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Pollination as natural capital: Accounting for nature's contribution to agriculture

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Agricultural production depends not only on purchased inputs such as seed, fertiliser, irrigation, and labour, but also on natural capital that provides essential ecosystem services. Pollination is one such service, supporting the productivity and quality of numerous fruit, vegetable, oilseed, pulse, spice, and seed crops. Yet, unlike conventional farm inputs, the contribution of pollinators is rarely measured or reflected in agricultural accounts. Pollination service accounting can make this contribution visible by linking pollinator-supporting habitats and populations with flower visitation, crop response, pollination-dependent production, and economic value. Such an approach is particularly relevant to diversified Indian farming systems and farm-forest landscapes of the Himalaya, where wild and managed pollinators depend on interconnected habitats. Accounting can also identify pollination deficits and reveal the costs associated with habitat degradation, pesticide exposure, and climate-related disruption. Recognising pollination as natural capital can therefore strengthen farm management, biodiversity conservation, and investment in resilient agrifood systems.

Keywords: Agrifood systems, Economic valuation, Ecosystem accounting, Ecosystem services, Pollinators

EVERY agricultural harvest represents the combined contribution of human, manufactured, and natural inputs. Farmers readily recognise the costs of seed, fertilisers, plant-protection chemicals, irrigation, machinery, and labour because these inputs are purchased and recorded. Nature's contribution is less visible. Healthy soil, water regulation, natural pest control, and pollination contribute continuously to agricultural production, but seldom appear in conventional farm accounts. Pollination provides a striking example of this accounting gap. More than three-fourths of the world's major food-crop types benefit to some extent from animal-mediated pollination, and an estimated 5–8% of global crop production is directly attributable to it. The annual contribution of pollination to the market value of global crop production has been estimated at USD 235–577 billion. The significance of pollination extends beyond crop quantity. Adequate pollination can improve fruit and seed set and, in many crops, influence size, shape, uniformity, and other quality attributes affecting marketability. Pollinater-dependent crops include many fruits, vegetables, nuts, oilseeds and other foods important for dietary diversity. Pollination is therefore simultaneously an ecological process, an agricultural input, and a contributor to food and nutritional security.

Pollination as natural capital

Natural capital refers to stocks of natural resources and ecosystems that generate benefits for people. Pollinators and the habitats and ecological processes that sustain them form part of this productive natural capital. An important distinction, however, is required. Pollinators constitute part of the natural asset, while pollination is the flow of ecosystem service generated by that asset. The agricultural benefit becomes evident when this service contributes to fruit or seed formation, produce quality, yield stability, and farm income. This relationship can be visualised as:

Pollinator-supporting habitats > pollinator populations > flower visitation and pollen transfer > fruit/seed set > marketable production > farm income and food-system benefits

Recognising this chain prevents the value of pollination from being confused with the total value of biodiversity. A bee, forest patch, or hedgerow has ecological functions extending far beyond the value of the crop it helps pollinate. Pollination accounting instead

asks a more specific question on how much agricultural benefit is being generated through the pollination service, and what natural assets sustain its delivery.

Beyond counting pollinators

Pollinator surveys commonly record the abundance and diversity of flower-visiting insects. Such information is essential for understanding the ecological condition of an agricultural landscape, but it does not by itself establish whether a crop is adequately pollinated. The ultimate agricultural service is successful pollen transfer resulting in improved crop performance. Two fields with similar numbers of flower visitors can differ in pollination because visitors vary in their effectiveness, activity periods, and behaviour. Weather during flowering, crop variety, floral density, and compatibility among cultivars can further influence outcomes. Pollination service assessment should therefore combine ecological observations with crop-response measurements. Flower visitation, pollen deposition, fruit or seed set, produce quality, and yield provide increasingly direct measures of service delivery. A particularly useful measure is the pollination deficit. Flowers receiving natural pollination can be compared with flowers receiving supplementary hand pollination. Better fruit or seed production following supplementary pollination indicates that the naturally available service is below the crop's potential requirement. This shifts the management question from 'Are pollinators present?' to the more useful question: 'Are crops receiving sufficient pollination?'

Accounting for pollination services

A practical accounting framework can contain four interconnected accounts. The natural asset account records the ecological infrastructure supporting pollinators. This may include forest and semi-natural vegetation, flowering field margins, hedgerows, native trees, fallows, home gardens, nesting substrates, and water resources. Their area, condition, floral diversity, and connectivity with croplands indicate the landscape's capacity to maintain pollinator populations. Pollination service accounts record the actual flow of pollination towards crops. Indicators may include pollinator abundance and diversity, flower-visitation rate, pollen deposition, fruit or seed set, and measured pollination deficit. Repeated measurements during flowering can reveal whether service delivery varies among locations, seasons, and years. Pollination-dependent production accounts suggest that different crops have different levels of dependence on animal pollination. A simple first approximation of production attributable to pollination can be obtained using:

Pollination attributable production = Total production × Pollination dependency ratio

For example, if 100 t of a crop is produced and its dependency ratio is 0.40, approximately 40 t may be attributed to animal pollination under this simplified approach. Dependency ratios are useful for broad accounting, but locally measured crop responses are preferable whenever available. Field experiments comparing pollinator exclusion, natural pollination, and supplementary pollination can better capture local ecological and management conditions. Monetary accounting states that the physical contribution can subsequently be expressed economically. At its simplest:



Framework for accounting pollination (Developed using Claude Sonnet 5)



Orchards under white netting



Honey bee pollination in agricultural ecosystems, highlighting role of managed bees in crop productivity

Value of pollination service = Crop production × Pollination dependency ratio × Farm gate price

A more complete farm-level analysis can account for changes in marketable yield, produce grade, quality, production costs, and net returns. This is especially important in horticultural crops where better pollination may increase the proportion of produce qualifying for higher market grades. Economic valuation should nevertheless be interpreted carefully. It represents the estimated contribution of a particular ecosystem service flow to agricultural production; it does not represent the complete ecological value of pollinators or their habitats.

The farm-forest connection

Pollination accounting cannot stop at the farm boundary. Pollinators require food, nesting sites, shelter, and suitable microhabitats throughout their life cycles, whereas a crop may flower for only a few weeks. The resources that sustain pollinators during the rest of the year often occur outside cultivated fields. This relationship is particularly important in the case of mountain agriculture that forms a mosaic of terraced farms, orchards, home gardens, field margins, hedgerows, fallows, scrublands, village commons and forests. Pollinators move among these habitats in search of floral and nesting resources. Forest edges, scattered native trees, and uncultivated patches can therefore function as part of the ecological infrastructure supporting agricultural production. Accounting at this landscape scale could reveal where pollination services originate, which crops benefit, and how forest proximity, habitat connectivity, floral-resource continuity, and farm management affect service delivery.

Wild and managed pollinators: Complementary natural and managed assets

Beekeeping is frequently treated as synonymous with pollination management. Managed honeybees undoubtedly make an important contribution and can provide additional livelihood opportunities through honey, wax, pollination services, etc. However, crop pollination cannot be secured through managed honeybees alone. Wild bees and other insects differ in their foraging behaviour, climatic tolerance, activity periods, and effectiveness on particular flowers. A diverse pollinator community therefore provides functional complementarity and can make pollination more reliable across crops, seasons, and variable weather. This distinction is also relevant for accounting. Hiring or maintaining managed colonies can be treated as a purchased or managed production input. Pollination delivered by wild populations represents an ecosystem service flow generated largely by surrounding natural and semi-natural capital. Both contribute to production, but they arise through different pathways and may require different investments.

Uncovering production risks through accounting

The usefulness of pollination accounting increases when measurements are repeated through time. Conventional production statistics may show stable or increasing output even as the natural capital supporting future production deteriorates. Indiscriminate pesticide use may suppress pests but simultaneously expose pollinators. Habitat fragmentation may increase the distance between nesting areas and crops. These changes may initially remain invisible in production statistics but progressively increase the risk of pollination deficits. Climate change adds another dimension. Temperature, rainfall, and extreme weather during flowering affect pollinator activity and crop flowering. Shifts in flowering time and pollinator emergence can alter their synchrony. Monitoring flowering phenology, weather, pollinator activity and crop response together can therefore provide an early-warning system for climate-related pollination risk.

From accounts to action

The purpose of pollination accounting is not simply to attach a rupee value to nature. Its greater value lies in showing where ecological investments can improve agricultural outcomes. Where pollination deficit is identified, farmers can enhance floral resources through suitable native flowering plants, conserve hedgerows and field margins, maintain nesting substrates, and reduce pesticide exposure during flowering. Pest management decisions can consider both pest control requirements and pollinator safety. Scientifically managed honeybee colonies may supplement wild pollination where appropriate. At landscape level, maintaining habitat corridors and floral continuity among farms, forests, and commons can support pollinators beyond individual holdings. Such interventions are particularly relevant for small and fragmented farms because no single

farmer necessarily controls all the habitats required by pollinator populations. Community institutions can therefore become important partners. Van panchayats, Farmer Producer Organisations (FPOs), beekeeper groups, women's groups, and youth can participate in habitat enhancement and monitoring. Agriculture, horticulture, and forest departments can use pollination information to coordinate interventions across administrative boundaries. A practical pollination-accounting framework can begin by identifying pollinator-dependent crops, their area, flowering periods, production, and level of dependence. This can be followed by mapping natural capital, including forests, semi-natural habitats, floral and nesting resources, and their connectivity with croplands. Pollination service delivery can then be assessed through pollinator visitation and diversity, fruit or seed set, crop quality, and pollination deficits. The resulting agricultural benefits can be estimated in terms of pollination-attributable production, marketable yield, and farm income. Finally, repeated monitoring can track changes in habitats, pollinators, pesticide exposure, climate, and service delivery. Combining field observations with spatial tools and farmer participation can enable such accounts to be scaled from farms to landscapes.

Making nature visible in agricultural decisions

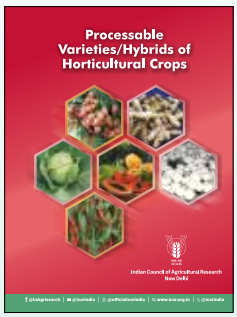
Agriculture ultimately draws upon two sets of accounts: the financial accounts visible to farmers and markets, and the ecological accounts maintained by nature. Sustainable agriculture requires that the second is not depleted to improve the first. Pollination demonstrates this relationship particularly well. A flowering hedgerow, patch of forest, uncultivated field margin, or nesting site may not produce a directly marketed commodity, yet it can support insects responsible for production elsewhere in the landscape. Removing such habitat may therefore represent the depletion of productive natural capital even when conventional farm accounts record no immediate loss. Recognising pollination as natural capital does not mean commercialising every insect or putting a price on all of nature. Rather, it means acknowledging that agricultural production depends on ecological assets, measuring the services flowing from those assets, and incorporating this information into management decisions.

SUMMARY

Pollination is an important component of agricultural natural capital, supporting crop production, quality, nutrition, farm income and resilience, yet remains largely overlooked in agricultural accounting. Pollination service accounting can link pollinator-supporting habitats and service delivery with attributable crop production and economic benefits. It should assess not only pollinator abundance and diversity but also pollination deficits and crop responses. In diversified Indian landscapes, forests, hedgerows, field margins and other semi-natural habitats form vital pollinator-support systems. Integrating ecological and economic information can reveal risks from habitat degradation, pesticides and climate change, guide pollinator-friendly management, and strengthen the productivity and resilience of agrifood systems.

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