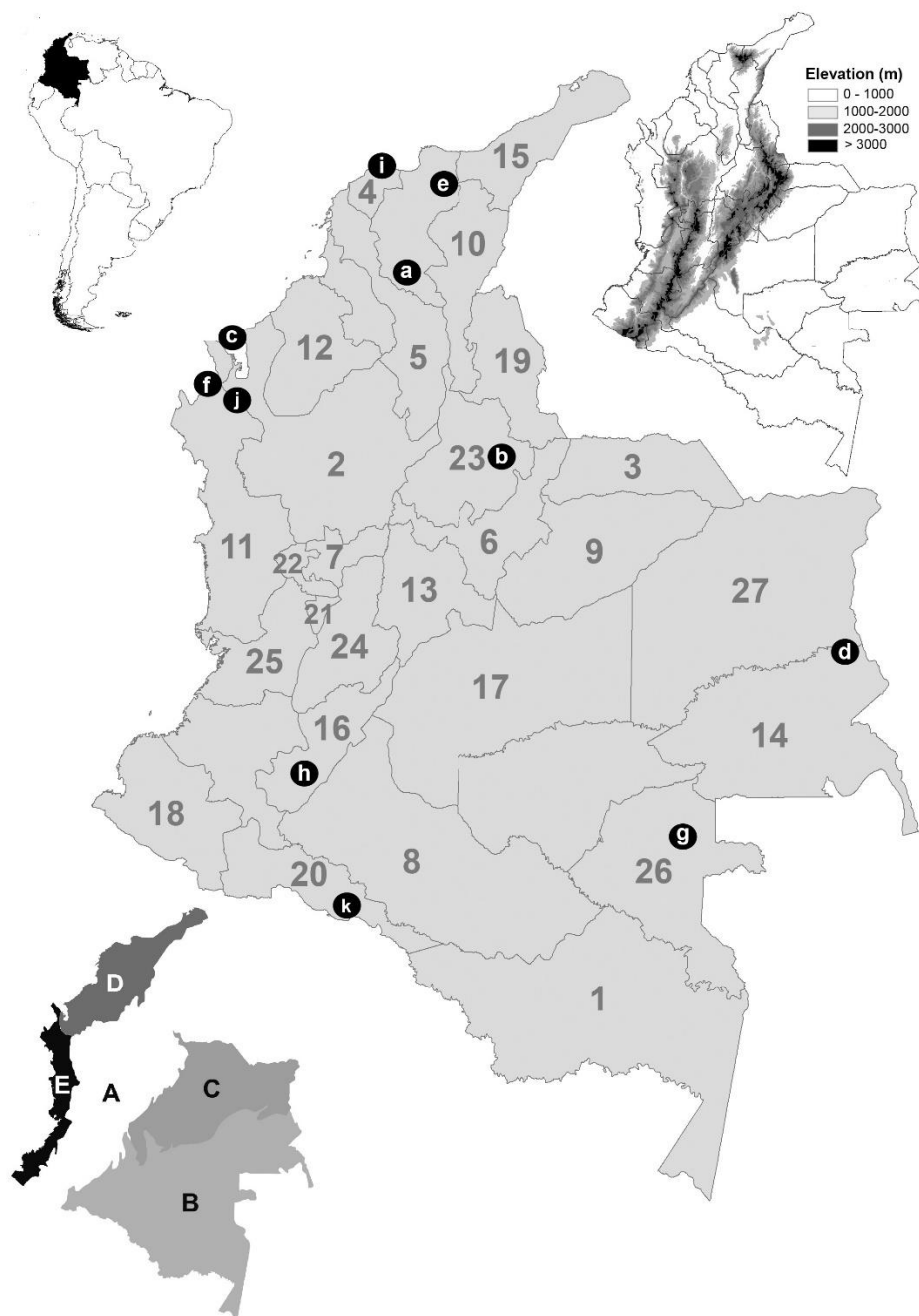
**Figure 1.** Location of Colombia in South America (upper left). Digital elevation map (upper right) (m) meters. Map of administrative boundaries (center) (number of each department in gray) **1.** Amazonas; **2.** Antioquia; **3.** Arauca; **4.** Atlántico; **5.** Bolívar; **6.** Boyacá; **7.** Caldas; **8.** Caqueta; **9.** Casanare; **10.** Cesar; **11.** Chocó; **12.** Córdoba; **13**. Cundinamarca; **14.** Guainia; **15.** Guajira; **16.** Huila; **17.** Meta; **18.** Nariño; **19.** Norte de Santander; **20.** Putumayo; **21.** Quindío; **22.** Risaralda; **23.** Santander; **24.** Tolima; **25.** Valle del Cauca; **26**. Vaupes; **27.** Vichada. Referenced localities are indicated with black dots and white letters. **a.** Depresión Momposina; **b.** Cañon del Chicamocha; **c.** Golfo de Uraba; **d.** Inirida interfluvial region; **e.** Sierra Nevada de Santa Marta; **f.** Serrania del Darien; **g.** Vaupes River; **h.** Valle de Laboyos; **i.** Salamanca National Park; **j.** Los Katios National Park; **k.** La Paya National Park. Five natural regions (bottom left) **A.** Andes; **B.** Amazonas; **C.** Orinoquia; **D.** Caribbe; **E.** Pacific.

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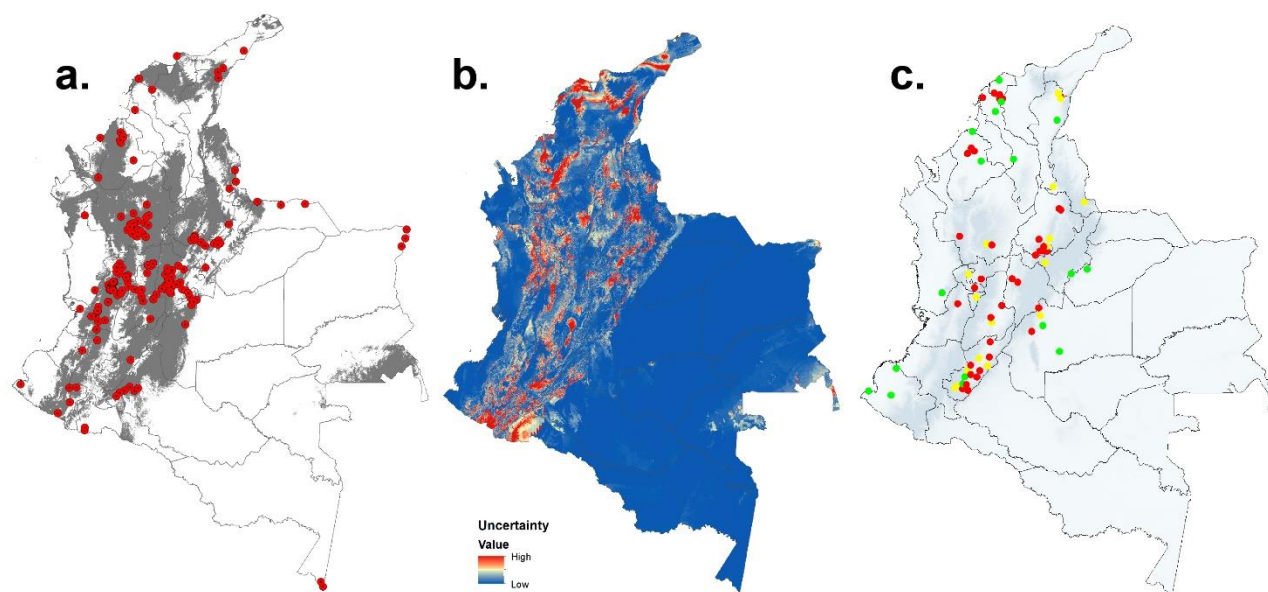
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Figure 2. a). Potential distribution of *Anastrepha striata* in Colombia for the current environmental conditions (suitable areas in gray); red dots are the localities of the compiled geographical records; **b).** Uncertainty of models in the range of median values of general circulation models for *Anastrepha striata*. The color scale represents the degree of variance (blue:low; red:high); **c).** Locations of guava producer municipalities and their vulnerability category for *Anastrepha striata* establishment under the current climatic scenario. Red) high; yellow: intermediate and green: low.

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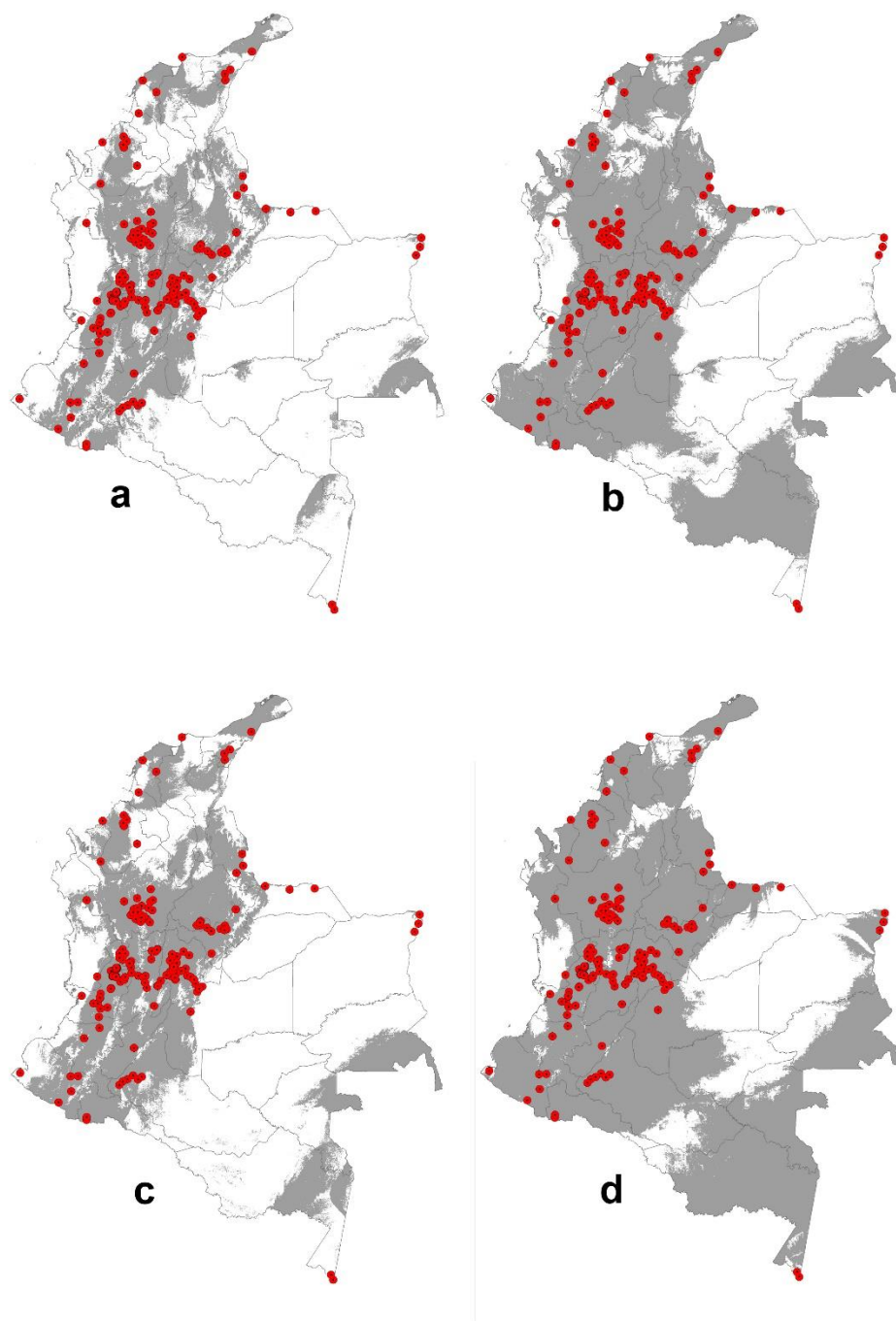
Figure 3. Potential distribution of *Anastrepha striata* in Colombia transferred to climate change scenarios. **a)**. 2050 under Representative Concentration Pathways (RCP) 2.6, **b).** 2050 under Representative Concentration Pathway (RCP) 8.5, **c).** 2070 and Representative Concentration Pathways (RCP)2.6, **d).** 2070 Representative Concentration Pathway (RCP) 8.5.
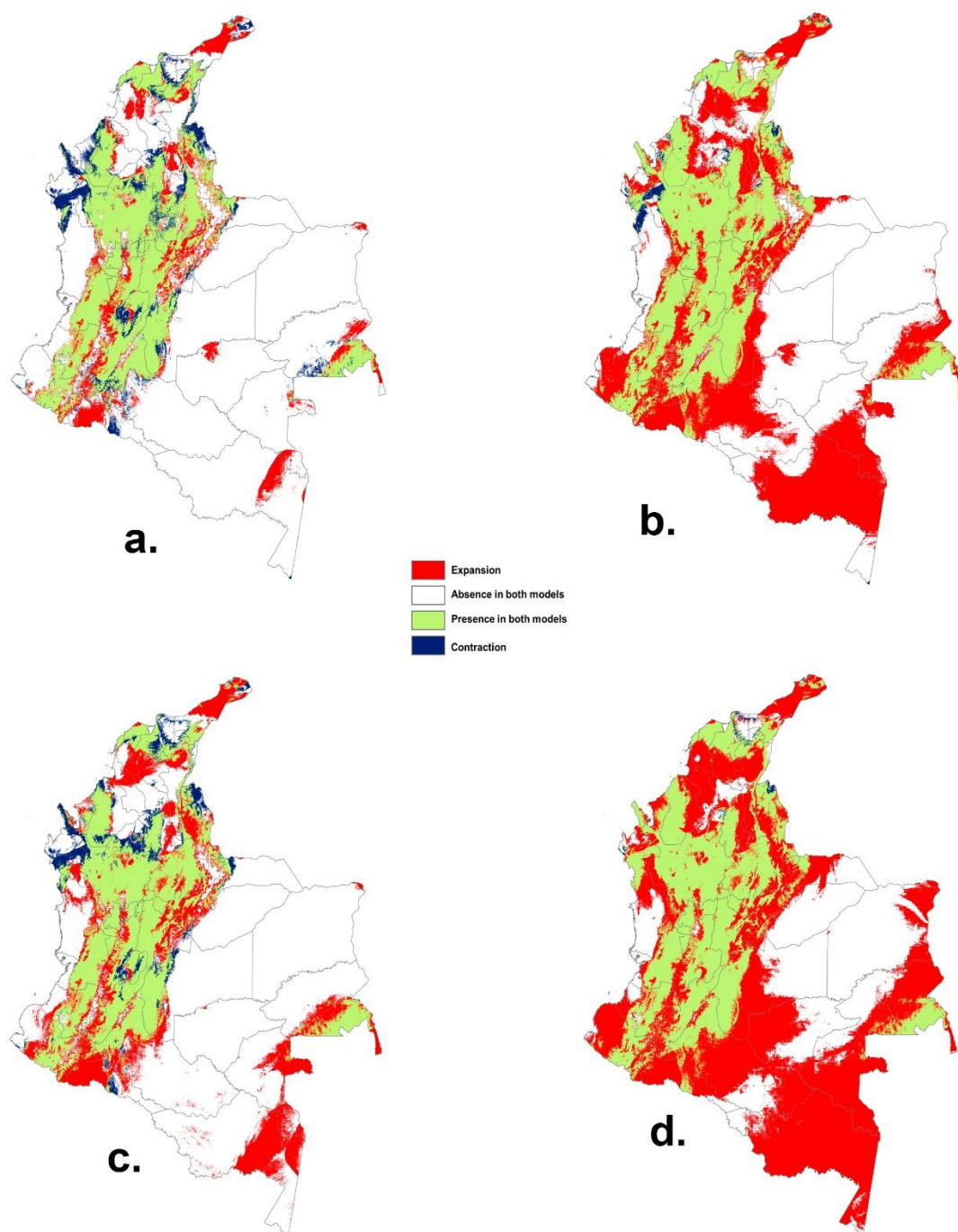
Figure 4. Changes in suitable climatic spaces for *Anastrepha striata* and the potential distributions between current and future conditions in Colombia, **a).** Current vs. time 2050 under RCP 2.6, **b.**) Current vs. 2050 under RCP 8.5 **c**). Current vs. 2070 under RCP 2.6, **d.**) Current vs. 2070 under RCP 8.5.

Table 1. Bioclimatic variables used in modeling the potential distribution for *Anastrepha striata* in Colombia.

Code	Environmental variable	Percent contribution	N° of correlated variables
Bio1	Annual Mean Temperature	4.9	3
Bio3	Isothermality (BIO2/BIO7) (* 100)	23.3	2
Bio4	Temperature Seasonality (standard deviation *100)	7.5	4
Bio5	Max Temperature of Warmest Month	6.5	3
Bio6	Min Temperature of Coldest Month	13.3	4
Bio11	Mean Temperature of Coldest Quarter	5.1	1
Bio12	Annual Precipitation	21	2
Bio14	Precipitation of Driest Month	5.8	3
Bio15	Precipitation Seasonality (Coefficient of Variation)	8.3	1

Table 2. Changes in the potential distribution area (km^2) of *Anastrepha striata* in Colombia between different climatic scenarios.

Model	Expansion	Absence in both	Presence in both	Contraction
Current/MIROC5-2050-RCP26	98,611	730,745	253,462	52,808
Current/ MIROC5-2050-RCP85	369,239	460,118	297,437	8,834
Current/ MIROC5-2070-RCP26	187,860	641,497	265,375	40,895
Current/ MIROC5-2070-RCP85	520,071	309,285	303,298	2,972

Table 3. List of guava-producing municipalities and their respective risk category for the establishment of *Anastrepha striata* according to the area deemed suitable by the ecological niche model under current climate conditions in Colombia.

Natural region	Department	Municipality	Suitable area (%)	Category of vulnerability
Andean	Antioquia	1.Carmen de Viboral	54.2	Intermediate
		2. Cocorná	95.4	High
		3.Urrao	86.8	High
	Boyacá	4.Moniquirá	98.4	High
		5.Ráquira	60.8	Intermediate
	Caldas	6.Manizales	71.8	High
	Cundinamarca	7.Guaduas	93.7	High
		8.Guayabetal	82.5	High
		9.Sasaima	97.5	High
	Huila	10.Acevedo	97.6	High
		11.Aipe	91.2	High
		12.Algeciras	49.0	Intermediate
		13.Garzón	77.0	High
		14.Gigante	83.9	High
		15.Isnos	37.1	Intermediate
		16.La Argentina	15.5	Low
		17.La Plata	38.5	Intermediate
		18.Nátaga	66.7	High
		19.Pital	75.1	High
		20.Pitalito	79.2	High
		21.Rivera	86.7	High
		22.Saladoblanco	29.5	Low
		23.San Agustín	36.5	Intermediate
		24.Teruel	41.4	Intermediate
		25.Timaná	87.3	High
	Norte de Santander	26.Toledo	65.3	Intermediate
	Quindío	27.Calarcá	96.3	High
	Risaralda	28.Belén de Umbría	59.8	Intermediate
		29.Pereira	89.6	High
	Santander	30.Albania	98.6	High
		31.El Guacamayo	50.3	Intermediate
		32.Girón	85.7	High
		33.Güepsa	35.9	Intermediate
		34.Jesús María	99.4	High
		35.Landázuri	67.0	High
		36.Lebrija	80.4	High
		37.Puente Nacional	89.0	High
		38.Vélez	90.4	High
	Tolima	39.Coello	89.1	High
		40.Coyaima	61.1	Intermediate
		41.Ortega	86.0	High
	Valle del Cauca	42.Bolívar	86.0	High
Caribbean	Atlántico	43.Manatí	81.5	High
		44.Repelón	70.6	High
		45.Santa Lucía	92.6	High
		46.Suan de la Trinidad	85.7	High

		47.Tubará	5.0	Low
	Bolívar	48.Achí	11.1	Low
		49.Calamar	6.3	Low
		50.Cartagena	87.1	High
		51.San Juan Nepomuceno	1.4	Low
	Cesar	52.Becerril	32.8	Low
		53.La Paz Robles	71.4	High
		54.San Alberto	39.6	Intermediate
		55.San Diego	47.2	Intermediate
		56.Valledupar	59.4	Intermediate
	Córdoba	57.Cereté	94.6	High
		58.Montería	98.9	High
		59.Pueblo Nuevo	2.3	Low
		60.San Antero	14.4	Low
		61.San Carlos	86.6	High
Orinoquía	Casanare	62.Chámeza	18.7	Low
		63.Yopal	0.6	Low
	Meta	64.Acacías	60.7	Intermediate
		65.Lejanías	90.2	High
		66.Puerto Rico	0.0	Low
		67.San Martín	6.9	Low
Pacific	Chocó	68.Sipí	19.7	Low
	Nariño	69.Barbacoas	3.6	Low
		70.Santa Bárbara	5.4	Low
		71.Tumaco	9.5	Low
	Valle del Cauca	72.Ansermanuevo	85.1	High
		73.Jamundí	84.1	High
		74.Pradera	67.1	High
		75.Roldanillo	98.1	High

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