Chapter 11
Modelling Forest Growth and Finance: Often Disregarded Tools in Tropical Land Management

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Abstract While many studies analyse patterns of tropical land management with a backward-oriented approach that utilises data of the past, we propose to consider future-oriented modelling approaches to find sustainable land-use options. This proposal is illustrated with application examples for advanced growth modelling in tropical forests, a short overview on financial performance analyses for tropical land uses, and the introduction of a new modelling approach. This modelling approach sees tropical land management as a financial portfolio of land-use options. Its advantage is the ability to make transparent effects of financial risk reduction that arise from mixing forestry and agriculture-based land-use options. The approach thus does not analyse land uses as stand-alone options, like most other analyses do. The land-use portfolio modelling shows that sustainable land use may also be financially attractive for farmers, if abandoned farm lands are reforested (with a native tree species in our case) and sustainable management in natural forests is carried out. We conclude that the combination of advanced growth with sound financial modelling may lead to improved bioeconomic models. Developed bioeconomic models are necessary to increase the biological realism and acceptability of the results obtained.

11.1 Introduction

Studies on tropical land use often describe given land-use patterns, their possible reasons, and consequences (e.g. Pichón 1996, 1997, Marquette 1998; Sierra and Stallings 1998; Paulsch et al. 2001; Browder et al. 2004; Pohle et al. 2009).

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In contrast, the modelling of consequences resulting from land-use activities is, in fact, rather seldom. Given the problems related to tropical deforestation (e.g. Stern 2006; Malhi et al. 2008), the lack of advanced land-use modelling approaches forms a great research challenge for the future.

The backward-oriented analysis of data recorded from the past certainly helps understanding the current land-use patterns. However, future-oriented forest growth and financial modelling of ecosystems may reveal new opportunities to control undesired and destructive management activities, such as ongoing deforestation. In this line, the inclusion of silvicultural activities into land-use modelling and the consideration of financial consequences bears potential to come to an improved bioeconomic modelling (Carpentier et al. 2000), which will primarily focus on the perspective of tropical land users.

In this chapter, we report briefly about the development of forest growth modelling and demonstrate one modelling example to show the opportunities of modern growth models for the tropics. Subsequently, we review some exemplary results on the financial attractiveness of several silvicultural options collected from the literature. We finish with a new modelling approach and conclusions on how to possibly achieve sustainable land use in tropical ecosystems.

11.2 Growth Modelling of Tropical Forests

Forest models aim at investigating long-term impacts of logging and silvicultural treatment. Thus, if the models work accurate enough, they represent an important tool to assess key aspects of sustainable forest management (SFM). Moreover, they form a crucial precondition for financial valuation. If we want to evaluate the sustainability of management strategies we need models as tools, which allow assessing the long-term dynamics of managed forests.

The first forest models have been very cryptic and had no user interface (e.g. Botkin et al. 1972). New forest models can take advantage of the progress in informatics, provide comfortable user interfaces, and have also the possibility to visualise predicted forest dynamics and used relations. Nevertheless, synthesis of the main dynamic processes in forests is still a laborious task, especially if we assess forests with more than one tree species. Please note that this is not caused by the models, but by the complexity of ecological processes in forests.

Forest modelling has been around since the 1970s providing a valuable approach to understand forest growth and ecology from a mechanistic standpoint (Shugart 1998; Bugmann 2001; Pretzsch 2007; Jeltsch et al. 2008). Due to the fact that empirical records of forest dynamics are limited in time and space, models are useful tools to scale up the available measurements.

Development of forests has been successfully analysed, for example with forest gap models, and the Sortie model for temperate and boreal forests (e.g. Shugart 1998; Pacala et al. 1996; Bugmann 2001). These models describe growth, mortality, regeneration, and competition processes for the different tree species parameterised with field data from long-term research plots. (The main challenge here is to find adequate statistical relations to describe a large range of competition situations.) They have been used to investigate, e.g. regeneration after disturbances and the role of species for the structure and succession dynamics of forests.

Since the 1990s, more and more process-based forest models have been developed (e.g. Landsberg and Waring 1997; Porte and Bartelink 2002). In this approach, forest growth is described on the basis of a carbon balance by modelling ecophysiological processes, especially photosynthesis of leaves, respiration, and allocation. These models also include a detailed description of light competition. There is a growing amount of available physiological data, which allows the application of this model type to more and more regions.

The number of forest models for tropical rain forests is small mainly due to the complexity of these forests (e.g. high tree species richness, tree age data is missing; Vanclay 1994, 1995; Sist et al. 2003). The FORMIND and FORMIX3 model family introduced the process-based approach to tropical forests and has been applied in many different sites (e.g. Huth and Ditzer 2000, 2001; Kammesheidt et al. 2001; Köhler et al. 2003; Köhler and Huth 2004; Rüger et al. 2008; Groeneveld et al. 2009; Gutierrez et al. 2011; Dislich et al. 2010).

For every individual tree, a set of quantities is calculated every time step in the FORMIX model, e.g. tree height, stem diameter, biomass, and leaf area index. The change of these variables is determined by applying fundamental ecological processes as growth, competition, regeneration, mortality, and disturbance. The model follows the gap-model approach, i.e. the forest stand is divided into patches, which have the size of treefall gaps. In each gap the vertical leaf distribution and light climate is calculated, which allows a detailed description of the light competition situation for each tree. This multi-layer description of the canopy is in contrast to the big leaf approach in global vegetation models (Friend 2001) or the use of aggregated competition indexes in statistical forest models (e.g. Kohyama et al. 2003; Vanclay 1995).

The concept of plant functional types is used to cope with the tree species richness in tropical forests (Smith and Shugart 1997; Köhler et al. 2000; Picard and Franc 2003). Tree species are classified into plant functional types based on physical attributes (e.g. maximum potential height and shade tolerance). The model belongs to the FORMIND and FORMIX3 forest model family, which has been extensively tested against field data (e.g. Huth and Ditzer 2000; Rüger et al. 2008; Groeneveld et al. 2009; Gutierrez et al. 2011) and applied by other research groups (Sato 2009; Pinard and Cropper 2000).

11.2.1 Example of Application: Analysis of Logging Scenarios for Dipterocarp Rainforest

We used the FORMIX3 model to analyse the long-term impacts of different logging strategies on yield, forest structure, and species composition. We distinguished conventional logging with high damages and low impact logging with low damages and analysed different cutting cycles for Dipterocarp rainforests in Deramakot, Southeast Asia.

The Deramakot Forest Reserve is situated in North Borneo (Malaysia, 5°25′ N, 117°30′ E). The region has the perhumid climate typical of the inner tropics (mean annual temperature is 27° and mean annual rainfall is about 3,500 mm). The prevailing forest type is Dipterocarp lowland forest. The forest remained essentially undisturbed until this century and commercial logging started in 1956.

For conventional logging with a cutting cycle of 20 years, each logging operation can be recognised due to the sudden decrease of total standing volume in the simulation (Fig. 11.1a). This decrease is composed of the harvested stem volume and losses due to damages. The cutting cycle of 20 years is so short that 20 years after the first logging operations, there are not enough harvestable trees in the forest to allow a new logging operation. Thus, the next logging is carried out later, at year 40. The same situation occurs at the years 80, 100, 120, 160, 200, 220, 300, 320, and 380. The high variation of yield per operation is strong evidence that the forest is overexploited (Fig. 11.1a right). After each logging operation the forest regrowth is constituted largely by increased growth of Macaranga species (group 3) compared

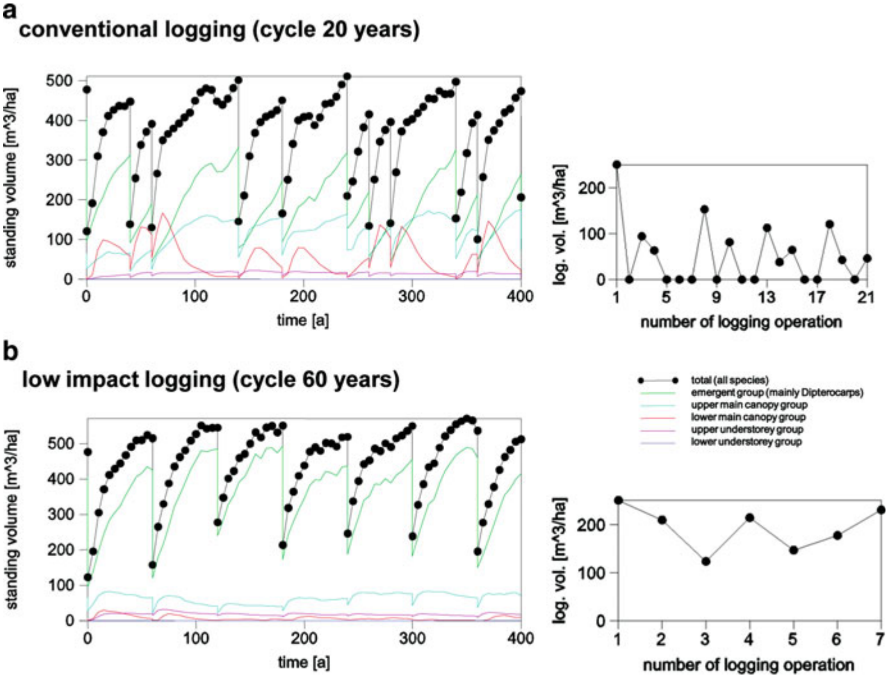

Fig. 11.1 Example for the simulation of different types of logging scenarios. Results are for Dipterocarp rainforest in South East Asia, Deramakot forest reserve assuming conventional logging with a cutting cycle of 20 years (**a**) and reduced impact logging with a cutting cycle of 60 years (**b**). *Left*: Standing timber volume over time for different species groups and all trees (above 10 cm diameter). *Right*: Logged volume over the number of the current logging operation

to the composition in primary forest (initial state). But also the species composition of the Dipterocarp species (groups 1 and 2) shifts to smaller and more light-demanding Dipterocarps (group 2).

In the low impact scenario with a cutting cycle of 60 years, the volume of all trees and the volume of harvestable trees reach nearly the same value as in unlogged forests before each logging event (Fig. 11.1b). Species composition remains rather stable. The logged volumes per cut still show some fluctuations (Fig. 11.1b right).

As shown for this example, growth models can help derive the sustainable timber harvest. A sustainable harvest may be derived for plantations with native tree species as well. Based on this information, financial valuation may be carried out to assess the financial attractiveness of silvicultural options.

11.3 Financial Modelling of Tropical Land Use

Among the manifold of management activities for tropical lands, we identify various silvicultural options (Fig. 11.2). We will first review studies about the profitability of natural forest management and land reforestation, as options

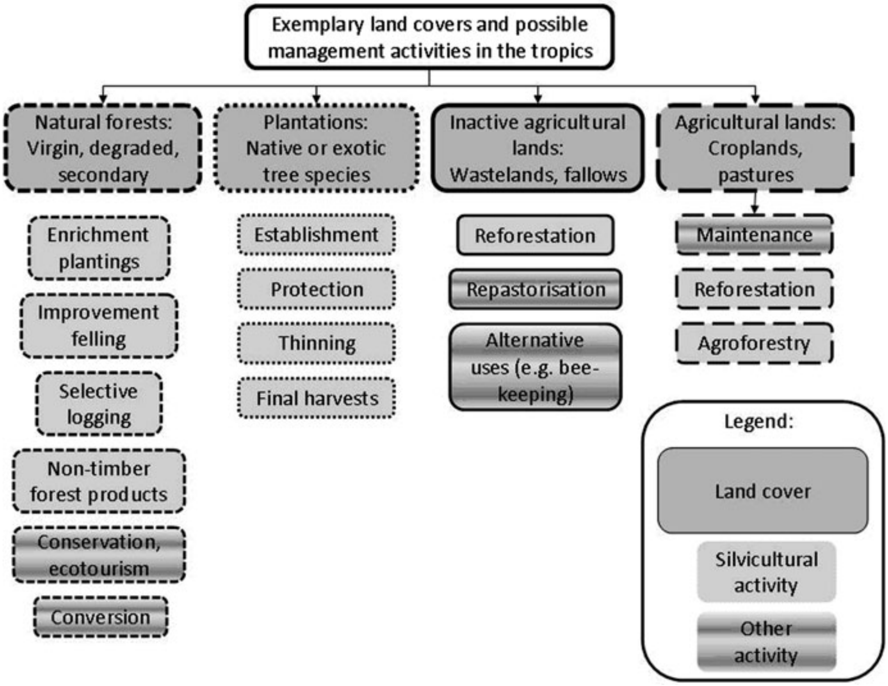

Fig. 11.2 Exemplary management activities on tropical lands

among the most important silvicultural management opportunities. Following this short overview, we will demonstrate a new, model-based approach in analysing and designing sustainable land-use concepts, which include both mentioned silvicultural options.

11.3.1 Profitability of Natural Forest Management

Given a flow of sustainably harvestable timber volumes, which may be predicted by a growth model or derived by data recorded from the past, one can calculate the profitability of SFM of natural forests and other forest management strategies (see Pearce et al. 2003). Various studies in this field show that net revenues from SFM in natural tropical forests are rather small; they may range between US$ 32 and 153 ha^{-1} year^{-1}(Table 11.1). In comparison to alternatives, mostly agricultural land uses, we regularly find, in part overwhelmingly, greater net revenues between US$ 72 and 468 ha^{-1} year^{-1} for the alternative options. From the perspective of a farmer, this rather simple comparison (reasons why simple given below) makes clear why tropical land use often excludes SFM.

Table 11.1 Net revenues from sustainable natural forest management (SFM) compared to those of alternative land-uses (ALU)

Country	Annualised net revenue SFM (US$ ha^{-1} year^{-1})	Annualised net revenue ALU (US$ ha^{-1} year^{-1})	References	Comment
Brazil	69[a]	58[a] (agriculture with no intensification) 90[a] (agriculture with intensification)	Carpentier et al. (2000)	Sustainable yearly harvest, labour costs in forest 10[a] R$ day^{-1}
Ecuador	31	72 (conversion to cattle pasture, 20-year cycle)	Knoke et al. (2009a)	Sustainable yearly harvest, 5% interest for agriculture
Cameroon	32	154 (conversion to small-scale agriculture) 178 (conversion to palm oil)	Studies cited by Turner et al. (2003)[b]	10% interest, 32-year cycle
Sri Lanka	123	468 (cultivation of tea)		8% interest, 20-year cycle
Malaysia	153	189 (unsustainable timber logging)		8% interest, 100-year cycle

[a] Brazilian real

[b] We calculated annualised net revenues as annuities from net present values (i.e. the sum of all appropriately discounted positive and negative financial flows) reported in Turner et al. (2003)

If net revenues to be generated by SFM are very low, an effective way towards long-term conservation of tropical forests is the allocation of market value to standing tropical trees. For example, the allocation of market-based carbon values to standing timber, where deforestation is to be avoided, may be a great opportunity to save tropical forests. However, the expected carbon values alone may often not cover the full land opportunity costs that farmers face when accepting the maintenance of tropical forests (Knoke et al. 2009b). As a consequence, the implementation of carbon values, for example through compensation payments financed by international carbon markets, will probably only be successful in combination with sustainable land-use concepts, which include timber-based SFM (Pearce and Pearce 2001). If, in fact, no or only small financial value is generated by the standing forests and their management, the natural forest has no direct advantage for the farmers, other than as insurance. Insurance means that the harvest of still existing standing timber of natural forests can serve to compensate for possible losses, if land-use options other than SFM perform more poorly than expected (Knoke et al. 2009a). The allocation of direct and permanent value to standing tropical forests – be it through ecosystem products (e.g. non-timber forest products) or services – is thus one of the most challenging future tasks to which tropical silviculture can contribute. However, the available analyses show that the maintenance of tropical forests will often be financially unattractive for tropical land users, given that ecosystem services are financially ignored and that SFM of tropical forests is seen as a stand-alone operation (see below for a detailed discussion of the latter point).

11.3.2 Plantation Forestry with Exotics vs. Reforestation with Native Tree Species

Industrial plantations, mainly established with exotic tree species, form about 6% of the world's forested area, but nevertheless stand for more than 25% of the world's timber production (Siry and Cubbage 2003). Tropical countries, such as Brazil, grow for example Eucalyptus or Pine plantations with internal rates of return (IRR) from 15% up to more than 20% (Cubbage et al. 2007). *Gmelina arborea* even reaches IRR of more than 30% on the Philippines (Harrison et al. 2005), while native tree species result in IRR of maximally 7% in Philippines' study. The annualised net revenues of plantations with exotics (US\$ 248–343 ha^{-1} year^{-1}) go far beyond those of SFM of natural forests and also exceed net revenues of plantations with native tree species, such as Andean alder (*Alnus acuminata*) or Laurel (*Cordia alliodora*) tested for Ecuador (Table 11.2).[1]

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[1] Note that various interest rates applied for calculations in Table 11.2 hinder a sound comparison. If we keep in mind that great interest rates reduce annualized net revenues substantially, the comparison between exotics and natives underlines even stronger the superiority of the exotics.

Table 11.2 Net revenues from forest plantations in the tropics (without costs for land, e = exotic, n = native, IRR = internal rate of return)

Country	Tree species	Annualised net revenue (US $ ha^{-1} year^{-1})	References	Comment
Brazil	*Pinus taeda* (e)	248	Cubbage et al. (2007)[a]	8% interest
	Eucalyptus grandis (e)	434		
Ecuador	*Alnus acuminata* (n)	58	Knoke et al. (2009a)[b]	5% interest, 20-year rotation
		2–25	Dunn et al. (1990)[c]	15% interest, 20-year rotation, Alnus as an agroforestry component
	Cordia alliodora (n)	6	Olschewski and Benitez (2005)	7% interest, 2 15-year rotations
Philippines	*Acacia mangium* (e)	50	Harrison et al. (2005)[d]	15% interest, 10-year rotation
	Gmelina arborea (e)	123		15% interest, 10-year rotation
	Eucalyptus deglupta (n/e)	44		15% interest, 20-year rotation
	Native species	Negative, maximum IRR 7%		15% interest, various rotations

[a] We calculated annualised net revenues as annuities from land expectation values (calculations considering an unlimited time horizon) reported in Cubbage et al. (2007)

[b] We calculated annualised net revenues as annuities from net present value (calculations considering a limited time horizon), we ignored risks considered by Knoke et al. (2009a) for the sake of comparability

[c] We calculated annualised net revenues as annuities from net present value (calculations considering a limited time horizon), we converted 166 sucres to the US dollar. Note that the reported net revenue is additional to pasture net revenues, which can be obtained from the same area. Pasture net revenues were, however, not reported

[d] We calculated annualised net revenues as annuities from net present value (calculations considering a limited time horizon), and converted 50 Philippines pesos to the US dollar

Environmental concern about economic losses in social ecosystem services, as probably induced by intensive plantation forestry with exotic tree species, will certainly outweigh short-term private financial benefits from this strategy. Particularly, if timber companies convert native forests into intensively managed plantations and thus destroy great biodiversity, release much carbon into the atmosphere, and possibly deplete site fertility in the long run, this option cannot be considered sustainable. However, until today the internalisation of the mentioned externalities has mainly not been carried out. Land-use practices in many parts of the world are thus still mainly driven by their expected short-term financial consequences (Pearce et al. 2003); a fact that actually still favours exotic tree plantations compared to natives.

11.3.3 Selective Logging, Reforestation, and Pasturing Combined in a Land-Use Portfolio

Despite the enormous IRRs achievable with exotic trees, an intensive land management, as necessary for a successful "industrial-style" timber production, is often not a favourable option for small land holders. Small holder households may often not raise the necessary investments and work intensity to establish large-scale exotic tree plantations. In the situation of small holders, *diversification* instead *intensification* of land use may be an adequate option to improve their livelihood. For such a diversification strategy, a clever reforestation based on robust and site-adapted native tree species, designed to re-integrate degraded, unproductive "wastelands" (i.e. abandoned pasture lands sensu Silver et al. 2000) into the production process, may be a key option to achieve private benefits for farmers.

In a case study carried out for a virtual farm located in South Ecuador (see Knoke et al. 2009b for details) to better understand financial reasons for the current land-use patterns, the agricultural land-use option "single pasturing" was most profitable among three mutually exclusive land-use options (the farm consisted of 20 ha pastures and 40 ha natural forests). However, this result (Fig. 11.3 and Table 11.1) was obtained only when considering all land-use options isolated and ignoring their financial risks. Financial risk may be measured as the standard deviation of the simulated average net present value (NPV). NPV results from applying the "discounted-cash-flow" method, when summing up all appropriately discounted future financial flows of land management (with 5% discount rate applied in the above study). The financial risk of single pasturing was medium: On the one hand, its risk was double compared to selective logging in the natural forests; on the other hand

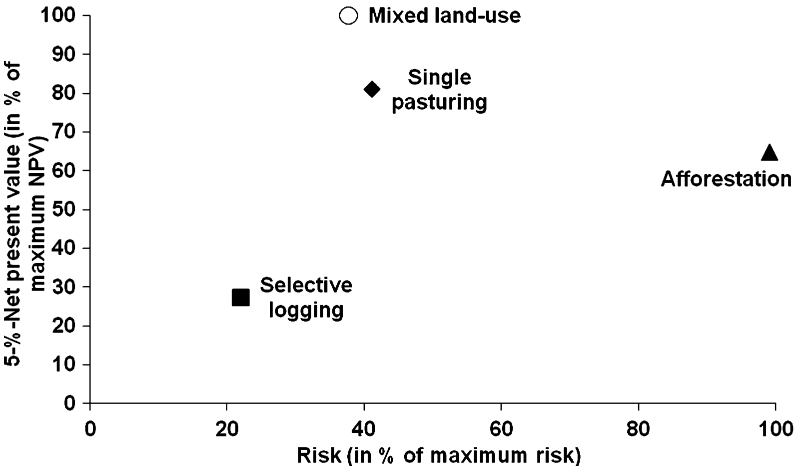

Fig. 11.3 Relative net present values for three land-use options in South Ecuador and their standard deviation, all values relative to the maximum values (data based on simulations carried out by Knoke et al. 2009b, with alteration)

it amounted only to around 40% the risk of reforestation (Fig. 11.3). Reforestation bears higher financial risk, because we assumed only one final harvest operation for this option and excluded thinning operations for this example. We thus have no compensation effects with regards to market-price volatility, which occur for the other land-use options, where yearly financial flows were considered (see Knoke et al. 2001 for a detailed explanation of this effect). In summary, we can say that the results of the shortly presented financial model calculation are well in line with the actual land use in South Ecuador, which mainly consists of cattle pasturing (Paulsch et al. 2001).

However, a direct comparison of mutually exclusive land-use alternatives is too simple of an approach. It ignores diversification options and the fact that most landholders are risk averters (Pichón 1996). Studies from the fields of forestry (Knoke 2008), fishery (Edwards et al. 2004), and managed grasslands (Koellner and Schmitz 2006) have shown that the consideration of less profitable options (which are selective logging and reforestation in the case presented above) is a reasonable option, if diversification effects occur, such as risk compensation from various products. In Fig. 11.3 we find the mixed land-use option, consisting of a combination of three land-use options, involved with the highest NPV (computed for an interest of 5% over 40 years) and only moderate risk (even slightly lower than single pasturing). The better profitability of the farm under mixed land use is mainly a result of the reforestation of areas, which have fallen unmanaged and abandoned because of degradation processes. In contrast to classical land management, the production at farm level under the mixed land use is immediately diversified into agricultural and forestry products and thus land use is stabilised (Fig. 11.4), whereas

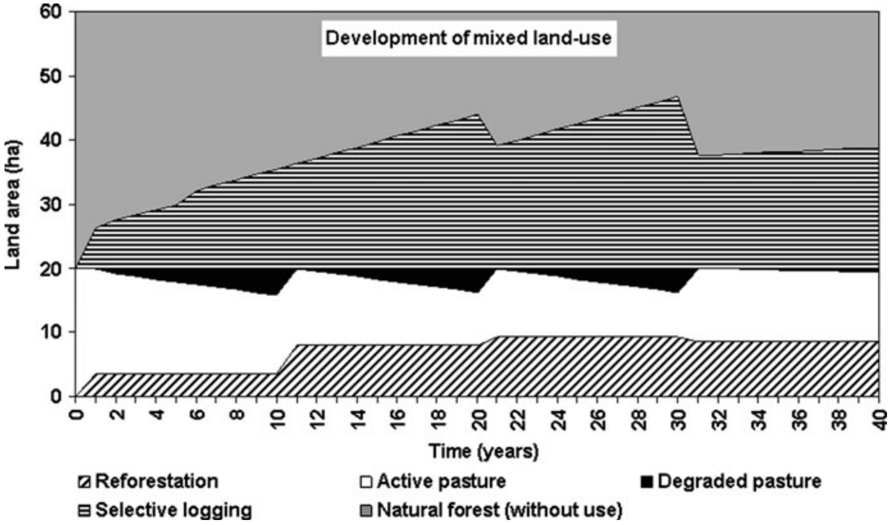

Fig. 11.4 Simulated development of the areas for three land-use options over 40 years under a mixed land-use concept for a virtual farm in South Ecuador (adopted from Knoke et al. 2009b, with alterations)

under classical single pasturing we face considerable pasture degradation and accumulation of wastelands (Knoke et al. 2009a, b).

Forest uses include reforestation, although involved with comparatively great risk. This disadvantage is balanced out in a portfolio of land uses by the risks of pasturing, which are independent from that of forestry. A small part of the pasture area will be reforested with Andean alder, a species native to the sites in South Ecuador, already at the beginning of the considered period with increasing areas when degraded pastures accumulate. Note that a reconversion of a part of the Alder plantations after 20 years back to pasture management was considered.

Besides the establishment of Alder plantations, selective but sustainable logging (SFM) was considered in a part of the natural forests (Fig. 11.4). The freed working capacity by means of reduced pasture area was allocated to selective logging activities in the natural forest area to compensate for missing early revenues from reforested pastures. This mixture of land uses, diversified into agriculture and forestry, stabilises net revenues and accumulates substantial monetary value by the natural growth of the newly established Alder plantations until they are harvested at age 20. In the meantime they deliver net revenues from thinning (from year 11 onwards). After the harvesting of the tree plantations, the areas were again used for pasturing. In summary, the mixed land-use concept stabilises net revenues, enhances livelihood for the farmers, and avoids deforestation, while single pasturing would result in a yearly deforestation rate of 1.3%.

However, forest modelling was based on rather simple assumptions in the reported case study, with transition probabilities for natural forest trees to move from one size class into the next bigger size class (estimated from past diameter increments) and mortality recorded in experimental plots (see Knoke et al. 2009b). Reforestation growth was estimated mainly based on existing references. We would like to point out that a future combination of the advanced forest growth modelling reported above with the demonstrated kind of financial land-use modelling will strengthen the validity of the results and thus bears great potential.

Despite this limitation, the above example shows that reforestation with natives and SFM in natural forests can show great advantage from the perspective of sustainability, because both options fit well into a portfolio of land uses and thus decrease the overall risk. These effects may outweigh relatively poor financial performance resulting from stand-alone financial analyses. When concentrating reforestation only on abandoned agricultural lands (so-called wastelands), this option does not compete with natural forests for land and can be obtained in addition to the classical land use. Moreover, site rehabilitation and consolidation from the effects of native tree species stress the advantages of this option. However, to convince farmers about the reforestation option, when based on native tree species, solid financial modelling is necessary. Particularly the fact of uncertainty needs being considered, since diversification effects between forestry and agricultural products will reduce risks of land management and thus also the demand for agricultural and plantation land. Uncertainty sensitive modelling reveals more realistic and thus rather acceptable results, compared to classical deterministic calculation (Knoke and Seifert 2008). It enables estimating financial consequences in a more realistic way, as it may include all available land-use options, and thus can make reforestation with native tree species and SFM in natural forests viable alternative for farmers (Knoke et al. 2008; Knoke et al. 2009a), while pointing out risk-reducing benefits obtained from less profitable tree species (Knoke 2008) and land uses. When combining the financial mixed land-use model with compensation payments for environmental services, also some limitations, such as the financing of the investment necessary for reforestation, may be eliminated (Knoke et al. 2009b).

11.4 Conclusions

We could show that a comparison of isolated and mutually exclusive land-use alternatives is probably inadequate to support land-use decisions. Based on a modelling approach, fed by growth and production data for forestry and agricultural land-use options, which includes financial risks modelling, the design of sustainable land-use options may be effectively improved. The presented approach may now be applied to improve land use in other parts of the world and to analyse other land-use concepts. We expect great demand for this kind of analysis, as socio-economic aspects of natural diversification are much underrepresented in other studies (Rice 2008). We conclude that linking modern growth modelling with advanced financial valuations, resulting in sound bioeconomic models, would increase the biological realism of economic studies and the acceptability of their conclusions. Improved bioeconomic modelling, based on solid financial theory and advanced growth models, thus bears great potential in supporting sustainable land use.

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