Economic Benefit of Crop Pollination by Bees: A Case of Kakamega Small-Holder Farming in Western Kenya

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ABSTRACT In most developing countries, crop production is by small scale farmers, who mainly produce for their own consumption and the extra for market. Pollination in such systems is unmanaged and is usually incidental, supported by nearby ecosystems. One of the reasons of not managing pollination is the lack of understanding of its economic value. The “public-good” nature of pollination in these systems also discourages individual initiatives intended to conserve pollinators. We evaluate the economic returns from bee pollination in small-holder farming systems. To do this we apply the factor of production method, a form of revealed preferences methods available for valuing ecosystem services. Our analyses show that bee pollination enhances the yield of most crops grown in the farmland and improves immensely the quality of produce. Almost 40% of the annual value of crops under consideration represented the net returns derived from bee pollination. More than 99% of this benefit is attributed to pollination by feral bees. We provide in-depth valuation of pollination service and discuss applicability and limitations of the factor of production method in developing countries.

KEY WORDS economic valuation, factor of production, pollinators, yield enhancement

Among animal pollinators, bees are the main agents relied on in agriculture to pollinate different crops. Their management for crop pollination (pollination in this current study should be assumed to be bee pollination unless otherwise stated) started in the early to mid-1900s mainly in United States (Olmstead and Wooten 1987). The practice has ever-since spread to most parts of the world, especially to developed countries where bees are used for commercial pollination of high-valued crops. In the rest of the world, most farmers rely on natural or unmanaged pollination services.

To provide an incentive for bee conservation, there is need to measure the value of bee pollination in crop production (CBD, unpublished data). However, the approaches used so far in establishing the economic value of these pollinators have drawn a lot of debate and up till now there is no universally accepted way for measuring contribution of bee pollination in agriculture (FAO 2006). Moreover, assessing the economic role of pollination in crop production is more challenging in developing countries where there are no management practices for pollination. Farmers in these areas are small-scale in operation and invest less in inputs. Here we try to measure the value of pollination from this perspective.

From an economic point of view, there are currently two main approaches that can be used to measure the value of pollination, depending on the source of the data. Revealed preferences approach (RP) uses data collected indirectly through observation of the economic agent making a transaction in a real market, whereas stated preferences approach (SP) relies on data derived directly from the users’ willingness to pay for the consumption of the good or willingness to accept compensation for forgoing its use (Freeman 2003). Most previous studies that have reported economic value of pollination come from the developed world and used methods within the revealed preferences approach. This has been made possible because bee pollination in these regions is tradable in the market (i.e., bees can be rented for pollination of crops), and hence, “privately” owned. There are specialized firms that rear bees in those countries (e.g., Koppert of The Netherlands) for this purpose. The bees are then often used in greenhouses or on large plantations keeping positive external effects on third parties to a minimum. In such cases, the pollination service is paid for and is obtained from the market.

In developing countries, farmers do not manage pollination in any way and they rely on pollination by feral bees and other biotic pollinators, mainly insects (thus also known as feral pollination), supported by nearby habitats. Pollination in such situations is thus a public good that is used in crop production. It is a positive externality of the conservation and management activities of the surrounding landscape. There
are some examples in developing countries where
large-scale (plantation) farmers are taking measures
to mitigate the perceived inadequate level of pollina-
tion. In Kenya, for example, large horticultural and
coffee firms have initiated beekeeping projects within
their farms, where they keep honey bees for pollina-
tion of their crops. However, they do so without con-
sidering whether honey bees are effective pollinators
of such crops. In contrast, several passion fruit growers
have cleared their plantations due to the lack of suf-
cient and effective pollinating agents (API 2007).

The factor of production (FP) method uses data
from observations of the supply and demand of the
commodity realized after bee pollination, and, it has
not been widely used (Kevan and Phillips 2001, Gor-
don and Davis 2003). Studies that have used this
method measured the change in consumer and pro-
ducer welfare as affected by the change in commodity
output due to a change in pollination (Kevan and
Phillips 2001). Some have extended this approach to
include industries supported by bees or commodities
resulting from bee pollination (Gordon and Davis
2003). Because the commodity attained after pollina-
tion can be traded in the market, it implies that pol-
lination supports an economic activity. One could
therefore say that pollination is an input of production.
It is against this background that we measure the
economic value of feral pollination in smallholder
farming system. Among the RP methods, FP method
was selected in this current study to measure the
effects of the change in pollination on the welfare of
the farmer, because the current situation in the Kaka-
mega farmland does not allow applicability of other RP
methods. This is because bees are not traded for pol-
lination and farmers have not been reported to re-
spond to the dwindling bee population through im-
plementation of defensive actions. We are aware of
the fact that this economic value will not be identical
to the value individual farmers would attribute to bees
or bee-keeping. The economic value of pollination
does, for example, not include the value of honey and
it does not take into account possible negative effects
of bees like attacks on people by managed bees. It is
thus not the value of bees that we aspire to assess, but
the economic value of the pollination that takes place
today in Kakamega.

Study Area. This study was conducted in Kakamega,
which is situated in the western region of Kenya. The
district has rich agricultural soils, plenty of rain
(>1,500 mm/annum), which is well distributed
throughout the year, and average temperatures of
22°C. These attributes makes it suitable for farming,
and the area is high potential for agricultural produc-
tion (Jaetzold and Schmidt 1982). Farm sizes are as
low as 0.2 ha, with an average of 0.7 ha per household
(MOA 2006). The farmland is densely populated with
a range of 433–713 inhabitants per km² (Greiner, un-
published data; BIOTA 2005), making it one of the
most populated rural areas in the world. Most house-
holds are small-scale farmers of crops and livestock.
They rely mainly on staple crops, vegetables and fruit
crops for their daily dietary requirements. Most of
these crops require pollination and are affected highly
by declining pollination service (BIOTA 2005).

One of the unique features of the area is the pres-
ence of the Kakamega forest, which is exceptional in
that it has a mixture of Guineo-Congolian and Afro-
montane fauna and flora species (KIFCON 1994). The
forest is one of the main sources of pollination service
to the crops grown in the farmland but due to the
continued disturbance and intensive farming, pollina-
tion service provision is threatened (BIOTA 2005). If
there are no measures taken to conserve pollinators in
the area, there is a high likelihood of reduced pro-
duction from pollinator-dependent crops. However,
measures needed to support improvement of popula-
tion sizes of the pollinators would demand changes in
the farmland landscape. Any intervention for pollina-
tor conservation would require participation of all
stakeholders likely to benefit from the bee pollination.
This can only happen if they are aware of the eco-
monic benefit of the pollination service, which we try
to measure in this study.

The FP Method. The FP method, otherwise known
as the productivity method, has been used to value
many different ecosystem services and environmental
resources in the past (Freeman 2003). It is used to
estimate the economic value of ecosystem services
that affect the production of commercially marketed
commodities, i.e., where the ecosystem service is used
as a factor or input in production along with other
inputs. A change in the service will affect the output
of the commodity, and this can be monetized to mea-
sure the marginal value of the ecosystem service (Per-
man et al. 2003). The value is therefore derived from
observation of consumer and producer surpluses of the
harvestable product, or that of the input substitu-
tes of the good. This method is limited to those
services that are used in, or have effects on the inputs
required for, the production process of commodities
sold in the market. In agriculture, for example, it has
been used to measure the value of wetlands in pro-
viding clean water for irrigation and/or fish, which in
turn affects the commodity output (Ellis and Fisher
1987, van Kooten and Bulte 2000, pp. 100–151). The
value of crop pollination that was measured in the
current study is affected by bees. This pollination
supports crop production, which produces a commod-
ity that fetches a market value. When measuring the
contribution of pollination to the crop yield, other
inputs used in the crop production such as fertilizer
remain constant and are said to be fixed, and only
changes in the pollination “quantity” affects the com-
modity output. The flexibility of the FP method makes
it suitable for valuing pollination of crops by bees in
Kakamega. However, it relies on empirical evidence
from experimental studies to provide the physical link
between the change in pollination as an input and the
change in the commodity output due to the different
levels of pollination (Pethig 1994, van Kooten and

The Valuation Context. The economic evaluation
used in this study is based on the notion that bee
pollination supports crop production. Therefore, bee
pollination contributes to the welfare of the farmers through improved yields, both in quantity and quality. This increases economic empowerment of a farmer through increased income. Using the normal crop production function, we can describe the relationship of pollination and the crop commodity it supports. The output \( y \) (also referred to here as a commodity) of a crop that is dependent on bee pollination services can be expressed as a function \( f \) of the pollination service \( q \), other variable inputs of production \( x \), and fixed costs \( k \) (e.g., of land, capital) (also see Freeman 2003, pp. 269–296). This can be stated formally as follows:

\[
y = f(x, q, k)
\]

Pollination has no substitute in the market at Kakamega. Therefore, we try here to measure the direct relationship of pollination and crop yield. We therefore require information to map the change in the pollination service, \( \Delta q \), into a change in the commodity, \( \Delta y \), for constant levels of \( x \) and \( k \). By converting the \( \Delta y \) into a monetary term, the value of pollination service as it affects production would be measured (Perman et al. 2003). However, if price reactions occur, this does not provide the correct net benefit from pollination service as it does not consider the demand and supply functions of the commodity as influenced by a change in pollination (Gill 1991). Ideally, we would have to estimate the change in consumer and producer surpluses of the commodities before summing them to get the societal value.

In this study, we assumed that a change in pollination of crops by bees will not affect the demand and price of the commodity in Kakamega, as this is determined in the larger (national) market. This goes together with the assumption that consumers in Kakamega would get the commodities from elsewhere at the old price even if production in Kakamega declined. Thus, the demand function can be seen as totally elastic and hence there is no change in consumer surplus. Therefore, only changes in producer surplus (PS) explain the societal value of pollination (Fig. 1). We are aware that this way of calculating welfare changes only holds if Kakamega is the only district where pollination would be threatened. If we assumed that the changes in production were important enough to affect market supply and thus prices were to increase, the change in welfare would be higher than what we estimate here. Producer surplus shows the difference between the costs of production and the revenue that can be earned in the market. Considering the Kakamega situation, we assume the farmers are operating at \( S_1 \) (supply with bee pollination) and producing \( Q_1 \). Loss of bee pollination will drive the production to \( Q_2 \) and supply at \( S_2 \). The societal value gained from bee pollination is thus the difference between the PS of the commodity when bees are present, \( S_1 \), and PS when bees are absent, \( S_2 \) (i.e., shaded area, Fig. 1). This is similar to the net benefit derived from pollination of crops by bees, which is the total revenue minus the variable costs associated with the use of bee pollination service (Varian 1993). Pollination allows farmers to produce more on the same acreage. It thus reduces marginal or average costs of producing one unit of the commodity. Generally speaking, it would thus be necessary to assess the change in revenue and subtract the change in costs.

When estimating the change in PS, we make use of the fact that most of the costs for farming in Kakamega are independent of the per hectare yield (such as land costs, land preparation, weeding, and watering). There is also no storage costs associated with pollination considering the Kakamega situation. In addition, we are using farm gate prices; hence, costs to farmers are not affected by transportation costs. We will thus assume that a change in costs per ton is only accompanied by a change in harvesting costs per hectare. For the situation in Kakamega where land is extremely scarce it seems reasonable to assume that no land will fall out of production and therefore even without pollination the amount of hectares under production would remain unchanged. Therefore, the change in PS is just the change in revenue minus the costs of harvesting. This implies that the change in income (\( \Delta I \)) of an individual Kakamega farmer due to change in bee pollination, \( \Delta q \), was determined by multiplying the \( \Delta y \) of each considered commodity with its farm gate price, \( p \), minus the harvesting costs, \( c_h \). This can be expressed formally as follows:

\[
\Delta I = \Delta y (p - c_h)
\]

Data Collection. The data used for the analysis were collected from various sources. The annual crop yield data, \( y \), of each crop for the Kakamega were obtained from the Ministry of Agriculture, Kakamega district reports (MOA 2006). These data are comprised of annual yield (kilograms), total area of production (hectares), and annual average farm-gate price for each crop. The data for 2005 were used, because they had information of most crops compared with the data of the previous years. These crops include beans (\( Phaseolus vulgaris \) L.), cowpeas (\( Vigna unguiculata \) Walp), green grams (\( Vigna radiata \) (L.) Wilczek), bambara nuts (\( Voandzeia subterranea \) (L.) Thouars),

![Fig. 1. Illustration of the producer and consumer surpluses for a commodity produced using pollination service provided by bees, case of Kakamega district in Kenya.](image-url)
out bee pollination (bagged flowers). The ratio quality coefficient value \( (qcv) \), represents quality improvement of a commodity due to bee pollination (0.1 if quality is improved and 0.0 otherwise; see Morse and Calderone 2001). The ratio is used for commodities where it plays a role in setting prices in the local market (Table 1).

Formally, the yield (kilograms) attributable to bee pollination, \( \Delta y \), can be expressed as follows:

\[
\Delta y = y \times (pdr)
\]

where \( y \) is the annual yield or yield per unit area (kilograms per year or kilograms per hectare).

### Results

Among the selected crops, only tomatoes, capsicum and passion fruit quality was important factor that determined their local prices (Table 1). Fruit that has bigger polar and equatorial diameters were priced higher than smaller ones. In addition, juiciness and fullness were important in pricing passion fruit and tomatoes. Providing bee pollination to these crops improved these properties. The overall dependence of the selected crops on bee pollination varied from 25% (tomatoes) to 66% (capsicum).

The area dedicated to crop production by farmers in the Kakamega district in the year 2005 was different for each crop (Table 2). Beans had the highest area under production, whereas capsicum had the lowest. It is, therefore, not surprising that beans had the highest annual value and returns to the farmer followed by passion fruit. Although bambara nut had the lowest annual value and returns in the district, its returns per hectare were higher than those from all other crops except capsicum and passion fruit (Table 2).

At the district level, the magnitude of the change in producer surplus of the commodity due to bee pollination was explained by the annual area of production and the farm-gate price for each crop. For example, at the farm level the magnitude of pollination impact is high on the income generated from capsicum and passion fruit; at the district level, the impact of pollination is highly felt in the production of beans. The net

### Table 1. Measurements used in analyzing the value of crop pollination by bees in Kakamega farmland, western Kenya in 2005

<table>
<thead>
<tr>
<th>Crop</th>
<th>( Y_{ub} )</th>
<th>( Y_{b} )</th>
<th>SE</th>
<th>( pda = Y_{ub} - Y_{b}/Y_{ub} )</th>
<th>( qcv )</th>
<th>( pdr = pda + qcv )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beans</td>
<td>1.22 (45)</td>
<td>0.73 (40)</td>
<td>0.07</td>
<td>0.40</td>
<td>0.0</td>
<td>0.40</td>
</tr>
<tr>
<td>Cowpea</td>
<td>1.33 (95)</td>
<td>0.75 (40)</td>
<td>0.06</td>
<td>0.41</td>
<td>0.0</td>
<td>0.41</td>
</tr>
<tr>
<td>Green gram</td>
<td>0.61 (32)</td>
<td>0.32 (32)</td>
<td>0.03</td>
<td>0.43</td>
<td>0.0</td>
<td>0.43</td>
</tr>
<tr>
<td>Bambara nuts</td>
<td>1.83 (71)</td>
<td>0.72 (39)</td>
<td>0.08</td>
<td>0.61</td>
<td>0.0</td>
<td>0.61</td>
</tr>
<tr>
<td>Sunflower</td>
<td>14.21 (33)</td>
<td>6.17 (48)</td>
<td>0.79</td>
<td>0.57</td>
<td>0.0</td>
<td>0.57</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>43.01 (152)</td>
<td>36.44 (66)</td>
<td>1.18</td>
<td>0.15</td>
<td>0.1</td>
<td>0.25</td>
</tr>
<tr>
<td>Capsicum</td>
<td>47.61 (62)</td>
<td>20.95 (31)</td>
<td>2.89</td>
<td>0.56</td>
<td>0.1</td>
<td>0.66</td>
</tr>
<tr>
<td>Passion fruit</td>
<td>35.09 (43)</td>
<td>31.20 (36)</td>
<td>0.66</td>
<td>0.15</td>
<td>0.1</td>
<td>0.25</td>
</tr>
</tbody>
</table>

\( pda \), pollination dependence amount; \( qcv \), quality coefficient value; \( pdr \), pollination dependency ratio; \( Y_{ub} \), yield from unbagged flowers; \( Y_{b} \), yield from bagged flowers; number in parentheses represents N value; SE, standard error of difference of means. The differences in yield with and without bees were all significant at \( P = 0.0001 \). Source: Kasina (2007).
benefit that accrued to the Kakamega farmers as a result of bee pollination of the eight selected crops was about US$3.2 million, which is almost 40% of the annual market value of these crops 2005. This is the amount that the Kakamega community would have lost if there were no bees to pollinate their crops. Approximately 5% of this net benefit accrued from bean production, whereas the rest is shared among the other crops.

Using the average farm size in the district of 0.7 ha (2005), we developed 36 scenarios to assess change in the annual net benefit that a farmer may experience due to bee pollination of the different crops (Table 3). We assumed farmers in Kakamega will use the normal two cropping seasons; hence, they will plant twice annually. With this assumption, and bearing in mind that the farmer has 0.7 ha to use for crop production, it can be seen that farmers will earn amounts ranging from US$183 to US$3,540 per household annually, with an average of US$1,025. Passion fruit are usually planted along fences (even beside trees that offer support to the passion fruit plants) by many local farmers and therefore do not need extra space. How- ever, farmers who may plant passion fruit in the field may not wish to plant them along the fences, thus this was not considered in the model where farmers were expected to plant them in the field. Although passion fruit are perennial, they bear fruit twice annually; hence, this has been factored. The lower value attained when cowpeas are planted does not mean that this crop has a low economic value in Kakamega. It is because farmers plant cowpea as a leafy vegetable and not for seed production. The productivity is lowered due to leaf harvesting. However, the performance of this crop in other parts of the country, where it is grown mainly for its seeds, is higher than of most legumes, and if Kakamega farmers were to grow it for seed production, then the scenario would change.

Discussion

The approach used in measuring the value of crop pollination by bees in this current study was different from that used in previous studies (Robinson et al. 1989, Southwick and Southwick 1992, Carreck and Williams 1998, Morse and Calderone 2001) in two aspects. The first aspect is the nature of provision. Pollination in Kakamega is a public good and is not managed, unlike in other countries where pollination

### Table 2. Amount and value of production of selected crops attributable to bee pollination, in Kakamega farmland, western Kenya 2005

<table>
<thead>
<tr>
<th>Crop</th>
<th>pdr</th>
<th>Annual area of production (ha)</th>
<th>Annual production, y, (kg × 10^3)</th>
<th>Annual value (US$ × 10^3)</th>
<th>Δ y (kg × 10^3)</th>
<th>p (US$)</th>
<th>c_h (US$)</th>
<th>Δ I/yr (US$ × 10^3)</th>
<th>Δ I/ha/yr/yr (US$)^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beans</td>
<td>0.40</td>
<td>22,970.00</td>
<td>14,888.00</td>
<td>7,933.33</td>
<td>5,935.20</td>
<td>0.533</td>
<td>0.026</td>
<td>3,019.29</td>
<td>313.45</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>0.41</td>
<td>429.00</td>
<td>140.90</td>
<td>37.33</td>
<td>57.77</td>
<td>0.265</td>
<td>0.026</td>
<td>13.81</td>
<td>32.18</td>
</tr>
<tr>
<td>Green grams</td>
<td>0.43</td>
<td>26.00</td>
<td>11.00</td>
<td>7.87</td>
<td>4.73</td>
<td>0.715</td>
<td>0.026</td>
<td>3.26</td>
<td>125.35</td>
</tr>
<tr>
<td>Bambara nuts</td>
<td>0.61</td>
<td>14.00</td>
<td>7.50</td>
<td>5.20</td>
<td>4.76</td>
<td>0.667</td>
<td>0.026</td>
<td>3.05</td>
<td>217.94</td>
</tr>
<tr>
<td>Capsicum</td>
<td>0.66</td>
<td>3.00</td>
<td>7.00</td>
<td>11.07</td>
<td>4.62</td>
<td>1.581</td>
<td>0.003</td>
<td>7.29</td>
<td>2,430.12</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>0.25</td>
<td>323.00</td>
<td>4,169.00</td>
<td>2,36.00</td>
<td>1,042.25</td>
<td>0.057</td>
<td>0.030</td>
<td>52.28</td>
<td>161.86</td>
</tr>
<tr>
<td>Passion fruit</td>
<td>0.25</td>
<td>42.50</td>
<td>467.50</td>
<td>306.67</td>
<td>130.90</td>
<td>0.656</td>
<td>0.003</td>
<td>55.48</td>
<td>2,011.24</td>
</tr>
<tr>
<td>Sunflower</td>
<td>0.57</td>
<td>27.00</td>
<td>12.80</td>
<td>6.67</td>
<td>7.30</td>
<td>0.521</td>
<td>0.023</td>
<td>3.64</td>
<td>134.64</td>
</tr>
<tr>
<td>Total</td>
<td>23.834.50</td>
<td>8,544.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,188.10</td>
<td></td>
</tr>
</tbody>
</table>

Price for each crop is an average of farm gate prices of 2005; source: MOA (2006); US$1.00 = KSh. 75.00. For calculation of the different parameters, see derivation of equation 1.

a,b The column represents the net benefit attributed to bee pollination at district and farm level respectively; Δ y, production attributable to bee pollination (kg); p, annual average farm gate price; c_h, cost of harvesting per unit kg; Δ I, income attributed to bee pollination; pdr, pollination dependence ratio.

### Table 3. Increase in income (US$) of a farmer that can be attributed to sufficient bee pollination service annually (two seasons) in Kakamega farmland, western Kenya, 2005

<table>
<thead>
<tr>
<th>Season 1</th>
<th>Beans</th>
<th>Cowpeas</th>
<th>Green grams</th>
<th>Bambara nuts</th>
<th>Capsicum</th>
<th>Tomatoes</th>
<th>Sunflower</th>
<th>Passion fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>184.03</td>
<td>114.54</td>
<td>179.79</td>
<td>244.57</td>
<td>1,793.10</td>
<td>205.32</td>
<td>186.26</td>
<td>1,499.59</td>
</tr>
<tr>
<td></td>
<td>45.05</td>
<td>110.27</td>
<td>175.08</td>
<td>243.00</td>
<td>1,723.61</td>
<td>135.32</td>
<td>116.77</td>
<td>1,430.40</td>
</tr>
<tr>
<td></td>
<td>175.49</td>
<td>240.30</td>
<td>1,753.83</td>
<td>2,36.00</td>
<td>1,568.31</td>
<td>181.99</td>
<td>1,495.62</td>
<td>1,905.62</td>
</tr>
<tr>
<td></td>
<td>305.12</td>
<td>1,853.64</td>
<td>2,65.86</td>
<td>1,795.33</td>
<td>1,560.43</td>
<td>1,905.62</td>
<td>1,795.33</td>
<td>3,108.95</td>
</tr>
<tr>
<td></td>
<td>3,402.17</td>
<td>1,814.39</td>
<td>1,795.33</td>
<td>1,795.33</td>
<td>1,560.43</td>
<td>1,905.62</td>
<td>1,795.33</td>
<td>3,108.95</td>
</tr>
<tr>
<td></td>
<td>226.60</td>
<td>207.55</td>
<td>1,521.17</td>
<td>1,521.17</td>
<td>1,521.17</td>
<td>1,521.17</td>
<td>1,521.17</td>
<td>1,521.17</td>
</tr>
<tr>
<td></td>
<td>188.50</td>
<td>1,502.12</td>
<td>2,815.74</td>
<td>2,815.74</td>
<td>2,815.74</td>
<td>2,815.74</td>
<td>2,815.74</td>
<td>2,815.74</td>
</tr>
</tbody>
</table>

In addition to the above-mentioned combination, passion fruit are perennial and are mainly planted on fences; hence, they do not occupy the farm space for other crops. Therefore a value of US$0.37.56 should be added to each value in the cells (except for passion fruits); 1.00 US$ = 75.00 KSh; Assumptions: a farmer has 0.70 ha (MOA, 2006) to cultivate and 1 m width of the fence around the farm, Source: own.
is managed (hence ‘private’ good) and to some extent is traded on the market. Therefore, the amount calculated represents the value of feral pollination if only Kakamega was affected by a total loss of bee pollination. This does not however reflect the value of bees or bee-keeping, a subject that is beyond the scope of this study. The second aspect is the crops of interest. All previous valuation studies of pollination address the role of pollination on crops grown for commercial purposes and in large scale operations. The crops dealt with in the current study are mainly food crops grown by small-holder farmers primarily to satisfy daily household requirements and not necessarily for profit maximization.

The magnitude of the net benefit gained by farmers due to change in pollination highlights its role in crop production and the wellbeing of the farmer, as well as society. The monetary values calculated in this study compares well with studies done elsewhere in the world, e.g., Robinson et al. (1989) and Morse and Calderone (2001) who measured the value of honey bee pollination in U.S. agriculture. However, their model did not capture both the consumer surplus and producer surplus as affected by the change in pollination of crops they had used in their model. Southwick and Southwick (1992) attempted to measure both consumer and producer surplus resulting from bee pollination of U.S. crops. In a similar way, we measured producer surplus of crop commodities resulting from bee pollination and assumed that consumer surplus in the study area will have negligible change in the short term. Our valuation shows that bees, as the main crop pollinators, affect the farmers’ welfare in Kakamega. Although past studies only measured the value of honey bees, we provide the value of pollination effected by different bee species. For instance, bean pollination is due to Xylocopa species, whereas A. mellifera pollination contributes to the value of sunflower pollination only. It is therefore notable that solitary bees, which are not managed in Kakamega, are vital in crop production.Apis mellifera, which is kept for production of honey and other hive products (MOA 2006), only contributes <0.1% of the net benefit gained by farmers due to pollination of the considered crops. However, the government policy encourages honey bee keeping for honey markets but does not emphasize their role in crop production. One of the reasons could be due to lack of evidence that bee pollination has economic benefits in crop production.

Because Kakamega farmers do not keep bees for pollination, this study estimates the economic gains of rearing different bees for pollination purposes. We did not compare economic benefits derived from honey bee keeping with the net benefits derived from crop pollination. Previous studies did so largely because in their research situation honey bees were kept by professional beekeepers mainly for renting to crop growers, and the honey business came second (Robinson et al. 1989). Therefore, it made sense for these studies to do cost-benefit analyses of the beekeeping industry. It was also felt that the beekeeping industry was declining and could result in insufficient pollination, therefore the studies target was to influence policies to support beekeeping. The intention of the current study was to show that different bee species are all important in crop production and need to be conserved. The value measured reflects on the role of feral pollination of crops in a developing country compared with rented pollination in developed countries. We can assume that total loss of bees in Kakamega would affect the income of the farmers in the same magnitude. Honey bees play an important role, but there is as yet no indication of their decline in the study area. In contrast, there are not enough solitary bees, which seem to provide pollination of most crops. We, therefore, need policies that encourage conservation of the different bee species.

This study used producer surplus to explain the societal benefit of bee pollination in Kakamega with the assumption that the market is perfectly competitive and hence the demand for the crop does not change. As has already been noted, this approach is not warranted if one intends to monetize the value of bee pollination services for a larger region. Therefore, in future, measurements of consumer surplus may be warranted to avoid undervaluation of the pollination service. This would involve measurements of the long-term welfare effects on the producers and consumers of the commodity due to changes in the pollination by bees (for review, Kevan and Phillips 2001). For example, when pollination is limiting at the national level, market supply may reduce and this will affect the market demand for the commodity.

The main shortcoming of the FP method is the inability to determine the total economic value of pollination for crop production, i.e., the use and non-use value. Another shortcoming is that the aggregated value is only limited to crops for which we have empirical evidence of the magnitude of the influence of bee pollination on their yield. For example, the value determined here was for only eight crops, but there are many more crops that require bee pollination and play a major role in the welfare of the farmers in Kakamega. However, no information is available on the pollination needs of these crops and production figures are also lacking.

Our findings provides a convincing tool for policy makers and all stakeholders involved in production agriculture to consider policies required to manage pollination within small holder farming systems. For example, whereas actions of Kakamega farmers, although not intentional, may be contributing to presence of bees in the farmland, they may not enjoy this service for long if they do not conserve the bees given the continued fragmentation of the forest and farmland landscape that has resulted to loss of habitats for the bees (BIOTA 2005). Thus, there is an important role for extension services to spread knowledge on the positive effects of bees for pollination and on possibilities to increase bee pollination. Due to the wide area in which pollination by bees takes place and the associated free rider problems these measures should be undertaken at a community level. This implies that
ecosystem approach would be the most appropriate for pollination management in Kakamega and other areas with similar ecology and farming system.

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