KURÚ
→Revista Forestal

Kurú: Revista Forestal (Costa Rica) 3(8), 2006

ARTÍCULO CIENTÍFICO

Application of a timber extraction vulnerability index in a Humid Tropical Forest

Oscar J. Valverde B.[1]

Abstract

Although there is an increasing concern about the suitability of timber extraction in tropical forests, the vulnerability of tree populations to logging has been scarcely assessed. In an attempt to improve the management of natural forests in the Caribbean lowlands of Costa Rica, I developed a vulnerability index considering ecological and socio-economical traits for 60 timber species consumed in local markets. In addition, I compared the timber harvest and economical profit between the traditional forest extraction scenario and the proposed assessment, which included harvest reduction for vulnerable and highly vulnerable species. The analysis of the species' ecological traits demonstrated that the floristic composition in the study area had a higher proportion of dioecious species than previous estimations in the area. Most of the tree species depend on vertebrates for seed dispersal and open areas for establishment. Most of them had a large geographic distribution with only eight endemic species to Costa Rica and only ten species qualified as highly-valuable wood. The assessment characterized 31 species as vulnerable and seven as highly vulnerable to timber extraction. Lower harvest rates for vulnerable species and no extraction for the highly vulnerable group would mean 16% reduction of the timber harvest in comparison with the traditional approach but almost 40% decrease on the net profit, highlighting the importance that vulnerable species have in forest management profitability.

Key words: Biological conservation, Tropical forest management, Timber production, Tree populations.

Resumen

Aplicación de un índice de vulnerabilidad en la extracción de madera en bosques húmedos tropicales. Si bien existe una preocupación creciente sobre la sostenibilidad de la extracción de madera en bosques tropicales, la vulnerabilidad de las poblaciones de especies de árboles a estas operaciones ha sido escasamente evaluada. Con el fin de mejorar el manejo de bosques naturales en las tierras bajas del Caribe de Costa Rica, se desarrolló un índice de vulnerabilidad a la extracción forestal, considerando rasgos ecológicos y socio-económicos de 60 especies de árboles utilizados comercialmente en los mercados locales. Además se comparó la rentabilidad de las operaciones tradicionales de madereo con el método propuesto. Este método incluye una disminución en el volumen de corta de árboles de especies vulnerables y altamente vulnerables según el índice propuesto. El análisis de los rasgos ecológicos de las especies encontradas en el área de estudio, indica que el número de especies dioicas es más alto de lo calculado en estudios

[1] Iowa State University, oscarval@iastate.edu

previos. La mayoría de las especies de árboles dependen de vertebrados para la dispersión de semillas y requieren áreas abiertas para su establecimiento. Muchas de las especies tienen un rango de dispersión geográfica alto, pero se encontraron 8 especies endémicas de Costa Rica, y se determinó que sólo 10 de ellas poseen madera de alto valor. La evaluación identificó 31 especies vulnerables y 7 como altamente vulnerables. Al disminuir la tasa de aprovechamiento de las especies vulnerables, y al no extraer especies altamente vulnerables, se obtuvo una disminución del 16% del volumen aprovechado, en comparación con un aprovechamiento tradicional, pero una disminución del 40% en la rentabilidad del aprovechamiento. Este resultado muestra la importancia de las especies vulnerables en la rentabilidad del manejo forestal de bosques húmedos tropicales como el evaluado.

Palabras clave: Biología de la conservación, Manejo de bosques tropicales, Producción forestal, Poblaciones de especies arbóreas

INTRODUCTION

Selective logging has been the most frequently employed method for timber extraction in tropical forests. Studies evaluating the effects of this technique on forest biodiversity and ecological dynamics are contradictory (McRae, 1997; Bawa & Seidler, 1998). Some authors denounced the remarkable negative effects such as the loss of valuable species, large canopy gaps, and increase in non-commercial populations (Uhl and Vieira, 1989; Johns *et al.,* 1996; Delgado *et al.,* 1997; Putz *et al.,* 2000; Pélisser *et al.,* 1998; Guariguata *et al.*, 2002). On the other hand, some studies suggested that disturbances maintain tree diversity and increase wood stand production (Toumela *et al.,* 1996; Webb, 1997; Panfil & Gullison, 1998; Magnusson *et al*., 1999; Molino and Sabatier 2001).

Most of the information about tropical forest logging impacts is based on evaluations after extractions and the assessment of a species' suitability before logging is rarely considered in most cases. Nevertheless, such a requirement is considered fundamental for the long-term sustainability of the activity (Lindenmayer *et al.,* 2000; Ghazoul, 2001). Martini *et al.* (1993) and Pinard *et al.* (1999) defined timber species' vulnerability to logging for Amazon forests regarding tree abundance, ability to withstand fire, regeneration abundance, susceptibility to liana invasion, adaptability to gaps and broadness of geographic range. They found that nearly 13% of 305 Amazonian timber species have some degree of vulnerability. Even so, their methodology included a higher sampling effort and additional measurements, which made the methodology rarely implemented in extraction practices (Putz *et al.,* 2000).

Market requirements have been rarely mentioned as an important factor defining forest vulnerability to timber activities. However, the final consumer market targeted may imply contrasting effects of logging activities in the forest structure and floristic composition (Macedo and Anderson, 1993). In general, moderate alteration by logging had been reported in forests providing raw materials to international markets, which are focused on few species and extracted under high logging standards (Withman *et al.*, 1997; Webb, 1997, 1999). On the other hand, timber practices at local scales remain poorly controlled and usually associated with higher rates of harvest, larger number of species exploited and stronger alterations in forest structure and tree regeneration (Uhl and Vieira, 1989; Macedo and Anderson, 1993). Considering that most of the timber demand from tropical forests is consumed in local or national markets (FAO, 1999), the necessity to develop new approaches evaluating timber species vulnerability to logging at local scales is evident.

This study is a first attempt to develop a vulnerability index for humid tropical forests located in the

Caribbean lowlands of Costa Rica. The objective of this study was to create a comprehensive evaluation of the species' potential to recover from logging activities in an altered forest located in the southern Caribbean lowlands of Costa Rica. This assessment included ecological traits as well as the market demand for every commercial species identified in the study area (Table 1). In addition, I compared timber volume, extraction costs and potential economical profit between this methodology —with the possible limitations related to species vulnerability— and the maximum potential harvest allowed by the traditional forest management plans required in Costa Rica.

Table 1. Ecological characteristics used to determine species vulnerability to timber extraction in the Caribbean lowlands of Costa Rica.

Characteristics	**Score**			
	1	**2**	**3**	**4**
Sexual classification	Dioecious (Obligated out breeding)	Monoiceous and hermaphroditic (Potential inbreeding)	-	-
Dispersion system	Self or wind dispersion	Endozoochorus	Dyszoochorus	-
Abundance	Minimun to first quartile (0.01-0.44 ind/ha)	First quartile to median (0.45-0.89 ind/ha)	Median to third quartile (0.90-2.44 ind/ha)	Third quartile to maximum (>2.44 ind/ha).
Seedling ecology	Large seeds (> 3 g). Cryptocotylar germination Reserve cotyledons	Medium-big seed (1.5-3 g). Epicotylar germination Reserve cotyledons	Medium-small seed (1.5-0.5 g). Epicotylar germination Foliaceous cotyledons	Small seed (<0.5 g). Epicotylar germination Foliaceous cotyledons
Geographic range	Endemic to Costa Rica	Humid forest of the Atlantic Isthmus	Central American Broadleaf Tropical Forest	Neotropical distribution
Market status	Very fine wood	Hard wood	Semi-hard wood	Soft wood

STUDY SITE

The study was conducted at the La Guacamaya farm, next to the Gandoca Manzanillo Wildlife Refuge, in the southern Caribbean lowlands of Costa Rica (9°35'30"N; 82°40'43"W). The area is classified as a humid tropical forest with 2200-2750 mm of annual rainfall, temperature ranging between 24-27°C, and located between 60-120 m of elevation (Herrera 1985). The study area is a 117 ha forest, with approximately 92 ha classified as suitable for logging. The productive area included well-drained foothills with medium to steep slopes as well as river terraces, most of which were selectively logged during the early 1980's. Previous logging activities focused on highly valuable species such as *Cedrela odorata*, *Cordia alliodora* and *Terminalia amazonia.* Unfortunately, there are no official records for previous extractions. Dominant species in the study area are *Iriartea deltoidea* (Arecaceae) and *Hura crepitans* (Euphorbiaceae) as canopy species and *Calatola costaricensis* (Icacinaceae) as midstory tree (Table 2).

Table 2. Basal area, abundance for the 10 most common species found in a humid tropical forest located in the Caribbean lowlands of Costa Rica.

Species	Family	Basal area		Abundance	
		(m^2ha^{-1})	%	(Nha^{-1})	%
Iriartea deltoidea Ruiz & Pav.	Areceaceae	2.60	6.98	76.40	14.29
Hura crepitans L.	Euphorbiaceae	2.78	7.47	7.20	1.35
Calatola costaricensis Standl.	Icacinaceae	0.87	2.34	28.00	5.24
Virola multiflora (Standl.) A.C. Sm.	Myristicaceae	1.80	4.84	10.80	2.02
Carapa guianensis Aubl.	Meliaceae	1.42	3.82	12.00	2.24
Cecropia obtusifolia Bertol.	Cecropiaceae	0.93	2.50	18.00	3.37
Mortoniodendron anysophyllum (Stand.) Stand. & Steyerm.	Tiliaceae	1.02	2.74	12.00	2.24
Otoba acuminata (Standl.) A. H. Gentry	Myristicaceae	0.75	2.01	14.40	2.69
Socratea exorrhiza (Mart.) H. Wendl.	Arecaceae	0.74	2.00	14.40	2.69
Poulsenia armata (Miq.) Standl.	Moraceae	1.21	3.24	8.80	1.65
Other 160 spp		23.12	62.03	332.80	61.95

Data were collected during February-May of 2002 fulfilling the required procedures for forest management plans in Costa Rica (CNCF, 1999). Fifteen 30 × 100 m plots were established randomly across the productive area in order to measure abundance of all individuals ≥ 10 cm diameter at breast height (dbh) following the methods recommended by Dallmeier *et al.* (1992). A detailed commercial survey and tree mapping was performed subsequently, locating all commercial trees (individuals of species accepted in the local market ≥ 60 cm dbh) in a geographic information system (GIS). I assigned a unique number in a serial numeration for each tree and determined species identity, dbh, and commercial height. Metal identification tags were located on the tree stump in order to identify harvested trees after cutting.

CHARACTER SELECTION

I compiled information about mating system, dispersion vectors, population abundance, geographic range, seedling ecology and establishment requirements, and commercial categorization for every tree species considered as commercial in the locality. Every trait was evaluated according to the categories identified, using 1 as the value for the more vulnerable condition (Table 1). Sexual system, dispersal modes and seedling requirements were compiled mainly from Chazdon *et al*. (2003), Kang and Bawa (2003), Hartshorn and Hammel (1994), and Foster and Janson (1985). For mating systems I defined dioecious species as more vulnerable to selective logging because of their higher likelihood of becoming isolated reproductive individuals and consequently lower vitality in seed production (Johns, 1992; Nason *et al.,* 1997; Rocha and Aguilar, 2001).

For dispersal systems I considered wind-dispersed and autochorous species as favoured by logging alterations. Several authors (e.g. Augspurger, 1984; Ingle, 2003) have demonstrated that species with wind-dispersed seeds could establish faster than vertebrate-dispersed species in forest gaps or secondary succession. Among animal-dispersed species, however, dispersal success varies substantially between endozoochorus and dyszoochorus species (i.e. swallowed and non-swallowed seeds respectively), especially those related to bird dispersal (Herrera *et al*., 1998). Therefore, I subdivided animal-dispersed species in these two categories (Table 1), assigning the highest value to the dyszoochorus group.

Species abundance is the most frequently considered parameter to determine harvest rates in tropical forests (Lamprecht, 1990). Several authors (e.g., Bawa and Seidler, 1998; Pélissier *et al.,* 1998) determined that scarce species are more likely to disappear in logging-altered tropical areas than abundant species, which usually keep or enhance their dominance. Moist tropical forests are characterized by local species scarcity and uneven distribution (Hubbell and Foster, 1986). For instance, Terborgh *et al.* (1999) found that 88% of 825 species had densities ≤ 1 tree ha^{-1} in a Peruvian Amazonian basin. They also highlighted the asymmetric distribution of most species and suggested the use of nonparametric statistics to describe tropical tree populations at local scales. Thus, I used abundance distribution as a vulnerability indicator and considered quartiles as the proper subdivision to assess vulnerability. Species whose abundance fit in the first quartile received a value of one, those between the first quartile and the median received two, between the median and the third quartile received three and the third quartile and up a four.

Geographical range is also a common factor used to determine species risk of disappearing from the ecosystem (Guevara and Siebert, 2001). Widely distributed species are considered less vulnerable to the extinction risk than very restricted species (Hubbell and Foster, 1986). Usually, timber species have low abundance but large ranges of distribution (Terborgh *et al.,* 1999; Berry, 2002), although endemism is influenced by the scale reference (Gentry, 1986). I used the Latin America eco-regions map provided by Dinerstein *et al.* (1995) to describe the species' geographical distribution. I considered species with Neotropical distribution (from South America to Mexico) as the non-vulnerable group; species in the Central American Broadleaf Tropical Forest (from Mexico to the north of Colombia and Ecuador) as the low-vulnerability group followed by species of the Humid Forest of the Isthmus eco-region (Nicaragua, Costa Rica and Panama.) and finally the endemic species to Costa Rica or restricted to Sixaola river basin as the most threatened group.

Seedling ecology was the last ecological trait considered. Regarding the scarce information about specific seedling light requirements for each identified species, I considered the described correlations among seed mass weight, germination and cotyledon type to estimate possible seedling light requirements and potential guilds among species (Foster and Janson, 1985; Clark *et al.,* 1993; Guariguata, 1998; Guariguata, 2000; Zanne *et al*., 2005). Species with heavy seeds (> 3 g dry weight), cryptocotilar germination and reserve cotyledon (i.e. thick non-photosynthetic cotyledons) were considered the shade tolerant group whereas species with small seeds, epicotilar germination and foliaceous cotyledons were considered the light dependent group (Table 1). Previous reports showed that regeneration of light-demanding species increases after timber extractions in tropical forests (Molino and Sabatier, 2001). So, I assumed that small-seeded species associated with disturbance would be less vulnerable to timber extractions (Table 1).

Economic categorization was the final factor assessed. Wood status in the Costa Rican market is highly variable. Nevertheless, it is possible to define a species series according to market classification and price (Herrera, 2002). I assigned the lowest vulnerability value to those species with low market values (< US$-15/$m^3$) used mainly in banana platforms for exportation package and referred locally as 'soft wood'; two was given to species denominated as 'semi-hard wood', which are used for rustic construction with prices ranging from US$15-25/$m^3$. Species considered as 'hard wood' reached the best prices (US$25-45/$m^3$) as well as higher demand in local markets. Finally, species reaching the highest values (>US$50/$m^3$) were those considered as very fine in the national market and usually associated with threatened populations (Jiménez, 1999).

I considered population abundance and reproductive-dispersion conditions as variables directly related to local conditions of the forest whereas geographic range, seedlings light ecology and commercial demand were external variables (i.e. variables unrelated to local conditions). Data for each category was summarized and multiplied by 0.5. Then, the two categories were added and used for the species vulnerability ranking. Species with vulnerability values > 8 were considered highly vulnerable (HV); values between 6 and 8 were defined as vulnerable species (V); low vulnerability species (LW) had values between 4 and 5.9; and non-vulnerable species (NV) with values < 4.

Harvest restrictions consisted of allowing 40% as the maximum volume to harvest on vulnerable species and no extraction for the highly vulnerable group whereas the low vulnerability and non-vulnerable species would be extracted at the same rate allowed by the traditional approach. This restricted scenario was compared with the traditional 60% of the total commercial volume, for any species, allowed by law in Costa Rican natural forest extractions. Information about field extraction costs and wood prices was taken from Herrera (2002), Amaral *et al.* (1998), and local consultation. Costs of timber extraction and transportation were made assuming the local rates for machinery rent, a crew of four persons working four weeks and the transportation cost toward a lumberyard located 180 km away from the farm.

RESULTS

A total of 170 species ≥ 10 cm dbh were found in the study plots, of which 60 species were classified as commercial. *Iriartea deltoidea* (Arecaceae) was the most abundant species in the forest, while *Hura crepitans* showed the largest basal area. The ten dominant species represented more than 37% of total basal area and 38% of abundance (Table 2). *Hura crepitans*, *Carapa guianensis* and *Virola multiflora* were the most important commercial species, representing more than 16% of the basal area.

Dioecious species encompassed 43% of the tree diversity in the forest, with Myristicaceae and Moraceae being the most diverse families. This value is higher than the 23% reported by Kang and Bawa (2003) for tree species in the Costa Rican Caribbean forests but is consistent with the increase in dioecious species found by Chazdon *et al*. (2003) in altered forests of the region. Seed dispersion associated with vertebrates was the most common vector system (85%), of which 35 were endozoochorus and 16 dyszoochorus. Only 9 (15%) had a wind or self dispersed system. Species distribution showed that 45% of analyzed species had less than 0.4 trees ha^{-1} while 18% had more than 2.5 trees ha^{-1} (Table 3). These findings agree with tendencies found by Chazdon *et al.* (2003) for altered forests in the same region.

Table 3. Number of timber species for six different categories (percentage between parentheses) used to define a logging vulnerability index for commercial species in a humid tropical forest in the Caribbean lowlands, Costa Rica. Scores assigned according to definitions are in table 1.

	Category			
	1	**2**	**3**	**4**
Sexual system	34 (57)	26 (43)	-	-
Dispersion system	16(26.7)	35 (58.3)	9 (15)	-
Population abundance	11 (18.3)	9 (15)	13 (21.7)	27 (45)
Geographic range	22(37)	14 (23)	16 (27)	8 (13)
Seedling ecology	14 (23)	21 (35)	15 (25)	10 (17)
Commercial demand	9 (13)	18 (30)	24 (40)	10 (17)

The geographic distribution was large for a substantial proportion of the species. Thirty-two species (60%) had a Mesoamerican or Neotropical distribution while only 8 (13%) were endemic to Costa Rica. Most of the species (58%) had small seeds with epicotylar germination, which suggests that most species depend strongly on canopy gaps for their reestablishment. In fact, some of the species are recognized as pioneers on heavily altered lands such as *Rollinia pittieri* (Annonaceae) and *Cordia alliodora* (Boraginaceae) (Guariguata, 2000). On the other hand, 24 tree species were classified as shade-tolerant, most of them belonging to the Myristicaceae and Sapotaceae. Important timber species such as *Carapa guianensis*, *Brosimun spp* and *Manilkara spectabilis* were included in this category.

This abundance of shade intolerant species may also explain the scarcity of valuable species in this forest. As much as 43% of the species were classified as soft or semi-hard wood (US\$15-25/m^3) and furnished almost 80% of all the commercial volume in the forest. Only ten species had values higher than \$50/m^3 (fine wood), which encompassed 16% of all commercial wood in the forest (Figura 1). This overabundance of 'soft wood' species seems an indicator of the previous extraction episode effect on the floristic composition. High demand species such as *Cedrela odorata* and *Terminalia amazonia* had adult individuals only in protected areas with almost no regeneration, whereas the abundance of disturbance-indicators such as *Cecropia obtusifolia* and *Trema integerrima* was higher than previous values reported in the area (Hartshorn and Hammel, 1994; Delgado *et al*., 1997).

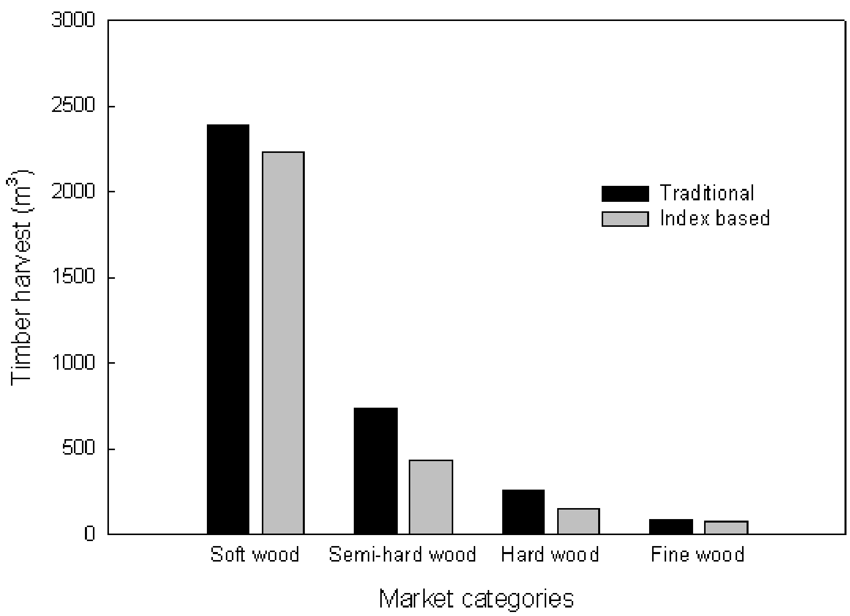

Figure 1. Possible timber harvest according to local market categories in a humid tropical forest in the Caribbean lowlands of Costa Rica. The comparison was made considering the total volume to extract following a traditional forest management plan and the possible harvest based on the species vulnerability to logging.

Scores for the vulnerability index ranged from 3.7 to 10 (mean = 6.4 ± 1.3 SD; n = 60). The scores had a normal distribution (Shapiro Wilk test, t = 0.967, P = 0.23) concentrating 32 species in the vulnerable group. Low vulnerability grouped 19; high vulnerability had seven and only *Hura crepitans* and *Poulsenia armata* (Moraceae) were qualified as non-vulnerable (Figure 2). The high vulnerability group included four endemic species (*Abarema barbouriana, Buchenavia costaricensis, Guettarda turrialbana* and *Styphnolobium aff sporadicum*) and three scarce and high valued species (*Dipteryx panamensis, Manilkara spectabilis* and *Sacoglottis trichogyna*). *Styphnolobium aff sporadicum* is a non-described species probably restricted to the Gandoca-Manzanillo Refuge area and previously misidentified as *Terminalia amazonia* in the region (N. Zamora, Heredia, Costa Rica, Instituto Nacional de Biodiversidad, personal communication).

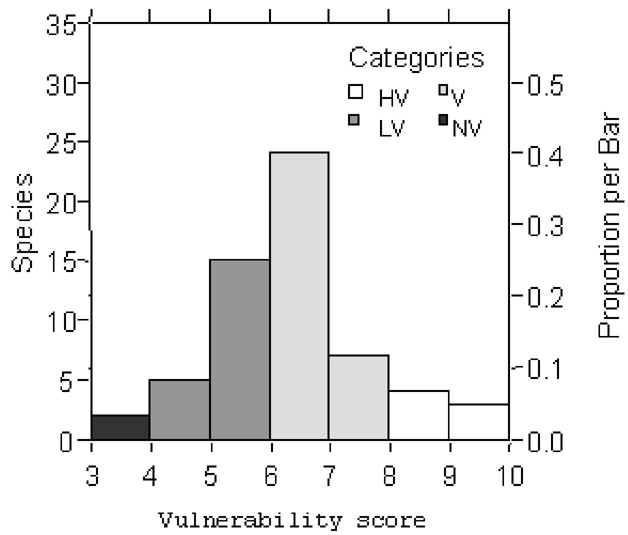

Figure 2. Distribution of the vulnerability index scores for 60 timber species assessed in a humid tropical forest in the Caribbean lowlands of Costa Rica. Higher scores represent higher species vulnerability. Acronyms: HV= high vulnerability; V=vulnerable; LV= low vulnerability; NV= non-vulnerable

Harvest restrictions applied to the high vulnerability and vulnerable groups did not significantly change the proportion of harvest extraction among categories (Contingency table test; $\chi^2 = 11.09$, $P = 0.26$; Figura 1). Soft wood was the dominant category in both scenarios with 68 and 77% of the total harvest for the restricted and traditional scenario respectively. Semi-hard and hardwood species accounted for 21 and 15%, with a decrease in the index scenario related to the protection of *Dipteryx panamensis* and *Manilkara spectabilis* trees (Table 4). The protection of those species, which accounted for 444 m^3 of timber (i.e. 14% of the total harvest based on the traditional scenario), would account for approximately 40% of the potential profit (Table 4).

Table 4. Comparison of two potential extraction scenarios for logging activities in a humid tropical forest in the Caribbean lowlands, Costa Rica. The traditional scenario considered as harvestable 60% of all commercial volume regardless species. The vulnerability index scenario considered extraction volume according with species vulnerability to extraction (see text for details). Budget according to local market costs and timber values during 2003.

	Traditional scenario	Vulnerability index scenario	Difference (%)
Total timber production (m^3)	3 469.28	2 893.80	16.59
Timber value on field (US$)	7 8920.69	5 5313.38	29.91
Harvesting and transportation cost (US$)	75 399.12	62 891.88	16.59
Timber value on timber yard (US$)	212 967.06	152 700.19	28.30
Net profit for timber logger (US$)	58 647.24	34 494.93	41.18

DISCUSSION

The aim of this study was twofold: (1) to identify a timber stand management classification system appropriate for the commercial species in a Costa Rican forest based on ecological traits and market demands and (2) to evaluate the compatibility of this recommended system with the traditional approach applied in the country. Based in our results, vulnerability to timber extraction is variable among species with most species (65%) showing some degree of vulnerability and 11% classified as highly vulnerable to extractions.

Forest management has been primarily concerned with timber production and has neglected to maintain the forest's primary functions necessary to assure its continual production (Silver *et al*., 1996; Bawa and Seidler, 1998). The ecological classification presented in this study attempted to identify specific key points that increase the criteria associated with the selective logging system. Findings such as the increase of dioecious species, the overabundance of high light-demanding species, and the restriction of some valuable species to isolated individuals in protected areas, indicated that previous selective extractions depleted the high-value timber species and that those populations were unable to overcome this impact after nearly two decades of recovery. Based on these findings, lower harvest rates and protection for vulnerable species seem to be an appropriate condition to ensure the permanence of the biodiversity in the forests.

However, such conditions could discourage investments of traditional loggers in forest management practices. For instance, most of the 16% decrease on timber production using the recommended restrictions would focus on two sensible species that encompass nearly 40% of the net profit in the activity. Evidently, higher harvest rates on those valuable species would mean higher incomes despite the disappearance of such species from the ecosystem. Unfortunately, ecological sensibility is commonly underrated from the timber producer's perspective (Pélisser *et al.,* 1998; Ghazoul, 2001). Balance between conservation and economical interest in tropical forest production must be a priority in suitable management policies. Forest authorities and certification institutions must consider forest management policies focused on local markets and specific restrictions for endemic or vulnerable species. In addition, market demand should fit the actual forest supply, understanding that some species are not available for forest production, at least in the short term, with the current methodologies.

The classification of tree species in this study represents a first attempt at evaluating the Caribbean lowland forests in Costa Rica but it is, in some degree, based on surmise and only preliminary data. Particularly lacking are reliable data about mating systems, mammal dispersion and seedling light requirements. Moreover, the abundance values relied on only one farm previously altered, which limits conclusions about the actual abundance of some species in the area. Therefore, the scores do not represent an absolute value of vulnerability and must be interpreted as relative to the analyzed forests. Even so, the simplicity of the methodology and the relatively abundant information about basic ecological traits for most timber species makes this index a possible tool to incorporate in future evaluations. Furthermore, studies at larger scales will be necessary to determine to what extent small-scale studies such as this one are relevant to regional-scale forestry planning.

Finally, I realize that some variables, like forest fragmentation (Benítez-Malvido, 1998), seedling regeneration (Kuusipalo *et al.,* 1996), stand growth rates (Atta-Boateng and Moser, 2000), and animal communities (Ingle, 2003; Pinard *et al.,* 1999) are important factors to monitor after extractions. Although there is some information about these variables (see Guariguata, 2000 for a review), our knowledge about timber species dynamics in tropical areas and their relationship with other biological components in the forest is still limited. Long-term studies would be invaluable to determine how the vulnerability index would change through time among species and which factors are more important for the population's recovery. Meanwhile, forest managers will have to find ways to adhere to upcoming environmental regulations and address the public's concern about forest health.

ACKNOWLEDGEMENTS.

I acknowledge the Biological Corridor Talamanca Caribe and Mr. Omar Peraza for letting me use his property and providing a means of transportation. Fieldwork was performed with the assistance of Magaly Zúñiga, Noelia Zúñiga, Erick Castro, Gustavo Alvarado, and Jesús Villegas. I thank James Raich, Robin Chazdon, Pablo Arroyo, Henry Wilson, Christopher Tyrrell and Lynn Clark for the corrections and critical comments in the manuscript. This paper was funded by the UNPD/GEF program.

REFERENCES

Amaral, P; Verissimo, P; Barreto, A; Vidal, E. 1998. Bosque para siempre. Manual para la producción de madera en la Amazonia. Traducido por Marcia Imamoto. WWF-IMAZON-USAID. 162 p.

Ashquit, N. 2002. La dinámica del bosque y la diversidad arbórea. **In** Ecología y conservación de bosques neotropicales. Eds. M. Guariguata, G. Kattan. Editorial Tecnológica de Costa Rica. Cartago, CR. p. 377-406.

Atta-Boateng, J; Moser, JWJr. 2000. A compatible growth and yield model for the management of mixed tropical rain forest. Canadian Journal of Forestry Research. 30:311-323.

Augspurger, C. 1984. Seedling survival of tropical tree species: interactions of dispersal distance, light gaps and pathogens. Ecology. 65(6):1705-1712.

Bawa, KS; Seidler, R. 1998. Natural forest management and conservation of diversity in tropical forest. Conservation Biology. 12(1):46-55.

Benitez-Malvido, J. 1998. Impact of forest fragmentation on seedling abundance in a tropical rain forest. Conservation Biology. 12(2):380-389.

Berry, PE. 2002. Diversidad y endemismo en los bosques neotropicales de bajura. Pp 83-96. In: M. Guariguata and G. Kattan (ed). Ecología y conservación de bosques neotropicales. Editorial tecnológica de Costa Rica. Cartago, CR. p. 83-96.

Chazdon, RL; Careaga, S; Webb, C; Vargas, O. 2003. Community and phylogenetic structure of reproductive traits of woody species in wet tropical forests. Ecological Monographs. 73(3):331-348.

Clark, DA; Clark, DB; Rich, P. 1993. Comparative analysis of microhabitat utilization by saplings of nine tree species in neotropical rain forest. Biotropica. 25(4):397-407.

CNCF (Comisión Nacional de Certificación Forestal, CR). 1999. Estándares y procedimientos para el manejo sostenible y la certificación forestal en Costa Rica. CATIE. 54 p.

Dallmeier, F; Kabell, M; Rice, R. 1992. Methods for long-term biodiversity inventory plots in protected areas. **In** Long-term monitoring of biological diversity in tropical forest areas. Methods for establishment and inventory of permanent plots. Ed. F. Dallmeier. UNESCO. París, FR. 71 p.

Delgado, D; Finegan, B; Zamora, N; Meir, P. 1997. Efectos del aprovechamiento forestal y el tratamiento silvicultural en un bosque húmedo del noreste de Costa Rica. Unidad de manejo de bosques naturales.

Serie técnica No. 298. 55 p.

Dinerstein, E; Olson, D; Graham, D; Webster, A; Primm, S; Bookbinder, M; Ledec, G. 1995. A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean. WWF-World Bank. Washington D.C., USA. 116 p.

FAO (Food and Agricultural Organization, IT). 1999. State of the world's forest (en línea). Rome, IT. Disponible en http://www.fao.org/forestry/FO/SOFO/SOFO99/sofo99-e.stm

Foster, S; Janson, CH. 1985.The relationship between seed size and establishment conditions in tropical woody plants. Ecology. 66(3):773-780.

Gentry, A. 1986. Endemism in tropical versus temperate plant communities. **In** Conservation biology. The science of scarcity and diversity. Ed. MA. Sinauer Associates Inc., Sunderland, Massachusetts, USA. p. 153- 181.

Guariguata, M. 1998. Consideraciones ecológicas sobre la regeneración natural aplicada al manejo forestal. Colección Manejo Diversificado de Bosques Naturales No. 14. CATIE. Turrialba, Costa Rica. 27p.

Guariguata, M. 2000. Seed and seedling ecology of tree species in neotropical secondary forest: management implications. Ecological Applications. 10 (1):145-154.

Guariguata, M; Arias-Le Claire, H; Jones, G. 2002. Tree seed fate in a logged and fragmented forest landscape, northeastern Costa Rica. Biotropica. 34 (3):405-415.

Ghazoul, J. 2001. Barriers to biodiversity conservation in forest certification. Conservation Biology. 15(2):315-317.

Guevara, M; Siebert, S. 2001. The abundance and population structure of some economically important trees of Piedras Blancas National Park, Costa Rica. Brenesia. 55-56:69-80.

Hartshron, G; Hammel, B. 1994. Vegetation types and floristics patterns. **In** La Selva. Ecologycal and natural history of a neotropical rain forest. Ed. L. McDade, L. Univ. Chicago Press. Chicago, USA. 486p.

Herrera, W. 1985. Vegetación y climas de Costa Rica. Vol 2. EUNED. San José, Costa Rica. 118p.

Jiménez, Q. 1999. Árboles maderables en peligro de extinción en Costa Rica. 2ª ed. INBio-Sida. San José Costa Rica. 187 p.

Herrera, C; Jordano, P; Guitián, J; Traveset, A. 1998. Seed production by wood plants: reassessments of principles and relationship to pollination and seed dispersal. The American Naturalist. 152(4):576-594.

Herrera, M. (ed) 2002. Precios de Madera de Bosque para Costa Rica. Revista Desde el Bosque. Cámara Costarricense Forestal. Diciembre 2002.

Hubbell, S; Foster, R. 1986. Commonness and rarity in neotropical forest: implications for tropical tree conservation. **In** Conservation biology. The science of scarcity and diversity. Ed. MA. Sinauer Associates Inc., Sunderland, Massachusetts, USA. pp 205-231.

Ingle, NR. 2003. Seed dispersal by wind, birds and bats between Philippine montane forest and successional vegetation. Oecologia. 134:251-261.

Johns, AD. 1992. Species conservation in managed tropical forests. **In** Tropical deforestation and species extinctions. Eds. TC. Whitmore; JA. Sayer. Chapman and Hall. London, UK. p. 15-53.

Johns, JS; Barreto, P; Uhl. C. 1996. Logging damage during planned and unplanned logging operations in the Earsten Amazon. Forest Ecology and Management. 89:59-77

Kang, H; Bawa, K. 2003. Effects of successional status, habit, sexual system and pollinators on flowering patterns in tropical rain forest trees. American Journal of Botany. 90 (6):865-876.

Kuusipalo, J; Jafarsidik, Y; Ådjers, G; Toumela, K. 1996. Population dynamics of tree seedlings in a mixed dipterocarp rainforest before and after logging and crown liberation. Forest Ecology and Management. 81:85-94.

Lamprecht, H. 1990. Silvicultura en los trópicos. Alemania. GTZ. 335 p.

Lindenmayer, DB; Margules, CR; Botkin, DB. 2000. Indicators of biodiversity for ecologically sustainable forest management. Conservation Biology. 14(4):941-950.

Macedo, DS; Anderson, A. 1993. Early ecological changes associated with logging in an Amazon floodplain. Biotropica. 25(2):151-163.

Martini, A; Rosa, N; Uhl, C. 1993. Espécies madereiras: primera tentativa de avaliar a resistencia aos impactos de exploracao. Ciencia Hoje.16(93):11-13.

Magnusson, WE; de Lima, OP; Reis, FC; Higuchi, N; Ferreira-Ramos, J. 1999. Logging activity and tree regeneration in an Amazonian forest. Nº 113:67-74.

McRae, M. 1997. Is 'good wood' bad for forests? Science. 275:1868-1869.

Molino, JF; Sabatier, D. 2001. Tree diversity in tropical rain forests: a validation of the intermediate disturbance hypothesis. Science. 294:1702-1704.

Nason, J; Aldrich, P; Hamrick, JL. 1997. Dispersal and the dynamics of genetic structure in fragmented tree populations. **In** Tropical forest remnants. Eds. WF. Laurence; RO. Bierregard. University of Chicago Press. Chicago, USA. p. 304-320.

Panfil, SN; Gullison, RE. 1998. Short term impacts of experimental timber harvest intensity on forest structure and composition in the Chimanes Forest, Bolivia. Forest Ecology and Management. 102:235-243.

Pélissier, R; Pascal, JP; Houllier, F; Laborde, H. 1998. Impact of selective logging on the dynamic of a low elevation moist evergreen forest in the Western Ghats (South India). Forest Ecology and Management. Nº 105:107-119.

Pinard, MA; Putz, FE; Rumíz, D; Guzmán, R; Jardim, A. 1999. Ecological characterization of tree species for guiding forest management decisions in seasonally dry forest in Lomerío, Bolivia. Forest Ecology and Management. Nº 113:201-213.

Putz, FE; Dykstra, DP; Heinrich, R. 2000. Why poor logging practices persist in the tropics? Conservation Biology. 14(4):951-956.

Rocha, O; Aguilar, G. 2001. Reproductive biology of the dry forest tree *Enterolobium cyclocarpum* (Guanacaste) in Costa Rica: a comparison between trees left in pastures and trees in continuous forest. American Journal of Botany. 88(9):1607-1614.

Silver, W; Brown, S; Lugo, AE. 1996. Effects of changes in biodiversity on ecosystem function in tropical forests. Conservation Biology. 10(1):17-24.

Terborgh, J; Silman, MR; Nunez, P; Pitman, NCA. 1999. Tree species distributions in an upper Amazonian forest. Ecology. 80:2651-2668.

Toumela, K; Kuusipalo, J; Vesa, L; Nuryanto, K; Sagala, APS; Adjers, G. 1996. Growth of dipterocarp seedlings in artificial gaps: an experiment in a logged-over rainforest in South Kalimatan, Indonesia. Forest Ecology and Management. Nº 81:95-100.

Uhl, C; Vieira, IC. 1989. Ecological impacts of selective logging in the Brazilian amazon: a case of study from the Paragonias region in state of Pará. Biotropica. Nº 21:98-106.

Webb, EL. 1997. Canopy removal and residual stand damage during controlled selective logging in lowland swamp forest of northeast Costa Rica. Forest Ecology and Management. Nº 95:117-129.

Webb, EL. 1999. Growth ecology of *Carapa nicaraguensis* Aublet (Meliaceae): implications for natural forest management. Biotropica. 31 (1):102-110.

Whitman, AA; Browak, VLN; Hagan, JM. 1997. Forest damage caused by selection logging of mahogany (*Swetenia macrophylla*) in northern Belize. Forest Ecology and Management. 92: 87-96.

Zanne, AE; Chapman, CA; Kitajima, K. 2005. Evolutionary and ecological correlates of early seedling morphology in East Africa trees and shrubs. American Journal of Botany. 92(6):972-978.

Annex 1. List of species and classification for each trait considered developing a vulnerability index for commercial timber species in a humid forest in the Caribbean lowlands of Costa Rica. Categories NV = non-vulnerable; LV = low vulnerability; V = vulnerable; HV = high vulnerability.

Tree species	Family	Mating and dispersion system	Population abundance	Geog. range	Seedlings ecology	Com. demand	Index score	Cat.
Abarema barbouriana	Mimosaceae	2	4	4	3	4	8.5	HV
Brosimun alicastrum	Moraceae	4	2	2	2	3	6.5	V
Brosimun guianensis	Moraceae	4	3	1	2	3	6.5	V
Brosimun lactescens	Moraceae	4	2	1	2	3	6	V
Buchenavia costaricensis	Combretaceae	4	4	4	2	4	9	HV
Carapa guianensis	Meliaceae	3	1	1	4	4	6.5	LV
Cedrela odorata	Meliaceae	3	4	1	2	4	7	V
Ceiba pentandra	Bombacaceae	2	4	1	1	1	5.5	LV
Celtis schippi	Ulmaceae	2	3	2	2	1	6	LV
Chimarris parviflora	Rubiaceae	2	4	1	1	1	4.5	LV
Chloroleucum eurycyclum	Mimosaceae	2	3	2	4	4	7.5	V
Cordia alliodora	Boraginaceae	2	3	2	4	3	7	LV
Couepia polyandra	Chrysobalaneceae	4	1	3	1	3	6	V
Cynometra retusa	Caesalpinaceae	4	3	3	2	4	8	V
Dipteryx panamensis	Papilionaceae	4	4	3	3	4	9	HV
Dussia tessmanii	Papilionaceae	4	4	1	3	2	7	V
Eschweilera calyculata	Lecythidaceae	3	3	2	3	2	6.5	V
Ficus crassiuscula	Moraceae	3	2	2	1	2	5	LV
Ficus insipida	Moraceae	3	4	2	1	2	6	LV
Ficus sp	Moraceae	3	4	2	1	2	6	LV
Genipa americana	Rubiaceae	4	4	1	1	3	6.5	V
Guarea guidonea	Meliaceae	3	4	1	1	1	5	LV
Guettarda turrialbana	Rubiaceae	3	4	4	3	3	8.5	HV
Hernandia didymantha	Hernandiaceae	4	1	3	3	2	6.5	V
Hyeronima alchorneoides	Euphorbiaceae	4	3	1	1	3	6.5	LV
Hura crepitans	Euphorbiaceae	2	1	1	2	2	4	NV
Inga alba	Mimosaceae	4	4	1	2	3	7	V
Lacmellea panamensis	Apocynaceae	3	4	2	2	2	6.5	V
Lonchocarpus ferrugineus	Papilionaceae	2	4	1	2	3	6	LV
Manilkara sapota	Sapotaceae	4	4	2	3	4	8.5	HV
Mortoniodendron anysophyllum	Tiliaceae	3	1	3	2	1	5	LV
Trichilia sp	Meliaceae	4	4	3	2	3	8	V
Ocotea sp	Lauraceae	3	3	4	3	3	8	V
Ormosia macrocalix	Papilionaceae	2	4	3	2	3	7	V
Otoba acuminata	Myristicaceae	4	1	4	4	3	8	V
Otoba novogranatensis	Myristicaceae	4	1	1	4	3	6.5	LV
Pentaclethra macroloba	Mimosaceae	2	1	1	3	3	5	LV
Persea rigens	Lauraceae	3	1	3	3	3	6.5	V
Pleurothyrium sp	Lauraceae	4	4	4	3	4	8	V
Poulsenia armata	Moraceae	4	1	1	1	1	4	NV
Pouteria campechiana	Sapotaceae	5	4	2	3	2	8	V

Tree species	Family	Mating and dispersion system	Population abundance	Geog. range	Seedlings ecology	Com. demand	Index score	Cat.
Pouteria foveolata	Sapotaceae	5	2	1	3	2	6.5	V
Prioria copaifera	Caesalpinaceae	2	2	3	4	1	7.5	V
Pseudolmedia spuria	Moraceae	3	4	3	2	2	8	V
Pterocarpus hayesii	Papilionaceae	2	2	2	2	3	5.5	LV
Quararibea asterolepis	Bombacaceae	3	2	3	2	2	6	LV
Rollinia pittieri	Annonaceae	3	2	3	1	2	6	LV
Sacoglottis trichogyna	Humiriaceae	5	4	3	4	4	10	HV
Sloanea medusula	Elaeocarpaceae	3	4	3	2	2	7	V
Sloanea guianensis	Elaeocarpaceae	3	4	3	2	1	6.5	V
Sterculea allenii	Sterculiaceae	2	3	4	2	3	7	V
Styphnolobium sporadicum	Papilionaceae	4	3	4	3	2	9	HV
Symphonia globuliflora	Clusiaceae	3	4	1	3	3	7	V
Tapirira myriantha	Anacardiaceae	4	2	1	1	3	5.5	LV
Terminalia amazonia	Combretaceae	4	4	1	2	3	7	V
Trattinnickia aspera	Burseraceae	4	3	3	1	3	7	V
Virola koschnyi	Myristicaceae	4	3	2	4	2	7.5	V
Virola multiflora	Myristicaceae	4	1	2	4	2	6.5	LV
Virola sebifera	Myristicaceae	4	3	1	4	2	7	LV
Xilosma intermedia	Flacourtiaceae	4	4	1	1	3	6.5	V