

A decline in pollinator dependent vegetable crop productivity in India indicates pollination limitation and consequent agro-economic crises.

Parthiba Basu*¹, Ritam Bhattacharya¹, Pietro P.M. Iannetta²

¹, Ecology Research Unit, Department of Zoology, Calcutta University, 35, B.C. Road, Kolkata 700019, India

² The James Hutton Institute, Invergowrie, Dundee DD2 5DA, Scotland UK.

*Corresponding author

Approximately 70% of the tropical crop species depend on pollinators for optimum yields (Roubik, 1995, Klein 2007). The economic value of such pollinated crops to India is \$726 million and India is the world's second largest vegetable producer (Sidhu, 2005). This status has been underpinned by large-scale changes in land-use and pesticide dependency (Fazal, 2000; Shaw & Satish, 2007). A method (*c.f.* Aizen et al. 2008) that partitions crops into categories depending on their relative pollinator dependence (Index of pollinator dependence, DI) was applied to analysis of vegetable yields for India over 45 years (1963-2008) using FAO data. This has revealed that since 1993, relative yields of crop production has either flattened or declined, while pollinator non dependent crops show no similar decline. This pattern of yield limitation may be due to several factors, among which 'pollinator limitation' would be a major factor (Kearns et al. 1998) and this risk is discussed. Pollinator decline will have serious socio-economic consequences for countries like India, which host a large population of small and marginal farms for whom falling yield level would be critical for subsistence (Kearns et al. 1998; Kremen et al., 2002; Klein et al., 2007; Potts et al., 2010). We show here for the first time any indication of pollination limitation in India, an emerging economy that is still predominantly agrarian. Detailed land use and ecological surveys are urgently required to assess the ecology of pollinating insects within and around agricultural systems in India.

India, despite the rapid transition in its economy, is still predominantly an agrarian country¹. A significant section of small and marginal farming community, who constitute 80% of the country's farm holdings^{1,2} is significantly dependent on the production of vegetables such as various gourds, brinjal (*Solanum melongena*, also known as aubergine and egg plant),

cucumber, tomatoes apart from potatoes, onions etc. Yield of the majority of these commodities is optimized by the activity of pollinating insects as approximately 70% of the tropical vegetable crop species produced are dependent on the activity of insect pollinators^{3,4}. This underpins the 7.53 million tonnes of vegetables grown in India representing 13.4 % of global production⁵ a sizeable proportion of which is pollinator dependent.

The high productivity of field vegetables is reliant on intensive agri-chemical dependent production⁶. . Negative impacts of pesticides and landuse change on beneficial (non-target) organisms such as pollinating insects have recently been highlighted^{4,8,12}. Globally, pollinator limitation has emerged as a potential risk to crop production and socio-economic stability too^{4,9,10,11,12}. In addition recent meta-analysis has shown that agricultural production in the developing world is becoming more pollinator dependent, as the area of land cultivated with pollinator-dependent crops has increased by 40% from 1961 to 2006¹³. Although the same study showed that there was no decline in relative yield growth rate in pollinator dependent crops globally- meaning there is no evidence for pollinator limitation¹³. also it did show a declining yield growth rate for crops with high pollinator dependence in the developing world. Considering the fact that there are indications of differing pollinator decline impacts between developing and developed world, the same requires closer scrutiny for a developing country like India which has undergone over four decades of pesticide dependent agricultural intensification and is also undergoing fast change in land use due to urbanization and industrialization⁷. Taking the methodology adopted by Aizen et al¹³ (that inferred pollinator limitation from analysis of long term yield data), we further looked at long term changes in relative yields of vegetable crops that has high level of pollinator dependency.

We assessed pollinator-dependent vegetable production in India using 45 years' (1963-2008) FAO data¹⁴, the first ever such assessment done for any country. We took into account index of crop dependence on pollination¹³ (DI) while analyzing for pollinator limitation (declining relative yield growth rate) and pollinator dependency (increasing area under pollinator dependent crops) . We premised that declining yield growth rate of pollinator dependent crops would be indicative of pollinator limitation¹² and declining area under pollinator dependent crops would indicate de-motivation for farmers to grow pollinator dependent crops.

We have also assessed the economic value of insect pollination (EVIP) and Consumer Surplus Loss (CSL) from pollinator decline for India using DI.

The % change of average relative yield for pollinator dependent crops (Δ Yield) between 1963 and subsequent years (using 1963 as the reference year) continued to increase until 1993, after which it started to plateau (Fig. 1). The same trend is even more apparent for crops with high DI (cucumbers and pumpkins) (Fig. 1). This decline in relative yield change rate contrasts with temporal Δ Yield patterns for pollinator independent crops, for which Δ Yield continued to increase during the entire period (1963 – 2008) (Fig. 1). There was significant difference in the average relative yield growth rate of pollinator-dependent and pollinator-independent crops between 1963 – 2008 ($t = 10.47$, $df = 44$, $p < 0.0001$).

Relative change in the cultivated area of pollinator dependent crops (Δ Area) increased by 217% ($6\% \text{ yr}^{-1}$) between 1963 and 1999. But between 2000 and 2008 the growth declined to 7.71% (Fig. 2; 7.6 %, or $0.96\% \text{ yr}^{-1}$). For the crops with high DI, the growth was 153% between 1963 and 1999 ($4\% \text{ yr}^{-1}$) but in the subsequent year there was no growth in cultivation area at all. In contrast, the cultivation area of pollinator-independent crops has continued to increase over the same period (Fig. 2).

The economic value of the 6 most commonly cultivated pollinator dependent crop species grown in India was US \$ 3720 million (Table 1). The total EVIP (Economic Valuation of Insect Pollination) of these 6 crops was calculated as US \$ 726 million. EVIP for moderate to high DI (0.25 – 0.95) vegetables, e.g., (brinjal, cucumbers, pumpkin, squash and gourds) account for over 80% of this. This highlights the extreme level of socio-economic dependence of Indian agricultural systems on pollination. Furthermore, the residual value can be 26% greater if CSL (Consumer Surplus Loss) is taken into account, which was calculated as \$ (US) 1274 million at ($\pm 20\%$ price elasticity (Table 1).

The above analysis prompts an urgent enumeration of the extent of natural pollinator loss in India and its impact on different pollinator dependent crop systems across various agro-ecological regions of the country. It is possible that the impact would vary across various

landscape scales and in different agro-ecological situations and a coordinated exercise towards such estimations would be essential.

Methods Summary:

The economic value of insect pollination (EVIP) index (Gallai et al , 2009; FAO 2010) was used to estimate the economic importance of pollinators for Indian vegetable crops. EVIP is calculated as: $EVIP = \sum_{i=1}^i P_i * Q_i * D_i$

Where, i = crop type ($i = 1$ to i); and D_i = Index of pollinator dependence for crop i , a measure of the reduction in pollination services, calculated from comparing relative yields of pollinator dependent crops as with:without pollinators (after Gallai et al., 2009; *c.f.* Klein et al., 2007; *c.f.* FAO, 2010). The EVIP and Consumer Surplus Loss (CSL) assessment was made in relation to pollinator loss for each crop using the FAO spreadsheet calculator and using the assessment framework suggested by Gallai (2009). EVIP was calculated for the year 2007 as producer price was not available beyond this year from the FAOSTAT database. For Indian production, these were standardized using total cropped areas (Ha) and yield (Hg/Ha) data from the FAOSTAT database for the period 1963 - 2008. Relative changes in the yield were calculated as % change of crop yield over the base year (1963) for every subsequent years till 2008. Cereals (including coarse grains), garlic, ginger and potatoes, roots and tubers were taken as pollinator independent crops for comparison.

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Figure 1. Changes in the relative yield (expressed as % change of productivity; Δ yield) of years 1964 – 2008 in comparison with base year (1963) for pollinator dependent, pollinator dependent crops with high DI and pollinator non dependent crops.

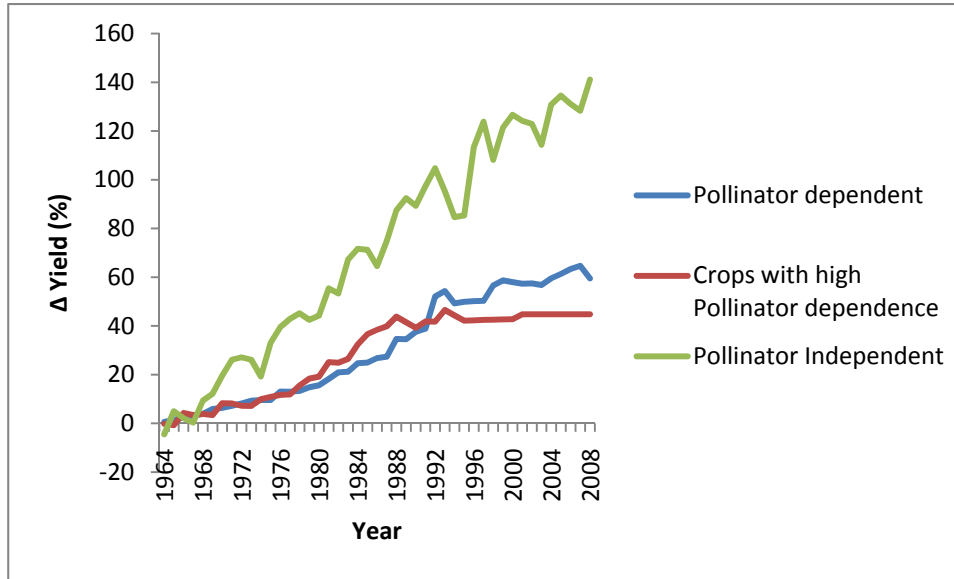


Figure 2. The relative change ($\% \Delta$ area) the land area cultivated for all other (non-pollinator dependent crops;) and pollinated crops with high and moderate pollinator dependency.

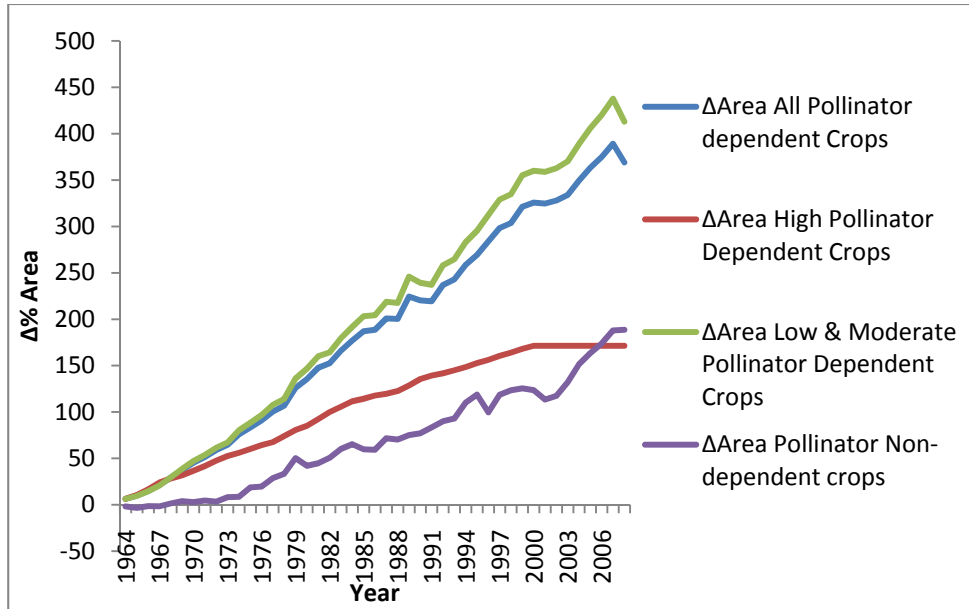


Table 1. The Economic Value of Insect Pollination (EVIP; **\$US millions**) for pollinator dependent vegetable crop production in India. Also, showing are the Total value of crops (TVC, Price * Production) and Consumer Surplus Loss (for definition and assessment method: Gallai et al. 2009) (TVC, CSL, EVIP are in **\$US millions**). TVC, EVIP and CSL are for 2007 FAOSTAT data (producer price was available only till 2007).

Crop Species	TCV	EVIP	CSL
Beans (green)	116.5	5.8	6
Chillies and peppers (green)	11.1	0.55	0.57
Cucumbers	14.3	9.3	14
Eggplant	877.9	219.4	245
Pumpkins, squash, gourds	395.4	375.6	891
Tomatoes	2305.3	115.3	118
Total	3720.5	726.1	1274