Environmentally-friendly forestry systems in Central America

This paper presents examples of sustainable forest management research by CATIE (Tropical Agriculture Research and Higher Education Center). Studies cover timber harvesting practices as well as research on uses of non-timber forest products and valuation of environmental services provided by forests. In addition, they consider strategies for the restoration of degraded ecosystems, including reforestation with native species. The studies described are part of larger programs to design techniques for sustainable forest management throughout the Central American region.

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The forest at La Selva Biological Station, in Costa Rica, is protected from hunting and connected to a national park. Seed dispersal by mammals and seedling survival were higher than at Tirimbina (a nearby, unprotected forest).
La forêt entourant la station biologique de La Selva, au Costa Rica, est interdite à la chasse et jouxte un parc national. La dispersion des semences par les mammifères et le taux de réussite des jeunes plants y sont plus élevés qu'à Tirimbina (une forêt proche, non protégée).
Photo F. Montagnini.

RÉSUMÉ

GESTION FORESTIÈRE RESPECTUEUSE DE L'ENVIRONNEMENT EN AMÉRIQUE CENTRALE

Comparées aux techniques classiques, les techniques d'exploitation forestière à faible impact favorisent la régénération des arbres et la biodiversité du sous-bois. Les traitements sylvicoles post-récolte augmentent le diamètre des arbres ; il reste à évaluer l'effet de ces traitements sur la composition floristique de la forêt. En général, les opérations sylvicoles modifient la diversité floristique. Cependant, avant la première coupe, il n'apparaît pas de changement important de la composition, y compris dans les peuplements dont la structure est modifiée par les traitements d'éclaircie. La dispersion et la germination des semences évoluent suite à la diminution de la faune et au changement des conditions micro-environnementales. Outre des recherches sur les techniques de gestion durable des forêts tropicales et de leur biodiversité, le Catie participe à la mise en place de systèmes de gestion forestière diversifiée et il réalise des études sur l'écologie et la sylviculture d'espèces ligneuses non productrices de bois d'œuvre. De nombreuses pratiques de gestion forestière sont très bien adaptées aux petits agriculteurs, aux coopératives et aux communautés forestières. Au Costa Rica, des coopératives gèrent leur forêt pour l'écotourisme et les produits non ligneux, elles pratiquent l'agriculture sur d'autres portions de terre et reboisent les terres dégradées avec des espèces locales souvent plantées en mélange. Tout en fournissant des produits ligneux, les plantations tropicales contribuent à la séquestration du carbone et à la restauration des terres dégradées. Elles favorisent également la régénération naturelle. La domestication d'espèces prometteuses suppose de sélectionner des arbres remarquables, d'évaluer la variabilité génétique, de contrôler la germination et le stockage des graines, d'évaluer le comportement de l'espèce selon des scénarios sylvicoles et de développer des vergers à graines pour produire des semences génétiquement améliorées.

Mots-clés : biodiversité, gestion forestière diversifiée, amélioration génétique, plantation mixte, restauration des écosystèmes.

ABSTRACT

ENVIRONMENTALLY-FRIENDLY FORESTRY SYSTEMS IN CENTRAL AMERICA

Sustainable logging practices can result in higher seedling regeneration, and higher understory biodiversity than in forests logged by conventional methods. Post-harvest silvicultural treatments increase the diameter growth of crop trees, although the consequences of their effects on forest composition need to be assessed. Management operations affect plant diversity in different ways, over different time scales, but there is no evidence of drastic changes in diversity during the first felling cycle, even in stands whose structure is altered by refinement/liberation treatments. Seed dispersal and germination can also be affected as a result of loss of fauna and changes in the forest microenvironment. In addition to research on technologies for sustainable management of tropical forests and their biodiversity, CATIE is also involved in designing systems for diversified forest management, which includes studies on the ecology and management of non-timber forest species. Many forest management practices are best suited to small farmers, farmer cooperatives, or community forest users. Some farmers'cooperatives in Costa Rica manage forests for ecotourism and non-timber forest products, and also cultivate other portions of their land as well as reforesting degraded land with native or exotic species, often as mixed-species planting schemes. Tropical plantations can supply wood products, contribute to carbon sequestration and land reclamation, as well as accelerating natural regeneration. Domestication of promising species for plantations involves selecting outstanding trees, evaluating genetic variability, seed germination and storage, evaluating the performance of species under different silvicultural systems, and developing seed orchards for the production of genetically improved seeds.

Keywords: biodiversity, diversified forest management, genetic improvement, mixed plantations, ecosystem restoration.

RESUMEN

MANEJO DE BOSQUES TROPICALES FAVORABLE PARA EL AMBIENTE EN AMÉRICA CENTRAL

Los bosques cosechados utilizando prácticas sostenibles pueden tener mayor regeneración arbórea, y mayor biodiversidad en el sotobosque, que bosques cortados utilizando métodos convencionales. Los tratamientos silviculturales post-cosecha aumentan el crecimiento diamétrico de árboles deseables, aunque las consecuencias sobre la composición del bosque deben aún ser evaluadas. Las operaciones de manejo afectan la diversidad de diferentes maneras, pero no existe evidencia de cambios drásticos en la diversidad durante el primer ciclo de corta, aun en rodales alterados por tratamientos de refinamiento/liberación. La dispersión de semillas y la germinación también pueden ser afectadas por la defaunación y cambios en el microambiente. Además de la investigación en tecnologías para el manejo sostenible de bosques tropicales y su biodiversidad, el CATIE también esta diseñando sistemas de manejo diversificado del bosque, incluyendo estudios de ecología y manejo de especies no maderables. Muchas prácticas de manejo de bosques son más adecuadas para pequeños agricultores, cooperativas o bosques comunales. Algunas cooperativas de agricultores en Costa Rica manejan los bosques para el eco-turismo y productos no maderables, cultivan otras porciones de sus tierras y reforestan tierras degradadas con especies nativas o exóticas, a menudo en plantaciones mixtas. Las plantaciones tropicales proveen productos maderables, contribuyen a la acumulación del carbono, recuperación de tierras y aceleración de la regeneración natural. La domesticación de especies promisorias para plantaciones incluye selección de árboles sobresalientes, evaluación de variabilidad genética, germinación y almacenamiento de semillas, evaluación del comportamiento de especies bajo diferentes sistemas silviculturales y desarrollo de huertos semilleros para la producción de semillas genéticamente mejoradas.

Palabras clave: biodiversidad, manejo diversificado de bosques, mejoramiento genético, plantaciones mixtas, restauración de ecosistemas.

Introduction

Most current forest management schemes for the production of timber result in physical disruption of the forest structure and its plant and animal life. However, various practices can greatly diminish the impacts of forest management on biodiversity. Many tropical countries have recently changed forest management regulations to make them compatible with the principles of sustainable yields and biodiversity preservation. Specific guidelines are needed to cover a vast array of forest conditions at both large and small scales. These guidelines should be adjusted to suit the scale and objectives of management as well as the resource requirements of the species involved.

To make systems more "environmentally friendly", silvicultural and management schemes have concentrated on decreasing forest damage by lowering the intensity of timber harvests and by improving logging practices (Bertault, Sist, 1997; Sist *et al.*, 1998). However, not much has been done to standardize procedures for the selection of remnant seed trees, or to avoid disruption of pollinators and seed dispersers. Additionally, forest management schemes often function in isolation with respect to the rest of the landscape.

Long-term studies on ecological and financial suitability of natural forest management

At CATIE, long-term research has focused on developing technologies for sustainable management of natural forests and their biodiversity. Researchers have recently created models to predict and simulate growth and yields in primary and secondary forests. CATIE has generated the most complete body of quantitative and qualitative information available on ecological and economic feasibility in the region.

For example, a financial analysis of sustainable management in a harvested forest was recently conducted at the Tirimbina Rain Forest Research Center, located in Costa Rica's Atlantic zone. The Tirimbina forest is part of a network of key sites for long-term research on sustainable forest management in tropical America. Based on studies on economic feasibility and impacts on plant biodiversity, it was found that at least 30 hectares, and 10-15 m^3 per hectare should be harvested if management is to be economically attractive (Campos *et al.*, 1998). In these forests, post-harvesting treatments increased growth, especially for commercial species. Simulations using SIRENA, a growth and yield model (De Camino, 1997), suggested that sustainable management can be achieved when harvesting is kept to moderate levels, when post-harvesting treatments are applied to maintain an appropriate composition of commercial species, and when a cutting cycle of 20 years is selected.

Research and experience on sustainable forest management at CATIE go hand in hand with the development and validation of criteria and indicators of sustainable forest management, and with the establishment of local procedures for forest certification. CATIE´s leadership in Forest Certification in Central America has been strengthened during the last couple of years. CATIE personnel are also involved in similar activities in the host country of Costa Rica (Comisión Nacional de Certificación Forestal, 1999).

Farmers of Coope San Juan, an agricultural cooperative located in Aguas Zarcas, NE Costa Rica, grow a medicinal plant, "raicilla" or "ipecacuana" (*Cephaelis ipecacuana*), in the natural forest understory.
Les fermiers de la Coope San Juan, une coopérative agricole située à Aguas Zarcas, au nord-est du Costa Rica, font pousser une plante médicinale appelée raicilla *ou* ipecacuana *(*Cephaelis ipecacuana*) dans les sous-bois d'une forêt naturelle.*
Photo F. Montagnini.

Effects of silvicultural intervention on tree diameter increments and forest diversity

A young plantation of *Vochysia guatemalensis*, one of the native species used for reforestation of degraded agricultural land in Coope San Juan.
Jeune plantation de Vochysia guatemalensis*, une des essences indigènes utilisées pour le reboisement des terres agricoles dégradées de la Coope San Juan.*
Photo F. Montagnini.

As part of CATIE's ongoing research on biophysical aspects of forest management, work is being conducted on the effects of timber harvesting and silvicultural treatments on stand productivity and dynamics, and plant species diversity and composition in a managed *Pentaclethra*-dominated rain forest typical of Central America's Atlantic coast. Timber was harvested from the whole area under strict planning and control in 1989 and 1990 (Finegan *et al.*, 1999). The total harvestable volume was 23 m^3/ha but actual harvest intensity was 42% of this (10.1 m^3/ha). Three different regimes of post-harvest silvicultural intervention were applied during 1991-1992: control (timber harvest only), a treatment combining refinement (general removal of weeds, defectives and other undesirable trees in the interests of better utilization of the site by the desired crop) and liberation (freeing potential crop trees from competing overtopping and neighbouring trees); and a shelterwood (thinning of the middle stories of the forest to create conditions for the regeneration of more light-demanding commercial species) (Finegan, Camacho, 1999).

The three different regimes brought about marked differences in stand structure, and diameter increments of potential crop trees were higher under the refinement-liberation treatment than in the control during the 1993-1998 period (Finegan, Camacho, 1999). Abundances of characteristic tree species were reduced by the refinement/liberation treatment. Species richness/ha, equal or superior to 10 cm diameter at breast height (dbh), did not differ significantly between silviculturally treated (mean 100/ha, s.d. 7.5, n=3) and control plots (mean 111/ha, s.d. 6.2, n=3) in 1996, even though there were small net declines in silviculturally treated plots in the first years after treatment, while control plots showed net increases. There were no statistically significant effects of treatment on diversity in the understory either. There were, however, significant differences in understory diversity at small scales, in the habitat mosaic formed by timber harvesting: undisturbed patches, canopy gaps and trails.

Many previous studies have demonstrated forest structure recovery and increased diameter increments of potential crop trees following liberation and refinement treatments in tropical forests, but few have focused on changes in overall plant diversity. The preliminary results of the study in the managed *Pentaclethra* forest show different forest responses, in different size-classes, at different scales of space and time. It is important to understand the causes and nature of species loss from permanent sample plots in such studies, in order to identify the implications of these results in terms of the relationship between silvicultural treatment and tree species diversity. In species-rich forests, species richness equal or superior to 10 cm dbh in 1.0 ha can show net declines after silvicultural treatment, because in a given plot, a proportion of the individuals eliminated are bound to be the only representatives of their species. The lack of significant differences between the refinement/liberation treatment and the control plots in the *Pentaclethra* forest, however, indicates that variation in species richness is affected by many factors and that silvicultural treatment like that applied, despite the drastic modification of forest structure it brings about, is not the single most important factor. However, the felling and extraction of timber, which disturbs the understory directly, showed marked, though localised, effects on stem density and species richness in the understory. The short-term effects of forest management on plant diversity clearly depend on the size-class under consideration and the nature of the operation, and full understanding of plant diversity changes in managed forests will probably only be achieved through the wider application of sampling protocols or experimental designs which permit the individual assessment of each operation. Long-term follow-up is clearly needed to assess overall changes in forest diversity.

Loss of fauna, seed dispersal and seedling establishment in logged forest with different levels of protection

At CATIE, the effects of loss of fauna on the dispersal, predation and survival of seeds and seedlings were recently studied in two selectively-logged forests with contrasting levels of protection (GUARIGUATA *et al.*, 2000). This is one of the first studies that suggest, through direct research, the potential role of fauna in the biological sustainability of some species that are animal-dispersed in managed forests of the neotropics. La Selva Biological Station, owned and operated by the Organization for Tropical Studies (OTS), is protected from hunting and connected to a national park, whereas Tirimbina remains unprotected and is not connected to a park. Seed dispersal rates by mammals were highest in the protected site. Seed removal under two protection treatments (caged *vs.* uncaged) varied both within species across sites and within sites across species, as a consequence of differences in the abundance of vertebrate seed consumers between the two sites (Table I).

Twice as many seeds were dispersed after 50 days of observation at La Selva (the protected forest) than at Tirimbina (unprotected). Seed survival was also higher at La Selva, which is probably related to altered mammal community composition as a result of hunting pressure and loss of habitat connectivity at Tirimbina. These results confirm earlier findings of other studies on the so called "fauna loss" hypothesis, which have also shown altered patterns of plant regeneration due to truncated trophic chains. In NE Costa Rica, production forests adjacent to parks and conservation areas may be more likely to maintain a wider spectrum of viable

Abundant woody and herbaceous vegetation growing under the canopy of a nine-year-old mixed plantation of native species at La Selva Biological Station, Costa Rica. *Une végétation ligneuse et herbacée abondante se développe sous la canopée d'une plantation mixte d'essences indigènes âgées de neuf ans à la station biologique de La Selva, Costa Rica.* Photo F. Montagnini.

populations of plants and animals, given the assumption that human intrusion is also controlled. Even if forests are logged with minimal stand and soil disturbance, sustained recruitment of at least mammal-dispersed timber species appears less likely if loss of habitat connectivity and excessive hunting pressure are combined. This baseline information may offer a starting point for developing ecological criteria for tree seed retention, and it may contribute to improving ecologically-based management prescriptions in order to enhance or at least maintain sufficient levels of natural regeneration without the need to rely on artificial regeneration.

Sustainable management of secondary forests

Throughout the lowland neotropics, secondary forest ecosystems are receiving increased attention as a timber source. Particularly in Central America, the area under secondary forest is rapidly growing on abandoned pasture lands (KAIMOWITZ, 1996). Although a large body of ecological information exists on secondary forest succession, few forestry-based experimental approaches have been implemented to investigate how secondary forests react to management practices. CATIE researchers are characterizing secondary forest structures and floristics and developing guidelines for sustainable management in Costa Rica, Nicaragua, Brazil and Peru (CURRENT *et al.*, 1998; GUARIGUATA, 1999).

In Costa Rica, CATIE is investigating the effects of silvicultural practices such as liberation thinning, whole-canopy removal, and substrate preparation techniques on stand dynamics and regeneration of secondary forests (defined as the woody vegetation that regrows after the abandonment of farmland or pastureland) in order to provide guidelines for sustainable management of timber (GUARIGUATA, 1999). In the Atlantic lowlands of Costa Rica, short-term growth responses in individuals of four commercial species (*Laetia procera, Simarouba amara, Tapirira*

Table I.
Number of sightings of mammalian fauna at the study sites in the Caribbean lowlands of Costa Rica over a 6 month period.

Species	Tirimbina Number (n/ha)	La Selva Number (n/ha)
Alouatta palliata (howler monkey)	4 (0.06)	8 (0.13)
Ateles geoffroyi (spider monkey)	2 (0.03)	15 (0.24)
Cebus capuchinus (white-faced monkey)	7 (0.10)	7 (0.11)
Dasyprocta punctata (agouti)	—	2 (0.03)
Puma concolor (puma)	—	2 (0.03)
Tamandua mexicana (tamandua)	—	2 (0.03)
Tayassu tajacu (collared peccary)	—	4 (0.07)
Sciurus variegatoides (squirrel)	1 (0.01)	2 (0.03)
Total	14 (0.19)	32 (0.52)

A mixed plantation of native species at La Selva Biological Station, Costa Rica: *Vochysia guatemalensis + Jacaranda copia + Calophyllum brasiliense + Stryphnodendron microstachyum*. *Plantation mixte d'essences indigènes à la station biologique de La Selva, Costa Rica :* Vochysia guatemalensis + Jacaranda copia + Calophyllum brasiliense + Stryphnodendron microstachyum. Photo F. Montagnini.

guianensis, and *Vochysia ferruginea*) were evaluated following liberation thinning in a young secondary forest. Liberation thinning significantly increased the diameter growth of future crop trees with respect to unmanipulated counterparts (Table II). The study concluded that young stands in the region may be attractive systems for simple silvicultural manipulations due to rapid growth responsiveness, facilitated by manageable tree size (Guariguata, 1999).

Table II.
Annual median diameter increment (in cm) of crop trees of the studied species, two years after thinning in control and thinned subplots in a young secondary forest in the Caribbean lowlands of Costa Rica (from Guariguata, 2000).

Species	Control	Thinned
Laetia	0.4	1.0
Tapirira	0.5	1.4
Simarouba	1.7	1.8
Vochysia	0.7	1.8
All species	0.7	1.2

Designing systems for diversified forest management

Designing systems for diversified forest management involves studies on the ecology and management of several non-timber species, including trees, herbs and palms used locally or regionally for medicinal, insecticidal, ornamental, craftwork and construction purposes (Marmillod *et al.*, 1998). Based on CATIE's experiences, a methodology was developed to incorporate species with non-timber products in forestry production processes. The use of these resources is based on a definition of the sustainable supply of forest products and on silvicultural criteria for each species, as opposed to traditional extraction lacking indicators of capacity and production limitations. The approach requires initial knowledge on the biology and uses of the species, development of tools to characterize its population structure and estimate the amount of harvestable product, and development of silvicultural systems and sustainable management plans. Examples of current studies by CATIE researchers on non-timber forest products that can be incorporated into diversified forest management systems in the neotropics are shown in Table III.

Identification and quantification of ecological services provided by managed forests

CATIE researchers are involved in the identification and quantification of the ecological services provided by managed forests in terms of biodiversity conservation and atmospheric carbon fixing and storage. Payment for environmental services (PSA) provided by forest ecosystems is an innovative Costa Rican mechanism that recognizes forest owners' contributions to the protection of forest services (Campos, Ortiz, 1999) (Table IV).

A recent Forestry Act (1996) has established financial and institutional mechanisms to implement this payment system for private farmers who protect and manage natural forests and plantations. CATIE researchers have recently focused on specific case studies to evaluate the feasibility of these legal mechanisms for the payment of environmental services. Some of these current efforts include:

- selection and evaluation of criteria and indicators (CandI) from biological, economic and social perspectives, to determine the benefits and risks associated with different forest ecosystems in biodiversity protection and carbon sequestration services;
- a study on the benefits which environmental services offer the population, based on consultations with experts and owners of natural forests and plantations;
- studies of carbon fixing and storage in secondary forests and wood products. Work in this field is part of the research conducted by the CATIE's Latin American Chairs in Ecology of Managed Forests and in Diversified Forest Management.

Table III.
CATIE research on systems of diversified forest management (MARMILLOD *et al.*, 1998).

Topic/result	Implication
Quassia amara	
Morphological, histological and molecular characterization of wild populations of *Q. amara* in Central America	
Statistically significant morphological and histological differences exist among *Q. amara* populations in diverse ecoregions of Central America	This highlights the need for studies on: Content of active ingredients in different populations Ecological behavior of the species in response to different silvicultural systems
Definition of the protocol to extract DNA samples in *Q. amara* leaves	Provides the opportunity to design molecular characterizations of wild populations of *Q. Pamara*
Utility of *Q. amara* as a natural insecticide	
Foliage and wood extracts of *Q. amara* were selected as anti-feedant substances for *Hypsipyla grandella*, the meliaceae's shoot borer, among 29 substances evaluated	This result verifies the potential use of this species for the control of tropical pests, and confirms previous results on the location of active substances within the individual
The anti-feedant effect of wood is higher than foliage	
Cardulovica palmata	
Environmental preferences	
The best environment for *C. palmata* is low tree canopies and high lateral illumination conditions	*C. palmata* is an interesting species for multi-strata agroforestry systems
Guidelines for harvesting young shoots (candles)	
Productivity of harvesting young *C palmata* leaves is related to size of individuals and decreases during the production of inflo and infrutescense.	It is imperative to consider plant size when diagnosing populations for sustainable management plans.
Smaller sized leaves are observed in populations with continuous and traditional harvesting	The study of harvest impact should continue, to prove species robustness levels
Calyptrogyne ghiesebreghtiana	
Demography and productivity of *C.ghiesbreghtiana*	
Variables to evaluate productivity are the number of leaves, stem diameter, and presence of inflo and infrutescense	This makes it possible to define the sample elements needed for inventories to support sustainable use plans
Environmental preferences	
C. ghiesbreghtiana prefers slightly compacted soils in lowland and hilly forests with two strata	This result partially explains the disappearance of the species as a result of deforestation
Guidelines for harvesting leaves	
Plants with a stem diameter of less than 80 mm are left for reproductive development	It is best to harvest leaves from plants of at least 80 mm in diameter, otherwise flowering will be hampered
The harvest of 50 to 75% of the leaves causes an increase in the production of inflo and infrutescense.	
Zamia skinneri	
Population characteristics in the natural area	
Statistically significant differences exist among wild populations. Larger plants and denser groups are found in the Lower Talamanca/Teribe areas	Since the seed is the main product harvested, more studies are needed on phenology of the species in different populations

Hieronyma alchorneoides (pilón), one of the most successful species at La Selva Biological Station experiments, is at present being widely planted by farmers in the region.
Hieronyma alchorneoides *(pilón), une des essences les plus performantes lors des expériences menées à la station biologique de La Selva, est largement utilisée par les paysans de la région.*
Photo F. Montagnini.

Table IV.
Total amounts and annual percentages of payments of environmental services in Costa Rica for different forestry options.

Activity	Total amount (US$/ha)	Year and percent of annual payment per ha				
		1	2	3	4	5
Forest management	371.5	50	20	10	10	10
Forest conservation and regeneration	237	20	20	20	20	20
Reforestation	608.6	50	20	15	10	5
Established plantations	237	50	20	15	10	5

Source: Executive Decree, MINAE-No.26977, 26 May 1998.

Table V.
Number of trees per hectare, diameter at breast height (dbh), height, basal area and volume of native tree species in pure and mixed plantations at La Selva Biological Station, Costa Rica.

Species	Trees (n/ha)	Dbh (cm)	Total height (m)	Basal area (m^2/ha)	Volume (m^3/ha)
Plantation 1: 86 months					
Calophyllum brasiliense	773	13.73	11.11	11.73	62.21
Vochysia guatemalensis	759	21.86	18.39	28.41	244.06
Jacaranda copaia	967	18.37	19.85	25.88	238.26
Mixture	507	22.82	20.21	21.14	215.99
Plantation 2: 81 months					
Virola koschnyi	863	17.76	14.21	21.53	141.35
Dipteryx panamensis	833	11.73	13.30	8.98	53.96
Terminalia amazonia	714	16.69	14.25	16.91	115.13
Mixture	878	14.08	13.05	17.21	115.19
Plantation 3: 70 months					
Genipa americana	907	10.55	9.00	7.68	33.35
Vochysia ferruginea	848	17.7	12.72	21.16	122.1
Hieronyma alchorneoides	818	13.00	13.66	11.97	81.01
Balizia elegans	1443	11.98	9.68	16.62	86.64
Mixture	952	12.29	11.07	14.33	79.86

Sustainable forestry options in communal lands

Because of their complexity, many of the more environmentally sound forest management practices are best suited to small farmers, agricultural cooperatives or community forest users. Recently, the Smart Wood Program certified the operations of five community concessions in Guatemala that have received support from CATIE to prepare the technical/legal framework for granting such concessions.

Some farmers'cooperatives in Costa Rica manage their natural forests for eco-tourism and non-timber forest products, and carry out other productive activities, including conventional agriculture, in other portions of their land. For example, the Coope-San Juan Agricultural Cooperative, in Aguas Zarcas, NE Costa Rica, has 16 members (eleven men and five women) who, along with their families, form a community of about 56 people (HÄGER, 1998). They collectively own 400 hectares of land, half of which is covered with primary forest. They are keeping their forest intact, have marked trails for tourism and are expecting to obtain payment for environmental services from the legal system currently in operation in Costa Rica. In their agricultural land they keep a dairy farm and sell the milk locally. They also grow cocoa and plantains commercially.

Additionally, they manage non-timber forest species for sale, including a medicinal plant, "*raicilla*" or

"*ipecacuana*" (*Cephaelis ipecacuana*), which they grow in the natural forest understory. There is an export market for ipecacuana (Germany and Belgium). In addition, they have been reforesting portions of degraded agricultural land since 1987 with native and exotic species, often using mixed-species planting schemes.

Cooperatives such as Coope-San Juan are a promising model for more environmentally-friendly forestry systems at small to medium scales. For these systems to be successful there may be a need for initial economic incentives and training programs in cooperative management and administration, as well as in the technical aspects of sustainable forest and agricultural management techniques.

Productivity and feasibility of mixed and pure plantations of native species

Tropical plantations can fulfill a variety of functions including supplies of wood products, carbon sequestration, land reclamation and acceleration of natural regeneration (Lamb, 1998). Results from a series of trials that were started in the mid-80s have identified the most promising native and exotic tree species for small farm reforestation of degraded pastures in the lowland regions of six Central American countries: Nicaragua, Costa Rica, Honduras, Guatemala, El Salvador and Panama (Ugalde, 1997). In Costa Rica, recent legislation provides incentives for the establishment of tree plantations, especially on abandoned pastures and other deforested areas. There is increasing interest among local farmers in making use of these incentives to plant native species.

In small farm reforestation, species diversification may be desirable because of uncertainties about species performance, scarcity of seedlings, or potential pest damage. If planned with consideration for each species' response to mixed conditions, mixed schemes can be more productive than single-species systems (Montagnini *et al.*, 1995; Montagnini, Porras, 1998). Mixed stands may also contribute to higher species and landscape diversity (Lamb, 1998).

Since 1990, CATIE researchers have studied growth, productivity, biomass accumulation and financial aspects in experimental plantations of native tree species in mixed and pure stands, at La Selva Biological Station in the humid Atlantic lowlands of Costa Rica. Of the 12 species tested in these experiments, the most successful (*Vochysia guatemalensis, Vochysia ferruginea, Hieronyma alchorneoides, Calophyllum brasiliense, Terminalia amazonia, Virola koschnyi*) (Table V) are now being planted by farmers on degraded pastures in the region. With estimated rotation periods of 15-25 years and expected standing volumes of 250-300 m³/ha on harvesting, planting of these species is attractive for farmers. Fuelwood from thinning and pruning would be an additional source of farm income.

Training in technical aspects of forest management, ecotourism, and administration is needed in the initial phases of projects involving communal forestry practices.
Les premières étapes des projets comprenant des pratiques forestières communautaires nécessitent une formation sur les aspects techniques de la gestion forestière, l'écotourisme et l'administration.
Photo F. Montagnini.

Progeny test of *Vochysia guatemalensis*. The scheme will allow conversion of the trial plantation into a seed orchard at the end of the evaluation period.
Test de descendance de Vochysia guatemalensis. *À la fin de la période d'évaluation, le plan d'aménagement prévoit la conversion de cette plantation en verger à graines.*
Photo F. Mesén.

Domestication of native tree species

Over the last twenty years, CATIE has developed strategies to domesticate native species with potential reforestation value. Initially, many of the species used were not native to the Central American region. A stronger focus on native species has been developed at CATIE over the last ten years. Strategies for the domestication of native species include selecting outstanding or "plus" trees in natural forests, evaluating genetic variability, research on the rooting of young shoots, and establishing clonal trials and seed germination and storage trials, evaluating species performance under different silvicultural systems, and developing seed orchards for the production of genetically improved seeds. Examples of recent advances in the domestication of important reforestation species include studies on *Vochysia guatemalensis* Sm., J.D., a fast-growing timber tree, found naturally in the wet lowlands from southern Mexico to Panama (Mesén *et al.*, 1999). Similar work at CATIE with other native species is focusing on *Alnus acuminata, Cupressus lusitanica, Bombacopsis quinata, Albizia guachepele* and others (Cornelius, 1997; Cornelius, Mesén, 1997).

Clearing, weeding, site marking and tree planting make the initial stages of reforestation expensive. Government subsidies are needed to cover the initial stages of projects to encourage small farmers to undertake reforestation projects.
L'abattage, le nettoyage, le marquage et la plantation rendent coûteuses les premières étapes du reboisement. Afin d'encourager les petits fermiers à entreprendre des opérations de reboisement, des subventions gouvernementales sont nécessaires.
Photo F. Montagnini.

Conclusions

There are several ways of implementing more environmentally-friendly forest management systems. For the systems to be successful, they need to be designed with due consideration for the actual technical and economic capabilities of local users or managers. They also have to be designed in accordance with their function in the ecology of the surrounding landscape.

The projects described in this article have a number of characteristics in common:

- they involve production systems that are designed in accordance with local human needs;
- they are intended to be financially attractive to local farmers;
- they are attuned to the prevailing social systems in each region (sometimes involving communal systems or cooperatives);
- they try to reconcile production with biodiversity conservation or restoration;
- they aim to make use of local biodiversity, including non-timber forest products, by designing diversified forest management systems;
- whenever possible, they make use of native species;
- they include strategies to restore degraded ecosystems;
- they make use of the existing legal system (forestry or environmental legislation);
- in turn, the projects aim to advise or modify the local legal system regarding such policies.

These characteristics identify such projects as "environmentally friendly", although we are not advocating them here as the only possibilities for systems of this type. Under different ecological, social or economic conditions, other characteristics may appear as more important for environmentally-friendly forestry systems.

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Vochysia guatemalensis has been studied at CATIE and other institutions in Central America, and farmers are willing to plant it because of its fast growth and consistent response.
Le Catie ainsi que d'autres institutions en Amérique centrale ont mené des études sur Vochysia guatemalensis. *Les fermiers sont favorables à son utilisation en raison de sa croissance rapide et de sa productivité.*
Photo F. Montagnini.

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Manual clearing reduces site damage and increases chances of survival of newly planted trees in reforestation projects.
Dans les projets de reboisement, le nettoiement par la coupe à blanc manuelle réduit les dommages infligés aux sites et accroît les chances de survie des arbres nouvellement plantés.
Photo F. Montagnini.

Synopsis

SYSTÈMES FORESTIERS ÉCOLOGIQUES EN AMÉRIQUE CENTRALE

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La variété des pratiques forestières peut considérablement amoindrir les conséquences de l'aménagement des forêts sur la biodiversité, rendant cette gestion compatible avec le principe de rendement soutenu et la préservation de la biodiversité. Afin de rendre ces pratiques plus « écologiques », les programmes de gestion sylviculturale se sont concentrés sur la réduction des dommages forestiers en diminuant l'intensité de l'exploitation et en améliorant ses pratiques. Nous présentons ici des exemples de recherches en aménagement durable des forêts effectuées par le Centre agronomique tropical de recherches et d'enseignement (Catie) situé à Turrialba, au Costa Rica. Ces études comprennent l'utilisation de produits forestiers autres que le bois et la mise en valeur des services écologiques rendus par les forêts. Par ailleurs, elles envisagent des stratégies de récupération d'écosystèmes dégradés, y compris le reboisement à partir d'essences locales. Les études ici décrites font partie de programmes plus larges visant à élaborer de nouvelles techniques de gestion forestière durable.

Pertinence économique et écologique de la gestion forestière

Au Catie, la recherche à long terme s'est concentrée sur les technologies de gestion durable des forêts tropicales et leur biodiversité. À partir d'études sur la faisabilité économique et les conséquences sur la biodiversité, il a été établi qu'au moins 30 ha et 10 à 15 m³ par hectare devraient être exploités pour rendre cette gestion économiquement attractive. Les traitements post-abattage améliorent l'accroissement, en particulier en ce qui concerne les essences commerciales. L'exploitation fondée sur des techniques de gestion durable permet une meilleure régénération des plants et une plus grande biodiversité des strates inférieures que l'exploitation conventionnelle. L'exploitation forestière affecte la diversité végétale de différentes façons et sur des périodes variées, mais aucun changement profond n'a pu être mis en évidence durant le premier cycle d'abattage, même dans des peuplements dont la structure a été altérée par des traitements d'amélioration ou de dégagement. L'appauvrissement faunistique et les bouleversements du microenvironnement forestier peuvent aussi affecter l'ensemencement naturel et la germination.

Les chercheurs du Catie sont également impliqués dans l'étude de plans d'exploitation forestière diversifiée, comme, par exemple, l'écologie et l'exploitation de produits forestiers non ligneux ou l'évaluation de services écologiques rendus par les forêts. Nombre de ces pratiques d'exploitation conviennent aux petits exploitants, aux coopératives ou aux utilisateurs des forêts d'État. Certaines coopératives au Costa Rica exploitent les forêts dans une perspective écotouristique, tirant des revenus de produits autres que le bois d'œuvre, tout en cultivant des parcelles arables et en reboisant les terres dégradées avec des essences indigènes ou exotiques, souvent dans des plantations mixtes.

Productivité et faisabilité de plantations d'essences indigènes pures ou mixtes

Les plantations tropicales sont en mesure de fournir du bois d'œuvre, de contribuer à la production de carbone, à la restauration des terres et à l'accélération de la régénération naturelle. Les chercheurs du Catie ont identifié les essences indigènes et exotiques les plus prometteuses pour le reboisement par les petits agriculteurs des zones pastorales dégradées des basses terres du Nicaragua, du Costa Rica, du Honduras, du Guatemala, du Salvador et du Panama. Au Costa Rica, la législation encourage toute nouvelle plantation, en particulier sur les zones pastorales abandonnées.

La diversification des essences offre maints avantages du fait des incertitudes sur les performances de certaines essences, de la rareté de certains plants ou des risques de dommages par les ravageurs. Par ailleurs, s'ils sont bien planifiés et gérés, les systèmes forestiers mixtes peuvent se révéler plus productifs que les systèmes monospécifiques. Depuis plus de dix ans, les chercheurs du Catie étudient la croissance, la productivité, la production de biomasse et les aspects économiques à partir de plantations expérimentales d'essences indigènes, en peuplements purs ou mélangés, à la station biologique de La Selva, située dans les plaines humides de la côte atlantique du Costa Rica. Des douze essences testées, celles qui ont obtenu les meilleurs résultats (*Vochysia guatemalensis, V. ferruginea, Hieronyma alchorneoides, Calophyllum brasiliense, Terminalia amazonia, Virola koschnyi*) sont désormais régulièrement utilisées par les fermiers pour reboiser les zones pastorales dégradées de la région. Avec des temps de révolution estimés de 15 à 25 ans et des volumes de coupe attendus de 250 à 300 m³/ha, la plantation de ces essences offre un attrait certain pour les fermiers.

La domestication d'essences prometteuses pour ces plantations implique la sélection d'arbres de première valeur, l'évaluation de la variabilité génétique, le stockage et la germination des semences, l'évaluation des performances des essences sous divers systèmes sylviculturaux et le développement de pépinières pour la production de semences génétiquement améliorées.

Les projets décrits dans cet article font appel à des systèmes de production définis en accord avec les aspirations de la population locale. Ils se veulent financièrement attractifs pour les paysans et en harmonie avec le système social qui prévaut dans les régions concernées, impliquant parfois des fonctionnements communautaires ou coopératifs. Ils concilient les besoins productifs et la conservation de la biodiversité sur laquelle ils s'appuient, sans exclure les produits forestiers autres que le bois, diversifiant ainsi les plans d'aménagement forestier. Chaque fois que c'est possible, ils font appel à des essences indigènes. Pour la récupération d'écosystèmes dégradés, ces projets incluent toute une gamme de stratégies et ils s'appuient sur le système légal en vigueur (législation forestière ou environnementale). Ils peuvent conseiller les acteurs de ce système légal local, voire l'amender.

Les possibilités d'aménagement forestier écologique sont nombreuses. Les plans mis en place doivent tenir compte des capacités techniques et économiques réelles des acteurs locaux. Enfin, ils doivent aussi prendre en compte l'impact qu'ils peuvent avoir sur l'écologie des paysages environnants.