Can tropical farmers reconcile subsistence needs with forest conservation?

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If tropical farmers cannot be provided with sustainable land-use systems, which address their subsistence needs and keep them gainfully employed, tropical forests will continue to disappear. We looked at the ability of economic land-use diversification – with reforestation of tropical "wastelands" as a key activity – to halt deforestation at the farm level. Our ecological–economic concept, based on land-use data from the buffer area of the Podocarpus National Park in southern Ecuador, shows that stopping deforestation after 10 years is possible without violating subsistence demands. Tropical, farm-level diversification may not only reduce total deforestation by 45%, but also increase farmers' profits by 65%, because the formerly unproductive wastelands have been returned to productive land use. We therefore conclude that a "win–win" scenario is possible: the subsistence needs of people can be reconciled with conservation objectives. However, inexpensive microcredits (at interest rates below 6%) and experience on alternative land-use opportunities must be offered to farmers.

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Currently, there are heated debates on the role of markets as forest "lifesavers" (Fearnside 2001; Knoke *et al.* 2008a; Potvin *et al.* 2008). However, ongoing discussions on reducing emissions from deforestation and forest degradation (REDD), conservation of non-market values such as biodiversity, and integration of deforestation into the international carbon markets by means of payments for ecosystem services (PES) are condemned to fail, both socially and economically, if the local people's needs are not taken into account in that debate. The problem is two-pronged: economic on the one hand and philosophical on the other. Economically, implementing strategies to avoid deforestation through PES may be expensive. Global estimates of the compensation costs for forest preservation amount to US$5–10 billion annually, if 70% of CO_2 emissions associated with current land-use practices are to be avoided (Stern 2006). To give credibility to the ongoing REDD efforts, realistic financial options must be found (Potvin *et al.* 2008). Philosophically, debates are suffering from what – in the context of biological conservation – could be defined as the "people versus parks dilemma" (Schwartzman *et al.* 2000; Terborgh 2000), where values such as wilderness and pristine (untouched) ecosystems prevail over the subsistence needs of local people. In this debate, it is doubtful whether conservation values can be harmonized with any tropical land-use system. However, even if it were possible to mobilize substantial PES to compensate people for not engaging in activities leading to deforestation, we cannot exclude humans from the landscape. It is unlikely that tropical farmers would remain idle while receiving PES; they need an economic system that keeps them employed in productive and sustainable activities that do not result in habitat destruction (Knoke *et al.* 2008a). Research should therefore be focused on identifying and evaluating new production systems and alternative management techniques (Bennett and Balvanera 2007).

We investigated a quantitative concept within ecological–economic farm diversification (EEFD) that is capable of convincing farmers of the benefits of sustainable practices and of halting deforestation. Our objective is to

In a nutshell:

- Tropical conservation values are seen as incompatible with livelihood demands; payments for ecosystem services are supposed to avoid destructive activities like deforestation
- However, there are inherent socioeconomic problems in choosing land-management options in tropical landscapes
- Alternative ecological–economic land-use systems may help to solve these problems, by restoring natural resources in conjunction with tropical forest conversion and product diversification
- These reduce farmers' risk of losses and the demand for land; this concept applies particularly to subsistence farms located in montane tropical ecosystems, where slow succession of overused, degraded, and abandoned lands toward secondary forests is characteristic
- Inexpensive microcredits, the establishment of local timber markets, the transfer of experience with alternative land-use options to farmers, and the allocation of higher value to standing forests are important preconditions for sustainable land use

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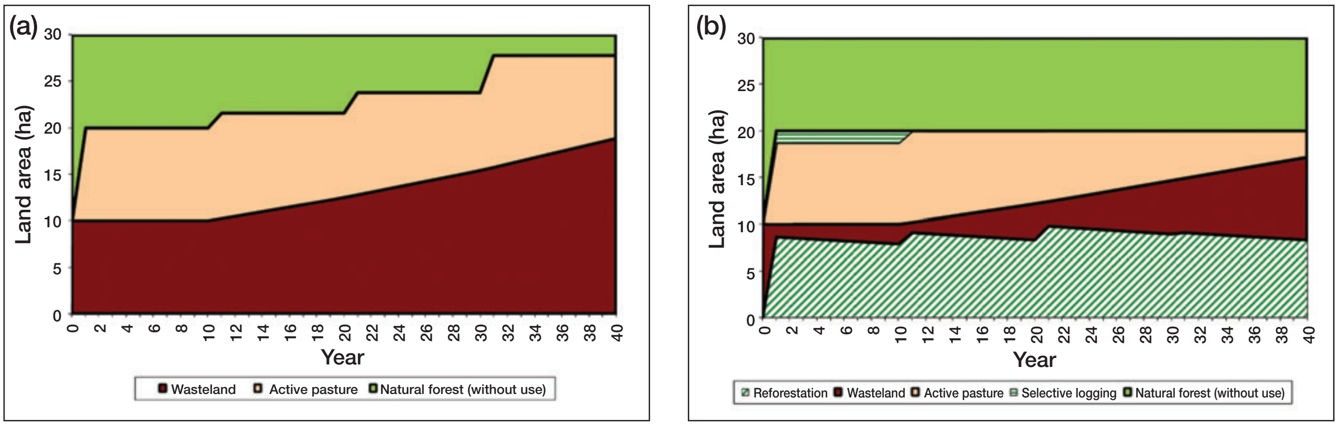

Figure 1. *Allocation of land-use activities to the available farm area under (a) a classical single-use pasture system as compared with (b) ecological–economic farm-level diversification.*

counter the following hypothesis: "As long as people use tropical landscapes for their livelihood, they will continue to convert native forests into alternative uses, as it is profitable for them" (Tschakert *et al.* 2007). After testing this hypothesis, we identified the basic conditions under which sustainable, non-destructive tropical land use would be possible.

Background

We developed the EEFD concept (WebModel 1) as a multi-partner project on biodiversity and sustainable management in a mega-diverse, montane, south Ecuadorian ecosystem (Beck *et al.* 2008), located near the Andean Podocarpus National Park. Here, and elsewhere in the tropics, farmers customarily convert tropical forests into new farmland to replace degraded – and ultimately abandoned – pastures (sensu Silver *et al.* 2000). These abandoned lands ("wastelands") are usually left unproductive, and this is followed by a very slow succession toward shrub vegetation and secondary forest (Paulsch *et al.* 2001). However, these overused and degraded wastelands can be reintroduced into the economical system, and thus serve as a powerful means to diversify land management.

Economics of land-use options

Our model shows that, for a small farm (30 ha) including 10 ha of previously degraded wastelands, the traditional land-development strategy would lead to deforestation of 18.3 ha over the course of one generation of farmers (40 years; Figure 1a). This type of land management provides relatively constant net revenues (Figure 2a) when a specific probability of pasture abandonment is given (WebTable 1). The risk of future yield losses due to pasture degradation promotes further deforestation; furthermore, after the establishment of new pastures, the conversion of tropical forests continues (after 10, 20, and 30 years), to compensate for yield losses as a result of pasture abandonment.

The financial consequences of three possible land-use options (reforestation of abandoned pastures, cattle pasture, and selective logging in natural forests; Figure 3) seem to confirm pasture as the most economically attractive option for the farmer (Figure 4). However, the uncertainty of the financial estimates, expressed by their standard deviation (WebTable 1), is by far the highest for this option. High uncertainty of financial consequences leads to the clear-cutting of larger new areas, to decrease potential risk. Management options that reduce the variability

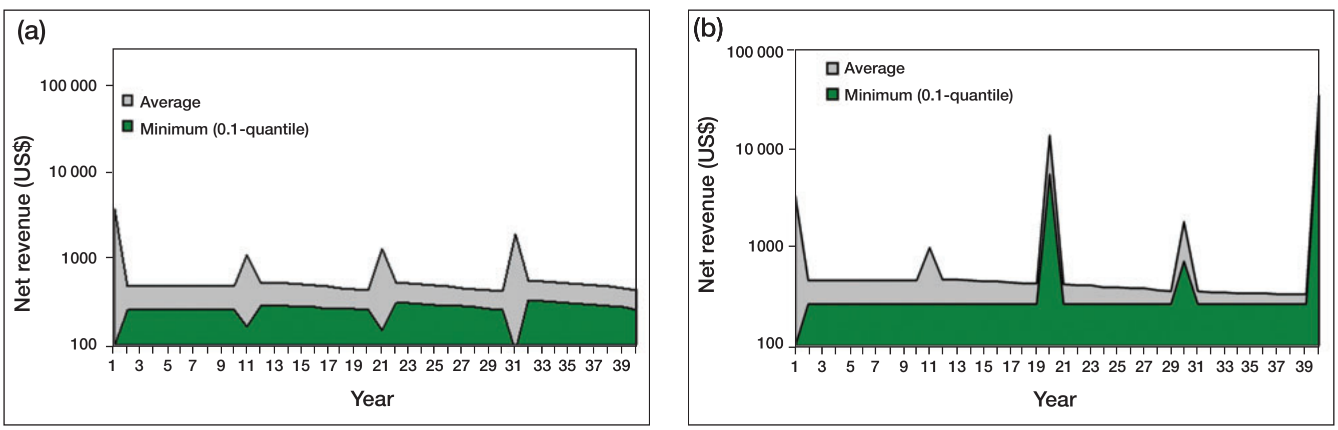

Figure 2. *Average expected and minimum net revenues under (a) a classical single-use pasture system as compared with (b) ecological–economic farm-level diversification. Note the logarithmic scale of the y-axis.*

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Figure 3. *Andean alder (*Alnus acuminata*) plantation surrounded by natural forest and cattle pasture.*

of financial flows and thus the risk of losses should therefore contribute to the prevention of deforestation and implementation of sustainable land use.

Addressing subsistence and restoration needs

Modeling sustainable land use should address farmers' subsistence needs under the given risks, and this should replace the often-assumed pure profit maximization of farmers (eg Carpentier *et al.* 2000). As a result, the EEFD model suggests an immediate land-use diversification that provides multiple products, ie agricultural commodities and timber obtained by selective logging (Figure 1b). Diversification stabilizes the uncertain net revenues and reduces the demand for land, which is necessary to provide subsistence net revenues. Agricultural and timber markets are uncorrelated (Lönnstedt and Svensson 2000); the price of timber may be moderate or high when the price of milk is low and vice versa, resulting in an effective compensation of market price fluctuations. Moreover, forestry production is independent of agricultural yields. Our model took these effects into account by integrating market price fluctuations, correlations and pasture degradation, and changes in dairy productivity, as well as uncertainties associated with sustainable harvest under selective logging and fire damage (WebTable 1).

The combination of pasture and selective logging (Figure 2b) produces higher minimum net revenues per year than does the single-use pasture system (Figure 2a), although the conversion of tropical forests is only 8.7 ha instead of 10 ha under the single-use pasture system. Modeling minimum net revenues is adequate to address the subsistence needs of the tropical farmer, whom we assumed to be risk adverse (Pichón 1996). For this farmer, it is not enough to achieve subsistence net revenues only on average; instead, it is necessary to obtain them every year. Given the data in WebTable 1, we estimated probability distributions of yearly net revenues for various combinations of different land uses. We defined those net revenues as the minimum that can be achieved with a probability of 0.9. The results show that the requirement of achieving subsistence net revenues is better fulfilled by the diversified land-use system, combined with a reduction in land demand.

The key activity in halting deforestation is the accumulation of "new" natural resources through wasteland reforestation. For every unit area of forest converted into pasture, the farmer must reforest a corresponding area of wasteland. To this end, farmers can use the productive native tree species Andean alder (*Alnus acuminata*) (Figures 3, 5), adapted to the landscapes of south Ecuador and also to a wide range of areas in Latin America. This nitrogen-fixing species is widely recommended for agroforestry or reforestation in Ecuador because of its fast growth, soil improvement capability, tolerance to diverse environmental conditions, and multiple uses (Dunn *et al.* 1990). The timber of Andean alder can be used for a variety of purposes, including firewood, packing boxes, or construction; the tree also has palatable, nitrogen-rich leaves and can be used as a source of "energy fodder". It resprouts vigorously after harvesting (Grau and Veblen 2000) and can be managed by means of a coppice system. The first commercial harvests can be expected from age 10 years onwards (Dunn *et al.* 1990). Andean alder achieves fire resistance from age 5 onwards, and this is strong enough to survive the low-intensity fires typical of open woodland sites (Grau and Veblen 2000). Furthermore, the aesthetic appearance of the landscape is only slightly affected by plantings of Andean alder (Figure 3), and biodiversity levels in Andean alder plantations may be high, even when compared with those in naturally regenerated forests (Murcia 1997).

Reforestation makes intuitive sense as well, because the farmer reintegrates unproductive areas into areas of productive use and simultaneously achieves restoration effects, given that Andean alder accumulates nitrogen in the soils. Increased levels of carbon sequestration are another ecological benefit of Andean alder plantations. From the perspective of the farmer, however, the main effect of the reforested areas is the compensation of yield losses from pasture degradation as a result of revenues from thinning and final harvesting operations.

Financial consequences of halted deforestation and mixed land use

The results of our model (WebModel 1) suggest that halting deforestation after 10 years is possible, when Andean alder fulfills diversification requirements (replacing timber from the natural forest), first by providing thinning revenues and – after a period of 20 years (rotation) – by harvesting the final crops and growing a second rotation of Andean alder. Despite some calculated losses of Andean alder through fire (Figure 1b and WebTable 1), reforestation areas diversify the land-use portfolio effectively and compensate farmers for losses due to pasture degradation and market price fluctuations of agricultural products. After 40 years, 8.3 ha of tropical forest per farm will have been conserved under the optimized concept of EEFD, as compared with that under the classical system, and valuable natural resources will be available, as a result of the Andean alder plantations. During the 40-year time frame, land devoted to Andean alder can be used to re-establish agriculture, while the areas degraded by pasturing can be reforested.

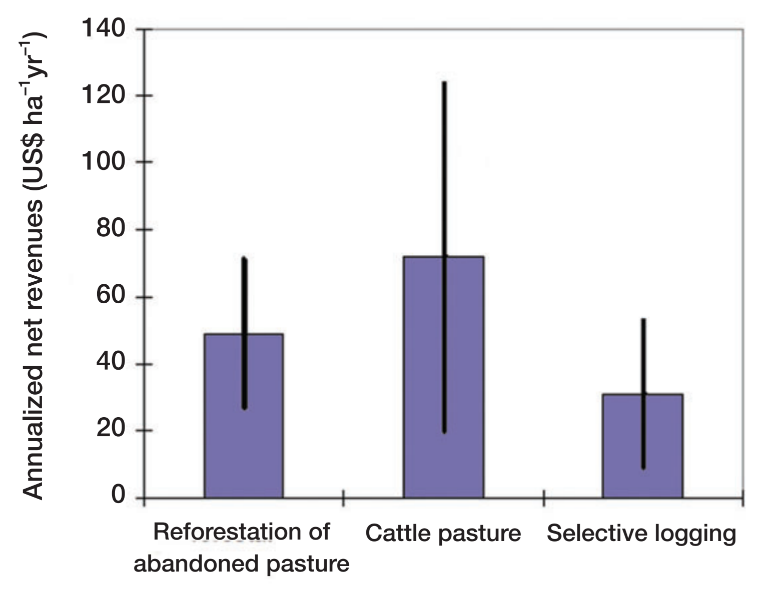

Figure 4. *Annualized net revenues (annuities) of land-use options and their standard deviation (black bars). The sum of annualized net revenues, discounted by 5%, forms the net present value (NPV) of land-use options (NPV is the sum of discounted actual net revenues, with the net revenues fluctuating from year to year in the cases of reforestation and pasture). We refer to a 20-year period for this example.*

Following the optimized management path under EEFD (WebModel 1), farmers can achieve a 65% increase in profit from their land (US$20 680 ± 2260, discounted at a risk-free 5%, versus US$12 560 ± 2560 with the classical system), with deforestation being limited to a maximum of 10 ha per farm. The farm profit at risk (profit that is achieved with a probability of 0.9), which we actually maximized (WebModel 1), is 109% greater for the EEFD approach (US$16 970 versus US$8100 for single-use pasture). Our model shows considerable peaks in revenue in year 20, 30, and 40 (Figure 2b), when final crops of Andean alder plantations can be harvested. These financial results should be attractive to farmers who are not necessarily interested in conservation, because – from their point of view – fulfilling subsistence needs and increasing profits are of primary importance. Although these results remain stable under changing revenue coefficients, as expected, the discount rate was critical to the success of this sustainable land-management system (Pearce *et al.* 2003).

Non-linearities as a result of the introduction of uncertainty led us to use non-linear programming to solve the problem of diversified farm management (WebModel 1; Knoke and Moog 2005). To estimate coefficients and uncertainties, we used data on montane tropical forests, reforestation, and pasture under site conditions in the Andes provided by the German-Ecuadorian multi-partner DFG (Deutsche Forschungs-gemeinschaft) research group, summarized in WebTable 1.

Conclusions

Our results are similar to those of Grafton *et al.* (2007), in that we were able to show a feasible win–win scenario; that is, it is possible to reconcile conservation objectives and the subsistence needs of local people. However, adequate land-use concepts and ecological–economic models are prerequisites to achieve this outcome. Risk integration into the model leads to realistic results and acceptability for farmers. Economic analysis often ends with the comparison presented in Figure 4. The comparatively high net revenues obtained from cattle pastures seem to support this option as the only attractive land-use alternative. However, ecological–economic farm modeling, focused on subsistence revenues and long-term effects, shows the economic benefits of diversification and reforestation of abandoned wastelands. We suggest that the absence of quantitative experience of the available land-use options and of land-use combinations is an important factor in the currently accelerating deforestation. Benjamin *et al.* (2008) also suggest that lack of knowledge about different land-use options that facilitate reforestation could explain why there is so little reforestation of abandoned farmland, even in developed countries. Next steps will include transferring the results to farmers and the establishment of a demonstration farm in our south Ecuadorian research area. Our model, based on experimental data, contradicts the original hypothesis that human subsistence and tropical forest conservation cannot be reconciled. Farmers can be provided with sustainable and profitable alternatives.

Resource managers, ecologists, and consultants can apply the EEFD modeling approach to analyze and optimize land-management opportunities and strategies from the farmers' perspective, taking into account individual preferences, requirements, and capacities. Decisions on land management would, however, remain with the

Figure 5. *Tree of the native species Andean alder (*Alnus acuminata*) at age 8. The measured stand already represented a volume of 75* m^3 ha^{-1}.

farmer, who has to be convinced mainly by the economic arguments. We have to estimate biophysical and financial coefficients for different regions. Also, the land-use options discussed here do not represent all possible options (eg bee keeping, nurseries of native tree seedlings and saplings, non-timber forest products, home gardens, etc). Our example therefore represents a first step in analyzing and modeling options to reconcile subsistence and conservation demands.

Finally, we provide some general conditions and requirements, based on our results, to achieve sustainable land use in the tropics:

(1) Alongside the conversion of tropical forests, alternative natural resources must be provided (in our case, by means of reforestation of wastelands). This follows a basic requirement of sustainable development, whereby exploited natural resources must be replaced by other natural resources (Daly 1990). Without such replacement, depletion of existing natural resources cannot be justified from a sustainability perspective. This is increasingly important in abandoned lands characterized by slow recovery, such as the pastures in montane southern Ecuador.

(2) To further improve the productivity of agricultural lands, it is important to establish alternative land uses (for example, forestry on so-far-unused wastelands), which do not compete economically with the standing natural forests. Relying on agricultural intensification alone is problematic, as exemplified by palm-oil plantations in lowland tropical ecosystems. Intensified production on pastures would reduce demand for land only under one specific set of circumstances: the farmer has to stop production immediately when subsistence net revenues are achieved. This does not seem very realistic; rather, the activities of farmers are limited by the availability of workers, who are normally family members (Tschakert *et al.* 2007). If (in our example) we double the net revenues from pasture to simulate intensification, the farmer could earn substantially more money during the first 10 years of farm management. This alone would enable payment of additional workers from outside the farmer's family, great enough to increase the deforested area by 5.2 ha. It is likely that the farmer would carry out extensive deforestation, because this would increase short-term profitability. In conclusion, therefore, we believe that improved agricultural productivity will probably increase deforestation (Carpentier *et al.* 2000).

(3) The economic diversification of farmlands has the potential to reduce land demand. Crop diversification is particularly important for subsistence farmers with small land holdings, because farmers with large land areas may have other alternatives to balance out the risks (eg financial investments). Whereas concentrating on a single crop exposes farmers to diverse risks (eg international market fluctuations, crop losses from inclement weather, pests, or diseases), having a diversity of products provides farmers with a form of economic insurance, should the market for any particular product decline (Pichón 1996). In spite of the obvious parallels with financial diversification (of one's personal investments) and diversification of natural assets (of crops by farmers), the virtues of diversification are generally not acknowledged with regard to natural systems (Figge 2004). Thus, the use of systematic diversification strategies – based on quantitative, theoretically well-founded optimization approaches – is only slowly becoming incorporated into ecosystem management. Only a few examples exist, from fisheries (Edwards *et al.* 2004), grassland (Koellner and Schmitz 2006), and forest (Knoke and Seifert 2008) management. However, to our knowledge, no application of the economic diversification concept to reduce tropical deforestation has been published so far.

(4) A high interest rate is detrimental to any long-term investment and thus to sustainable land use. The applied discount rate, if too high, can accelerate unsustainable land use (Pearce *et al.* 2003). The discount rates applied to natural systems should not be much above 5%. In our approach, we not only discounted all net revenues by 5%, but also assumed reforestation to be financed at a rate of 5% (WebTable 1). Credit repayment after 20 years, including accumulated interest, should be secured, giving a probability of 0.9 that the value of the timber

obtained through reforestation will exceed the repayment amount at year 20 (WebModel 1). A 5% interest rate is very low. So far, farmers' access to inexpensive credit is limited in Ecuador. Commercial credit has an average interest rate of about 12% (Banco Nacional de Fomento), whereas credit for this type of initiative may be even more expensive. Agricultural credit can be obtained for 5%, but this is limited to a period of 5 years, US$5000, and requires securities. This type of credit is not available for establishing tree plantations. In order to support sustainable land-management concepts, policy makers need to establish local and inexpensive microcredits for farmers. It is also crucial to establish personal contact between farmers and members of the credit institute (Yunus 2003). Furthermore, this type of credit should be extended mainly to women, since they are seen as particularly reliable. Under these preconditions, repayment rates of 99% have been reported (Yunus 2003). The provision of inexpensive credit, being a type of subsidy, could perhaps be supported by PES and might be preferable to pure subsidies, because if farmers need to repay the credit they will be motivated to care for reforested areas, since this will deliver the repayment amount in 20 years.

(5) Well-established markets for forest products are a further precondition for the success of the land-use concept described here. So far, the principal reforestation species (Andean alder) has been successfully used in many Latin American countries (Dunn *et al.* 1990; Murcia 1997). In central and northern Ecuador, markets already exist for its timber, and these markets can also be established in southern Ecuador. Establishment of a timber market could be accelerated by the government, by permitting the use of firewood or construction wood within appropriate legal frameworks.

(6) Barbier (2007) identified agricultural expansion as a fundamental feature of economic development in poor countries. Yet, such development only generates small amounts of additional net revenues, and these small sums are not being reinvested in other sectors, leading to inherently unsustainable development. Reforestation may be able to generate sufficient extra money to allow farmers to engage in additional economic activities and may therefore help to achieve both sustainable land use and substantially improved quality of life among farmers. As mentioned above, the Andean alder plantations can generate substantial amounts of money. Whether this is used for reforestation of abandoned land or to re-establish pasture, there will still be a considerable amount left over, which can be saved or invested in other parts of the economy.

One of the limitations of our approach is that the standing natural forest has no value for the farmers, other than as insurance. If reforestation or pasture re-establishment efforts perform more poorly than expected, the standing timber of natural forests will probably be harvested to compensate for these losses. Allocating more value to the standing natural forests (Hartman 1976) would increase the probability of their continued survival. According to our financial comparison of land-use options (Figure 4), the additional revenue from natural forests should be at least US$40 ha^{-1} yr^{-1} to offset the financial advantages of pasture management (ie the cost of retaining the tropical forest under selective logging). However, it is debatable whether this amount would be enough, since it does not represent a financial incentive for farmers to choose reforestation (Knoke *et al.* 2008b). Given the possible cost of retaining tropical forests, the economic value of the ecosystem services they provide is huge (more than US$2000 ha^{-1} yr^{-1}; Costanza *et al.* 1997). Unfortunately, this value (so far) is only theoretical. Future research should focus on sustainable, non-destructive, and market-based uses of natural forest products (eg seeds of native tree species to generate saplings for reforestation, etc). Farmers might view reforestation as a more attractive option if they were offered earlier positive net revenues. In our model, the farmer would not obtain this added revenue until the 10th year; a solution involving mixed crops could perhaps solve this problem.

We need to offer farmers alternative options to tropical deforestation. The sustainable use of landscapes should be seen as a practical way of guaranteeing social and ecological sustainability, not only in the tropics, but in any ecosystem. Ecologists and natural resource managers should use ecological–economic concepts to support the development of more sustainable, alternative land-management systems.

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