

## Article Addendum

# Pollinator shortage and global crop yield

## Looking at the whole spectrum of pollinator dependency

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**Abbreviations:** FAO, food and agricultural organization of the united nations

**Key words:** agricultural production, developed world, developing world, ecosystem services, environmental degradation, FAO, pollination crisis

A pollinator decline caused by environmental degradation might be compromising the production of pollinator-dependent crops. In a recent article, we compared 45 year series (1961–2006) in yield, production and cultivated area of pollinator-dependent and nondependent crop around the world. If pollinator shortage is occurring globally, we expected a lower annual growth rate in yield for pollinator-dependent than nondependent crops, but a higher growth in cultivated area to compensate the lower yield. We have found little evidence for the first “yield” prediction but strong evidence for the second “area” prediction. Here, we present an additional analysis to show that the first and second predictions are both supported for crops that vary in dependency levels from nondependent to moderate dependence (i.e., up to 65% average yield reduction without pollinators). However, those crops for which animal pollination is essential (i.e., 95% average yield reduction without pollinators) showed higher growth in yield and lower expansion in area than expected in a pollination shortage scenario. We propose that pollination management for highly pollinator-dependent crops, such as renting hives or hand pollination, might have compensated for pollinator limitation of yield.

Meeting the growing demand in the amount and diversity of food, while dealing with increasing environmental degradation, is a major challenge for humanity. As a result of anthropogenic activities, managed and wild pollinators are declining in many regions of the world.<sup>1-7</sup> This could have important consequences for our food

supply, because approximately three-quarters of the crops cultivated worldwide depend to some degree on pollinators to produce seeds, fruits and vegetables.<sup>8-10</sup> Indeed, pollinators promote either yield quantity or quality for crops; even those with a long history of artificial selection and/or more recently genetically engineering, such as canola, soybean and sunflower.<sup>11-13</sup> There is evidence at the local scale that diminished pollinator populations due to environmental degradation are limiting crop yield,<sup>12,14-17</sup> but only recently have we assessed if this phenomenon affects global food production.

In a recent paper,<sup>18</sup> we tested the hypothesis that a reduction in pollinator abundance is limiting crop yield at the global scale. We compared 45 year series (1961–2006) in yield, production and cultivated area of pollinator-dependent and nondependent crops.<sup>8</sup> These temporal trends could differ between the developed and developing world because of differences in agricultural intensification, and socio-economic and environmental conditions.<sup>19-22</sup> We found that crop yield (Mt/ha) has increased on average by 1.5% per year from the values shown in 1961. This trend was similar for pollinator-dependent and nondependent crops in either the developed or developing worlds, thus providing no evidence that pollinator decline has yet affected crop yield at a global scale.

However, there are reasons to expect that the pollinator shortage may have a global impact in the near future. First, we found that the area devoted to pollinator-dependent crops has increased faster than that of nondependent crops in both the developed and developing worlds.<sup>18</sup> Therefore, the demand for animal pollination service is rising at the same time that pollinator abundance and diversity are declining. Indeed, if a pollinator shortage is limiting crop yield, a higher growth in area in pollinator-dependent crops is expected to maintain production rates. Second, we have found a trend of lower growth rate in yield in crops that depend highly on pollinators compared to those with low or none dependence.<sup>18</sup> All these results could be interpreted as an early warning sign of global pollinator declines effects.

Estimation of pollinator dependency effects on global crop production must recognize that the degree of crop dependence varies greatly, such that absence of pollinators would reduce yield by 100% in some crops, and by only a few percent for other crops.<sup>9,11</sup> In our recent paper, we classified crops into three categories of pollinator

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dependency: no dependence, low dependence and high dependence.<sup>18</sup> Here, our analysis classify crops into five categories of pollinator dependency based on Klein et al.<sup>8</sup> We also provide new estimates of pollinator dependency effects by regression analyses of the relationship between crops annual growth in relative yield, and cultivated area, with their level of pollinator dependency.

We used the dataset described by Aizen et al.,<sup>18</sup> and compiled annual data on yield and cultivated area for 87 crops during 1961–2006 for the developed and developing worlds from the FAO statistics.<sup>23</sup> These crops collectively accounted for 83% of total global food production during 2006. Using information from pollinator-exclusion experiments provided by Klein et al. review,<sup>8</sup> we classified each crop into one of five categories according to the average reduction in yield due to the absence of pollinators: 0% (no dependence), 5%, 25%, 65% and 95%. The nondependent category included crops pollinated abiotically (wind) or autogamously, and crops that depend on pollinators but are cultivated for the vegetative parts (e.g., leaves, stems, tubers). For each crop in each region, we first standardized the change in each variable  $x$  (i.e., yield or area) during year  $t$  relative to its value during 1961 as  $\Delta x_t = 100 \cdot (x_t - x_{1961})/x_{1961}$ . We then estimated the slope,  $\beta$ , of the linear relation between  $\Delta x_t$  and year (i.e., %/yr) as an unbiased estimate of the linear average annual growth in the relative yield or area, despite temporal autocorrelation.<sup>24</sup> For example, a slope of 2 for area indicates that the cultivated area of a given crop increased, on average, by 2%/yr in relation to the area cultivated in 1961. For these analyses we excluded crops that were not cultivated in 1961 as explained in Aizen et al.<sup>18</sup>

Pollinator shortfalls would produce lower annual growth in yield in crops with greater dependency on pollinators. We also expect a higher annual growth in area in crops with greater dependency on pollinators to compensate the lower yields. In both the developed and developing worlds, we found evidence that support these predictions for the crops that range in dependency levels from 0 to 65% (Fig. 1). However, those crops for which animal pollination is essential (i.e., 95% yield reduction without pollinators) showed higher growth in yield and lower growth in area than expected by a pollination shortage scenario (Fig. 1).

Pollination management in these highly dependent crops might be decreasing the pollinator limitation on yield produced by environmental degradation. Brazil nuts showed a negative growth in yield but cultivated area did not rise as fast as expected (Table 1). This is reasonable because Brazil nut trees are not commercially planted; the nuts are collected within the Amazonian rainforest that has been decreasing in area because of deforestation. Watermelon, melon and pumpkin (all vines in the family Cucurbitaceae) are frequently pollinated by managed honeybees in large-scale<sup>25,26</sup> or by hand in small-scale production systems (authors' personal observation). Cocoa trees are managed in agroforestry systems which usually provide resources for their pollinating midges.<sup>27,28</sup> Finally, vanilla is commercially grown only under hand pollination management techniques.<sup>29</sup> Therefore, we propose that there is an interaction between

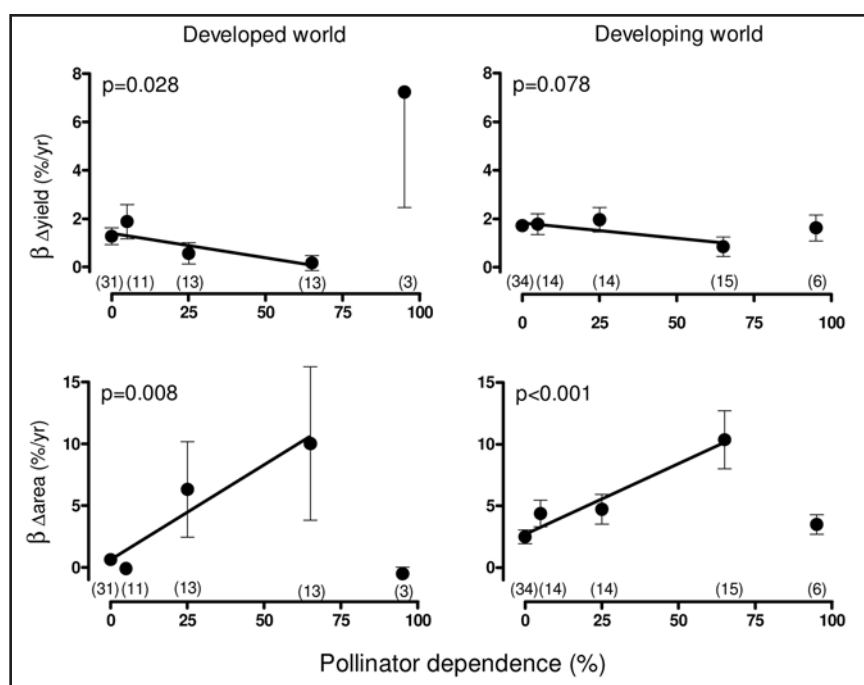


Figure 1. Mean  $\pm$  1 SE of the annual relative growth in yield and cultivated area for crops differing in their pollinator dependence. The lines are linear regressions without considering the 95% dependence group and taking each crop as a replicate. In parenthesis is the number of crops within each group.

the pollinator-dependence spectrum and management responses. At the low end of the range, where pollinators make less difference in yield, management will commonly ignore pollinators. At the high end of the range, where crops will fail or be hugely diminished in the absence of pollinators, most growers will actively manage their pollination.

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Table 1 **Annual growth in yield ( $\beta_{\Delta\text{yield}}$ ) and cultivated area ( $\beta_{\Delta\text{area}}$ ) during 1961–2006 for highly pollinator-dependent crops (i.e., 95% average reduction in yield in the absence of pollinators) in the developed and developing world**

Species	Crop	Developed world <sup>1</sup>		Developing world	
		$\beta_{\Delta\text{yield}}$ (%/yr)	$\beta_{\Delta\text{area}}$ (%/yr)	$\beta_{\Delta\text{yield}}$ (%/yr)	$\beta_{\Delta\text{area}}$ (%/yr)
<i>Bertholletia excelsa</i>	Brazil nut, Para nut, Cream nut	-	-	-0.144	1.072
<i>Citrullus lanatus</i>	Watermelon	3.003	-0.921	3.814	3.635
<i>Cucumis melo</i>	Cantaloupe, Melon	1.935	0.554	1.895	3.369
<i>Cucurbita maxima</i> , <i>C. mixta</i> , <i>C. moschata</i> , <i>C. pepo</i>	Pumpkin, Squash, Gourd, Marrow, Zucchini	16.775	-1.150	0.945	5.103
<i>Theobroma cacao</i>	Cocoa	-	-	2.085	1.690
<i>Vanilla planifolia</i> , <i>V. pompona</i>	Vanilla	-	-	1.149	6.135

<sup>1</sup>Brazil nut, cocoa and vanilla are not commonly cultivated in the developed world and thus do not appear in the FAO statistics.

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