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Title: **Global Malnutrition Overlaps with Pollinator-Dependent Micronutrient Production**

Short title: Malnutrition and Pollination Dependence

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1 Summary

2 Pollinators contribute around 10% of the economic value of crop production globally, but the
3 contribution of these pollinators to human nutrition is potentially much higher. Crops vary in the
4 degree to which they benefit from pollinators, and many of the most pollinator-dependent crops
5 are also among the richest in micronutrients essential to human health. This study examines
6 regional differences in the pollinator-dependence of crop micronutrient content and reveals
7 overlaps between this dependency and the severity of micronutrient deficiency in people around
8 the world. As much as 50% of the production of plant-derived sources of vitamin A requires
9 pollination throughout much of Southeast Asia, while other essential micronutrients such as iron
10 and folate have lower dependencies, scattered throughout Africa, Asia and Central America.
11 Micronutrient deficiencies are three times as likely to occur in areas of highest pollination
12 dependence for vitamin A and iron, suggesting that disruptions in pollination could have serious
13 implications for the accessibility of micronutrients for public health. These regions of high
14 nutritional vulnerability are understudied in the pollination literature, and should be priority
15 areas for research related to ecosystem services and human well-being.

16 **Keywords:** ecosystem services, agriculture, pollination, global, spatial, nutrition

17 Introduction

18 Reliable and high quality crop yields are critical to food security, and are underpinned by natural
19 processes often not considered in global agricultural forecasts. Pollination is one of these
20 important processes, supporting 75% of the 115 major crop species grown globally, and up to
21 35% of global annual agricultural production by weight [1]. Pollination also improves the quality
22 of fruit produced, leading to higher-value crops for the same yields [2]. Many ecosystem services
23 operate over broader spatial scales, creating flexibility to reduce greenhouse gases or nitrogen
24 pollution in one location by enhancing carbon sequestration or water purification in other
25 locations. Pollination, in contrast, is a smaller-scale process; while managed pollinators can be
26 transported to crop fields, wild pollinators from natural and semi-natural habitats cannot, and
27 landscape-level habitat factors such as homogeneity and fragmentation impact pollinator nesting
28 and foraging behaviours and can ultimately reduce pollination and fruit set [3,4]. Therefore, it is

29 important to identify where pollination is most critical to agricultural production, in order to
30 prioritize regions for pollinator conservation. Furthermore, the pollinators most important to
31 agriculture, mainly the domesticated honey bee, *Apis mellifera* L., and a wide array of wild bees,
32 are in decline, likely due to land-use intensification (deficiencies of resources and high risk of
33 poisoning by pesticides) at field and landscape scales [5-8]. Evidence of this decline and
34 susceptibility to further threat has raised concern among both national and international policy-
35 makers [9-12], with calls to prioritize conservation of pollinators and the services they provide.
36 Making actionable policy out of these general concerns requires an understanding of the areas
37 most vulnerable to further declines in pollination services, and the possible ramifications to
38 human well-being.

39 The importance of wild pollinators to agriculture has been demonstrated in many local studies
40 documenting the contribution of pollination to production of target crops (reviewed by [13,14])
41 as well as several global assessments of the economic value of pollination. Estimates of the
42 contribution of animal-mediated pollination to total world agricultural production used for
43 human food range from 5-8% [15] to 9.5% [16], depending on the metric considered (total
44 production or economic value) and annual variability. Spatial analysis shows that agriculture's
45 dependence on pollinators is not uniform across the globe, with several hotspots of up to 20-
46 30% [15]. Furthermore, pollinator-dependent crops have slower-growing and less stable yields
47 than pollinator-independent crops [16]. The relatively small contribution of pollinators to total
48 agricultural revenues is explained by the fact that the nine highest revenue-generating crops,
49 which together account for nearly half of global agricultural production value (Table S1 in the
50 Electronic Supplementary Material; [17]), are all either wind-pollinated or predominantly self-
51 pollinating. However, economic value of crop production is only one facet of its importance to
52 human well-being; more holistic assessment should include the value of nutrition to human
53 health, and such an assessment will provide a different estimate of relative importance or value
54 of pollination services than for economic valuation alone.

55 Crops that are at least partially dependent on animal-mediated pollination comprise the vast
56 majority of crop types grown, and therefore help maintain the diversity of human diets and the

57 resilience of our food supply. While the cereals that drive the main trends in agricultural
58 revenues can meet the bulk of our caloric needs, overall nutrition relies upon a much broader set
59 of crops. Significant portions of global micronutrient supplies come from pollinator-dependent
60 crops [20,21]. As is the case for economic value, pollinator contributions to micronutrient supply
61 are not expected to be uniform across the globe, and such spatial heterogeneity may have
62 important implications for regional nutrition patterns that are constrained by purchasing power
63 and food access. Here, we map the micronutrients supplied by pollinator-dependent crops
64 globally, and examine overlap between pollinator-dependence and malnutrition. The results
65 highlight priority locations for future research on pollination services by identifying agricultural
66 regions where pollination is most critical to micronutrient production.

67 **Methods**

68 Spatial datasets for crop yields and harvested area at 5 min resolution [22] were used to
69 calculate production of 115 food crops. Proportional areas of harvested acreage for each crop in
70 each 5 min grid cell were first multiplied by the area of that grid cell to calculate total ha of each
71 crop harvested, and then multiplied by the yield (tons/ha) in each grid cell to calculate
72 production (tons) for each crop. These production values were reduced to reflect only the
73 amount used as human food based on national-level data compiled by the Food and Agriculture
74 Organization [23]. This food-only production was then multiplied by the proportion of each crop
75 that is edible (leaving aside refuse such as peels, pits, shells, ends, and stems) derived from a
76 database cataloguing the composition of food created by the U.S. Department of Agriculture
77 [24]. All production in this analysis therefore comprises only that contributing to human
78 nutrition.

79 Production values were reduced by the fraction of their pollination dependence, according to
80 Klein et al.'s [1] classification of 124 crops, which designated animal-mediated pollination as
81 "essential," for instance, if its absence decreases yields by 90% or more. The averages for the
82 ranges of pollination dependence (0.95 for "essential", 0.65 for "great", 0.25 for "modest," 0.05
83 for "little") were used to multiply by the corresponding crop's production to calculate pollinator-
84 dependent production in each pixel for the crops analysed here that are dependent to some

85 degree on animal-mediated pollination. Some mismatches occurred between the Klein et al. [1]
86 and Monfreda et al. [22] datasets; 22 of the crops reported by Klein et al. [1] were grouped into
87 broader categories (e.g., different types of pulses, tropical fruits, and other uncommon crops). In
88 this case an average of the pollinator-dependence and nutrient value of the component crops
89 was used. Pollinator-dependence for 13 crops reported by Monfreda et al. [22] but not by Klein
90 et al. [1] was estimated from additional literature review [25-28].

91 Following the approach set out by Eilers et al. [20], nutritional content was collected for each
92 crop from the USDA database referenced above [24]. Micronutrients examined include minerals
93 (calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, copper, manganese, selenium,
94 and fluoride), water-soluble vitamins (vitamin C, thiamine, riboflavin, niacin, vitamin B5, vitamin
95 B6, folic acid), and fat-soluble vitamins (E, including tocopherol precursors, K, A, and related
96 carotenoids: carotenes, cryptoxanthins, lycopene, lutein, and zeaxanthin). The database includes
97 nutritional information for nearly 8,000 food items, both processed and whole, prepared in a
98 variety of manners; all nutrients considered for this analysis were taken from the values listed for
99 the raw, fresh food crop. Micronutrient content was converted to g per ton values and
100 multiplied by total crop production and pollinator-dependent crop production for each crop.
101 Micronutrient production was summed across all crops per pixel for each micronutrient. We
102 limit our examination of results here to three plant-derived micronutrients particularly important
103 to nutritional health: vitamin A, iron, and folate. The remaining micronutrients can be seen in the
104 Electronic Supplementary Material (Figure S1). Iron and vitamin A are two of the three
105 micronutrient deficiencies of greatest public health significance in the developing world [29-30];
106 plant content of iodine, the third of these, is highly dependent on the abiotic environment and
107 thus not as easily mapped. Folate is essential for the prevention of birth defects, and is thus
108 increasingly considered a public health concern [30].

109 Pollinator-dependence was derived for each of the tracked nutrients by dividing pollinator-
110 dependent nutrient production by total nutrient production in each pixel. This ratio varies
111 according to the mix of crops grown in that pixel, the amount of nutrients in those crops, and the
112 dependence of those crops on pollination. As this measure of pollinator-dependence approaches

113 1, the nutrient produced in a pixel comes from crops increasingly dependent on pollination. Each
114 nation was ranked by the maximum value for pollinator-dependence occurring in that nation to
115 formalize identification of “hotspots” of pollinator-dependence. We excluded from this
116 designation of “hotspot” nations whose mean pollinator-dependence values were $< 2\%$, as this
117 indicated the maximum values were outliers and not representing a large area of pollinator-
118 dependence.

119 In order to understand the nutritional context for these hotspots of pollinator-dependent
120 micronutrient production, we examined the overlap between pollinator-dependence and
121 nutritional deficiency. The observed values of the distributions of different levels of prevalence
122 for these micronutrient deficiencies between nations designated hotspots and the remaining
123 nations were compared using a chi-squared test for independence. The expected values were
124 taken from the total distribution of nations into categories of “severe,” “moderate,” “mild”
125 deficiency and “no known deficiency” categories established by World Health Organization
126 (WHO) [31] for Vitamin A, and the categories of $>50\%$, $25-50\%$, $<25\%$ and 0 incidence of iron-
127 deficiency anaemia among pregnant females [32], then scaled in the same proportions to the
128 total number of nations in hotspots and non-hotspots. No deficiency incidence data were
129 available at the global level for folate, so overlaps with pollination dependency are considered
130 more qualitatively for this micronutrient.

131 A third of the total number of nations were selected as pollinator-dependent hotspots, so as to
132 obtain an adequate sample size for statistical comparison within different categories of nutrient
133 deficiency, as described above. For vitamin A, this designation of hotspots corresponded to
134 $>38\%$ maximum pollinator-dependence within a nation, which defined 52 hotspots of a total of
135 157 nations ranked by the WHO for severity of vitamin A deficiency [31] and for which we were
136 able to obtain crop production data to derive pollinator-dependence. For iron, the hotspots
137 corresponded to $>15\%$ maximum value for pollinator-dependence within a nation, designating
138 51 hotspots out of 152 nations with data on the prevalence of iron-deficiency anaemia [32].

139 To aid in the interpretation of our results concerning pollination dependency of micronutrient
140 production, micronutrient demand was also calculated for each country. Male and female age-

141 structure population data were gathered from the UN Population Division [33]. Micronutrient
142 recommended daily allowances (RDAs) and adequate intake data specific to each sex and age
143 class were gathered from the Institute of Medicine (IOM) Dietary Reference Intake Report [34].
144 The age-structure breakdown of the IOM RDAs was modified to be consistent with UN age
145 classes where necessary. The population within each sex and age class was multiplied by the
146 appropriate RDA and 365 days to determine annual demand within each class. Summing across
147 all sex and age classes determined the annual total micronutrient demand for each country.

148 **Results and Discussion**

149 *Patterns of pollination dependence*

150 Areas of highest dependence on pollination services are different for different nutrients.
151 Production of vitamin A, the most pollinator-dependent nutrient of the those examined here,
152 approaches 50% dependence on pollination in Thailand, north central and south-eastern India,
153 western Iran, Romania, eastern and south-western Australia, and scattered throughout Mexico,
154 parts of the US and Argentina (Fig. 1a). Iron and folate have lower pollinator-dependence,
155 reaching 12-15% in western China, Central African Republic, north-eastern South Africa,
156 northern Mexico and the Yucatan, and scattered throughout Brazil for iron (Fig. 1b), and
157 throughout South East Asia for folate (Fig. 1c). These relative hotspots of pollination dependence
158 show where local micronutrient production is most vulnerable to pollinator declines, but does
159 not capture the overall contribution of pollination to global micronutrient production. For
160 example, while iron production is highly dependent on pollination across Africa (in Fig. 1), the
161 lower productivity overall in that region means the pollination dependence ranks fairly low on a
162 global scale (Fig. 2).

163 The crops responsible for the bulk of production of each nutrient also vary by region and by
164 nutrient (Table S2 in the ESM). Pumpkin, melon, and mango are among the top crops for
165 production of Vitamin A in many of the pollination dependence hotspots, but other crops are
166 equally or more important in different regions. Okra in India, tropical fruits (e.g., cherimoya,
167 guava, jackfruit, passion fruit, etc.) in India and Thailand, apricot and sour cherry in Iran, apricot
168 and plum in Romania, and peach in Mexico are important sources of vitamin A highly dependent

169 on pollinators. Carrot and sweet potato are two common pollinator-independent crops
170 contributing highly to vitamin A production in all regions. In China, in particular, where there is
171 high vitamin A production but low pollination dependence (bright green area in Fig. 2a), the top
172 crops contributing to vitamin A production are sweet potato, carrot, lettuce, and spinach, all
173 pollinator-independent (although all require pollination for seed production, which suggests
174 declines in pollination could still damage propagation of these crops, a consideration not
175 included in this analysis). Most of the pollinator-dependent production of iron is attributed to
176 pumpkin, sesame, and avocado, along with anise in Brazil and China, buckwheat and watermelon
177 in China, melon seed in Central African Republic, and lupin in South Africa. Wheat, groundnut
178 (peanuts), rice, and maize produce the bulk of plant-derived iron in these regions, without
179 requiring pollination. For folate, coconut is the only top crop shared among all regions, with
180 nutmeg providing the highest production of this micronutrient in Malaysia and Indonesia, and
181 other important contributors including pumpkin in Malaysia, avocado and soybean in Indonesia,
182 and tropical fruits in Papua New Guinea. Important crops that contain folate and do not require
183 pollination include groundnut and banana.

184 *Hotspots for micronutrient dependence on pollination and malnutrition*

185 Interestingly, the areas of highest micronutrient dependence on pollination do not match up
186 with the areas of greatest economic value for pollination. This study identified India, Southeast
187 Asia, and central and southern Africa as recurring hotspots for pollinator-dependence of
188 micronutrient production, rather than the US, Europe, China, and Japan that Lautenbach and
189 colleagues [18] demonstrated to be of greatest importance to overall agricultural and economic
190 value. This disparity in micronutrient and economic importance means that different places
191 would experience the impact of pollinator losses to different degrees and in very different ways.
192 Micronutrient dependence on pollination coincides more with areas of poverty, which suggests
193 that they will be less resilient to shocks to crop production due to possible decline or fluctuations
194 in pollination services [29,35].

195 In fact, hotspots for micronutrient dependence on pollination correspond with areas of high
196 deficiency for some nutrients. Vitamin A deficiency is nearly three times as likely to occur in

197 regions of high (>30%) pollination dependence of this micronutrient, compared to more
198 pollinator-independent regions (Table 1). Vitamin A deficiency can cause severe visual
199 impairment and blindness, especially in children, significantly increases the risk of fatality from
200 common childhood infections, and may increase the risk of maternal mortality [36]. Occurrence
201 of iron-deficiency anaemia in pregnant women is over three times higher in regions of at least
202 15% pollination dependence for plant-derived iron (Table 1). Iron-deficiency anaemia has been
203 linked to complications in pregnancy (contributing to 20% of maternal deaths), impaired physical
204 and cognitive development, increased risk of morbidity in children and reduced work
205 productivity in adults [37]. Global folate deficiencies have not been mapped, but folate
206 requirements increase significantly during pregnancy and deficiencies are one of the leading
207 causes of neural tube defects (NTD) such as spina bifida and anencephaly [30,38]. Vulnerability of
208 folate production may be of particular concern in nations with high rates of NTDs and limited
209 resources for fortification and supplementation programs. The World Health Organization
210 recommends intervening in nations where NTD rates exceed 0.6/1,000 live births [39]. Many of
211 the regions with high pollinator-dependent folate production also have high rates of NTDs,
212 including Guatemala (where NTD rates reached 2.8/1,000 live births in 2001; [40]) and in the
213 Sarawak region of Malaysia (1.09/1,000 live births; [41]). One caveat to identifying such overlaps
214 is that regions that are too deficient in certain micronutrients will likely not be impacted by a
215 disruption in pollination, if the health problem is already so extreme that additional
216 micronutrient shortage cannot cause any additional deterioration in conditions.

217 Regions with high micronutrient dependence on pollination and high nutrient deficiencies may
218 be even more vulnerable to pollinator losses if pollinator-dependent production constitutes a
219 major part of regional demand. While plant-derived micronutrients are only one source of
220 nutrition, comparing the amount of pollinator-dependent micronutrient production relative to
221 the amount demanded based on population and demographics can provide a sense of how the
222 importance of this source of nutrition may vary regionally. For folate (Fig. 2c), the pollinator-
223 dependent production alone exceeds global demand by 13 times, suggesting that access to
224 rather than availability of these micronutrients would be a cause of deficiencies. In contrast,
225 pollinator-dependent iron production (Fig. 2b) meets only 31% of global demand, but in central

226 Africa around one major pollinator-dependent hotspot, production and demand align more
227 closely. Pollinator-dependent production is 7×10^{10} mg, or 93% of regional demand for Central
228 African Republic, Sudan, and Cameroon. Regional patterns for vitamin A production (Fig. 2a) also
229 buck global trends; whereas total global pollinator-dependent production is five times global
230 demand, locally vitamin A production can be much more limiting. In Southeast Asia (India,
231 Bangladesh, Myanmar, Cambodia, Laos, Vietnam, Thailand, and Malaysia), pollinator dependent
232 production of vitamin A is 1.5×10^{14} μg RAE, which is 48% of demand for that region. While
233 global trade obviously plays a large role in determining how local demand for nutrition is met,
234 this mismatch is in stark contrast to another area of high pollination dependence, Central
235 America, where pollinator-dependent production of vitamin A is nine times the demand for that
236 region. This is not meant to suggest that local production of nutrition is necessary or even
237 possible in these regions, but only to highlight differences across regions and across scales. For
238 example, while both Mexico and India present public health concerns for vitamin A deficiencies,
239 Mexico is in a region that follows the broader global pattern of higher production of vitamin A
240 than is needed to meet dietary guidelines. This overproduction at the global and regional level
241 may buffer the nutritional impacts of possible declines in pollination. India, on the other hand,
242 being part of the region where pollinator-dependent production of vitamin A meets only half of
243 demand, may be much more vulnerable to pollinator declines.

244 *Adaptations to reduce nutritional dependence on pollination*

245 There are many aspects of nutrition that this global analysis was unable to capture, and which
246 deserve further scrutiny at finer scales, especially for regions that are highly dependent on
247 pollination and known to have high nutrient deficiencies. The value of pollination services,
248 whether economic or nutritional, is generally considered to be the replacement value or the
249 difference between the current situation and a possible future without any pollination services
250 [42]. It is therefore important to note that regions that are vulnerable to changes in
251 micronutrient production due to pollinator declines could adapt by reducing their overall
252 dependency on pollination services. Such adaptations may involve utilising other forms of
253 pollination than wild pollinators and finding novel ways of meeting nutritional needs if pollinator-

254 dependent crops were not available, including crop switching, nutrient supplementation and
255 other (non-crop) sources of nutrition, and access to global markets for nutrition via trade.

256 Wild pollinators are obviously not the only form of pollination available to crop growers.
257 Managed pollinators like the honeybee currently meet most of our pollination needs, and while
258 they may benefit from the same landscape resources that support wild pollinators, they are also
259 able to be transported when and where they are needed [43]. However, as previously noted, the
260 massive die-offs of honeybee colonies in recent years have underscored the precariousness of
261 relying on one managed species, and there may be increasing occurrences of honeybee scarcity
262 in the future that result in price spikes for honeybee rentals, as was seen in the case of almonds
263 in California in the late 2000s [44]. Additionally, wild pollinators have been shown to increase the
264 effectiveness of pollination in honeybees, and we do not know the extent to which this
265 phenomenon operates in many systems [45]. Hand pollination can provide an effective
266 substitute for insect pollinators, as has been shown in apple in China, but this certainly comes at
267 higher cost [46]. For malnourished regions that are typically also impoverished, the cost of such
268 additional inputs as managed pollinators or additional labour for hand pollination may simply not
269 be bearable.

270 Shifting local production from pollinator-dependent to pollinator-independent crops could
271 reduce the reliance on pollination to some degree. However, pollinator-dependent crops are the
272 primary sources of certain micronutrients in several regions (Table S2), suggesting that fully
273 transitioning this micronutrient production to new pollinator-independent crops would require
274 significant changes to growing and eating habits. Some such transitions, such as from pumpkin to
275 sweet potato as a source of Vitamin A in India or Thailand, may be culturally feasible if the crops
276 occupy similar flavour and texture profiles. Diet preferences are often deeply ingrained in
277 different cultures and acceptable substitutes may not always be easily identified [47].

278 Furthermore, even crops that are not reliant on pollination to produce the part of the plant that
279 is consumed (like tubers and leafy greens) may still require pollination for seed production [1].
280 Finally, certain pollinator-dependent crops provide high sources of several nutrients in a single
281 serving. For example, pumpkins, tropical fruits, and melons appear as top crops for two or all

282 three of the nutrients examined here; this is not the case for any of the pollinator-independent
283 crops.

284 Other sources of nutrients, especially animal products and fortified food or supplements, can
285 and do contribute to meeting nutritional requirements, and including these sources of nutrients
286 would provide a more complete picture of the total nutritional profile produced from region to
287 region. Pairing this nutrient production data with information on actual nutrition deficiency
288 would require dietary assessments such as 24-hour dietary recalls or food frequency
289 questionnaires, which are not available on a global scale. This is an important next step when
290 focusing on areas that are particularly pollinator-dependent, in order to better understand the
291 vulnerability of the local population to declines in particular sources of micronutrients.

292 A true vulnerability assessment would require a much more in-depth analysis of trade patterns
293 and consumer purchasing power, to track how much of nutrient production is locally consumed
294 and what flexibility there may be in transitioning to global markets if local nutrient supply
295 declines. However, the pollinator-dependent regions that overlap with malnutrition in places like
296 Iran, the Democratic Republic of Korea, and throughout much of Africa are further challenged by
297 high (>30%) incidence of undernourishment and/or high food price index (>2, meaning it costs
298 twice as much to buy food as in the United States, relative to other goods), which suggests little
299 flexibility to adapt in these pollinator-dependent, malnourished areas [48]. Despite the simplicity
300 of this approach to valuing the contribution of pollination to human nutrition, it is still able to
301 reveal the implications for pollinator-dependence in regions of high micronutrient deficiency and
302 low purchasing power, where any further reduction in availability of already scarce sources of
303 certain nutrients could directly impact human well-being.

304 *Nutrient dependence can focus pollination research where it matters for human health*

305 This analysis was a preliminary step in understanding the relative importance of pollination to
306 micronutrient production in different regions of the world, and as such, it provides a global
307 screen for prioritizing where to devote resources to more intensive local study. The identification
308 of high pollination dependence does not indicate the degree to which crop pollination needs are
309 met, by either wild or managed pollinators. Much finer scale analysis is needed to locate specific

310 crop fields requiring pollination and natural and other elements in the landscape influencing
311 pollinator behaviour. In regions that are both highly pollinator-dependent and nutritionally
312 vulnerable, local ecological studies should be undertaken to quantify the ecosystem service
313 provided by wild and managed pollinators and to estimate the value of natural or semi-natural
314 habitat to maintaining that service. Research in the field of pollination services is moving toward
315 mapping supply and demand of pollination at very small scales [49], but such research is not
316 being undertaken in the places it is most needed to inform pollinator conservation decisions for
317 enhanced nutritional security. The best-studied areas for understanding the magnitude of
318 pollination services provided by nature and the consequences of their disruption to human well-
319 being include Costa Rica, California, New Jersey, and Europe, none of which appear in the list of
320 regions most dependent on pollination for micronutrient production. The regions where crop
321 micronutrient production is most reliant on pollination and where malnourishment is already a
322 problem, such as India, Africa, and parts of Southeast Asia, are also typically underserved by
323 academic research and may lack the resources to assess the potential for wild pollinators to
324 meet crop pollination demands. Aside from very preliminary evidence that India may already be
325 pollinator-limited [50] and that natural and semi-natural habitats do play a role in maintaining
326 bee diversity in Mexico, and Romania [51-52], much further study is needed in areas of high
327 importance to nutrition.

328 Joining this global micronutrient pollinator-dependence screening approach with the smaller
329 scale empirical studies on pollination services actually delivered is important for conservation
330 planning when improving human well-being is a goal. It is a question for policy as to whether the
331 quantity of crop production, the quality (i.e., diversity of nutrients or amount of specific
332 nutrients) of crop production, or the monetary value of crop production derived from pollinators
333 is most important to consider when identifying the regions of greatest concern for pollination
334 services declines. It is clear that these different metrics lead to different conclusions about focal
335 regions for further study, and until now human health considerations have not been driving the
336 choice of study location. The patterns in the importance of pollination to human health should
337 set a new research agenda, prioritizing these regions of high micronutrient dependence on

338 pollination for future field study to gain an understanding of the function and integrity of
339 pollination services where it is most critical to human health.

340 Conservation projects often must strike a balance between preserving biodiversity and
341 maintaining flows of multiple ecosystem services. Deciding which ecosystem services should be
342 included when weighing such trade-offs depends upon understanding the relative importance of
343 any particular service to human health and prosperity. While carbon sequestration and water-
344 related services often receive a great deal of attention in global ecosystem service assessments,
345 more localized services like pollination deserve special consideration in areas where nutritional
346 health is particularly vulnerable and micronutrient production is especially dependent upon
347 pollination. Highlighting such areas, as done in this study, is a first step toward better
348 understanding the reliance of such systems upon pollination. Future research providing a finer
349 scale analysis of the pollination services actually provided in such areas, especially by wild
350 pollinators, will inform local conservation decisions about when and where to prioritize
351 pollination services for improved nutrition and human health.

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481

482 Figure Legends

483 Figure 1. Fractional dependency of micronutrient production on pollination. This represents the
484 proportion of production that is dependent on pollination for a) Vitamin A (in IU, RAE), b) Iron,

485 and c) Folate. This was calculated as the fractional pollinator dependence of each crop grown in
486 a pixel, multiplied by the total production of that crop and the nutrient content of that crop,
487 summed across all crops in each pixel. To aid in visibility, the upper limit of the colour bar is set
488 to the 95th percentile value for each figure.

489 Figure 2. Micronutrient production, across a spectrum of pollinator-dependence, for a) Vitamin A
490 (in IU, RAE), b) Iron, and c) Folate. Here, regions that are highly dependent on pollination,
491 identified in Fig. 1, are further differentiated by the magnitude of their micronutrient
492 production. Total micronutrient production, calculated as the total production of each crop (by
493 weight) multiplied by the nutrient content of that crop, summed across all crops, is denoted by
494 colour intensity, with brighter colours corresponding to more production. This total
495 micronutrient production is plotted against the fractional dependency of micronutrient
496 production on pollination (from Fig. 1), represented by the colour bar from green to red, with
497 green representing little dependency and red representing maximal dependency. Colours are
498 plotted such that the upper limit of the brightness scale, corresponding to 90th percentile
499 nutrient production to aid visibility.