THE EFFECT OF LANDSCAPE OVER THE PRODUCTIVITY OF COFFEE

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INTRODUCTION

Habitat fragmentation is defined as a process in which a territory extension is transformed in a cluster of patches (fragments) isolated by a different habitat matrix (Fahrig 2003). From this aspect, a landscape may be qualitatively classified as a continuum or as a fragmented area, but a continuous variation between these extremes may be described by a set of fragmentation parameters that characterize the landscape structure. The main parameters of interest in this case are (1) the habitat reduction, (2) the increase of number of fragments, (3) the reduction of fragment size and (4) the increase of isolation between fragments, which represent the base of most quantitative fragmentation measures (Fahrig 2003).

For instance, the landscape that can be observed from Zona da Mata in the state of Minas Gerais, Brazil, is a good example of extensive deforestation process that affects the Atlantic Forest of Brazil. The result is a set of many forest fragments immersed in an agrarian - urban matrix. The structure of this landscape should determine animal dispersal rates and, considering the important effect of animals in fruit and seed dispersal, the genetic flow of forest plants (Bawa 1990). In this way, the persistency of animal and plant populations could be directly linked to the landscape characteristics, including the level of resistance to the dispersion caused by the new matrix (Fahrig 2003, Jules *et al.*, 2003, Murphy & Lovett - Doust 2004).

Landscape scale studies have shown a negative effect of the loss of natural habitats over the insect communities including bees, wasps, ants, flies, beetles and butterflies and moths (Kruess & Tscharntke 1994, Steffan - Dewenter *et al.*, 2002, Steffan - Dewenter & Kuhn 2003, Steffan - Dewenter 2003). Taki & Kevan (2007) showed that these effects are higher for insect compared to plant communities. The authors suggest that in the interaction plant - pollinators, the insects are more sensitive and/or respond faster than plants to habitat losses, which implies a higher vulnerability of the insects in a given landscape system.

Many native plants present in the fragments of tropical forests are pollinated by insects (Bawa 1990, Liow *et al.*, 2001) but the use of these fragments as a pollinator source for agriculture present at the matrix has only begin to been explored. The exceptions are recent papers which show the importance of pollinators present in these fragments for coffee plantation (*Coffea* sp.)(De Marco & Coelho 2004, Klein *et al.*, 2003b, Klein *et al.*, 2003c, Ricketts *et al.*, 2004, Ricketts 2004), atemóia (*Annona squamosa, Annona cherimola*), macadâmia (*Macadamia integrifolia*) and lichia (*Dimocarpus longan*) (Blanche *et al.*, 2006) and orange (*Citrus paradisi*) (Chacoff & Aizen 2006). In general these studies show a relation between the distance of fragments of native vegetation and the advantage comes from the pollination services (Klein *et al.*, 2003c, Kremen *et al.*, 2002, Ricketts *et al.*, 2004). In their studies about coffee pollination in agroforest systems, Klein *et al.*, (2003c) verified that the number of social bee species diminished with the distance of fragments. De Marco & Coelho (2004) verified that cultivation near fragments (distance $<$ 1km) produce in average, 14.6% more when compared to distant systems and Ricketts *et al.*, (2004) found an even higher increase of 20% in Costa Rica. This distance effect suggests that variables related to landscape ecology as the permeability of the matrix to dispersion of pollinators, may be essential in this type of study.

However, other studies have emphasized the importance of local habitat variables to determine the insect community structure (Collinge 2001, Taki *et al.*, 2007). Taki *et al.*, (2007) studied the wasp communities that use trap - nest and noticed that the community is more affected by the complexity in local habitat, indicated by the flowered plant species richness than by the loss of natural forests.

Therefore, both matrix and fragments and the transition area between these environments may take an important role for the conservation of those species. Murphy & Lovett - Doust (2004) observes that the matrix strongly affects the processes that occur in the fragments through (1) reduction or increase of levels of dispersion and colonization, (2) offering great alternative habitats and (3) acting as a source of invading species. The matrix represents a dynamic environment especially regarding to agriculture components, and may provoke different responses in the community altering the availability of resources for pollinators and the dispersion of seeds and herbivores (Jules *et al.*, 003).

OBJECTIVES

The aim of this paper is to identify variables related to the landscape structure that may be related to the preservation of pollination service. Our analysis come from the following hypothesis: (1) The increase in the proportion of forest affect positively the coffee productivity and (2) The degree of fragmentation (measured by current fragmentation metrics as edge size) of the landscape that surrounds the culture are negatively related to individual plant coffee productivity.

MATERIAL AND METHODS

This study was realized in five coffee plantations with conventional cultivation techniques (SC) and in five agroforests systems (AFS) in the county of Araponga, state of Minas Gerais, Brazil. The conventional cultivation system is characterized by the presence of bushes of Coffea arabica exposed to direct sunlight, while the agroforest cultivation is characterized by a high floristic diversity with at least two extracts (arboreous, bushes and low grass). Each AFS plantation had its own tree composition and also varied in abundance, but its general properties related to exposition to sun and the presence of other flowering plants are similar.

In each of these plantations 10 coffee bushes were marked. In each plant two branches of approximately 1 meter in height are selected. One of them was covered by a screen (1.5mm) to prevent the access of possible pollinators to the flowers and the other branch was free access to pollinators visit. In each branch the total number of floral buds is counted in the beginning of the flowering period and beforehand the number of fruits allowing estimating the fruit proportion produced by flowers and the variation of productivity in relation to pollinator access and the system of production. Productivity is here defined as the difference between the proportion of fruits produced in the control (free access of pollinators) and the treatment (pollinator excluded), characterizing a measure of increase in production related to pollinators visit. We also included in the analysis the data of coffee productivity collected in the county of Viçosa, in the state of Minas Gerais, Brazil, in 2001 with the same method (De Marco & Coelho 2004).

The proportion of forest around each plantation was estimated in a classified Landsat 5 image. In this study we only use the forest and reforestation (Eucaliptus and Pinnus) categories of the Instituto Estadual de Floresta vegetation map, as only they could be related to the presence of native insect pollinator maintenance. We calculated the proportion of forest in 50, 100, 250, 500 and 1000 meters radius based on a point at the center of each plantation using Arcview 3.2.

We also calculate other fragmentation measures inside each 1000 meters buffer using the FRAGSTATS (McGarigal & Marks 1995). Such procedure was used to identify the variables regarding the landscape fragmentation that affect the culture productivity. The measures of fragmentation used in this paper were: 1) fragment density; 2) total edge; 3) edge density; 4) average of proximity rate of 500 meters range; 5) total fragment area; 6) fragment number, 7) landscape form rate; 8) perimeter area average; 9) bigger fragment rate (% of the biggest buffer fragment); 10) fragment cohesion rate.

To identify which is the proportional effect surrounding the plantation and the descriptive variables of the landscape over the coffee productivity, it was utilized a SAM program (Rangel *et al.*, 2006), that chose the best Minimum adequate model (MAM) methods based on in the Akaike information criteria (AIC) in the presence of space autocorrelation through the minimum ordinary square of regression (OLS) (Diniz - Filho *et al.*, 2008). AIC delta values which are smaller than 3, are considered adequate for the analyzed processes.

RESULTS AND DISCUSSION

The average explicative power of variables in all the valid models found showed that buffer areas from 100 to 250 meters may affect coffee production, but with contrasting effects. In these analyses and also for the best model results there is a positive effect of the forest area in the 100 meters buffer and a negative relation with the forest area in the 250 meters buffer.

As to the measures of landscape fragmentation and its relation with culture productivity, the best model includes only total edge as an important variable.

Many studies had shown a relation between the distance to native vegetation fragments and the advantage that comes from pollination services to the culture (Klein *et al.*, 2003c, Kremen *et al.*, 2002, Ricketts *et al.*, 2004, Ricketts 2004). De Marco & Coelho (2004) and Ricketts *et al.*, (2004) developed their works evaluating the effects of fragment presence in a maximum distance of 1 km over the productivity of coffee plantations and verified that the present pollinators in such fragments contribute in average, with 14.6% to 20% respectively in the increase of fruit production. For Klein *et al.*, 2003a) these results may be explained by the variations on the diversity of social species which play and important role in exploration of floral resources.

Kremen *et al.*, (2004) argue that the stability and predictability of pollination services, increases with the increase of natural habitat areas, leading to a positive relation between the level of pollen deposit an the proportion of natural habitat. Their models predicted that for a watermelon producer to get a satisfactory production over the quality - quantitative point of view, his plantation should be placed in an area with a minimum of 40% of natural habitat equivalent to 2.4 km range or larger.

The results presented here suggest something much more complex. Why it is observed a productivity increase related to fragments down to 100 meters of distance and the opposite to distances superior to 250 meters? The results suggest that the presence of forest fragments close by has a positive effect probably because the presence of bee species in the culture border. The interface culture - forest may facilitate the presence of nests and forage more immediate in these circumstances. The causes of the decrease in production related to the forest more distant than 250 meters, is much more difficult to explain. One possible explanation is that those more distant forest fragments may represent a source

of other floral resources that compete to the coffee plantation to foraging bees. Based on the optimal foraging theory (Charnov 1976), it is expected that resident bees in a given fragment search for a richer and closer resource. Bees possibly optimize forage visiting places with high availability of resources, and closer to the nest. This is even more probable for social species, capable of interfering in the behavior of their fellow mates through recruiting for the collection of resources (Pyke 1978).

Klein *et al.*, (2003c) verified that the number of social bee species diminished with the distance of fragments while the number of solitary species increases with the intensity of light. A similar result was found by Chacoff & Aizen (2006) for Citrus paradisi culture. The frequency of visitors in flowers of this species diminished with the increase of fragment distance and the visitor fauna losses diversity. The number of Apis mellifera individuals, more abundant species, also suffered a reduction in distances superior to 500 meters in the fragment border. Those results reinforce the importance of matrix permeability (Townsend & Levey 2005) that may represent costs to the movement under an optimal foraging theory approach and help to explain how and why bees move in landscape in search of resources.

There are three types of edge effects on fragments, (1) the abiotics, involving changes in the environment condition as a result of matrix proximity, (2) the direct biological effects which involve changes in the distribution and abundance of species, caused directly by physical conditions and (3) the indirect biological effect which involve changes in the interaction between organisms such as parasites, predators and pollinators (Murcia 1995). The edge is characterized as an adequate environment for general species as Apis mellifera and Trigona spinipes which had larger tolerance to physical conditions variation. Light incidence and contact with the matrix make this environment similar to successional areas, dominated by a few plant species that attract a larger number of visitors. The edge may shelter a number of species able to build their nests there (Chacoff & Aizen 2006), which along the increase of surface of contact with matrix fragment should enable the movement of these organisms is search of resources.

CONCLUSION

Our results support the prediction that the presence of remnants near coffee plantation affects the pollination service in rural landscape. Otherwise, we show a much more complex dynamics that could occur in small scales. From the fragmentation measures, only the total edge affect the productivity of coffee plants, probably related to the availability of nest sites for social bee species. The overall results put in doubt recent proposal legal cooperative reserves outside rural properties and it could decrease the pollination services and direct affect both agricultural biodiversity and coffee production.

Acknowledgements

We thank to land - owners from Viçosa and Araponga who were extremely helpful during this study. A special thanks to FAPEMIG for financial the project.

REFERENCES

Bawa,K.S., 1990. Plant - pollinator interactions in tropical rain forest. Annual Review of Ecology and Systematics, 21:399 - 422 pp.

Chacoff,N.P. and Aizen,M.A., 2006. Edge effects on flower - visiting insects in grapefruit plantations bordering premontane subtropical forest. Jounal of Applied Ecology, 43:18 - 27 pp.

Charnov,E.L., 1976. Optimal foraging, the marginal value theorem. Theoretical Population Biology, 9:129 - 136 pp.

Collinge,S.K., 2001. Spatial ecology and biological conservation. Biological Conservation, 100:1 - 2 pp.

De Marco,P.Jr. and Coelho,F.M., 2004. Services performed by the ecosystem: forest remnants influence agricultural cultures' pollination and production. Biodiversity and Conservation, 13:1245 - 1255 pp.

Diniz - Filho,J.A.F., Rangel,T.F.L.V., and Bini,L.M., 2008. Model Selection and Information Theory in Geographical Ecology. Global Ecology and Biogeography.

Fahrig,L., 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology and Systematics,34:487 - 515 pp.

Jules,E.S. and Shahani,P., 2003. A broader ecological context to habitat fragmentation: Why matrix habitat is more important than we thought. Journal of Vegetation Science, 14:459 - 464 pp.

Klein,A.M., Steffan - Dewenter,I., and Tscharntke,T., 2003b. Fruit set of highland coffee increases with the diversity of pollinating bees. Proc. R. Soc. Lond. B, 270:955 - 961 pp.

Klein,A.M., Steffan - Dewenter,I., and Tscharntke,T., 2003c. Pollination of Coffea canephora in relation to local and regional agroforestry management. Journal of Applied Ecology., 40:837 - 845 pp.

Kremen,C., Williams,N.M., and Thorp,R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences of the United States of America, 99:16812 - 16816 pp.

Kruess,A. and Tscharntke,T., 1994. Habitat fragmentation, species loss, and biological control. Science, 264:1581 - 1584 pp.

Liow,L.H., Sodhi,N.S., and Elmqvist,T., 2001. Bee diversity along a disturbance gradient in tropical lowland forests of south - east Asia. Journal of Applied Ecology., 38:180 - 192 pp.

McGarigal, K.; Marks, B.J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW - GTR - 351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 122 p.

Metzger,J.P., 1999. Estrutura da paisagem e fragmentação: análise bibliográfica. Anais da Academia Brasileira de Ciências, 71:435 - 463 pp.

Murphy,H.T. and Lovett - Doust,J., 2004. Context and connectivity in plant metapopulations and landscape mosaics: does the matrix matter? Oikos, 105:3 - 14 pp.

Pyke,G.H., 1978. Optimal foraging in bumblebees and coevolution with their plants. Oecologia (Berlin), 36:281 - 293 pp.

Rangel,T.F.L.V., Diniz - Filho,J.A.F., and Bini,L.M., 2006. Towards an integrated computational tool for spatial analysis in macroecology and biogeography. Global Ecology and Biogeography, 15:321 - 327 pp.

Ricketts,T.H., 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops. Conservation Biology, 18:1262 - 1271 pp.

Ricketts,T.H., Daily,G.C., Ehrlich,P.R., and Michener,C.D., 2004. Economic value of tropical forest to coffee production. Proceedings of the National Academy of Sciences of the United States of America, 101:12579 - 12582 pp.

Steffan - Dewenter,I. and Kuhn,A., 2003. Honeybee foraging in differentially structured landscapes. Proc. R. Soc. Lond. B, 270:569 - 575 pp.

Steffan - Dewenter,I., Munzenberg,U., Burger,C., Thies,C., and Tscharntke,T., 2002. Scale - dependent effects of landscape context on three pollinator guilds. Ecology, 83:1421 - 1432 pp.

Steffan - Dewenter,I., 2003. Importance of Habitat Area and Landscape Context for Species Richness of Bees and Wasps in Fragmented Orchard Meadows. Conservation Biology, 17:1036 - 1044 pp.

Taki,H. and Kevan,P., 2007. Does habitat loss affect the communities of plants and insects equally in plant–pollinator interactions? Preliminary findings. Biodiversity and Conservation,16(11):3147 - 3161

Townsend,P.A. and Levey,D.J., 2005. An experimental test of whether habitat corridors affect pollen transfer. Ecology, 86:466 - 475 pp