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

by

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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 & Benitez 2005, 2009).

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 (Kremen et al. 2002, Klein et al. 2003, Ricketts 2004, Ricketts et al. 2008, Vergara & 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 submitted).

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 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 analyze 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. Material and Methods**

### *Characteristic features of the ecosystem services considered*

We conducted the study in a highly fragmented area in north-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 (Olschewski & Benitez 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 *Cordia 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 & Tschardtke 2001, Ghazoul 2005, 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 availability, 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.

### *Timber production*

We assume an afforestation project to be conducted on a site of medium suitability for *Cordia 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 & Montenegro, 1999).

$$\text{Eq. 1} \quad h = h_{max} \exp(\beta \cdot T^{-0.25})$$

$$\text{Eq. 2} \quad \beta = 0.073 \cdot S - 3,496$$

$$\text{Eq. 3} \quad h_{max} = S / \exp(0.562 \cdot \beta)$$

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

Where  $h$  = tree height,  $T$  = age,  $S$  = site index (22),  $N$  = tree density (400 trees/ha), and  $V_{20}$  = timber volume for dbh >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 diameter at breast height (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<sup>3</sup> minus harvesting and administrative costs. Additionally, costs of land preparation, plantation, and maintenance of the project are taken into account.

### *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).

$$\text{Eq. 5} \quad V_{10} = 0.0000411 \cdot h^{3.152} \cdot N^{0.889}$$

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

$$\text{Eq. 7} \quad B = B_s \cdot BEF$$

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

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<sup>3</sup>) (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).

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 & Benitez 2009). Based on current prices for permanent credits, we estimated the value of tCER according to Eq. 9:

$$\text{Eq. 9:} \quad p_{temp} = p_{perm} (1 - 1/(1+i)^t)$$

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

### *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, where the relation between berry weight and forest distance has been tested (Klein et al. 2003, Olschewski et al. 2006). We found that the mean coffee berry weight of 50 randomly sampled ripe coffee berries from each of 24 agroforestry systems was negatively correlated to the distance to continuous forest as given by Eq. 10.

$$\text{Eq. 10} \quad y = 1.65 - 0.01x^{0.5}$$

(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.

Table 1: Overview of data base and sources

<b>Timber production</b>			<b>Based on</b>	<b>Source</b>
Growth model	Cordia alliodora	medium site quality	empirical finding	Alder & Montenegro 1999
Timber volume	128 m <sup>3</sup> /ha	> 20 cm dbh	empirical finding	Alder & Montenegro 1999
Tree density	400 trees/ha	reduced to 300 and 200	assumption	Olschewski & Benítez 2009
Rotation	30 years		assumption	UNFCCC 2003
Timber price	20\$/m <sup>3</sup>		assumption	Olschewski & Benítez 2005
<b>Carbon sequestration</b>			<b>Based on</b>	<b>Source</b>
Growth model	Cordia alliodora	medium site quality	empirical finding	Alder & Montenegro 1999
Rotation	30 years		legal framework	UNFCCC 2003
Carbon certificates	5 year validity	temporary credits	assumption	UNFCCC 2003, Olschewski & Benítez 2005
Price of certificates	3.4 \$/tCO <sub>2</sub>		empirical finding	Derwisch et al. 2009, Point Carbon 2008
<b>Coffee pollination</b>			<b>Based on</b>	<b>Source</b>
Berry weight	decreases with forest distance		empirical finding	Olschewski et al. 2006
Fruit set	decreases with forest distance		empirical finding	Klein et al. 2003, Ricketts 2004
Main effect	within 400m from forests		empirical finding	Olschewski et al. 2006
Forest patch	20 ha		empirical finding	Ricketts 2004

et al. 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**

#### *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<sup>3</sup> 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.

However, additional revenues from carbon sequestration might change this result. These can be expected every five 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 five 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 2,700, 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.

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)

### *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.

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 hectares 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 submitted), we built concentric circles around the forest, each 100m 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.

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

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?

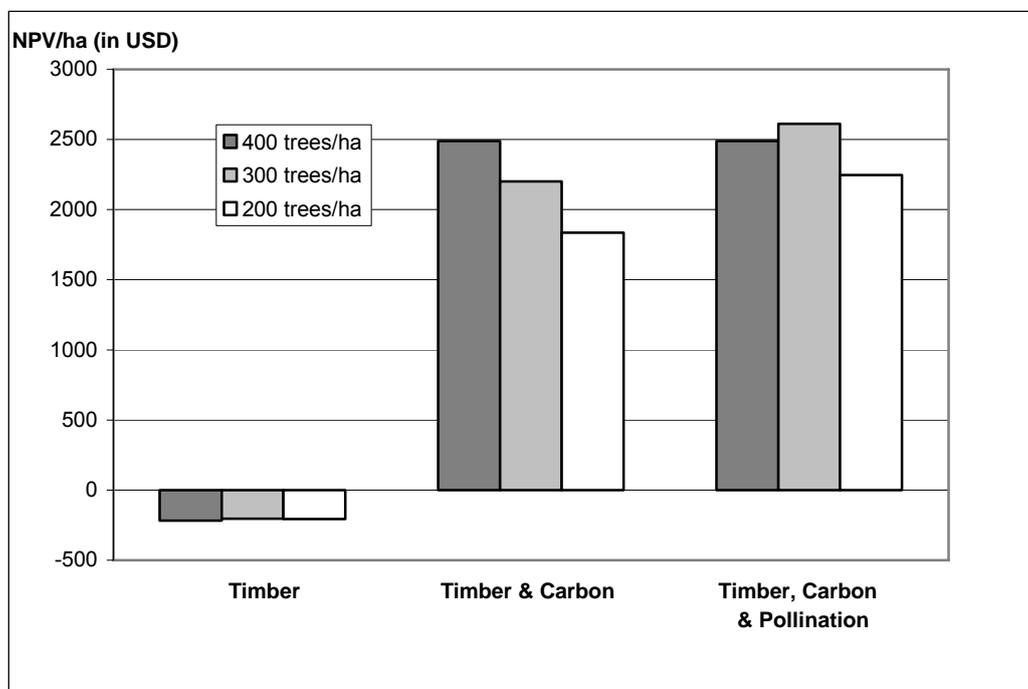


Figure 1: Net Present Value (NPV) depending on different services and management regimes (in USD/ha)

Figure 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 2,488 to 1,837 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 Figure 1. The NPV of a 200-trees/ha plantation including all services sums up to around USD 2,250. 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.

#### **4. Discussion**

We analyze 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.

##### *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.

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

		Tree density (per ha)					
		400		300		200	
		NPV	%-change	NPV	%-change	NPV	%-change
<b>Reference situation</b>		2488		2612		2'247	
<b>Timber price</b>	+25%	2629	6	2726	4	2'331	4
	-25%	2346	-6	2498	-4	2'163	-4
<b>Carbon price</b>	+25%	3164	27	3214	23	2'758	23
	-25%	1811	-27	2011	-23	1'737	-23
<b>Interest rate</b>	+25%	1771	-29	1994	-24	1'742	-22
	-25%	3521	42	3501	34	2'970	32
<b>Coffee area</b>	+25%	2488	0	2715	4	2'350	5
	-25%	2488	0	2510	-4	2'145	-5

#### *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 *Cordia 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, 2009).

### *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.

### *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 that 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.

### *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 & Klein 2009). However, in tropical landscapes, managed honeybees are usually not available, so crop pollination completely depends on feral, non-managed bees (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, Olschewski and Klein 2009). Alternatively, sowing of nectar and pollen rich herbs, which has been observed in Ecuadorian organic coffee farms (pers. observ.) 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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