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# Economic trade-offs between carbon sequestration, timber production, and crop pollination in tropical forested landscapes

Roland Olschewski [a,*], Alexandra-Maria Klein [b], Teja Tscharntke [b]

[a] Swiss Federal Research Institute WSL, Zürcherstr. 111, CH-8903 Birmensdorf, Switzerland
[b] Agroecology, Göttingen University, Waldweg 26, D-37073 Göttingen, Germany

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ABSTRACT

The Millennium Ecosystem Assessment distinguishes between supporting, regulating, provisioning, and cultural ecosystem services. We focus on three services, namely the provision of timber, the regulation of atmospheric carbon dioxide, and the supporting service of bee pollination for coffee production. Possible trade-offs between the different ecosystem services might result in a reduced attractiveness of afforestation projects when taking pollination services into account. We found that economic losses due to a limited reduction of tree density of a *Cordia alliodora* plantation can be overcompensated by generating pollination services to adjacent coffee agroforestry systems. Thus, for moderate silvicultural interventions such trade-offs do not necessarily occur. Including additional ecosystem services such as biological pest control or seed dispersal, which are also associated with the enhanced functional biodiversity in less dense tree plantations, might further emphasize the hump-shaped relationship between tree density and forest revenues.



## 1. Introduction

The Millennium Ecosystem Assessment (MA, 2005) distinguishes supporting, regulating, provisioning, and cultural ecosystem services. Many of these services have the typical characteristics of public goods, where (i) nobody can be excluded from the positive effects and (ii) there is no rivalry in enjoying these positive effects (Heal, 2000). As a consequence, markets for such services are not likely to be established and their value is often not included when making land-use decisions.

In our study we focus on three services, namely the provision of timber, the regulation of atmospheric carbon dioxide, and the supporting service of bee pollination for coffee production. While timber is a private good traded on markets, carbon sequestration and pollination can basically be described as public goods as long as a legal framework for their provision is lacking.

For carbon sequestration as a global regulating service of forests such a framework is given by the Clean Development Mechanism of the Kyoto Protocol (UNFCCC, 2003), which offers the opportunity to issue Certified Emission Reduction (CER) for carbon sink projects. In contrast to permanent credits, e.g. for reducing carbon emissions at the source, these credits have a non-permanent character. Both types are traded on markets and might substitute each other (Olschewski and Benítez, 2005, 2010).

For pollination as a local regulating and supporting ecosystem service, a legal compensation scheme is lacking. However, recent studies have shown the importance of landscape and local management practices in promoting wild bee communities and crop pollination (e.g. Kremen et al., 2002; Klein et al., 2003; Ricketts, 2004; Ricketts et al., 2008; Vergara and Badano, 2009). Patches of natural habitat like rainforest fragments within a landscape might produce these services by providing diverse forage resources and nesting sites, thereby enhancing bee pollination of adjacent crop production, such as coffee or other crops (Ricketts, 2004; Ricketts et al., 2008). Many bee species, while profiting from forest flower resources, need open habitat resources like dry and sunny soils for nesting, too (Williams and Kremen, 2007; Winfree et al., 2007). Hence, bee diversity and crop visitation frequency is often highest at forest margins when multiple, forested and open habitats are accessible. In comparison, dense forests do not provide such favorable conditions, and thus, pollinator availability is supposed to be low (Klein et al., 2002; Winfree et al., 2007; Klein, 2009).

Although not traded on markets, the value of pollination services can be determined based on the monetary advantage generated by increased coffee yields (Olschewski et al., 2006; Veddeler et al., 2008). In our study, we choose a landscape

* *Corresponding author.* Tel.: +41 44 739 2562; fax: +41 44 739 2215.
*E-mail address:* roland.olschewski@wsl.ch (R. Olschewski).

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perspective as adequate approach to identify and evaluate possible trade-offs between the described services. We focus on three different ecosystem services in order to analyse possible economic trade-offs between services, which are often not taken into account, but important for management decisions in multi-functional landscapes. We focus on the questions, (i) under which circumstances particular services are economically more attractive and (ii) how an efficient joint production of multiple ecosystem services can be determined.

## 2. Materials and methods

### 2.1. Characteristic features of the ecosystem services considered

We conducted the study for a highly fragmented area in western Ecuador. Data on timber production and carbon sequestration are based on a growth model for *Cordia alliodora*, a tree species often occurring in our study region and widely used for construction and furniture production. In contrast to former studies (De Koning et al., 2005; Olschewski and Benítez, 2005), which focused on timber production and carbon sequestration, we additionally address the bee habitat function of forests by taking different silvicultural management regimes into account. Here, we consider that reducing the number of trees per hectare in a *C. alliodora* plantation will improve bee habitat conditions by providing (i) more nesting sites in sunny soils for ground-nesting bees (Klein et al., 2002; Williams and Kremen, 2007) and (ii) a higher diversity of nesting materials such as dry soil particles and plant materials of the herb layer, which are rare in densely forested habitats (Potts et al., 2005; Winfree et al., 2007). In parallel, the diversity of foraging resources, which is known to promote pollinator diversity and frequency of flower visitation (Steffan-Dewenter and Tscharntke, 2001; Ghazoul, 2006; Ebeling et al., 2008), will increase through a more diverse flowering herb layer (Klein et al., 2002). The possible trade-off consists of enhancing pollination services by increased pollinator abundance, which comes at the cost of reduced timber and carbon revenues. An overview of the underlying assumptions and data sources is given in Table 1.

### 2.2. Timber production

We assume an afforestation project to be conducted on a site of medium suitability for *C. alliodora* in a highly fragmented landscape in coastal Ecuador. The applied model allows for an estimation of timber volume based on the following equations (Alder and Montenegro, 1999).

$$\beta = 0.073 \cdot S - 3.496 \quad (1)$$

$$h_{\max} = S/\exp(0.562 \cdot \beta) \quad (2)$$

$$h = h_{\max} \exp(\beta \cdot T^{-0.25}) \quad (3)$$

$$V_{20} = 0.0187(h - 13.5)^{1.96} N^{0.7527} \quad (4)$$

where $S$ = site index (22; relative measure of forest site quality based on the height of the dominant trees at a specific age), $h$ = tree height, $T$ = age, $N$ = tree density (400 trees/ha), and $V_{20}$ = timber volume for a diameter at breast height (dbh) above 20 cm. The merchantable timber volume at the end of the rotation is calculated as 70% of the volume of all trees with a minimum dbh of 20 cm, thereby taking waste during processing into account (Benítez et al., 2001). Standing timber value is determined as average price per m$^3$ minus harvesting and administrative costs. Additionally, costs of land preparation, plantation, and maintenance of the project are taken into account.

### 2.3. Carbon sequestration

In a first step, we calculate physical carbon units based on stem biomass estimations for trees with a minimum dbh of 10 cm (Eq. (5)) and apply general expansion factors for tropical broadleaf species to take biomass of branches and leaves into account (Brown, 1997).

$$V_{10} = 0.0000411 \cdot h^{3.152} \cdot N^{0.889} \quad (5)$$

$$B_s = V_{10} \cdot \delta \quad \text{with} \quad \delta = 0.45\,\text{t/m}^3 \quad (6)$$

$$B = B_s \cdot BEF \quad (7)$$

$$BEF = \exp(3.213 - 0.506 \cdot \ln(B_s)) \quad \text{for} \quad B_s < 190 \quad (8)$$

where $V_{10}$ = timber volume for dbh >10 cm, $B_s$ = stem biomass/ha, $B$ = total biomass/ha, $BEF$ = biomass expansion factor, and $\delta$ = specific wood density (t/m$^3$) (Olschewski and Benítez, 2005). We derived the accumulation of carbon by multiplying the overall dry biomass derived from Eq. (7) by 0.5, representing the proportion by mass of carbon. Finally, we obtain mass of carbon dioxide as the basis for credit calculation by multiplying the carbon content by the molecular mass (44/12).

**Table 1**
Overview of data base and sources.

| | | | Based on | Source |
|---|---|---|---|---|
| *Timber production* | | | | |
| Growth model | *Cordia alliodora* | Medium site quality | Empirical finding | Alder and Montenegro (1999) |
| Timber volume | 128 m$^3$/ha | >20 cm dbh | Empirical finding | Alder and Montenegro (1999) |
| Tree density | 400 trees/ha | Reduced to 300 and 200 | Assumption | Olschewski and Benítez (2010) |
| Rotation | 30 years | | Assumption | UNFCCC (2003) |
| Timber price | 20 $/m$^3$ | | Assumption | Olschewski and Benítez (2005) |
| *Carbon sequestration* | | | | |
| Growth model | *Cordia alliodora* | Medium site quality | Empirical finding | Alder and Montenegro (1999) |
| Rotation | 30 years | | Legal framework | UNFCCC (2003) |
| Carbon certificates | 5-year validity | Temporary credits | Assumption | UNFCCC (2003) and Olschewski and Benítez (2005) |
| Price of certificates | 3.4 $/t$CO_2$ | | Empirical finding | Derwisch et al. (2009) and PointCarbon (2008) |
| *Coffee pollination* | | | | |
| Berry weight | Decreases with forest distance | | Empirical finding | Olschewski et al. (2006) |
| Fruit set | Decreases with forest distance | | Empirical finding | Klein et al. (2003) and Ricketts (2004) |
| Main effect | Within 400 m from forests | | Empirical finding | Olschewski et al. (2006) |
| Forest patch | 20 ha | | Empirical finding | Ricketts (2004) |

In a second step, and following the decision of the Conference of the Parties of the Kyoto Protocol (UNFCCC, 2003), we assume that non-permanent certificates are rewarded in the form of temporary credits (tCER), which expire at the end of the commitment period subsequent to the period when they were issued (Olschewski et al., 2005). Carbon revenues are calculated based on current market prices for permanent credits, taking into account that temporary credits have a lower value than permanent ones (Olschewski and Benítez, 2010). Based on current prices for permanent credits, we estimated the value of tCER according to Eq. (9):

$$p_{temp} = p_{perm}(1 - 1/(1+i)^t) \tag{9}$$

where $p_{temp}$ and $p_{perm}$ are prices for temporary and permanent credits, respectively, $i$ is the interest rate (3%) and $t$ indicates the tCER expiring time of 5 years (for details see Olschewski et al., 2005).

### 2.4. Pollination

Although highland coffee, *Coffea arabica* L., is known to be mainly self-fertile, several studies indicate that bee pollination can substantially increase fruit set, berry weight, and harvested yields (Manrique and Thimann, 2002; Roubik, 2002; Klein et al., 2003; De Marco and Coelho, 2004; Ricketts, 2004; Veddeler et al., 2008). In the present study, we focus on the impact of pollinators on berry weight. Pollination values at harvest are determined by adapting results of earlier studies from Indonesia, where the relation between berry weight and forest distance has been tested (Olschewski et al., 2006). We found that the mean coffee berry weight ($y$) of 50 randomly sampled ripe coffee berries from each of 24 agroforestry systems was negatively correlated to the distance to continuous forest ($x$) as given by Eq. (10).

$$y = 1.65 - 0.01x^{0.5} \tag{10}$$

(with $F = 4.70$, $R = -0.42$, $N = 24$, $P = 0.0413$; confidence limits at 95%: intercept coefficient (1.48; 1.82); slope coefficient (−0.0181; −0.0004); compare Olschewski et al., 2006). Ricketts (2004) found corresponding results for case studies in southern America, which motivated us to assume that similar functional relationships can be expected in our study region.

### 2.5. Scenarios

In the basic scenario, we assume an afforestation project with a fast growing monoculture plantation of 400 trees/ha. The high density of fast growing trees leads to a rapid closure of the canopy and results in a relatively low plant and insect diversity within the plantation. In consequence, nesting and food resources for many bee species are decreased, because canopy cover and tree density are negatively related to herb cover and diversity (see Steffan-Dewenter et al., 2007; Kessler et al., 2009). Consequently, pollination services provided by this forest type are negligible. Given the highly fragmented landscape, we assume that only minor pollination services provided by wild bees are generated by some forest remnants in about 1000 m distance (compare Olschewski et al., 2006). In a second scenario, we take silvicultural measures into account. Decreasing tree density is often related to increasing herb cover, thereby enhancing bee diversity and abundance (Klein et al., 2002; Vergara and Badano, 2009). A subsequent reduction of tree density leads to a more open canopy cover, thereby allowing for a higher diversity and density of flowering plants in the under storey layer and an improvement of ground-nesting and floral resources for bees (Klein et al., 2002, 2003). Due to these changes in habitat conditions, bee abundance and diversity is supposed to increase and consequently to enhance pollination services for adjacent coffee fields.

## 3. Results

### 3.1. Basic scenario

According to the formal requirements given by the CDM, we chose a rotation period of 30 years (UNFCCC, 2003) and calculated costs and revenues of a 400-trees/ha plantation. Comparing the present value of plantation and maintenance costs of USD 784 with the revenues of USD 566 from producing 215 $m^3$ of timber at the end of the rotation, results in a discounted net loss of USD 218 (see Table 2). Consequently, a 30-year afforestation project focusing exclusively on timber production is not attractive from the economic point of view, which partly explains low afforestation activities in our study region.

**Table 2**
Costs and revenues of afforestation projects depending on tree density.

| Year | Density (trees/ha) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 400 | | | | 300 | | | | 200 | | | |
| | Timber | | Carbon | | Timber | | Carbon | | Timber | | Carbon | |
| | Costs | Revenues | tCER | Revenues | Costs | Revenues | tCER | Revenues | Costs | Revenues | tCER | Revenues |
| 0 | 408 | | | | 317 | | | | 232 | | | |
| 1 | 90 | | | | 81 | | | | 72 | | | |
| 2 | 90 | | | | 81 | | | | 72 | | | |
| 3 | 48 | | | | 45 | | | | 42 | | | |
| 4 | 36 | | | | 36 | | | | 36 | | | |
| 5 | 27 | | 267 | 917 | 27 | | 236 | 811 | 27 | | 198 | 680 |
| 6 | 87 | | | | 72 | | | | 57 | | | |
| 7 | 9 | | | | 9 | | | | 9 | | | |
| 8 | 9 | | | | 9 | | | | 9 | | | |
| 9 | 9 | | | | 9 | | | | 9 | | | |
| 10 | 9 | | 387 | 1329 | 9 | | 345 | 1185 | 9 | | 293 | 1006 |
| 15 | | | 464 | 1594 | | | 414 | 1422 | | | 354 | 1216 |
| 20 | | | 510 | 1752 | | | 454 | 1559 | | | 387 | 1329 |
| 25 | | | 546 | 1875 | | | 486 | 1669 | | | 414 | 1422 |
| 30 | | 4310 | | | | 3471 | | | | 2558 | | |
| PV | 784 | 566 | | | 660 | 456 | | | 542 | 336 | | |
| NPV | | −218 | | 2706 | | −204 | | 2406 | | −206 | | 2043 |
| Total | | 2488 | | | | 2202 | | | | 1837 | | |

In USD per hectare, PV = Present (discounted) Value, NPV = Net Present Value.

**Table 3**
Valuation of pollination services provided by forests.

| Distance to forest (m) | Area virtual circles (ha) | Coffee area (ha) | Net coffee revenues ($/ha/year) | Total net revenues ($/year) |
|---|---|---|---|---|
| 0–100 | 20 | 10 | 52 | 520 |
| 101–200 | 26 | 13 | 46 | 598 |
| 201–300 | 30 | 15 | 43 | 645 |
| 301–400 | 38 | 19 | 41 | 779 |
| Total with forest (A) | 114 | 57 | | 2542 |
| Total without forest (B) | | 57 | 33 | 1881 |
| Difference between (A) and (B) | | | | 661 |
| Difference per hectare forest | | | | 33 |

However, additional revenues from carbon sequestration might change this result. These can be expected every 5 years in case that temporary CER are issued. The number of credits is indicated in Table 2, where the first 267 tCER are issued in year five. Note that tCER expire after 5 years, but can be reissued, if the forest keeps on growing. The price of credits is calculated based on Eq. (9). Inserting USD 25 as an average price of permanent credits in 2008, leads to a temporary credit price of USD 3.4 (Derwisch et al., 2009). Under these conditions, carbon revenues sum up to a discounted value of about USD 2700, thereby considerably improving the financial outcome of the plantation project in the basic scenario. As a result, the joint production of timber and carbon sequestration can be characterized as economically attractive to land owners in our study region.

### 3.2. Enhancing pollination services

Given the positive outcome of the basic scenario, an important question for the landowner is, whether an adapted 'bee-friendly' silvicultural management would be economically advantageous. On the one hand, reducing tree density comes at a cost of lower timber and carbon revenues. On the other hand, additional revenues might be generated by providing pollination services to adjacent bee-dependent crops (Ricketts, 2004).

Therefore, we calculated timber revenues based on the assumption of a subsequent reduction of tree density to 300 and 200 per ha. As a consequence, establishing and harvesting costs, as well as timber revenues are diminished. The results of a 30-year plantation considering the respective alternatives are given in Table 2. Similar to the findings of the basic scenario, the economic outcome is negative when focusing on timber revenues, only. In contrast, the joint production of timber and carbon sequestration still leads to positive results. However, compared to the basic scenario a landowner would have to face a loss of USD 286 or 651 (present value) when deciding to reduce tree density to 300 or 200 per hectare, respectively (Table 2). This overall loss can be interpreted as a minimum compensation requirement of the forest owner for providing pollination services.

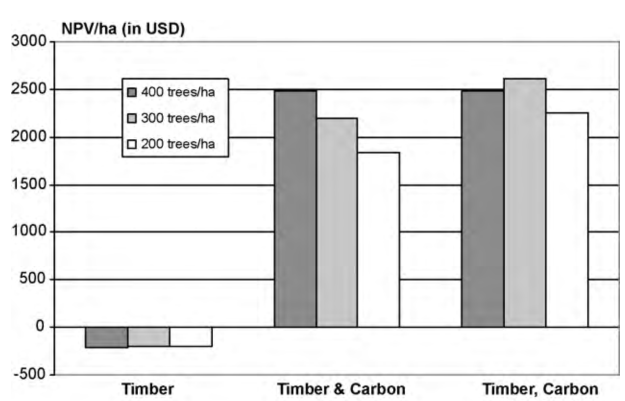


**Fig. 1.** Net Present Value (NPV) depending on different services and management regimes (in USD/ha).

In the following, we determine the value of pollination services from the coffee farmers' perspective in order to compare it to the forest owners' calculus. In contrast to the negligible pollination services generated by a high-tree-density afforestation project, we now consider that a reduced tree density improves nesting and habitat quality for bees. These conditions favor bee abundance and diversity, thereby enhancing pollination and berry weight, which in consequence leads to increased coffee yields and revenues. Here, we refer to the results of our earlier studies, where berry weight was found to be negatively correlated with distance to continuous forest (Olschewski et al., 2006), and base our analysis on Ricketts' findings (2004) that a forest parcel of 20 ha is big enough for assuring the required habitat conditions for an appropriate pollination of adjacent coffee fields. Taking into account that bee diversity and pollination services are promoted by accessibility of natural forested and open habitats (Klein, 2009), we built concentric circles around the forest, each 100 m wide, and assumed that half of the area inside these circles is used for coffee production. For circles farer away from the forest, reduced flower visitation rates are assumed due to increased forest isolation (compare Olschewski et al., 2006). The results are given in Table 3.

Compared to the situation without pollination services of our forestry project, annual net coffee revenues might increase considerably from USD 33 per hectare without forest to USD 52 nearest to the forest. Calculating the respective impact for the whole coffee area (57 ha) results in an economic advantage of USD 661 per year. If this value is assigned to the afforested area (20 ha), a service value of USD 33 per hectare forest is derived, which can be included as an annuity in the economic analysis of the respective afforestation projects. The question is, whether this financial contribution is sufficient for compensating the forest owner for his losses?

Fig. 1 shows that, comparing a 400 and 200-trees/ha plantation, the discounted net revenues (NPV) from joint production of timber and carbon sequestration decline from 2488 to 1837 USD. This reduction by about USD 650 can partly be compensated by providing pollination services, as presented by the white column on the right side of Fig. 1. The NPV of a 200-trees/ha plantation including all services sums up to around USD 2250. However, compared to a 400-trees plantation, it is still too low to compensate for timber and carbon revenue losses. Hence, a trade-off exists and, consequently, there is no incentive for the forest owner to switch to a 'bee-friendly' management in an extreme way, such as reducing tree density by half. A different situation results in case of the 300-trees/ha plantation. Here, moderate losses of timber and carbon revenues (minus USD 286) in combination with compensation payments for pollination services (plus USD 410) lead to an overall improvement of the economic outcome compared to the basic scenario, and consequently, there is no trade-off between providing multiple environmental services.

**Table 4**
Sensitivity analysis (Net Present Value in USD/ha).

| | | Tree density (per ha) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 400 | | 300 | | 200 | |
| | | NPV | %-change | NPV | %-change | NPV | %-change |
| Reference situation | | 2488 | | 2612 | | 2247 | |
| Timber price | +25% | 2629 | 6 | 2726 | 4 | 2331 | 4 |
| | −25% | 2346 | −6 | 2498 | −4 | 2163 | −4 |
| Carbon price | +25% | 3164 | 27 | 3214 | 23 | 2758 | 23 |
| | −25% | 1811 | −27 | 2011 | −23 | 1737 | −23 |
| Interest rate | +25% | 1771 | −29 | 1994 | −24 | 1742 | −22 |
| | −25% | 3521 | 42 | 3501 | 34 | 2970 | 32 |
| Coffee area | +25% | 2488 | 0 | 2715 | 4 | 2350 | 5 |
| | −25% | 2488 | 0 | 2510 | −4 | 2145 | −5 |

## 4. Discussion

We analyse a possible economic trade-off between regulating and supporting ecosystem services resulting in a reduced attractiveness of afforestation projects when taking pollination services into account. Forest owners might face such a trade-off, when planning to provide multiple ecosystem services simultaneously and should take it into account to avoid disadvantages. We show that economic losses due to a limited reduction of tree density can possibly be overcompensated by generating pollination services, thus, for moderate silvicultural interventions trade-offs do not necessarily occur. However, several aspects of our analysis deserve a deeper consideration.

### *4.1. Sensitivity analysis*

In order to proof the sensitivity of our results, we tested how far our results depend on changes in decisive input variables. We took changes in interest rate, timber and carbon prices, and overall coffee area into account (Table 4). Interestingly, the Net Present Value (NPV) as indicator for the economic attractiveness is not very sensitive to changes in timber prices and extension of the coffee area. A 25%-change in these variables leads to a variation of about 5%, only. In contrast, the relative impact of changes in carbon prices and interest rates is similar or even higher (23–42%). As a general finding, afforestation projects are more sensitive to changes when tree density is high, except for changes in the coffee cultivation area. Here, lower tree density leads to a relatively high contribution of pollination revenues to the overall economic outcome of the forestry project, and consequently, these plantations are more susceptible to changes of this variable.

### *4.2. Economic attractiveness of timber production*

The results of our basic scenario indicate that afforestation projects with the sole purpose of producing timber are economically not attractive in our study region. This seems to be surprising given that *C. alliodora* is a fast growing species and widely used for construction and furniture production. The outcome can partly be explained by our assumption that the harvesting period is adapted to the rotation length of 30 years determined by the carbon accounting rules within CDM. Dropping this assumption would lead to far shorter optimum rotation periods and substantially increase economic attractiveness (compare Olschewski and Benítez, 2010).

### *4.3. Minimum size of forest patch*

We defined a forest patch with a minimum of 20 ha as sufficiently large for providing abundant pollinators. This assumption reflects findings of former studies, where smaller forests (e.g., 18 ha forest strips) did not fulfil these requirements (Ricketts, 2004). Recently, additional concepts related to the optimal design of landscapes for pollination services have been developed. Brosi et al. (2008) found that an optimal configuration not just relies on a uniform habitat size and spacing, but can combine large patches to ensure pollinator population persistence with small dispersed parcels to ensure spatially continuous pollination.

### *4.4. Reliability of the estimated correlation between weight and distance*

Given the current unavailability of an ecological process model to explain the relation between coffee weight and forest distance, we applied a statistical model despite several caveats related to it. The reliability of our findings is indicated by the respective confidence intervals. Note that former studies showed an even higher economic impact of forest distance results when combining the effects of an enhanced fruit set and berry weight (Olschewski et al., 2006). Applying these findings to our example generates a positive economic outcome even in case of a 200-trees/ha afforestation. Thus, following a conservative approach and considering berry weight, only, results in an underestimation of the overall pollination services impact.

### *4.5. Technology dimension in multiple-purpose management*

Our study present a first step towards analysing possible trade-offs between the various environmental services. Further and more detailed aspects have to be taken into account to address the technology dimension in multiple-purpose management of landscapes. There is a substantial need for more empirical analysis related to questions, such as how to design the tree distribution within parcels and how to optimally distribute forest patches in the landscape (Brosi et al., 2008). Additionally, the impact of supporting measures such as sowing pollen- and nectar-rich herbs should be considered as part of the design alternatives.

## 5. Conclusions

Although we are far from comprehensively understanding the relative contribution of each of the measured ecosystem services and from adequately modelling realistic trade-offs (Henry et al., 2009), our study shows that considering multiple ecosystem services can have substantial impact on recommendations for land-use management decisions. The inclusion of additional ecosystem services such as biological pest control or seed dispersal, which are also associated with the enhanced functional biodiversity in less dense tree plantations, may further emphasize the hump-shaped relationship of tree density to the forest revenues.

The crucial condition for the economic attractiveness of a bee-friendly management is that forest owners are rewarded for the services they provide. For carbon sequestration a global legal framework exists, which requires an official acceptance by CDM entities as a carbon sink project. Additionally, many voluntary private initiatives exist to reward land owners for mitigating climate change through afforestation projects. However, current carbon markets are highly volatile with substantial price changes within short time periods (PointCarbon, 2008). Consequently, uncertainty about future carbon revenues prevails, causing risk-averse land owners to postpone their long-term land-use decisions.

In the case of pollination services, as a local public good, a legal framework is lacking. Thus, coffee farmers cannot be excluded from the positive effects, and are expected to behave as 'free riders'. Incentives to participate in a payment scheme strongly depend on the institutional arrangements made at the local level, but also on opportunities to replace pollination services by e.g. renting private bee hives (Olschewski and Klein, 2010). However, in tropical landscapes, managed honeybees are usually not available, so crop pollination completely depends on feral, non-managed bees (Klein et al., 2003; Hoehn et al., 2008). In addition, a general decline of managed honeybees and recent honeybee colony collapses highlight the fact that it is risky to rely on single species for pollination management and not likely to be a sustainable strategy (Tscharntke et al., 2005; Winfree, 2009). Alternatively, sowing of nectar and pollen rich herbs, which has been observed in Ecuadorian organic coffee farms (personal observation) may further enhance pollinator availability to crops of short, seasonal flowering periods.

Finally, it has to be taken into account that a land owner has always the alternative to use his land for further alternatives, such as crop production instead of forestry. This implies that even if compensation schemes for forest projects exist, the more efficient land use could be a different and ecologically less favorable one.

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