

1 Key tropical crops at risk from pollinator loss due to climate change
2 and land use

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16 **One sentence summary**

17 Pollinator losses from agriculture and climate change risk production of key crops in the tropics, especially
18 cocoa.

19 **Short title**

20 Pollinator losses and crop pollination risk.

21 **Abstract**

22 Insect pollinator biodiversity has been shown to be changing rapidly, with potential consequences for the
23 provision of crop pollination. However, the role of land-use-climate interactions in pollinator biodiversity
24 changes, and consequent economic effects via changes in crop pollination, remains poorly understood. Here,
25 we present a global assessment of the interactive effects of climate change and land use on pollinator abun-
26 dance and richness, and predictions of the risk to crop pollination from the inferred changes. Using a
27 dataset containing 2673 sites and 3080 insect pollinator species, we show that the interactive combination of
28 agriculture and climate change is associated with large reductions in the abundance and richness of insect
29 pollinators. As a result, it is expected that the tropics will experience the greatest risk to crop production
30 from pollinator losses. Localised risk is highest, and predicted to increase most rapidly, in regions of sub-
31 Saharan Africa, northern South America, and south-east Asia. Via pollinator loss alone, climate change and
32 agricultural land use could be a risk to human health and well-being.

33 Introduction

34 Recent studies have highlighted rapid ongoing changes in terrestrial insect biodiversity,^{1–3} including among
35 pollinating species.^{4–8} Some of these studies have reported net declines,^{1,3} while others have shown mixtures of
36 gains and losses.² Pollinator biodiversity changes have potential consequences for the provision of pollination
37 to wild plants and crops. Importantly, evidence for insect biodiversity trends has been biased toward Western
38 Europe and North America,^{9,10} with little coverage of tropical and subtropical regions.^{11,12} Although a few
39 studies have shown steep declines of insects in the tropics,³ evidence about insect biodiversity trends there
40 often remains anecdotal,¹³ with global syntheses^{1,2} having strong geographic biases towards non-tropical
41 regions.

42 Among the drivers of insect and pollinator biodiversity changes, human-driven land-use changes and climate
43 change are prominent.^{5,10,14–17} Climate change, in particular, is emerging as an increasingly important
44 driver,^{8,14,18–21} although among taxa responses are likely mixed to some extent.²² Synergistic interactive
45 effects of land-use and climate change are often associated with further reductions in insect biodiversity
46 compared to if the pressures acted in isolation.^{23–27} A key mechanism underpinning interactive land use and
47 climate effects is the altered microclimatic conditions in areas where vegetation has been modified for human
48 land use.²³ Tropical insects are expected to be more susceptible to climate change, including interactive effects
49 with land use, given their narrower physiological tolerance compared to non-tropical species.²⁸ Indeed, recent
50 studies show greater effects in tropical than non-tropical insect biodiversity.²⁷

51 Changes in the biodiversity and composition of pollinator communities are expected to have large effects on
52 the provision of pollination services. Pollen limitation from animal pollinator losses has already been shown
53 to reduce the reproductive success of wild plants,^{4,29} and the productivity of certain crops,^{30–34} although
54 there is no clear evidence that pollen limitation is yet causing wholesale reductions in yields of crops that
55 rely on animal pollination.³⁵ Evidence that insect biodiversity responds to human pressures more strongly
56 in the tropics than elsewhere^{17,27} is noteworthy, given that the majority of animal-pollination-dependent
57 crops are grown in the tropics.³⁶ However, it is not only tropical countries that will experience the effects
58 of pollinator losses and subsequent pollen limitation, with high income countries benefiting from imports
59 of animal-pollination-dependent foods from tropical areas.³⁷ Abundance, species diversity, and functional
60 diversity of pollinators have all been implicated as determinants of the delivery of pollination service.^{33,38–42}
61 Previous attempts to model the provision of crop pollination service are often based on predictions of
62 pollinator abundance, which bears a direct relation to pollination of plants, and has been shown to give a
63 reasonable approximation of pollen deposition in at least some study systems.⁴³ A key uncertainty however
64 relates to the shape of the functional relationship between pollinator abundance and crop production.⁴³

65 Here, we present a global assessment of the interactive effects of climate change and land use on pollinator
66 abundance, and predictions of how the inferred abundance changes might translate into risk to crop pollina-
67 tion worldwide based on a range of possible abundance-pollination relationships. Because species richness
68 has also shown to be important for provision of crop pollination, we also tested the robustness of our mod-
69 els and projections to using Chao-estimated species richness in place of total abundance.⁴⁴ Our underlying
70 analyses are based on a space-for-time framework using the PREDICTS (Projecting Responses of Ecological
71 Diversity In Changing Terrestrial Systems) database of biodiversity recorded in different land uses,⁴⁵ to-
72 gether with a list of species identified in the literature as likely pollinators.¹⁷ We use mixed-effects models to
73 fit total pollinator community abundance as a function of land use (primary vegetation versus cropland) and
74 a measure of historical temperature change between a baseline period (1901–1930) and the year prior to the
75 end month of biodiversity sampling (see Figure S21 for the duration of each sampling period), standardized
76 by monthly temperature variability in the baseline period.^{27,46} We standardised temperature changes in this
77 way to capture where temperatures have exceeded the baseline seasonal and interannual variation, a consid-
78 eration that has previously been identified as important for insects in general.²⁷ Given that the PREDICTS
79 database contains a set of biodiversity measurements collected from across studies, we include a set of ran-
80 dom intercepts to account for study-level variation, as well as an adjustment for sampling effort. Our set
81 of likely insect pollinators were compiled through an automatic literature scrape, combined with a manual
82 search and verification by a group of pollination ecology experts.¹⁷ We then apply these models to predict
83 which locations and crops are likely to be exposed to the greatest losses of pollinator abundance, and thus

84 to face the greatest risk of crop pollination shortfalls. We moderate estimates of risk according to estimates
85 of where crops are grown,⁴⁷ how dependent these crops are on animal pollination,³⁶ projections of historical
86 and future climate change, and a set of assumptions for the relationship between local pollinator abundance
87 and crop pollination (from linear to highly concave to convex). We focus on future climate projections under
88 two Representative Concentration Pathways (RCP) scenarios: RCP 2.6, which has a multi-model-median
89 predicted 1.5°C increase in global average temperatures by 2100 compared to the pre-industrial climate; and
90 RCP 6.0, which has a multi-model-median predicted 3°C increase in global average temperatures.⁴⁸ Finally,
91 we combine projected pollination risk with estimates of the trade in pollination-dependent crop production,³⁷
92 to predict regions of the world that may be vulnerable to the indirect consequences of crop pollination risk
93 via trade connections.

94 Results and Discussion

95 The abundance of insect pollinators responded strongly to the interaction of recent climate change and land
96 use (Figure 1). Within cropland experiencing novel temperatures (Standardized Temperature Anomaly =
97 1), pollinator abundance is 61.1% lower than in natural habitat that has not experienced temperature in-
98 creases. The causal mechanism underpinning this interaction is unclear, but the moderation of microclimatic
99 conditions⁴⁹ and the absence of a buffering effect of forest within cropland,⁵⁰ are likely partly responsible.
100 Our results are qualitatively consistent with recent results for a sample of all insects,²⁷ but importantly we
101 show that responses to the interactive effects of climate change and land use are stronger for pollinating than
102 non-pollinating insects (Figure 1). This is important as it would indicate that risk inferred from all insect
103 groups will be lower than from insect pollinating taxa alone. We also show that the strength of the inter-
104 active effect varies among taxonomic groups, with the strongest effects seen in dipteran and hymenopteran
105 pollinators (Figure S1). Whether the sensitivity of pollinating insects to the interaction of climate change
106 and land use relates directly to their reliance on floral resources, or to other correlated traits typical of
107 pollinators, is unclear, and a combination of both factors is likely to operate. For example, selection of
108 animal pollinated plants is thought to be highly sensitive to climatic conditions such as precipitation and
109 temperature,⁵¹ suggesting that plant-pollinator interactions are highly sensitive to thermal changes. Pol-
110 linator pilosity (i.e. hairiness), on the other hand, likely affects an insect's ability to adapt to changes in
111 climate,⁵² and given its nature as a trait typical of bees and hoverflies, tends to be correlated with a reliance
112 on floral resources.⁵³

113 The modelled effects of land-use-climate interactions on pollinator abundance are robust to using threshold
114 temperatures to restrict the months considered to those in which insects are likely to be active (Figure S3),
115 to jack-knifing the predictions for the top 10 sampling methods (Figure S22, see Figure S23 for the full set
116 of sampling methods), and to including an interaction between mean annual temperature and predominant
117 land-use (Table S6; also see Figure S24 showing the correlation between standardised temperature anomaly
118 and mean annual temperature, and Figure S25, suggesting that mean annual temperature may have an effect
119 on primary vegetation but not in cropland). Although the lepidopterans are the only group represented for a
120 standardised temperature anomaly greater than 2 (Figure S1), our results are robust to dropping individual
121 taxonomic families from the model dataset (Figure S2).

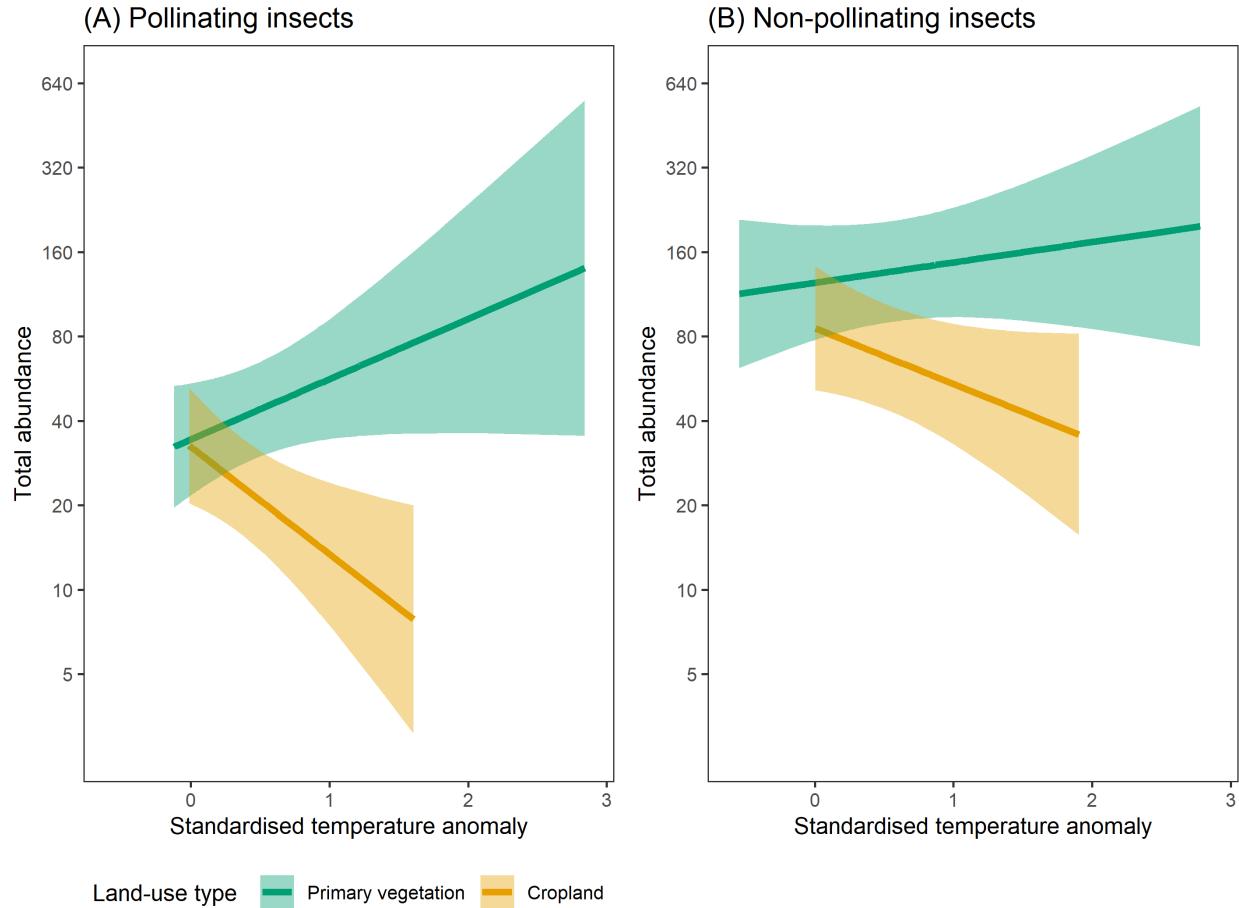
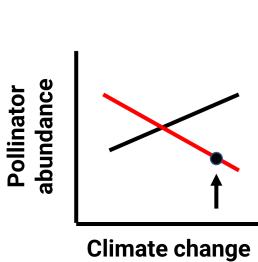


Figure 1: Response of pollinating (A) and non-pollinating (B) insect total abundance to the interactive effect of standardised temperature anomaly and land use (primary vegetation versus cropland) (A: $F = 22.4068$, $p < 0.001$; B: $F = 10.7520$, $p < 0.01$). Note that abundance is plotted on a log_e scale (although the labels are back-transformed). Results are based on linear mixed-effects models. Site numbers are as follows (also see Table S1 and Figure S14 for site spatial distribution): insects known to pollinate (primary vegetation = 1166, cropland = 1507); insects not known to pollinate (primary vegetation = 1747, cropland = 922). See Table S2 for the number of species represented in both the pollinating and non-pollinating groups, Table S3 for AIC and R^2 values for each model, Figures S18 and S19 for the number of insect pollinating species, Figure S20 for the same figure but with the values of total abundance, and Figure S1 for models by taxonomic order. Shading represents 95% confidence intervals around the mean fitted effect. Green = primary vegetation; yellow = cropland.

Models



Inputs



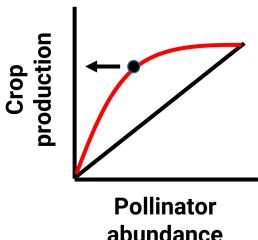
Climate data (46)



Biodiversity assemblages (45)



Likely animal pollinators (17)



Crop production (47)



Pollination dependence (36)



Crop price (74)

Figure 2: A schematic of models and inputs for our local production risk measure. Top row: The PREDICTS database ('Biodiversity assemblages', subset for a set of 'Likely animal pollinators') is used to build a space-for-time model of pollinator biodiversity change, fitting total abundance as a function of an interaction between land-use type and a standardised temperature anomaly of climate change ('Climate data' from the Climatic Research Unit). Bottom row: Change in insect pollinator abundance relative to a baseline (where standardised temperature anomaly is 0) is converted into a crop production loss via a set of linear functions, and then converted into a pollination dependent risk by multiplying the expected change by the pollination dependent production in each cell ('Crop production' and 'Pollination dependence'). Economic loss is calculated from production at risk multiplied by crop price. Numbers in brackets for each input represent the source from which the data originated (as listed in the bibliography). Image credits: Bottom right photo, Ionutzmovie (CC BY 3.0); top right photo, gailhamshire (CC BY 2.0).

122 We predict that total pollination production risk will increase under all climate scenarios (Figure 3, see Figure
 123 2 for a schematic of our crop pollination risk inputs and models). For all scenarios, our projections use change
 124 in pollinating insect abundance as a proxy for the relative risk to the production of crops dependent on insects,
 125 incorporating information on where crops are grown worldwide⁴⁷ as well as the fractional dependence of crops
 126 on animal pollination.³⁶ Our projections are based on the assumption that a projected loss in pollinator
 127 abundance will be associated with risk to crop production from loss of pollination services, according to
 128 a function that translates abundance loss into production loss. This linked cascade model allows us to
 129 account for uncertainty of the biodiversity-production relationship, which although typically described as
 130 positive concave, may vary for crop-pollinator interactions.⁵⁴ We made a decision to focus on abundance
 131 in the main text given the mechanistic link between pollinator abundance, pollen load, pollen deposition,
 132 and crop pollination. To be complete however, in the supplementary information we also present a measure
 133 of risk based on species richness alone (Figure S15 and S16). Our estimates of both relative risk as well
 134 as absolute production risk should be interpreted as indices of risk, rather than predictions of the actual
 135 amount of production likely to be lost, given the very high uncertainty in how pollinator abundance changes
 136 will translate into actual production losses,⁵⁵ and that we do not account for the spatial context of individual
 137 cropland areas.

138 Increases in risk are seen for all assumed relationships between abundance loss and production risk, although

139 the magnitude of changes in relative risk and especially absolute production risk varied widely (Figure 3).
140 The predicted rate of increase in average production risk was substantially higher under RCP (Representative
141 Concentration Pathway) 6.0 than RCP 2.6, suggesting that efforts to mitigate climate change will reduce the
142 risk to future crop production, alongside the many other benefits.⁵⁶ Relative production risk varied strongly
143 between years under an assumption of a concave relationship between pollinator abundance and production
144 (Figure 3). This volatility may be explained by the way in which the non-linearity of abundance/production
145 relationships interacts with inter-annual climate variability caused by the El Nino Southern Oscillation.⁵⁷
146 While increasingly concave assumed relationships between insect abundance loss and crop production risk
147 led to steeper increases in relative production risk with future climate change, absolute production risk was
148 markedly lower, owing to a lower baseline in the present day (Figure 3). Our estimates of risk are based on
149 the distribution of crops as grown in 2000 (see Table S4 for the full list of crops), meaning we do not account
150 for changes in the distribution of crops over time, which are likely to occur as a result of the direct impacts
151 of climate change, indirect effects through the loss of pollinator biodiversity, and socio-economic factors such
152 as price changes in the global markets for particular crops.

153 Our projections of crop production risk are robust to variation in climate predictions under different individ-
154 ual climate models (Figure S4), and do not change markedly when abundance loss is capped at the maximum
155 model-fitted value (Figure S5), when lower-quality estimates of crop distribution are dropped (Figure S6),
156 when Chao-estimated species richness is used in place of total abundance in the models and projections
157 (Figure S15 and S16), or when projections are based only on bees as a key pollinating taxon (Figure S17).

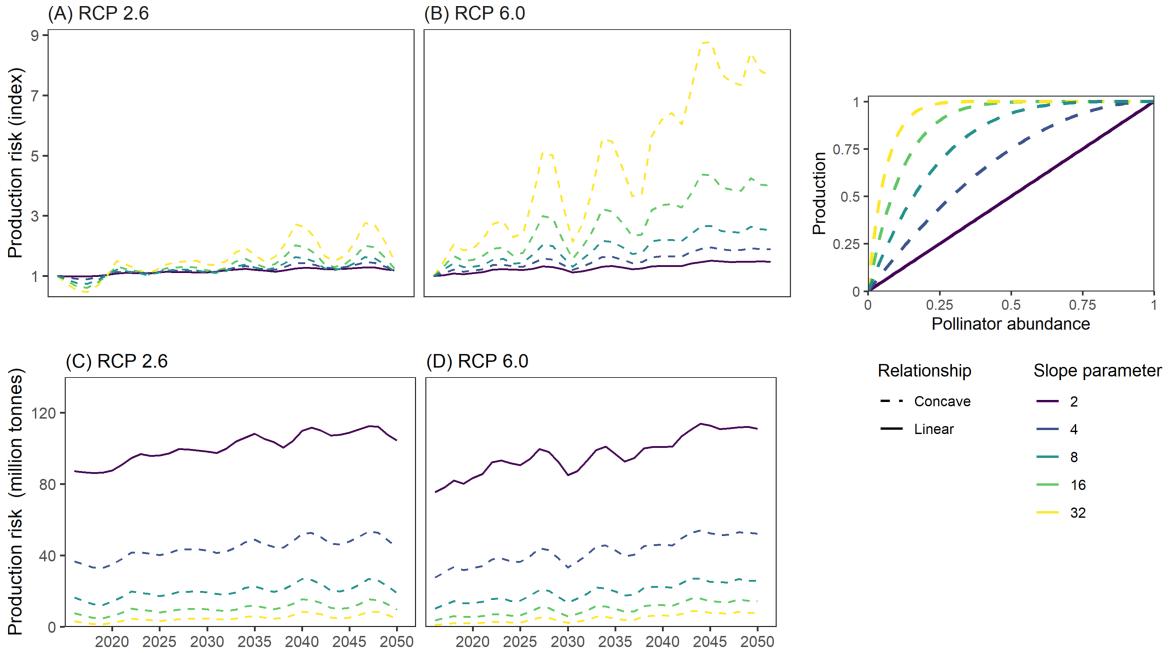


Figure 3: Projected change in total production risk under two RCP scenarios (2.6 and 6.0, see Figure S7 for 8.5) and a set of hypothetical relationships between pollinator abundance and crop production (linear and varying degrees of concavity, defined in the right hand panel). Results are shown both for an index of change in relative risk (A and B) and for the total production potentially at risk (in tonnes) (C and D). For each year into the future, the standardised temperature anomaly was projected globally for all cells with production of crops dependent on animal pollination, using a 3-year rolling average of temperature anomaly estimates in each cell, from an ensemble of different climate models. We used data on crop production for the year 2000 (the latest year when such data are available for all crops). For each annual projection of standardised temperature anomaly, insect pollinator abundance on cropland was predicted according to the model shown in Figure 1A, and then expressed as proportional abundance loss compared to cropland that has experienced no warming (i.e. standardised temperature anomaly of 0). In each cell, the total production of each crop⁴⁷ was multiplied by dependence on animal pollination,³⁶ and then adjusted for the predicted percentage reduction in insect pollinator abundance in that cell. These estimates of crop production at risk were summed across crops, and then across all terrestrial cells globally. Lines show different assumed relationships between insect pollinator abundance and crop production: dashed = concave relationships (of differing degrees, indicated by different colours: yellow = most concave; purple/blue = least concave); and solid = linear relationship. See Figure S7 for a set of convex relationships.

158 Projected risk to crop production in 2050 from insect pollinator abundance losses, as a proportion of all
 159 production in a given location, is highest in the tropical regions of sub-Saharan Africa, South America,
 160 and south-east Asia (Figure 4A; see Figure S8 for individual maps of pollination-dependent crop production
 161 and the standardized temperature anomaly). In terms of total production potentially at risk, China, India,
 162 Indonesia, Brazil, and the Philippines emerge as being most at risk (Figure 4B). Among crops, cocoa is
 163 estimated to be at highest risk, by a large margin, especially in Africa, followed by mango (particularly
 164 in India) and watermelon (notably in China) (Figure 4B). The risk to cocoa production is particularly
 165 significant in light of the social and economic context, as most cocoa is produced on small farms (two to
 166 four hectares) that provide income to between 40 and 50 million people globally.⁵⁸ Coffee is also expected
 167 to have a combination of relatively high production risk (Figure 4B) and high value, suggesting that regions
 168 in which it is grown may experience economic difficulties, unless the pollination service can be replaced

169 cost effectively. Similarly to cocoa, coffee production provides income to millions of small-scale farmers and
170 their families in the tropics.⁵⁹ Therefore, the increased production risk due to loss of pollinators could lead
171 to increased income insecurity for some of the most vulnerable people globally. Our projections of local
172 crop production risk are sensitive to the assumed abundance-production relationship (Figure S9), with the
173 exception of South East Asia, which is consistently projected to have high risk, and the temperate realm,
174 which is consistently projected to have low risk (Figure S10).

175 It is impossible to predict exactly how our estimates of production risk measure will translate into actual crop
176 production losses. There are multiple uncertainties associated with predicting pollinator biodiversity changes
177 and how this impacts crop production, some of which we explore here (e.g. the relationship between pollinator
178 abundance and crop production), but many of which we do not or cannot (e.g. the changing distribution
179 of crops,⁶⁰ the economic viability of hand pollination,⁶¹ the buffering effects of managed pollinators,⁶² the
180 effects of climate change alone,⁶³ the uncertainty over whether pollinator abundance is more important
181 than other measures of pollinator diversity,^{34,64} the buffering or magnifying effects of landscape composition
182 or agroforestry,^{65,66} and other technological solutions such as the breeding or engineering of pollinator-
183 independent cultivars).⁶⁷ As one example, crops in which hand-pollination is already widely practiced, in
184 particular apple, tomato, kiwi, oilpalm, and vanilla,⁶¹ will likely be more resilient than our models would
185 predict. Regardless, at the global scale, assuming that our modelled relationships between standardised
186 temperature change and pollinator abundance are genuine and hold into the future, and that the distribution
187 of pollination dependent production does not significantly change, the relative risk we project is likely to be
188 reflected in challenges for crop production. For cocoa, recent research has focused on the direct effects of
189 climate change on crop production,^{68,69} often overlooking those that might be pollinator-mediated, probably
190 because the direct effects of climate change are easier to capture, and because the set of cocoa pollinating taxa
191 other than midges is unknown.⁷⁰ Importantly, solutions to direct and pollinator-mediated effects of climate
192 change may differ. For example, shade trees might protect crops from the detrimental effects of extreme
193 temperatures,⁶⁸ but might not for the ceratopogonid fly pollinators on which cocoa pollination depends.⁷¹
194 The focus in previous research on direct climate impacts rather than pollinator-mediated effects is a key
195 gap (but see),⁷² given that some cocoa varieties are limited more by pollination availability than resource
196 availability.⁷³

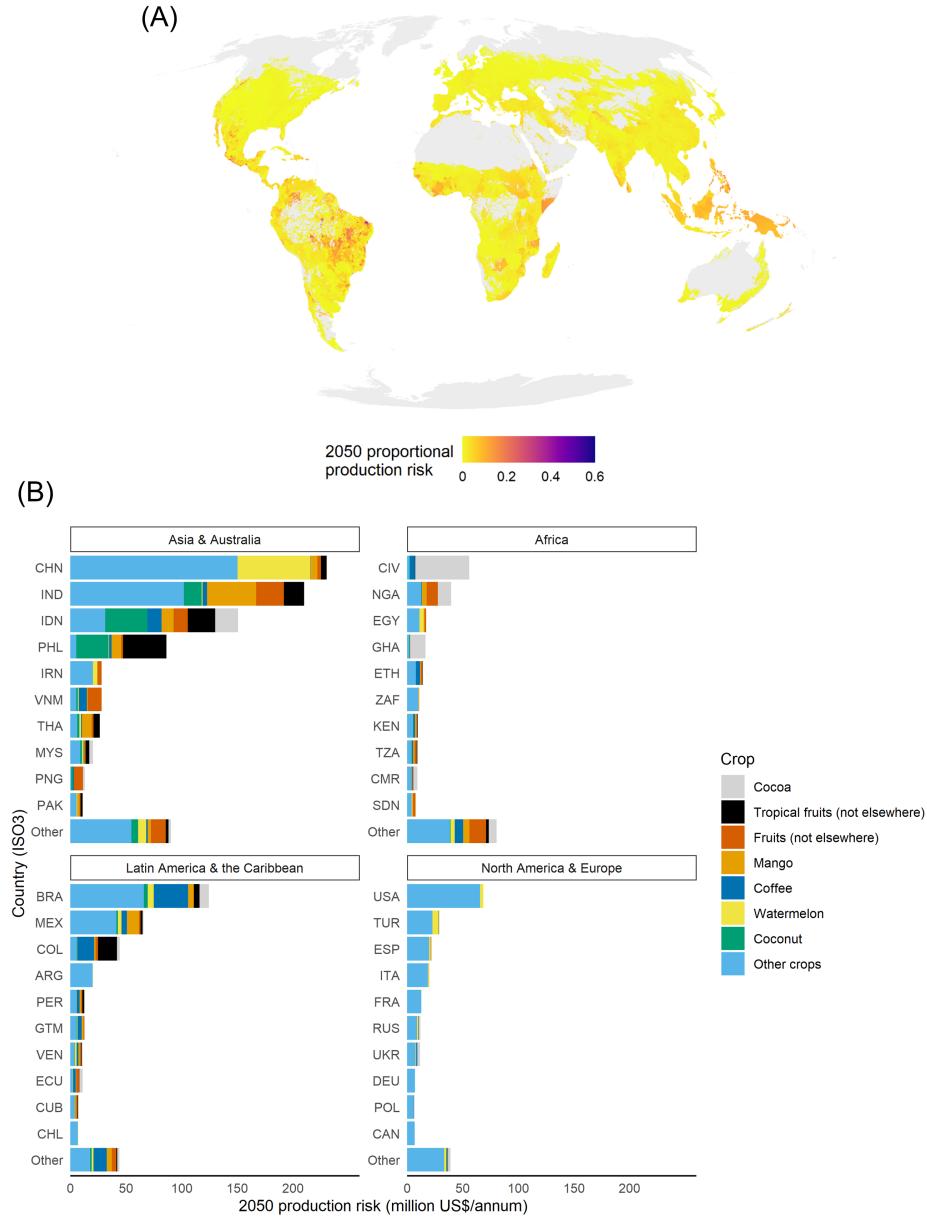


Figure 4: Projected change globally in crop production estimated to be at risk in 2050 under the RCP 6.0 climate scenario, assuming a linear relationship between insect pollinator abundance loss and production loss for crops dependent on animal pollination. All projections are based on mean projections of the standardized temperature anomaly based on temperature estimates from an ensemble of individual climate models. (A) The sum of crop production at risk across all crops with some dependence on animal pollination, as a proportion of the production of all crops grown in a location ('proportional production risk'). (B) The total crop production at risk for the 7 crops with the highest total pollination dependent production value globally (see Figure S11 for the top 20 crops by pollination dependent production alone, Figure S12 for country level proportional production risk, and Figure S13 for crop level proportional production risk), in million US\$ per annum, broken down into four main geographic regions. Each coloured bar represents a pollination dependent crop group: Grey, cocoa; black, tropical fruits (not recorded elsewhere); red, fruits (not recorded elsewhere); orange, mango; dark blue, coffee; yellow, watermelon; green, coconut; and other crops, light blue. Per tonne values of each crop are for the years 2015-2019 (US\$ in 2015-2019 values) taken from,⁷⁴ and total pollination dependent production according to⁴⁷ and.³⁶ Each country is indicated according to its ISO3 code.

197 Countries besides those with high production risk will feel the impact of losses of pollinators and the crops
198 that depend on them, through disruption to imports, especially as the most vulnerable crops tend to be
199 valuable export products such as coffee and cocoa. In absolute terms, large countries such as China and
200 the United States have the highest total import risks (Figure 5B). The Netherlands emerges as having
201 surprisingly high risk given its size, the third largest overall import risk (Figure 5B), consistent with its
202 status as the greatest importer and second greatest processor of cocoa beans worldwide.^{75,76} Import risk
203 per capita (Figure 5A) highlights the challenges that could be faced by nations with limited agricultural
204 production capacity, such as many island countries (e.g. Cayman Islands, Aruba, Singapore, the second,
205 third and fourth highest import risk per capita, respectively) or countries with unfavourable environmental
206 conditions for agriculture (e.g., Mongolia, with the 19th highest import risk per capita). Total import risk per
207 capita tends to be high also in northern and high-income countries, particularly continental western Europe,
208 which has large processing industries for crops such as coffee and cocoa. High income and unfavourable
209 environment for agriculture could both account for high import risk per capita for some countries in the
210 Middle East (United Arab Emirates, Kuwait, Saudi Arabia, which have the 5th, 13th, and 27th highest
211 estimated pollination import risk per capita). Our predictions of import risk are based on trade patterns in
212 the present day,³⁷ meaning we do not account for changes in trade flows that will likely occur in the future.
213 Our approach also assumes that all crop production produced in a given country is exported. In other words
214 we used our trade pattern data to determine how production at risk within a given country should be split
215 among its importers, but did not have a value for the proportion of production staying in that country.

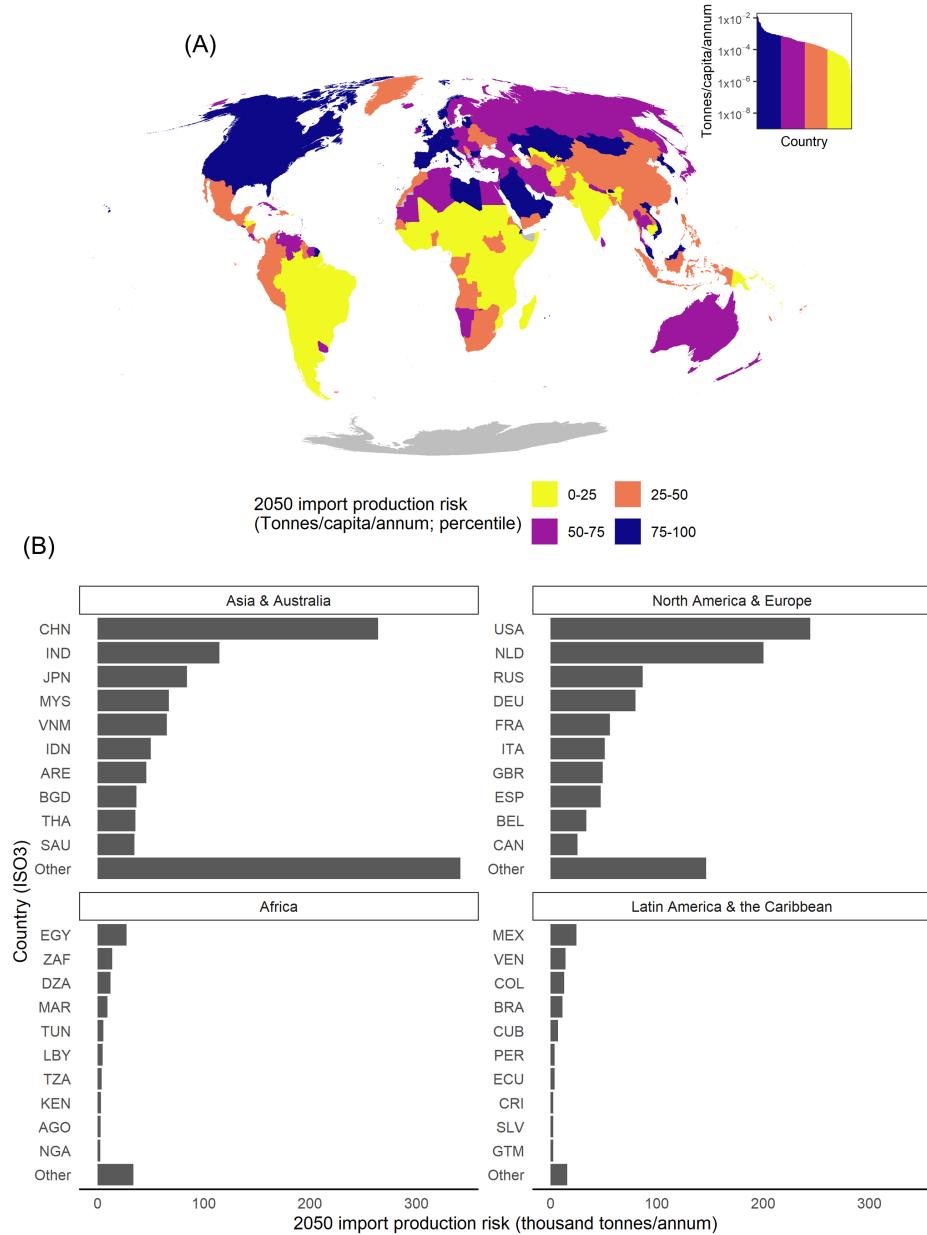


Figure 5: Projected total import risk for 2050 under the RCP 6.0 scenario, assuming a linear relationship between insect pollinator abundance loss and production loss. Projections are based on projected changes in the mean standardized temperature anomaly from an ensemble of individual climate models. Import risk is a measure of how the effects of localised production risk might be distributed among other countries, calculated using trade flow data from.³⁷ For each yearly time step into the future, local production risk in each spatial cell is attributed to importers according to the quantity of pollination trade imported from each country. For example, if an importer is dependent on 3 countries for imports, at a proportion of 30%, 50%, and 20%, then any change in import risk should scale as a function of the local production risk aggregated at those same proportions. (A) The geographic distribution of total import risk adjusted for country population size and then converted to a percentile. Colours represent each percentile grouping: yellow, 0-25th percentile; orange, 25-50th; purple, 50-75th; dark blue, 75-100th. Inset plot represents the absolute import risk values on a log10 scale (although note that the labels are back-transformed), with the same percentile breakpoints. (B) The total import crop production at risk in thousand tonnes per annum, for the 10 countries with the highest import production at risk. Each country is indicated according to its ISO3 code. ‘Other’ is the sum of import risk for all other countries in that geographic region.

216 Interacting effects of climate change and anthropogenic land use are rapidly restructuring biodiversity.^{27,77}
217 Here we show that the combination of agricultural land use and recent climate change is associated with
218 particularly large reductions in the abundance of insect pollinators. As a result, we predict that the tropics
219 will likely experience the greatest risk of future crop pollination shortfalls, putting at risk the production of
220 crops that depend on insect pollination. Future crop pollination risk is estimated to be highest in areas used
221 to produce cocoa, mango, watermelon, and coffee. Given the many factors that determine crop production
222 and crop price,⁷⁸ the likely effects of insect pollinator losses on crop production are unclear, and even if
223 they do occur, conclusive attribution is likely to be challenging. Such complications likely in part explain
224 why identifying a strong effect of pollinator losses on global crop yield and price has thus far been so
225 difficult.^{35,79,80} Regardless, there is sufficient evidence to suggest that declining insect pollinator abundance
226 will influence crop production risk, particularly for those in the global south.⁸¹ Such risk could manifest
227 in the form of direct and immediate losses to crop production through pollinator shortfall, fluctuations
228 over time in the stability of production,⁸² or through decreased resilience to changes that will happen in
229 conjunction (e.g. the effects of extreme temperature and drought on crop growth). Given the likely buffering
230 effects of landscape composition,^{27,65} greater surrounding natural habitat may help to mitigate these risks.
231 The health, well-being, and livelihoods of a high proportion of the global population, from small farmers
232 to consumers, relies to some extent upon the availability and affordability of crops dependent on animal
233 pollination, which is likely to be put at greater risk as a result of future pollinator losses as land-use and
234 climate changes intensify.

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413 **Author Contributions**

414 JM and TN conceived the study. JM, CO, FDSS, JO, LD, LGC, SC, and TN designed the methodology of
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417 **Competing Interests**

418 All authors declare that they have no competing interests.

419 **Data and Materials Availability**

420 All code needed to evaluate the conclusions in the paper are present on Zenodo (<https://zenodo.org/badge/latestdoi/256482859>) and on GitHub (https://github.com/Joemillard/key_tropical_crops_at_risk_from_pOLLINATOR_loss).

423 **Code Availability**

424 Links to all data are currently hosted openly on GitHub here (<https://github.com/Joemillard/Worldwide-vulnerability-of-local-pollinator-abundance-and-crop-pollination-to-land-use-and-climate>). On publication
425 all primary data and links will be versioned on Zenodo.
426

427 **Materials & Correspondence**

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