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Services performed by the ecosystem: forest remnants influence agricultural cultures' pollination and production

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Abstract. Ecosystem services are natural functions of an ecosystem that can be, secondarily, used for the benefit of humans. A recent estimate showed that ecosystem services equal, on average, 33 trillion dollars a year, with pollination being responsible for 112 billions dollars. The alteration of natural systems and the loss of pollinating species have caused a decrease in many crops' productivity. The objective of this work is to evaluate the pollination as an ecological service in agriculture, testing the hypothesis that the presence of forest remnants increases coffee agricultural productivity through an increase in pollination. This argument is based on the assumption that areas of preservation of native forest required by Brazilian law provide pollinators to local agroecosystems. Fruit production was compared among three different planting regimes: agrosilviculture, and conventional monoculture with and without preserved forest remnants nearby. The average flower production by branch was different among the farms and was not related to the planting methods. The first flowering was larger than the second, representing 81–98% of the flowers' total production. The farms near forest fragments had an increase of 14.6% in production that can be related to the pollinating services.

Introduction

Ecosystems are complex biological structures that involve biotic interactions and close dependence of organisms with abiotic factors. Based on the Biotic Integrity theory approach (Karr 1981; Angermeier and Karr 1994), ecosystems are considered functional groups composed of elements and processes (Keddy and Lee 1993). The elements are the biological species which can be organized according to the functions they have in the system (i.e. their trophic level). The processes, or functions, are the ecosystem mechanisms directly related to species maintenance (e.g. nitrogen fixation by micorhyzae increasing the maintenance of plant species in nitrogen-poor soils).

Ecosystem services are natural functions that can be, secondarily, used for human benefit (Costanza et al. 1997; Fearnside 1998; Masood and Garwin 1998; Altieri 1999; Daily 1999). These services involve biological, chemical and geological processes (Kearns et al. 1998) and include nutrient recycling, water and gas regulation, biological control, genetic resources, pollination as well as the scenic beauty explored in ecotourism.

Of the current angiosperm flora, estimated at 25 000 species, about 90% are pollinated by animals, especially insects (Costanza et al. 1997; Chichilnisky and

Heal 1998; Kearns et al. 1998). The human-domesticated animals depend, directly or indirectly, on pollination for approximately 1/3 of their food. A recent estimation shows that the services performed by the ecosystem equal 33 trillion dollars a year, with pollination being responsible for 112 billion dollars (Costanza et al. 1997). Independent estimates show that the annual value of agricultural pollination is 20–40 billion dollar in the USA alone. For global agriculture this value ranges around 200 billion dollars (Kearns et al. 1998).

Many characteristics associated with modern agriculture make the agricultural habitats poor for pollinators because they do not provide all the necessary resources for survival, such as places for nesting, food and other physical conditions (Heard 1999). Natural systems alteration and loss of pollinating species cause a decrease in agricultural productivity, as can be seen in many different plantations (Manzoorulhaq-Rafieuldin and Ghaffar 1978; Bhatia et al. 1995; Moreti et al. 1996; Vaissiere et al. 1996; Ish-Am and Eisikowitch 1998; Vicens and Bosch 2000).

Considering ecological sustainability as the capacity to keep vital processes for ecosystem functioning, the state determination of ecosystem services must be acknowledged as an essential evaluation procedure for systems under human control, especially agroecosystems (Petrzelka et al. 1996; Dix et al. 1997; Naeem and Li 1997; Ruark 1999; Bezerra and Veiga 2000; Novaes et al. 2000). It should be remembered that this sustainability concept is distinguished from the so-called economical sustainability, but has a narrow relation with it.

Introduced in Brazil in the beginning of the 17th century, coffee plantations were greatly responsible for the development and subsequent industrialization of some brazilian states, such as São Paulo and Minas Gerais. The coffee's current contribution, in agribusiness terms, is about 4.52 billion dollars annually. Besides, coffee plantation is not only an income generator but also a distributor of it, for it presents great capacity of direct and indirect labor absorption. In the Zona da Mata in Minas Gerais, coffee began to be cultivated around 1830, with an agricultural activity marked by forest clearance by fire and felling. In the beginning this culture developed due to availability of fertile soils, but the lack of proper conservation measures made, with time, these soils infertile, resulting in a migratory agriculture. Coffee crop in Brazil still represents, for many farmers, the main family income, but great parts of these agrosystems are characterized by a decreasing productivity.

Among important variables, which affect the coffee productivity, are the soil characteristics of each area, plantation shadowing and spacing between coffee bushes (Moguel and Toledo 1999; Gobbi 2000; Pinto et al. 2000), culture age (Pinto et al. 2000), climatic variations (Pinto et al. 2000), annual variation production and the planting system (Moguel and Toledo 1999; Gobbi 2000; Pinto et al. 2000; Cardoso et al. 2001), among others. Besides these, this plant pollination, in spite of being mainly due to physical processes (especially gravity) is also affected by pollinating insects (Carvalho and Krug 1996). Carvalho and Krug (1996) concluded that the wind and the insects have equal importance in coffee pollination in Brazil. Roubik (2002a,b) also demonstrate that ripe berries produced by bee pollination are heavier and more abundant per flower (a total increase of 49%).

The objective of this work is to evaluate the pollination as an ecological service in agriculture, testing the hypothesis that the presence of forest remnants near the culture increases coffee productivity through an increase in pollination, a hypothesis presented by Roubik (2002a) for coffee plantations in Panama. This argument is based on the assumption that these areas of native forest demanded by brazilian law (Machado 1989) provide pollinator species to the nearby agroecosystems.

Methodology

Study area

This work was carried out in the Viçosa region (20°45′ S, 45°52′ W), located in the Zona da Mata of Minas Gerais State, Brazil, at an altitude of about 649 m. In this region there are some agroforest system experiments with coffee, but the dominant system is coffee monocultures (Cardoso et al. 2001).

In this study three types of coffee planting method will be compared. In the first type, we sampled monocultures near native remnants (secondary rain forest fragments) in three farms (Forest 1, Forest 2 and Forest 3). The second type composes an agroforest system, which is associated to the culture Australian Cedar trees (*Tooan ciliata* – Meliceae) planted in the spacing of 3 m × 3 m, constituting an agrosilvicultural system (Agro). The third type was coffee monocultures isolated from any type of native forest fragmentation, by at least 1 km (Isolated 1 and Isolated 2).

In all these areas the coffee planted was the Catuaí variety (*Coffea arabica* – Rubiaceae), planted in a hilly area with a typical red yellow latosoil in an average spacing of 2.5 m × 1.0 m. The main flowering occurs in August, with secondary peaks in September and October. As few flowers opened during October and did not resist the climatic conditions, all the data of this study were collected in the August and September flowerings. Another relevant aspect is that the data of the first flowering were collected only for the properties Forest 1, Forest 2, Isolated 1 and Agro.

Experiment of pollination and productivity

In each farm we selected 15 coffee plants distributed uniformly in the lines of the culture, and at least 5 m distant to the edge to avoid possible edge effects in the production.

On each coffee plant we marked four branches, two at 1 m and two at 1.5 m from the soil. One of the farms consisted of smaller sized plants, and because of that, the heights used were 0.5 and 1 m. One of the branches placed in the same height was wrapped up in a mesh net (1.5 mm pore size), making it impossible for possible pollinators to visit the flowers, but allowing pollen grains passage. We compare the height of the branches to control a possible self-pollinating effect from gravity.

We count the number of flowers present and the number of fruit produced on each marked branch in August and September. From this data the proportion of fruit produced was calculated as the ratio of number of fruits and number of flowers present per branch.

Data analysis

In the statistical analyses each plant was considered a sample. We tested the cultivation system effect (native vegetation presence, agrosilvicultural and native vegetation absence) on the flower number and the proportion of fruit formed using the Kruskal–Wallis non-parametric analysis of variance and the *t*-test for dependent samples, respectively, according to Zar (1999). These tests were used due to the non-homogeneity of variances among the groups analyzed from the Levene test. We tested the height effect on the proportion of fruit formed with the *t*-test for the independent samples.

There would be a problem in considering individual plants as replication for the test of the forest effect on proportion of fruits. They are actually pseudoreplicates (Hurlbert 1984). A possible approach suggested in the literature is to use a nested-ANOVA (Hurlbert 1984; Underwood 1997) to at least produce a test with a proper degree of freedom. As heterocedasticity prevents the use of ANOVA, we try an even more robust approach using the paired *t*-test for each farm. If the predict pattern holds then we expect differences in forested but not in the other areas. In this test individual plants are not pseudoreplicates, but proper replicates for within-farm variation.

The *t*-test for dependent samples was used because the treatments, with and without the net, were done on the same plant, generating dependence in the response. Besides, this experimental design has the advantage of eliminating the possible differences in the coffee production, resulting from individual differences in the plants, soil fertility, and different agricultural procedures among farms.

Results

The average flower production per branch was different among the farms (Kruskal–Wallis test; first flowering $H = 135.2243$, $p < 0.001$; second flowering $H = 98.8$, $p < 0.01$; flower total $H = 139.8$, $p < 0.01$; Figure 1). The Forest 1 and Forest 2 farms produced more flowers, followed by the Isolated 2, Isolated 1, Forest 3 and Agro farms. The non-parametric test was used because the flower number variances in all the flowerings were statistically different among the treatments (Levene Test; first flowering: $F = 54.1$; $p < 0.001$; second flowering: $F = 38.7$; $p < 0.001$; and flower total: $F = 63.4$; $p < 0.001$).

In all cases in which the comparison between the first and the second flowering was possible, the first flowering was much bigger than the second, representing between 81 (Forest 2) and 98% (Forest 1) of the flower total production. It could

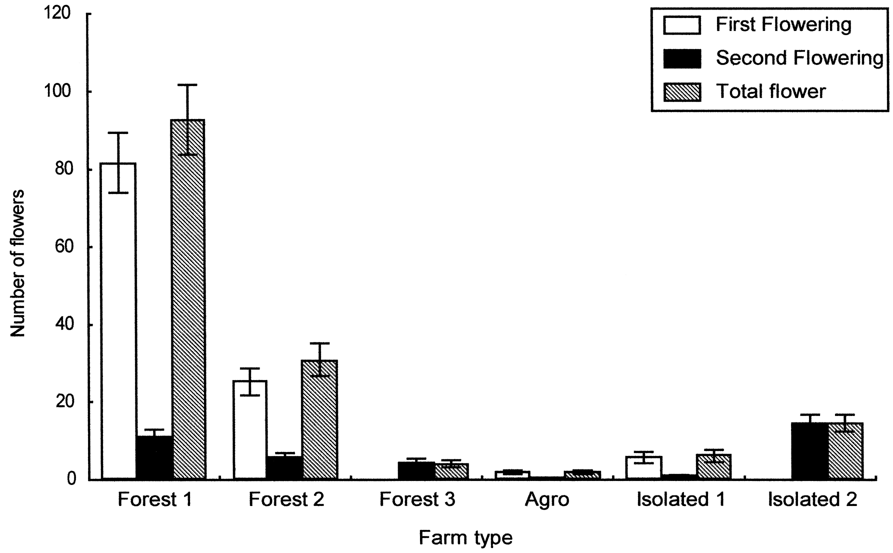

Figure 1. Mean of flowers produced (bars presenting standard error) per branch in each farm. Data of first flowering was not collected for Forest 3 and Isolated 2.

Table 1. Exceeding proportion of fruits (proportion of fruts in open branches above that produced by netted branches, where pollinators were excluded) for the different planting systems in each coffee property (T = paired t-test; degrees of freedom = 29 for all cases).

	Exceeding proportion of fruits provided by pollination	T	p
Forest 1	0.11	2.44	0.020
Forest 2	0.15	2.97	<0.001
Forest 3	0.18	2.36	0.020
Agro	−0.02	1.19	0.240
Isolated 1	0.01	0.83	0.400
Isolated 2	0.07	1.18	0.240

also be noted that the flower production was not related to the cultivating system, showing great variations within each system. This variation can be partially explained by the age differences among the coffee plantations. The Forest 1 area, which represents the youngest plantation (5 years), achieved a production of 92 flowers per branch, on average, while the older plantations (10–15 years) like the Forest 2 and the Isolated 1 produced only 30 flowers and 6 flowers on average per branch (Figure 1), respectively.

The results indicate that the branches with free access to pollinators produced a higher proportion of fruits in farms where there are forest fragments, but this effect did not occur in other cultivation systems (Table 1, Figure 2). Considering that the treatment without the exclusion net allows pollinators visitation, it could be said that the pollinating services generate an increase that varied from 11 (Forest 1) to

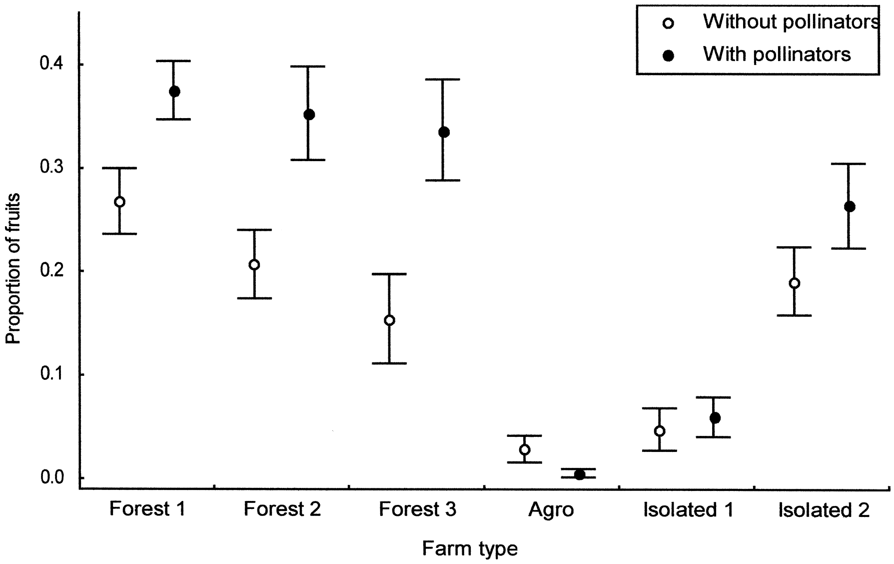

Figure 2. Mean and standard error of proportion of fruit (number of fruits by number of flowers) produced per branch with and without pollinators in the farms.

18% (Forest 3) in the fruit production (Table 1), which represented an average value of 14.6% of the production increase. Even if we use each farm as a replicate, the 14.6% of increase in the farms near forested areas was statistically significant (independent t-test = 3.800; df = 4; p = 0.019).

The very low fruit proportion in the agrosilviculture system suggests that with few flowers the pollination by abiotic factors, especially gravity, is inefficient as well as the attraction that the plant exerts over the pollinator insects.

There are no differences in the fruit proportions produced between the branches of different heights (t-test = −1.82; df = 238; p = 0.06), which shows that all branches are under the same pollinating conditions, that is, are affected in the same way by pollinating by gravity, wind and insects.

Discussion

Differences in the flower numbers and their meaning in the production

The difference in the flower production among the areas is directly related to coffee plantations' age and to an inter-annual variation characteristic of the culture. Younger coffee plantations, under favorable planting conditions, produce greater numbers of flowers than the older ones, which justifies the pruning use for older coffee plantations to increase their production. The inter-annual variation in the production is characterized by the energetic investment of the plant expressed by the time needed for the plant to be able to produce another set of flowers.

Differences in the flower numbers can be of extreme relevance, influencing the abiotic as well as the biotic pollination, and, consequently, the system productivity. Considering that in abiotic pollination the wind, and mainly gravity are involved, in plants with a greater flower number per branch, there is an increase in pollen offer making the pollination easier. In the same way, considering the coffee flower rich in nectar, a greater flower number can make a plant more attractive to its pollinators for concentrating the resource and making it more easily located (Veeresh et al. 1993; Collevatti et al. 2000). This phenomenon has been previously described for some plant species, and probably also affects the coffee culture.

It could be argued that increase in flower number could produce an increase in the proportion of fruits at the open compared to the netted branches. If this phenomenon occurs we expected a correlation between total number of flower and proportion of fruits. An inspection of Figures 1 and 2 shows that, despite considerable variation in flower number in forest areas (4–92), the proportion of fruits was fairly constant (0.34–0.38), and we reject this hypothesis.

Who can be pollinating and why does fragment presence increase pollination?

Roubik (2002b) demonstrated the importance of bee pollination on coffee plantations in Panama. He suggested that *Apis mellifera* (the introduced honey bee) plays the most important role in coffee pollination in this area, but also native bees could be involved.

Different bee species can use the forest fragment for nesting and the agricultural culture for foraging (Aizen and Feinsinger 1994). The opposite also occurs, depending on each species' behavior. *Xylocopa violacea*, for example, frequently flies to the forest reserves to collect pollen, but their nests are found in wooden structures of old houses and in trees near the forest areas (Matheson et al. 1996).

Previous studies (Ramalho et al. 1990; Carvalho and Krug 1996; Malerbo-Souza and Nogueira-Couto 1997) verified that *A. mellifera* (Hymenoptera: Apidae) is the main visitor of coffee flowers (88.9% of the total visits). *Chloralictus* spp. (Hymenoptera: Halictidae), *Xylocopa* spp. (Hymenoptera: Apidae) and *Tetragonisca angustula* (Hymenoptera: Apidae) were also collected in these areas. Another important bee in coffee pollination in Brazil is *Melipona quadrifasciata* (Carvalho and Krug 1996). Moreover, preliminary observations during this work verified that *Trigona spinipes* was present in collecting activities.

The native forest proximity can provide resources to the pollinators in the periods in which the coffee culture is not flowered, and, mainly, provide a variety of nesting sites and material for nest building. The local diversity and landscape heterogeneity are extremely important here, considering that many species build their nests in tree hollows, not found in coffee plantations (Matheson et al. 1996).

Besides the contribution of the pollinating insects, the forest can also play an important role in the control of pest species. Natural predators could find and control many insects that cause damage to crops (Hassell 1985; Lys and Nentwig

1992) and also plague population outbreak is more frequent when their natural enemies are at low population sizes (Graham and Jain 1998).

The fact that farms with adjacent or nearby forests produced more coffee is here interpreted as related to the pollination. Although coffee is not a culture highly dependent on pollinators, their presence was relevant, altering the culture productivity. If other cultures that are widely dependent on pollinators are considered, the value of the pollinating service will be even greater.

There are other possible explanations, mainly related to different soil fertility regulating fruit production. Our experimental design do not prevent this effect. Nonetheless, if soil fertility play an important role here, it also could affect the total number of flowers. There is a considerable variation in this quantity, as discussed above, but it is not correlated with proportion of fruits (the key variable of this study), weakening this possibility.

Economical analysis: what does 14.6% more coffee production mean?

If it is considered that in a 1 ha property 4000 coffee bushes can be planted in a spacing of 2.5 m × 1 m, and that a coffee plantation around 5 years old produces an average of 4680 fruits per coffee tree (from our data), there will be an 18 720 000 fruit production corresponding to 176.56 coffee sacks. A 14.6% average increase was verified to be associated to the pollinating services in areas with close native vegetation. This increase refers to 25.4 more coffee sacks for the producer.

If one coffee sack is worth today (April 2003), in the Brazilian market, US$73.25 (www.cafesall.com.br), this producer has a total of US$14793.57 a year from coffee production. In these terms, the pollinating value as an ecosystem service for the cultures close to native forests would be US$1860.55 per ha per year.

Maybe it would not be economically interesting to keep the forest, depending on the farm area. A decrease in the planting area to preserve native vegetation brings about an active financial loss greater than the 14.6% fruit production increase. However, part of this loss could be lessened not only by the extra production generated by the pollination, but also by the costs linked to not obeying Brazilian laws.

The Brazilian environmental laws demand that the rural landowner keeps 20% of the native vegetation on his farm. There is a law project process in the Brazilian Congress whose objective it is to substitute these preservation areas in the farms by a native vegetation area bought in association with other landowners in another area, which would represent the same preservation area (20%) of the present law. This strategy may not be interesting in productive terms based on the results of this work, which suggest that forest cutting on the property would lead to a loss in the pollinating service performed by the ecosystem.

Conclusions

The average flower production per branch was different among the farms. The Forest 1 and Forest 2 farms produced more flowers, followed by the Isolated 2, Isolated 1, Forest 3 and Agro farms. In all cases in which the comparison between the first and the second flowering was possible, the first flowering was much bigger than the second, representing from 81 (Forest 2) to 98% (Forest 1) of the total flower production. It could also be noted that the flower production was not related to the cultivating system, showing great variations within each system. The branches with free access to pollinators produced more fruits in farms where there were forest fragments, but this effect did not occur in other cultivation systems. Considering that the treatment without the exclusion net allows pollinator visits, it could be said that the pollination services generate an average value of 14.6% of the production increase.

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