FOREST
HARVESTING
CASE-STUDY

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Commercial Timber Harvesting in the Natural Forests of Mozambique

by
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FOREWORD

This case study is one of a series of publications produced by the Forest Harvesting, Trade and Marketing Branch of FAO in an effort to promote environmentally sound forest harvesting and engineering practices. The purpose of these studies is to highlight both the promise of environmentally sound forest harvesting technologies as a component of sustainable forest management, and the constraints that must be overcome in order to assure widespread adoption of those technologies.

The FAO Forest Products Division wishes to express its appreciation to the Forest Harvesting and Transport Branch of Eduardo Mondlane University, Maputo, Mozambique for its cooperation in the publication of this revised and translated version of a report on forest harvesting in the natural forests of Mozambique. The earlier, Portuguese-language version of the report was published in November 1999 under the title “Eficiência no Aproveitamento Comercial de Madeira em Toros”.

FAO and the author also wish to acknowledge the kind support given by the management and field staff of the companies ECOSEMA in the Province of Sofala, ÁLVARO de CASTRO in the Province of Gaza, MITI in the Province of Cabo Delgado, SOMANOL in the Province of Nampula, and ARCA as well as SRZ in the Province of Zambézia, throughout the implementation of this study.

The field studies and analyses described in this report were carried out by Henning Fath, until recently Docent of Forest Harvesting and Transport in the Faculty of Agriculture and Forestry at Eduardo Mondlane University under a GTZ/CIM-assignment, who also prepared the written report. FAO Forestry Officer Joachim Lorbach managed the preparation of the report for publication in the FAO Forest Harvesting Case-Study Series. Editing and final layout for publication were done by Dennis Dykstra.

SUMMARY

Forests that are potentially available for the production of timber in Mozambique cover 25% of the land surface. Low increment and reduced commercial timber stocks in repeatedly exploited areas restrict sustainable logging potential to 500,000 m^3 of commercial timber per year. Since current harvesting practices concentrate on few species covering just 20% of the productive forest area, timber volumes extracted tend to be close to, and in some cases are beyond, their sustainable harvest potential.

Forest industry in Mozambique, mostly composed of small-scale enterprises with production capacities below 2,500 m^3 per year, is considered to be a driving force for industrialization in rural areas. However, specific data verifying its performance are scant.

In order to establish information on the efficiency of commercial forest harvesting, the present study analyses five enterprises in northern, central, and southern Mozambique. Efficiency is evaluated by means of operational, organisational, energy, and financial indicators. Operational data were collected through time studies with continuous timing. Costs per machine-hour were calculated with the "Production and Cost Evaluation Programme – PACE" (FAO 1992). Intermediate results on output (log volume, travel distance) were then related to those on input (work-cycle time, tree volume, logged area, workforce, equipment, fuel consumption, costs per machine-hour), yielding indicators for operational efficiency (productivity, recovery rate, extraction intensity), organisational efficiency (labour productivity, utilisation rate, capital intensity), as well as for energy and for financial efficiency (unit costs, break-even point).

Logging operations, although well synchronised and productive within work cycles, occurred in a scattered and unsystematic scheme. Lack of harvest preparation, low recovery rates, and improper working techniques in felling and crosscutting resulted in low extraction intensity. Transport was the main bottleneck in operational efficiency. Poor road conditions and low load capacities of vehicles used in first (short-distance) transport and second (long-haul) transport prevented a consistent flow of raw materials and consequently held annual production volumes well below technological capacities.

As to organisational efficiency, only one enterprise showed favourable results in utilisation rate as well as in labour productivity and capital intensity. The other enterprises in the study, because of hampered raw-material flows, excessive numbers of personnel, and low timber potential in the logging areas, scored poor rates between timber output and input of equipment and workforce.

Indicators for energy efficiency in logging and first transport displayed favourable ratios between calorific values of produced timber and those of consumed energy. However, high fuel consumption and low productivity in second transport and processing precluded efficient energy use for the operations as a whole.

Financial efficiency varied depending on production volume, the degree of conversion of the final products, and the distance between the logging area and sawmill or sale site. Second transport and processing incurred the largest share of production costs per unit. In most cases low annual production volume and low productivity in transport and processing boosted unit costs and created pronounced deficits. Only one company managed to limit unit costs and create profit by efficiently employing machinery and workforce, producing on a comparably high volumetric level and externalising second-transport and processing costs to the buyer. Break-even points were in most cases beyond actual production volumes but still within limits of technological capacity. Due to higher prices obtained for finished products and lower transport costs, enterprises processing timber near the logging areas would have attained break-even point at a lower production level than those selling logs far from their origin.

As a consequence of operational and organisational impediments, production was extensive in terms of extraction volume and intensive as to workforce, energy, and capital. Results suggest that the efficiency of commercial timber harvesting, as it was practised under the conditions observed during this study, generates little or no benefit and hardly justifies extracting resources which should be considered precious and polyvalent assets for rural communities, the national economy, and the global biosphere. Recommendations from the study focus on raising extraction intensity through harvest preparation and optimised use of all available commercial species, and on reducing production costs by restricting transport distances and allocating processing units as close as possible to logging areas.

In order to guarantee operational, organisational, energy and financial efficiency, commercial timber harvesting should be confined to areas rich in commercially valuable tree species, and conducted by means of systematically structured and operationally optimised procedures. Further studies are required to verify whether more efficient logging practices would comply with standards on reduced environmental impacts and socio-economic performance.

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SYMBOLS, ACRONYMS, AND EXCHANGE RATE

Symbols

cm	centimetre
DBH	diameter at breast height
h	hour
ha	hectare
hp	horsepower (1 hp ≅ 0.7457 kW)
kW	kilowatt
kWh	kilowatt-hour
m	metre
m^3	cubic metre
min	minute
t	metric ton
yr	year

Acronyms

DNFFB	Direcção National de Florestas e Fauna Bravia (National Directorate for Forests and Wildlife), Maputo, Mozambique
INE	Instituto Nacional de Estatísticas (National Institute of Statistics), Maputo, Mozambique
MAP	Ministério de Agricultura e Pescas (Ministry of Agriculture and Fisheries), Maputo, Mozambique

Exchange rate applied (average for 1998-99)

US$ 1.00 ≅ 12,000 Meticais (Mt)

1. INTRODUCTION

A basic premise of the *FAO Model Code of Forest Harvesting Practice* (DYKSTRA & HEINRICH 1996) is that it is possible to conduct forest harvesting operations in ways that are consistent with the concept of sustainability. This requires that such operations do not compromise the forest's potential to regenerate properly and to yield products that are essential for the well being of both current and future generations. Consequently, timber resources must be utilised by means of efficient practices that comply, on the basis of clear legal regulations and adequate planning and control instruments, with all aspects of environmental and socio-economic sustainability.

The natural forests of Mozambique, although vast and rich in biodiversity, are dominated by low stocking levels of commercial timber species and low increment of wood biomass. The scattered distribution of timber resources particularly affects commercial harvesting by imposing long access distances. With increasing distance, harvesting and transport costs progressively dissipate the resource's in-situ value up to a point where commercial use is economically no longer feasible (HYDE *et al.* 1996). Addressing socio-economic sustainability of natural-forest management in the tropics, PRETZSCH (1997) suggests an inductive approach by means of case studies in order to verify its performance.

Timber production in Mozambique is considered to be a driving force for industrial development in rural areas, having the potential to create an economic and structural basis for small-scale industry and handcrafts and to offer employment opportunities (DEJENE 1991). At the same time fuelwood, non-wood forest products, and game meat contribute considerably to subsistence of rural communities (DNFFB 1996). Although both utilisation patterns might be practised complementarily within an integrated system of forest-resource management, they are perceived as antagonistic concepts. Commercial harvesting claims legitimacy through its anticipated economic benefits. However, specific information on its efficiency is scant and needs to be established by means of applied research (FAO 1998).

By conceiving and applying a set of operational, organisational, energy, and financial indicators the present case study investigates the efficiency with which forest harvesting is actually conducted in Mozambique. It identifies impediments and their impacts on production and costs, and derives proposals for improvement. Results suggest some substantial conclusions as to which obstructions have the largest impact, and which requirements must be accomplished in order to improve the efficiency of commercial timber harvesting in the natural forests of Mozambique.

2. DESCRIPTION OF COMMERCIAL TIMBER HARVESTING

2.1 Areas and species in timber-productive forests

The portion of Mozambique (Map 1, Appendix 1) covered to various degrees with trees or other woody vegetation amounts to about 620,000 km^2 or 78% of the territory. Productive forests incorporate vegetation types where trees and bushes occupy at least 25%. Classified as having high, medium, or low productivity, the productive forests cover in total an area of about 20 million hectares or 25% of the terrestrial surface of Mozambique (SAKET 1994).

The list of arboreal species producing timber of commercial value covers 118 species and is divided into five classes of value ("precious" and classes 1 through 4). It includes eight species protected by law: *Diospyros mespiliformis* (Ébano or jackal-berry), *Spirostachys africana* (Sândalo or Tamboti), *Dalbergia melanoxylon* (Pau Preto or African blackwood), *Berchemia zeyheri* (Pau Rosa or pink ivory), *Guibourtia conjugata* (Chacate), *Ekebergia capensis* (Inhamarre or Cape ash), *Milicia excelsa* (Tule or Iroko), and *Entandrophragma caudatum* (Mbuti or bottle tree) (RIBEIRO 1992). Physical, mechanical, and processing properties of 52 arboreal species are already known (BUNSTER 1995).

The most demanded commercial species (Table 2.1) cover only 20% of productive-forest's timber stock, while the remainder are species with commercial value but which are less sought-after by domestic and export markets.

Table 2.1 *Names, main provinces of origin, and main uses of the most demanded species.*

Commercial name	**Scientific name**	**Primary sources (Province names)**	**Main uses**
Umbila	*Pterocarpus angolensis*	Cabo Delgado, Nampula, Sofala	Logs (Export), Lumber, Veneer
Chanfuta	*Afzelia quanzensis*	Cabo Delgado, Nampula, Inhambane	Logs (Export), Lumber, Parquet
Panga-Panga	*Millettia stuhlmannii*	Cabo Delgado, Sofala, Manica	Logs (Export), Lumber, Parquet
Missanda	*Erythrophleum suaveolens*	Sofala	Lumber
Mecrusse	*Androstachys johnsonii*	Inhambane, Gaza	Parquet (Export), Sleepers
Umbáua	*Khaya nyasica*	Sofala, Manica	Logs (Export)
Pau Preto	*Dalbergia melanoxylon*	Cabo Delgado	Logs (Export)
Pau Ferro/Rosa	*Swartzia madagascariensis*	Cabo Delgado, Zambézia	Logs (Export)
Messassa	*Brachystegia spiciformis*	Zambézia, Sofala, Manica	Sleepers, Lumber
Messassa encarnada	*Julbernardia globiflora*	Zambézia	Lumber

Source: compiled from DNFFB (Direcção Nacional de Florestas e Fauna Bravia) reports, 1990-98.

2.2 Potential for sustainable timber extraction

Table 2.2 summarises the productive-forest area and its sustainable extraction volume for Mozambique's 10 provinces and for the country as a whole. Low increment of commercial species as well as reduced stocks in provinces dominated by already over-exploited forests restrict the potential for sustainable timber use. Potential extraction intensity in the provinces ranges between 0.007 and 0.043 m^3/ha, and attains at national level a sustainable extraction intensity of 0.025 m^3 per hectare, which is equivalent to a sustainable timber extraction volume of 500,000 m^3 per year from the total productive-forest area of 20 million hectares.

Table 2.2 *Productive-forest area and potential for commercial timber extraction.*

Province	**Area of productive forest (FP, ha)**	**Potential for sustainable extraction, m^3/year**	**Annual harvest potential per hectare of FP (m^3/ha·year)**
Maputo	488,213	3,503	0.007
Gaza	1,437,162	13,141	0.009
Inhambane	1,752,026	20,790	0.012
Sofala	2,168,358	93,573	0.043
Manica	1,046,734	21,369	0.020
Tete	1,135,698	28,898	0.025
Zambézia	3,074,324	88,014	0.029
Nampula	1,822,636	54,410	0.030
Cabo Delgado	2,958,895	67,592	0.023
Niassa	3,851,351	108,946	0.028
Mozambique	19,735,397	500,236	0.025

Source: adapted from SAKET 1994

Extraction potential is additionally restricted by the industry's demand for only a few arboreal species sharing merely 20% of the of the productive-forest area (Section 2.1). Consequently, species most frequently sought after can be extracted up to a volume of just about 100,000 m^3 a year. On the basis of their volumetric sustainability, harvesting should cover all species with commercial value, in order to make the most of sustainable timber potential and make extraction both technologically and logistically more viable.

2.3 Structure of the forest industry

Commercial timber harvesting, transport, and processing are carried out by logging companies and sawmills. Although several new medium-scale companies have been founded in recent years, Mozambique's industry comprises mostly small-scale companies with low technological capacities and low levels of mechanisation. The few mechanised companies—one plantation company, two veneer and plywood companies, four parquet companies, and a paper company (recycled paper and imported pulp)—are producing on a low level or have suspended production altogether.

Most companies involved in commercial logging and processing are labour-intensive enterprises with few machines. A total of 33 logging companies have integrated a processing unit with simple technical equipment. There are also eleven construction companies, ten furniture factories and one shipbuilding factory possessing their own logging units (DNFFB 1999). Based on a sector study (RIBEIRO 1992) and the annual report of the forest administration (DNFFB 1992, mentioned by

CUCO 1993), 74 logging companies and 87 sawmills are involved in logging and processing timber from native forests.

Table 2 shows that in 1992, 77% of the logging companies and 90% of the sawmills were small-scale enterprises with technological capacities below 2,500 m^3. Comparing the capacities in the table with actual production volumes (120,000 m^3 and 32,000 m^3 respectively), in 1998 the forest industry attained utilization rates of 51% in logging and 33% in processing.

Table 2.3 *Structure of forest industry (logging companies and sawmills).*

Province	**Logging companies (capacity, m^3)**	**Structure < 2500-7500-12500 >**				**Sawmills (capacity, m^3)**	**Structure < 2500-5000 >**		
Cabo Delgado	7 (57,700)	4	2		1	9 (12,400)	Structural data for sawmills not available by province		
Niassa	3 (10,000)	2	1			6 (2,900)			
Nampula	8 (36,000)	5	2	1		12 (19,350)			
Zambézia	4 (30,000)	1	1	2		10 (7,350)			
Tete	1 (2,500)	1				3 (1,000)			
Sofala	33 (63,500)	28	4	1		10 (14,050)			
Manica	14 (17,500)	13	1			10 (2,100)			
Inhambane	2 (16,000)	1			1	4 (7,900)			
Gaza	1 (2,000)	1				7 (4,650)			
Maputo	1 (500)	1				16 (23,850)			
Mozambique	**74 (235,700)**	**57**	**11**	**4**	**2**	**87 (95,550)**	**78**	**4**	**5**

Sources: RIBEIRO 1992 and CUCO 1993. The table excludes production of timber from plantations.

2.4 Analysed companies and their activities

Five companies were studied in detail for this report. The locations of these companies' operations within Mozambique are shown in Map 1 (Appendix 1), with more detail shown in Maps 2-6, also in Appendix 1.

ECOSEMA, in the Province of Sofala (Map 2, Appendix 1), was founded in 1995 when it started logging in an area close to Condue in the District of Cheringoma. In 1996 it acquired a new logging license with an area of 53,000 ha east of the road to Inhaminga, and a permitted extraction volume of 2,000 m^3. Initially the headquarters were situated in Beira, but in 1997 they were moved to Dondo. The technical base was located in Muanza, 130 km north of Beira, on road Nº 213 between Dondo and Inhaminga. It comprised a landing and a fenced yard with carriage and band-saw (under construction), workshop, space for parking vehicles, fuel and water tanks, and a mobile home. In 1996 when the case study was conducted, the company produced 600 m^3 of Umbila logs (*Pterocarpus angolensis*). In 1998 the company suspended logging due to a shortage of commercial timber in the area of the granted cutting license.

ÁLVARO de CASTRO, in the Province of Gaza (Map 3, Appendix 1), was founded in 1925. It has always been operating in the same concession area of 20,000 ha. In the first decades the company's sawmill specialized in the production of sleepers. After independence it started to manufacture parquet scantlings for export. In the recent past the company has worked with logging licenses of 100 m^3, requested sequentially as sawmill production progressed. The headquarters are located in Maputo. The technical base in Macuáquà, in the District of Manjacaze, 330 km north of Maputo, consisted of houses for logging managers and workers, a log-yard, the sawmill with a storeroom for final products, a shelter with generator, and an administrative section with office and medical post. In 1996 and 1997, due to the machinery's continuously declining technical availability, the company manufactured only 30 m^3 of parquet scantlings of Mecrusse (*Androstachys johnsonii*), which equals 150 m^3 of logs per year. The company closed down production in January 1998.

MITI, in the Province of Cabo Delgado (Map 4, Appendix 1), was founded in 1995. Since then the company has worked with logging licenses in three areas. The logging area of Muatide covered about 50,000 ha. The production was intended primarily for log export. Only logs rejected by the importers were converted into lumber for the local market. The headquarters were located in Pemba. The technical base in Muatide, 291 km north of Pemba, comprised a landing and a fenced yard with the foreman's cabin, a porch for equipment storage, as well as fuel and water tanks. At the main log-yard in Muxara, 12 km west of Pemba, the logs were stored, scaled, and prepared for sale and shipping according to species and dimension. Rejected logs were sawn into boards with a mobile band-saw. In 1998 when data were collected, the company attained a production level of 1600 m^3 of Umbila logs (*Pterocarpus angolensis*) of which 400 m^3 were converted into lumber.

Originating from a privatised state company, SOMANOL, in the Province of Nampula (Map 5, Appendix 1), was founded in 1995 and since then has worked on the basis of licenses in five logging areas. The company's headquarters and sawmill are located in the city of Nampula. The factory consists of a log-yard, sawmill, two storerooms, workshops for saw-doctoring and vehicle maintenance, carpentry, joinery, manager's house and four bungalows. Production was laid out for manufacturing of locally marketed school furniture, doors and windows, as well as truck decks. Due to the lack of transport vehicles, extraction in 1998 was restricted to Mutivasse/Tchaiane, which was the most easily accessible logging area, 49 km north of Nampula, covering 40,000 ha. There the company extracted 480 m^3 of Murroto logs (*Cordyla pinnata*) for factory processing.

ARCA, (formerly ISPO), in the Province of Zambézia (Map 6, Appendix 1), is involved in logging and timber trading. The company's headquarters are located in Mocuba. In recent years the company has operated on the basis of licenses in several logging areas. In June 1998 it started logging in Mauela, in the northern part of Maganja District, 252 km northeast of Nicoadala. In this logging area the entire production, 2400 m^3 of Mucarala (*Burkea africana*), Umbila (*Pterocarpus angolensis*), Morroto (*Brachystegia spiciformis*) and Muanga (*Pericopsis angolensis*) logs were sold to Serrações Reunidas da Zambézia (SRZ), which provided ARCA with a front-end loader for second loading and organized second transport from the main landing in Mauela to the sawmill in Nicoadala, 37 km north of Quelimane.

Table 2.4 summarizes the activities, equipment, and transport distances in logging, extraction and processing carried out by the five companies. (For additional details on the equipment used, see Table 3.2.) The operations observed among the five companies used similar equipment and working methods. Chainsaws or two-man crosscut saws were used for felling and crosscutting, tractors for skidding, loading and first transport (the latter using attached trailers), and trucks with flat-bed semitrailers for second transport. Differing somewhat from the norm were manual loading at ÁLVARO de CASTRO, mechanised second loading at ARCA, and first transport by truck at MITI.

Concerning the integration of second transport and processing, the studied companies were heterogeneous. ECOSEMA and MITI, after hauling logs initially to a landing at the technical base within or close to the logging area, then loaded the logs on trucks for long-distance transport to the final destination at the provincial capital. ARCA delivered logs to a main landing within the logging area; second loading and transport were then undertaken by SRZ, a separate sawmilling company. ÁLVARO de CASTRO and SOMANOL, the former because its processing unit was located near the logging area, the latter for lack of transport vehicles, hauled logs directly from the logging area to the sawmill, without intermediate landings. They processed timber with a stationary sawmill, while MITI had a mobile band-saw set up in its main log-yard. ECOSEMA's sawmill at the technical base was not yet operational in the year the company was visited. Processing at SRZ's sawmill was not integrated into this study.

In summary, ECOSEMA and ARCA/SRZ sold logs in or close to the provincial capital (with SRZ doing second loading and transport for ARCA), while ÁLVARO de CASTRO and SOMANOL produced sawn products (parquet scantlings and truck decks, respectively), the former close to the logging area and the latter in the provincial capital. MITI sold 75% of its annual production as logs and the remainder as sawn timber in the province capital.

Table 2.4 *Matrix of activities, technologies, transport distances, and final products.*

	Company				
Activity	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
Felling & Crosscutting	Chainsaw	Crosscut Saw	Chainsaw	Crosscut Saw	Chainsaw
Extraction	Tractor	Tractor	Tractor	Tractor	Tractor
1st Loading	Tractor + cable	Manual	Tractor + cable	Tractor + cable	Tractor
1st Transport	Tractor + 2 Trailers (6 t) ↓ 23.4 km	Tractor + Trailer (5 t) ↓ 23.5 km	Truck (8 t) ↓ 14.5 km	Tractor + Trailer (3 t) ↓ 49.0 km	Tractor + Trailer (3 t) ↓ 2.5 km
2nd Loading	Tractor + cable		Tractor + cable		Front Loader
2nd Transport	Truck (25 t) ⬇ 130 km		Truck (25 t) ⬇ 279 km		Truck (25 t) ⬇ 252 km
Processing	—	Circular Saw (88.9 cm)	Band Saw*	Band Saw Carpentry	**
Final product	Logs (Umbila)	Parquet (Mecrusse)	Timber* (Umbila)	Truck Decks (Murroto)	Logs (Mucarala)

Notes:

* 1200 m^3 Umbila sold as export logs, 400 m^3 rejected logs converted into lumber

** Processing by SRZ was not included in the analysis

— Activity did not occur

↓ 23.4 km: Hauling distance in 1st Transport ⬇ 130 km: Hauling distance in 2nd Transport

The companies in this study employed between 17 (ARCA) and 22 (ECOSEMA) workers in logging and first transport. Between 11 (ÁLVARO de CASTRO) and 18 (SOMANOL) were employed in subsequent activities. Felling and crosscutting were carried out by one or two teams (each team consisting of two crosscut-saw operators or one chainsaw operator and assistant). Extraction and transport teams were made up of a tractor or truck driver and assistant. Between 4 and 6 workers were employed in loading. The same number of employees prepared skidtrails and maintained forest roads. Except for tractor and truck drivers, workers were untrained. They were generally recruited in the villages within or adjacent to the logging area.

3. METHODOLOGY

Since records on national and provincial level related to commercial harvesting in Mozambique were scant, data to analyse efficiency had to be collected on-site. Therefore the case study was chosen as the methodological framework for this investigation. In order to take into account distinctive bio-physical and commercial conditions, five companies were selected in the northern (Cabo Delgado, Nampula), central (Sofala, Zambézia), and southern (Gaza) provinces of Mozambique. Criteria for selection were that the enterprise should be of small scale and harvesting timber throughout the period of the field studies. Data were collected by the author during five field visits of one week at each enterprise, in November 1996, October 1997, and July 1998.

According to SILVERSIDES & SUNDBERG (1989) efficiency in forestry is defined as the effective use and economical management of forest resources. The same authors emphasise that efficiency describes the quality of production, indicated by the ratio between two parameters (*e.g.,* cubic metres of extracted timber per unit of extraction time). The present study considers efficiency to be an indicator of the viability (and hence sustainability) of timber production.

Figure 3.1 reflects the methodological approach used in this study. Data collection relied on work studies and the appraisal of equipment and personnel. Together with a descriptive analysis of the processing sequence within work cycles, the collected data were put into ratios, resulting in operating time per cubic metre, including mean production volume and distance, and in costs per machine-hour. On the basis of these preliminary results efficiency was analysed. To this purpose a set of indicators was conceived that relate production data (*e.g.,* log volume) to consumption data (*e.g.,* time), or, as LÖFFLER (1990) suggests, that establish a ratio between output and input. Operational, organisational, energy, and financial output data were rated with input data of the same origin, quantifying the extent to which the indicators measure efficiency.

3.1 Collecting operational and financial data

Field studies concentrated on collecting operational and financial data that would be essential for subsequently quantifying efficiency indicators. For this purpose work studies in logging and transport operations were conducted. Additionally, directors and managers were interviewed in order to obtain basic data on equipment and personnel.

3.1.1 Time and production study

Time and production data were recorded by means of time studies. Time studies proceed by structuring a specific activity into repetitive cycles. Every cycle is made up by elements. A time-study record registers the type and measures the duration of elements occurring in work cycles. By means of recorded time data, the mean duration of a cycle is calculated and rated with the mean volume produced in the cycle, yielding operating time per production unit and technological productivity in the studied activity (KANAWATY 1992). Table 3.1 illustrates how the activities observed during the field studies were structured into repetitive work cycles and defined, codified elements.

Time studies not only measure time and production, but also identify *time types* according to the elements occurring. Total time recorded is subdivided into main time (productive) and general time (unproductive) (REFA 1991). Main time appearing in productive processes is separated into effective time that occurs during production (*e.g.,* travel with load), and auxiliary times (*e.g.,* fasten chain to log in skidding). General time that interrupts the productive process is divided into times for preparation and conclusion, maintenance, rest and technical/personal interruptions. LÖFFLER (1990) refers to these times as “non-cyclic times”. KANAWATY (1992) uses the term “inefficient time”, and APUD & VALDEZ (1995) speak of “secondary time” (as distinct from “principal time”). The present study prefers the notion of "unproductive time" (as distinct from "productive time"). Note that these terms are synonymous and specify those times occurring in elements which cannot be associated to one cycle, and are therefore expressed as a percentage of total time of all recorded cycles.

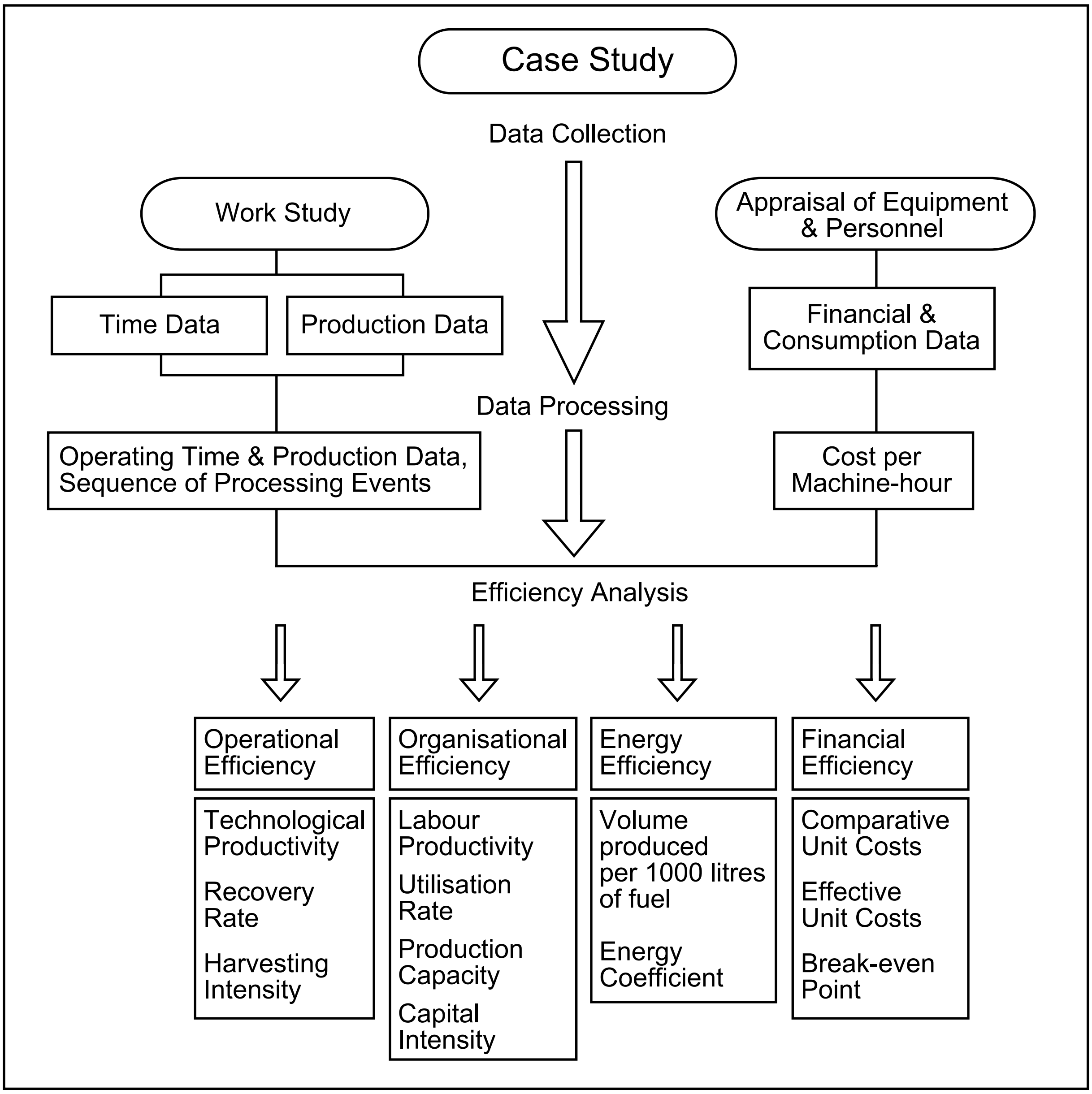

Figure 3.1 *Methodological components and procedures.*

(a) Preparing time and production records

In a preparatory phase the elements constituting a work cycle as well as their initial and final timing points were defined. Furthermore, the beginning and end of the repetitive cycles that jointly constitute the activity had to be determined. Each element was specified by a code, a description with its associated time type, and the initial and final point of timing. Table 3.1 shows the specifications as defined in this study for the analysed activities.

Table 3.1 *Definition of cycles, elements, and time types in the analysed activities.*

SPECIFIC ACTIVITY Code and description of element	**Time type***	**Initial point of timing**	**Final point of timing**
FELLING+CROSSCUTTING			
Productive elements:	TP		
a Approach tree to be felled	TA	Crew leaves previous tree	Arrival at next tree to be felled
b Remove obstacles	TA	End of previous element	Base of tree is clean
c Start chainsaw	TA	End of previous element	Engine starts to run
d,e,f Cut and fell tree	TE	End of previous element	Tree top touches the ground
k Approach crosscutting site	TA	End of previous element	Arrival at crosscutting site
l Remove obstacles	TA	End of previous element	Crosscutting site is clean
m Cut trunk/branches	TE	End of previous element	Log or branch severed
Unproductive elements:	TI		
g,h Periodic maintenance	TM	End of previous element	Fuel or tools put away
i Rest	TR	End of previous element	Work resumed
j Technical or organisational interruption	TL	End of previous element	Interruption cause remedied
EXTRACTION			
Productive elements:	TP		
a Travel unloaded to the load	TA	Tractor leaves landing	Tractor arrives at load point
b Extension of cable/chain	TA	End of previous element	Cable/chain arrives at log
c Hooking	TA	End of previous element	Chain/cable loop fastened
d Haul load to the tractor	TE	End of previous element	Load arrives at the tractor
e Travel loaded to the landing	TE	End of previous element	Load arrives at landing
f Unhooking	TA	End of previous element	Chain/cable released from load
g Decking	TE	End of previous element	Load piled up in final position
Unproductive elements:	TI		
h Preparation and Conclusion	TPC	End of previous element	Fuel/lubricant deposit closed
i Periodic Maintenance	TM	End of previous element	Tools put back
j Rest	TR	End of previous element	Work resumed
k Technical or organisational interruption	TL	End of previous element	Interruption cause remedied
LOADING			
Productive elements:	TP		
a Move log to ramp, fix ropes	TA	Gather rope, cant hook, spring	Log positioned, rope fixed
b Lift log up the ramp	TE	End of previous element	Log arrives on deck
c Position log on load	TE	End of previous element	Load piled in stable position
d Fasten and secure load	TA	End of previous element	Stakes and binders secured
Unproductive elements:	TI		
e Prepare deck and ramp	TPC	End of previous element	Deck positioned, ramp placed
f Periodic maintenance	TM	End of previous element	Tools put back, deposit closed
g Rest	TR	End of previous element	Work resumed
h Technical or organisational interruption	TL	End of previous element	Interruption cause remedied

(Table continues on the following page)

Table 3.1 *(continued)*

SPECIFIC ACTIVITY Code and description of element	**Time type***	**Initial point of timing**	**Final point of timing**
TRANSPORT			
Productive elements:	TP		
a Travel unloaded	TA	Vehicle departs unloading site	Vehicle arrives at loading site
b Travel loaded	TE	Vehicle departs loading site	Vehicle arrives at unloading site
g Unloading	TE	End of previous element	Last log unloaded
Unproductive elements:	TI		
c Preparation and conclusion	TPC	End of previous element	Trailer connected, chain fastened
d Periodic maintenance	TM	End of previous element	Tools put away
e Rest	TR	End of previous element	Work resumed
f Technical or organisational interruption	TL	End of previous element	Interruption cause remedied

* *Time types as defined in the study:*
TP = Productive times: TE = Effective time, TA = Auxiliary time
TI = Unproductive times: TPC=Preparation and conclusion time, TM=Maintenance time, TR=Rest time, TL=Lost time

From the definitions in Table 3.1 it was possible to attribute a time to each component element of a specific activity, to evaluate its duration and portion of total time, and to distinguish productive from unproductive times. In all five companies the same element codes and time-type associations were used for the time studies in order to facilitate cross-company comparisons.

(b) Conducting the time studies

The time studies were designed to record both element times and their chronological sequence in order to obtain a detailed image of how production was performed. For this purpose an electronic chronometer was used in continuous timing (CT) as described by KANAWATY (1992). In comparison with other timing methods, continuous timing has the advantage of not only registering separate element times but also facilitating analytic reconstruction of the sequence in which elements occur during the operations (REFA 1991).

An electronic chronometer RUCANOR™ was used, which has a digital display that simultaneously measures both partial times and accumulated time in minutes and seconds. Time study was started by activating the chronometer. At each timing point (end of a work element) the partial time (time elapsed from the previous timing point) was displayed by pressing the lap-time button. The element time and the code of the elapsed element were recorded (see 3.1.1(c) below). Meanwhile the accumulated time continued to be measured internally and appeared again on the display whenever the split-time function was disabled. At the end of time study the last partial time was recorded and the chronometer was stopped, indicating total elapsed time for the entire timing period.

The beginning and end of the time study were recorded (in daytime hours and minutes) with a normal watch. Subtraction of the beginning daytime from the ending daytime yielded a control time (REFA 1991), which was then compared to the total elapsed time during the study. As recommended by LÖFFLER (1990), time-study records with a divergence between total accumulated time and control time of more than 3% were rejected.

Reference data for subsequent calculation of efficiency indicators were measured and recorded in each observed cycle. Depending on the activity, distances between adjacent felled trees, species, DBH, tree height, stump height, log lengths, log diameters at centre points, and extraction and transport distances were recorded. A reversible metric tape and a diameter tape were used for measuring log lengths and diameters.

(c) Recording data

A form was developed for recording the sequence and duration of work elements as well as reference data. In the first column the cycle number was registered, in the second column the element code, in the third column the partial time in minutes and seconds, and in the fourth column the partial time in centiminutes. The remaining columns were dedicated to observations and reference data.

The header included cells for page number, production unit and team, observed activity, calendar date and control time. After having filled all 35 lines of a page, accumulated time was registered in the footer. The remaining space on the last page served to calculate total and mean values of time and production in recorded cycles.

3.1.2 Appraisal of equipment and personnel

Directors and managers were interviewed in order to obtain data on equipment and personnel employed in production. For this purpose a form was developed to identify equipment types and purchase prices as well as the number of workers and their annual wages in logging and transport (including roading), maintenance, processing, and supervision.

For subsequent cross-comparison of the companies' financial efficiencies, baseline data for the following parameters were determined. Table 3.2 compiles the results in summary.

(a) Annual working time and wages

Annual production period varied, depending largely on local climatic conditions, between eight and nine months. Cost calculations were based on the assumption that companies produced eight months a year and that during the rainy season the logging area was not accessible. In general, 20 working days per month and nine hours of daily working time yielded an annual working time (AWT) of 160 days or 1440 hours. Since rains had little affect on AWT for maintenance crews, a production period of nine months was determined for these crews, equivalent to 1620 hours. SOMANOL's sawmill worked eleven months a year and nine hours a day, resulting in an AWT of 220 days or 1980 hours.

Data on wages reflect the system applied in each company. Total crew wage per hour was calculated on the basis of the number of crew members and their annual wages in Meticais (Mt), divided by total annual work time and converted into US dollars (US$) per hour.

(b) Depreciable value and repair rate

Purchase prices were recorded as indicated by each company's management. In order to obtain depreciable values the price for consumable commodities (*e.g.,* tyres) and the residual value, generally assumed to be 10% of the purchase price, were subtracted. Where very old equipment was used it was assumed not to have any residual value at the end of depreciation period.

Table 3.2 *Baseline data for efficiency analyses.*

COMPANY, Equipment	Depreciable value* [US$]	Ownership Period [h]	Repair Rate	Power [hp]	Fuel consump-tion [l/h]	Workers per crew	Crew wage [US$/h]
ECOSEMA							
Chainsaw 70 cm^3 (2)	560	1,600	0.8	5.4	0.86	2	0.34
Tractor MF60 (5)	8,280	8,000	1.0	60	7.0	2	0.34
Semitrailer 3 t (8)	540	8,000	0.5			4	0.64
Road maint. equipment	370	1,600	0.5			4	0.64
Tractor MF80	8,280	8,000	1.0	80	9.0	2	0.34
Semitrailer 25 t (2)	1,530	8,000	0.5			6	0.99
Truck REO240	21,600	8,000	1.0	240	27.0†	2	0.62
Workshop equipment	17,500	7,200	0.5			2	0.46
Mobile home	12,996	14,400	0.5	4.0	0.45	2	0.34
Tractor MF60	8,280	8,000	*Non-operational*				
Truck REO240	21,600	8,000	*Non-operational*				
Truck REO143	12,600	8,000	*Non-operational*				
Semitrailer 25 t (2)	1,530	8,000	*Non-operational*				
Trailer 12 t (2)	5,940	8,000	*Non-operational*				
Trailer 3 t (4)	540	8,000	*Non-operational*				
Manual winch	305	8,000	*Non-operational*				
Generator, chariot	11,700	8,000	*Non-operational*				
ÁLVARO de CASTRO							
Crosscut-saw (1 set)	114	1,600	0.5			2	0.28
Tractor MTZ (2)	2,970	8,000	1.0	82	10.0†	2	0.27
Semitrailer 5 t	764	8,000	0.5			6	1.04
Road maint. equipment	94	1,600	0.5			6	0.84
Workshop equipment	3,010	7,200	0.5	4.0	0.45	5	2.51
Generator and saw rig	13,500	12,800	0.5	155	12.0	4	3.42
House and radio	28,800	14,400	0.5			2	1.30
Tractor MF165 (2)	1,750	8,000	*Non-operational*				
Tractor ZT303	3,628	8,000	*Non-operational*				
Semitrailer 3 t (3)	764	8,000	*Non-operational*				
MITI							
Chainsaw 110 cm^3 (2)	1,360	1,600	0.8	7.0	1.1	2	0.52
Tractor Fiat7066	26,000	8,000	1.0	66	10.0†	2	0.52
Tractor MF265	30,500	8,000	1.0	65	8.0	2	0.52
Equipment loading	50	1,600	0.5			4	0.68
Truck MB1513 8 t	42,500	8,000	1.0	150	16.0	2	0.63
Road maint. equipment	30	1,600	0.5			4	0.68
Truck Nissan	87,500	8,000	1.0	350	27.0	2	0.92
Workshop equipment	3,150	7,200	0.5			4	2.03
Generator, mobile saw	43,500	12,800	0.5	90	10.0	4	1.78
Trailer pers. transport	625	8,000	0.5				
4×4 supervision car	17,600	2,880	0.5	120	13.0	2	0.32
Truck MB1013 8 t	42,500	8,000	*Non-operational*				

(Table continues on the following page)

Table 3.2 *(continued)*

COMPANY, Equipment	Depreciable value* [US$]	Ownership Period [h]	Repair Rate	Power [hp]	Fuel consumption [l/h]	Workers per crew	Crew wage [US$/h]
SOMANOL							
Crosscut saw (1 set)	95	1,600	0.5			2	0.32
Tractor MF275	6,300	8,000	1.0	75	8.0	2	0.28
Semitrailer 3 t	845	8,000	0.5			6	0.84
Tractor Ford 6600	6,300	8,000	1.0	66	7.0	2	0.28
Road maint. equipment	85	1,600	0.5			6	0.84
Workshop equipment	1,125	7,200	0.5			6	1.29
Equipment sawmill	142,500	17,600	0.5		4.53‡	4	5.28
Equipment carpentry	43,500	17,600	0.5		4.53‡	4	9.08
4×4 supervision car	17,600	2,880	0.5	120	13.0	4	0.58
Buildings	77,000	16,200					
Generator Caterpillar	27,000	17,600	*Non-operational*				
ARCA / SRZ							
Chainsaw 110 cm^3	1,670	1,600	0.8	7.0	1.1	2	0.56
Tractor Valmet 78	26,930	8,000	1.0	78	8.5	2	0.41
Semitrailer 3 t (2)	2,312.50	8,000	0.5			5	1.75
Tractor MF265/290 (2)	26,930	8,000	1.0	77.5	8.5	2	0.41
Road maint. equipment	600	1,600	0.5			6	1.09
Loader Volvo BM250	88,330	8,000	1.0	250	19.0	1	0.46
Truck Nissan	51,500	8,000	1.0	350	27.0	5	1.46
Workshop equipment	6,255	7,200	0.5			5	1.99
4×4 supervision car	13,100	7,200	0.5	90	10.0	1	0.93

Notes:

* Purchase price reduced by residual value and cost of tyre set.
† Based on company records
‡ Energy from public net (3670 US$ for 1760 hours) equivalent to 4.53 litres of fuel per hour.

Treating the repair rate as a percentage of depreciation allows evaluating repair costs during the machine's useful life. According to recommendations by GRAMMEL (1988), repair factors of 1.0 were used for extraction and transport vehicles, 0.8 for chainsaws, and 0.5 for sawmill machinery as well as equipment used for loading, road maintenance, and workshop, and for vehicles used in supervision. These assumptions seem to reflect real production patterns, since the equipment had been purchased second-hand, having already been used extensively and exposed to heavy wear by abrasive sand and corrosion.

(d) Costs of consumable commodities (fuel, lubricants and tyres)

Fuel prices varied among provinces and during the years in which data were collected. In order to keep companies comparable to one another, a standard price was determined and applied to all calculations. From 1996 to 1998 costs averaged 5,500 Mt (0.46 US$) per litre of diesel, 6,500 Mt (0.54 US$) per litre of gasoline and 36,000 Mt (3.00 US$) per litre of lubricant.

Fuel consumption (L_h) was estimated on the basis of company records when they were available. Otherwise it was calculated as a function of engine power (P_{hp}) as suggested by FAO (1992):

$$L_h = \frac{L_{hp} \times P_{hp} \times F_c}{W} \tag{1}$$

where L_{hp} = fuel consumption rate per horsepower = 0.17 kg/hp·h for diesel and 0.21 kg/h·ph for gasoline
P_{hp} = engine power, hp
F_c = load factor, estimated to be 0.54 for tractors and chainsaws and 0.38 for trucks and generators.
W = fuel weight = 0.84 kg/*l* for diesel, 0.72 kg/*l* for gasoline

It was assumed that machine engines consume lubricants equivalent to 10% of fuel consumption. Costs for tractor, truck, and trailer tyres were determined according to the companies' records.

(e) Rates of interest and exchange

From 1996 to 1998 effective interest rates varied depending on financing sources. To facilitate comparison among the companies, a uniform effective interest rate of 15% a year was applied. Due to particular funding conditions in the case of ECOSEMA, costs for that company were calculated with an interest rate of 25%. From 1996 to 1998 exchange rates for the Meticais ranged between 11,500 Mt and 12,500 Mt per US$. Cost calculations applied a uniform exchange rate of 12,000 Mt for 1 US$.

3.2 Data processing – efficiency analysis

Recorded data were processed in order to calculate efficiency ratios. This section identifies the indicators that were used for efficiency and describes how they were evaluated and quantified on the basis of recorded data, comparing outputs against inputs. Distinctions are made among **operational indicators** derived from time and production data, **organizational indicators** evaluating synchronization and coordination of equipment and workforce, and **financial indicators** based on the calculation of unit costs. Additional indicators were used to estimate **energy efficiency**.

Compilation and processing of data collected in the time studies was carried out with Microsoft® Excel. Machine rates (costs per hour) were calculated using PACE (FAO 1992).

3.2.1 Operational efficiency

Operational efficiency is defined by the equilibrium of procedures and equipment in all production phases, in order to maintain production on a sufficient level and to avoid interruptions (SILVERSIDES & SUNDBERG 1989).

The present study evaluates operational efficiency in logging and transport. Due to the limited time available for data collection, processing of logs into final products was not analysed.

In total 256 cycles were observed. Table 3.3 summarises the number of cycles, broken down into activities by company, and shows the statistical variation in the data as collected. Transport occurred with low frequency during data collection. Therefore only nine cycles were observed for first transport and seven cycles for second transport.

Table 3.3 *Number of cycles (coefficient of variation in %) for the analysed activities.*

	Company				
Activity	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
Felling and crosscutting	10 (51)	11 (41)	10 (65)	13 (19)	10 (33)
Extraction	10 (42)	8 (27)	14 (31)	17 (24)	10 (25)
1st Loading	29 (74)	30 (61)	12 (50)	13 (64)	*
1st Transport	1	3 (14)	3 (13)	1	1
2nd Loading	32†	–	*	–	11 (39)
2nd Transport	1	–	1	–	5 (12)

Notes:

* Activity not observed
† Only mean time and mean production available
– Activity did not occur

Operational efficiency was evaluated by processing relevant time and production data collected during the time studies. The sequence of elements as well as their temporal distribution within the work cycles was identified. Technological productivity was calculated from operating time and production volume. And finally, the ratio between tree volume and log volume yielded the recovery rate associated with primary production.

(a) Element sequence and temporal distribution

The order in which element codes were listed in the record form reflected the sequence of work elements within observed activities. In order to evaluate the temporal distribution of elements, both total productive and unproductive times and their shares of total recorded time were calculated. Then the portions of total productive and unproductive time occupied by each element were calculated. In addition, cycle elements that consumed time disproportionately, and thus constituted critical elements, were identified for each operation.

(b) Technological productivity and recovery rate

Recorded total time (T_t) (without interruptions longer than 15 minutes) and mean log volume (V_m) per cycle were calculated and put into relation, yielding operating time (T_o) expressed in minutes per cubic metre. Technological productivity (PT) was obtained by dividing the number of minutes in one hour by operating time, expressed in cubic metres per machine-hour (LÖFFLER 1991):

$$PT = \frac{V_m \times 60}{T_t} \qquad \text{or} \qquad PT = \frac{60}{T_0} \tag{2}$$

PT is one of the most frequently used measures of operational efficiency in a specific activity. However, it only reflects procedures during recorded production periods. Non-productive periods, which under prevalent conditions occupied a large portion of annual working time, are not measured by this indicator (see Section 3.2.2(a)).

Additional reference data were processed to determine logging intensity in cubic metres per hectare as well as average distance and average speed in extraction and transport.

Recovery rate was evaluated comparing log volume and commercial tree volume, based on the assumption that commercial tree volume contains wood for commercial purposes to a diameter of 20 cm. The tree volume (V_t) was estimated by multiplying basal area, total tree height (H_t) and a taper factor (f_t) that varied between 0.4 and 0.6 depending on the particular species. Thus commercial tree volume was calculated as follows:

$$V_t = \left(\frac{DBH}{2}\right)^2 \times \pi \times H_t \times f_t \tag{3}$$

where $\pi = 3.14159\ldots$, the ratio of the circumference of a circle to its diameter. Similarly, log volume (V_L) was calculated by the formula:

$$V_L = \left(\frac{D_m}{2}\right)^2 \times \pi \times H_L \tag{4}$$

where D_m is the log diameter at the midpoint of the log, and H_L is the log length. Then the ratio:

$$RR = \frac{V_L}{V_t} \times 100 \tag{5}$$

yields the average recovery rate (RR) expressed in percent.

3.2.2 Organisational efficiency

This set of indicators is related to synchronization and coordination of activities that are essential for maintaining production on a sufficient level, and expresses the relative efficiency with which machinery, workforce, and capital are employed.

(a) Utilisation rate and production capacity

According to LÖFFLER (1991), utilisation rate is intended to measure the efficiency with which a company uses its machinery, indicating the quality of synchronisation among activities and machinery. Since company records on annual machinery utilisation were not available, the present study estimated the production capacities of equipment involved in logging and transport (in cubic metres per year) by calculating the product between number of machines used in the specific activity (N_e), technological productivity per machine (PT), and total annual work time (TT_a). Utilisation rate (UR) was then obtained by comparing annual production volume (E_a) with technological capacity, through the formula:

$$UR = \frac{E_a}{N_e \times PT \times TT_a} \times 100 \qquad (6)$$

UR, expressed in percent, indicates the average efficiency of applying equipment in a specific activity during one year. With regard to the entire production, the equipment with the lowest production capacity determined the company's annual production capacity and served as reference for overall utilisation rate.

(b) Labour productivity

To estimate workforce productivity (P_L), the timber volume (E_a) produced in the year in which the company was analysed was divided by the number of the workers (N_p) in logging, extraction, and transport, and the number of months (N_m) worked during that year:

$$P_L = \frac{E_a}{N_p \times N_m} \qquad (7)$$

The result, expressed in cubic metres per worker-month, is a measure of the efficiency with which the workforce was employed in production.

(c) Capital intensity

Capital intensity (IC) indicates the amount of money with which the company's investments debit each cubic metre of timber produced. Although linked with financial parameters, IC is an organisational indicator showing the extent to which the company was able either to minimize the sum of mean annual investments (I_{ma}) or to maximize annual production (E_a). Capital intensity, expressed in US$ per cubic metre, was calculated with the formula:

$$IC = \frac{\sum I_{ma}}{E_a} \qquad (8)$$

3.2.3 Energy efficiency

In addition to labour, land, and capital, it is becoming more and more common to include energy among the most important production factors in forestry. The concept of energy balance (LÖFFLER 1991) covers consumption of direct energy, human energy, and energy spent in machine manufacturing. The present study evaluates energy efficiency on the basis of direct energy input by fuel consumption in logging, transport and processing. On the output side, the potential energy represented by timber products is considered.

First, energy consumption per hour (L_h, see 3.1.2(d)) was converted to energy consumption per cubic metre of timber produced within the specific activity ($L_u = L_h / PT$). Then the specific consumption values for all machines involved in production were summed for logging and first transport and for subsequent activities (second transport and processing) and expressed per 1,000 litres of fuel, using the formula:

$$\eta_e = \frac{1000}{\sum L_u} \tag{9}$$

where η_e is expressed in cubic metres of timber produced per 1000 litres of fuel.

According to LÖFFLER (1991), one cubic metre of timber contains energy corresponding to a calorific value of 200 kWh, and the energy content of one litre of fuel is around 10 kWh (diesel 9.88 kWh/*l*, gasoline 9.72 kWh/*l*). Thus, an energy coefficient (η_c) can be calculated with the formula:

$$\eta_c = \frac{200}{\sum L_u \times 10} \tag{10}$$

Both Equations (9) and (10) show the ratio between energy that results from products (logs, sawn timber) and the direct energy that is consumed as fuel during production, providing an indication of the efficiency with which fuel energy was employed. In this context, designing an energetically efficient process means using machines with low fuel consumption and maximising technological productivity, particularly in transport and processing.

3.2.4 Financial efficiency

Indicators frequently used to evaluate the viability of an enterprise include production costs and their relation to sales revenues. Unless sales revenues cover the cost of production, a firm's activities are deficient and economically unable to sustain production, to create value added, and to contribute to the national economy (PRETZSCH 1997).

The present study is based on a model that evaluates harvesting and processing costs, without considering royalties or additional costs eventually associated with silvicultural activities. Subtracting costs from sales revenues yields profit margin, *i.e.,* the monetary value that the resource renders.

The results of this analysis indicate the degree to which production generates profits and is economically efficient, and the production level at which costs would be covered by sales revenues.

(a) Costs per machine-hour

By means of the computer program "Production and Cost Evaluation – PACE" (FAO 1992), data on equipment and personnel (compiled in a standardised form, see Section 3.1.2 and Table 3.2) were processed, resulting in costs per machine-hour for primary (logging and first transport) and secondary activities. Digital data processing for each activity resulted in a compilation of ownership costs, operating costs, and labour costs, as well as an overall summary. The types of costs and formulae used by the PACE program are compiled and described in Table 3.4.

Table 3.4 *Cost components and their calculation.*

Cost component	**Description**	**Formula**
Annual depreciation	Depreciable value (purchase price P less accessory price A and residual value V) divided by ownership period N in years.	$D=\frac{(P-A-V)}{N}$ (11)
Mean annual investment	The average amount invested in an item of production over the period of its useful life, divided by the ownership period N in years.	$I_{ma}=\frac{(P-V)(N+1)}{2N}+V$ (12)
Annual interest cost	Mean annual investment multiplied by the real interest rate *j* (nominal interest rate less inflation).	$J=I_{ma}\times j$ (13)
Annual cost of taxes, insurance & storage	Assumed to be 5% of the depreciable value.	$I=0.05\times D$ (14)
Annual ownership cost	Sum of depreciation, interest, taxes, insurance & storage cost per year.	$C_{fa}=D+J+I$ (15)
Ownership costs per hour (C_{fh})	Annual ownership cost divided by annual machine-hours (U_a).	$C_{fh}=\frac{C_{fa}}{U_a}$ (16)
Repair costs (C_r)	Product of repair coefficient *r* and depreciation divided by annual use.	$C_r=\frac{r\times D}{U_a}$ (17)
Fuel costs (C_c)	Fuel consumption L_h in litres per hour, multiplied by fuel price P_f per litre.	$C_c=L_h\times P_f$ (18)
Lubricants costs (C_q)	Product of lubrication coefficient *q* (0.1) multiplied by fuel consumption per hour and lubricant price per litre P_q.	$C_q=q\times L_h\times P_q$ (19)
The cost of tyres and other accessories (C_p)	Price P_p of tire set or accessory, divided by the useful life U_p in hours.	$C_p=\frac{P_p}{U_p}$ (20)
Operating costs per hour (C_{vh})	The sum of the costs described above.	$C_{vh}=C_r+C_c+C_q+C_p$ (21)
Total crew wage per hour (W_{lh})	Sum of crewmembers' annual wages W_{ma} divided by total annual hours TT_a.	$W_{lh}=\sum\frac{W_{ma}}{TT_a}$ (22)
Direct labour costs per hour (C_{lh})	Total crew wage W_{lh} multiplied by ratio between total annual work time TT_a and annual equipment utilisation U_a.	$C_{lh}=\frac{W_{lh}\times TT_a}{U_a}$ (23)

Source: FAO (1992)

The machine-hour (see Section 3.2.1), as a reference unit for calculating machine costs per hour, is derived from annual utilisation. A machine-hour corresponds to one hour's use of a particular machine, including interruptions of less than 15 minutes (LÖFFLER 1991). Conversely, wages refer to total annual working time. In order to be compatible with ownership and operational costs, PACE converts them into labour costs per machine-hour (see Equation (23)), thus avoiding fragmentation of the results, referring the costs for both equipment and personnel to the machine-hour. Furthermore this conversion creates a uniform reference for calculating unit costs for all activities, dividing the costs per machine-hour by technological productivity (see Section 3.2.4).

Additional processing of financial data was carried out with Microsoft® Excel. Costs per machine-hour for primary activities (logging and first transport) as well as secondary activities (second transport, maintenance, and processing) and supervision were compiled. Whenever two or more equipment/personnel units were used for the same activity, respective costs were added accordingly; *e.g.,* in truck loading with tractor assistance, the operational costs of the truck were not integrated into the cost scheme.

(b) Comparative unit costs (logging and first transport)

Technological productivity evaluated on the basis of time-study data (Section 3.2.1(b)) were used to derive unit costs. Dividing the cost per machine-hour for a particular activity by its technological productivity yielded the activity's unit cost in US$ per cubic metre. Then ownership, operating, labour, and total costs in US$ per cubic metre were compiled for logging and first transport. Subsequent activities were not included, as they did not occur in all cases (second transport, processing) or were not directly associated with production (maintenance, supervision).

The resulting unit costs provide an indication, under uniform conditions, of the relative efficiency of equipment and personnel when producing one cubic metre of logs. The influence of annual machine utilisation on unit costs was neutralised by assuming that in all cases. equipment and personnel were employed according to the standardised annual utilisation (*e.g.,* 800 machine hours in skidding, which corresponds to an utilisation rate of 56%). Thus companies' activities and their cost structures could be compared with one another, independently of their actual production level. However, comparative unit costs assume conditions related to machine utilisation that do not necessarily reflect the company's actual production pattern.

(c) Effective unit costs and margin of profit

Effective unit costs are those associated with an entire year's production, expressed in US$ per cubic metre of timber produced. Fixed and semi-variable costs were calculated by dividing annual ownership costs (C_{fa}), annual repair costs ($C_{ra} = C_r \times U_a$), and annual labour costs ($C_{la} = C_{lh} \times U_a$) by the volume produced (E_a). Purely variable costs (fuel, lubricants, tyres) were added, dividing variable costs per hour without repair costs (C_{vh} - C_r) by technological productivity (PT). Summing these yields the effective unit cost of production (C_{au}) for a specific activity:

$$C_{au} = \frac{C_{fa}}{E_a} + \frac{C_{ra}}{E_a} + \frac{C_{vh} - C_r}{PT} + \frac{C_{la}}{E_a} \quad (24)$$

Activity costs were then summed to derive total effective unit costs (C_{tu}). In order to facilitate comparison among the companies, these total effective unit costs were subdivided into those associated with primary activities (logging and first transport) and those incurred in subsequent activities or in support (second loading and transport, maintenance, non-operational equipment, processing and supervision).

Sales revenues from final products (R_s), obtained from company records, were then compared to the total effective unit costs in order to evaluate the margin of profit (M_p) per cubic metre of timber produced:

$$M_p = R_s - C_{tu} \tag{25}$$

where M_p is expressed in US$ per cubic metre.

Finally, effective unit costs were interpreted as to their origins. As formula (24) suggests, there are basically two components determining the magnitude of effective unit costs: the ratios between annual fixed costs and production volume, and between fuel consumption per machine-hour and productivity. Consequently, effective unit costs provide a measure of the efficiency with which the company was able either to minimise heavy-machine use and fuel consumption or to maximise annual production and technological productivity.

(d) Break-even point

The break-even point marks the volume of production at which effective unit costs are covered by sales revenue. Its level depends on the magnitude of annual fixed costs (ownership, repair, and labour) and the ratio between fuel consumption and technological productivity.

In order to analyse unit costs as a function of the volume of timber produced, the costs of ownership, repair, and labour (C_f, influenced by production volume) were multiplied by annual production volume (E_a) and then divided by the potential production volume (E_p). Then purely variable costs ($C_v = C_{vh} - C_r$) were added. Thus the unit costs of a proposed production pattern (C_{pu}, in US$/m^3) were:

$$C_{pu} = \frac{C_f \times E_a}{E_p} + C_v \tag{26}$$

Following OSWALD *et al.* (1997), the break-even point (BEP) where production costs are covered by sales revenues, was calculated with the formula:

$$BEP = \frac{C_{fa} + C_{ra} + C_{la}}{R_s - C_v} \tag{27}$$

where C_{fa} = annual ownership costs
C_{ra} = annual repair costs
C_{la} = annual costs for wages
R_s = sales revenue per cubic metre
C_v = variable costs excluding repair costs ($C_{vh} – C_r$)

Finally, the break-even point was compared to the company's technological capacity, in order to determine whether the break-even volume could have been produced with the existing equipment.

4. RESULTS AND DISCUSSION

This section describes the course of operations and the sequence of their work elements, compiles data resulting from analysis, cross-compares indicators designed to measure the relative efficiencies of the operations studied, and discusses both causes and possible remedies for identified shortcomings.

4.1 Operational efficiency

The logging operations observed for this study, although proceeding fluently and in a reasonably well-synchronised way within work cycles, suffered from low extraction volumes and poor recovery rates. With particularly low productivity, transport constituted the most important operational impediment to a sustained flow of raw materials.

4.1.1 Operational efficiency in felling and crosscutting

Most of the companies divided their logging areas into blocks in an improvised manner, without systematically structuring the blocks through feeder roads and marked skidtrails. Trees to be felled were previously determined and marked by the foreman. Only ÁLVARO de CASTRO and ARCA invested in roading and spatial structuring in order to facilitate extraction. None of the companies' felling crews applied appropriate techniques for directional felling. Trees were felled in the direction of lean, without using wedges. Motor-manual felling applied a circular fan cut around the base of the tree without an appropriate notch cut. In manual felling, a horizontal notch cut was followed by the felling cut. Because of poor felling techniques damage to neighbouring trees was common and hang-ups occurred frequently. Often twisted and torn fibres in the basal section resulted in a devalued butt log (see Photo Series 3, Appendix 2). In crosscutting, defective log sections and branches were removed, and the log was separated from the trunk. Generally only one log was recovered per tree. At ÁLVARO de CASTRO and SOMANOL, bucking two logs per tree resulted in superior timber recovery rates.

In the companies that used manual felling (ÁLVARO de CASTRO and SOMANOL), two cutters used crosscut saws with straight profile, triangular teeth, and 140 cm length. On the three motor-manual felling operations (ECOSEMA, MITI, and ARCA), crews consisted of a chainsaw operator and an assistant. The chainsaws ranged between 5.4 and 7.0 hp, with bars 63 cm in length.

Technological productivity (PT) of manual methods ranged between 1.11 and 1.99 m^3/h (Table 4.1). Most of the productive time was employed in making the felling cuts and crosscuts, due to the slow process of manual sawing. This was particularly true at SOMANOL where the saws were dull and improperly set throughout the period of the field study. Only 10-12% of operating time was occupied in unproductive activities, which were divided into rest and interruption times. Most interruptions were associated with releasing lodged trees. To bring them down, improper and extremely dangerous practices were often used (see Photo Series 2, Appendix 2). Maintenance times did not occur during normal working hours. At ÁLVARO de CASTRO this was because the felling crew used two crosscut saws on alternating days, with the saw not in use being sharpened and set by a saw doctor. At SOMANOL it was due to the lack of sharpening and setting tools for the crosscut saws.

In motor-manual felling, PT varied between 2.13 and 6.79 m^3/h, indicating big differences in operational efficiency. Between 67% and 83% of operating time was occupied by productive time. At ECOSEMA the large share of time related to felling cuts and crosscuts reflect delays caused by lack of spatial structuring and the use of improper cutting techniques with the chainsaw. At MITI, apart from lacking spatial structuring, hilly terrain and comparatively dense vegetation made movements between trees and the removal of obstacles occupy a large portion of productive time. ARCA performed more efficiently than the other companies, since blocks were prepared with feeder roads and skidtrails, thus avoiding delays when advancing to the next tree and removing obstacles. Overall, 17-33% of operating time was occupied by unproductive time in the motor-manual felling operations, mainly for chainsaw maintenance.

Table 4.1 *Operational efficiency in felling and crosscutting.*

Variable	ECOSEMA	ÁLVARO de CASTRO	MITI	SOMANOL	ARCA/SRZ
Distance [m]	79	22	68	30	75
V_m [m^3/cycle]	0.60	0.26	1.34	1.25	1.26
V_{ex} [m^3/ha]	0.96	5.17	2.90	13.89	2.24
PT [m^3/h]	2.13	1.11	5.83	1.99	6.79
TP:TI [%]	67:33	88:12	83:17	90:10	77:23
RR [%]	41	51	35	63	43

Notes:

Distance = the mean distance from one felled tree to the next
V_m = mean log volume produced per cycle
V_{ex} = extraction intensity
PT = technological productivity as calculated in Eq. (2)
TP = total productive time as defined in Table 3.1
TI = total unproductive time as defined in Table 3.1
RR = recovery rate as calculated in Eq. (5)

Recovery rate (RR) ranged between 35% and 63% (Table 4.1). The low end of this range was at MITI, where felled trees had a mean commercial volume of 3.44 m^3. Only logs with maximum diameter were extracted and much of the felled volume was thus wasted. This was due to MITI's focus on the production of logs for export. Furthermore, cutting techniques with the chainsaw tended to provoke precocious falling and fibre splitting in the butt log, so that the damaged wood had to be bucked out. RR was also reduced by the prevalence of high stumps; on average, felling cuts were made at heights above ground between 32 and 76 cm. Similar shortcomings were also observed at ARCA and at ECOSEMA. ÁLVARO de CASTRO and SOMANOL achieved better recovery rates by crosscutting two logs per tree and thus increasing timber volume prepared for extraction to 51% and 63% of commercial tree volume.

Mean volume produced per cycle (V_m) varied between 0.26 m^3 and 1.34 m^3, and mean distance from one felled tree to the next ranged from 22 to 79 m. ECOSEMA showed the most unfavourable ratio of small logs and large distance between trees, resulting in an extraction volume of only 0.96 m^3/ha. Conversely, SOMANOL, by extracting a species not previously exploited in its logging area, was able to achieve an extraction intensity (V_{ex}) of 13.89 m^3/ha. This relatively intensive extraction could have resulted in a high level of productivity, if trees had not been cut with crosscut saws that were poorly sharpened and improperly set.

Retrospectively, manual felling seems to result in more efficient felling and crosscutting (potential PT around 2.00 m^3/h), if crosscut saws and their maintenance were optimised, and if spatial structuring as well as better cutting techniques were being implemented. The motor-manual method reduces times for some productive elements (potential PT about 6.00 m^3/h). However, more demanding requirements as to maintenance and logistics (fuel and oil) made it seem to be less appropriate and more costly (see Section 4.4.1) than the manual method. Furthermore, improper cutting techniques with chainsaws appeared to significantly increase the risk of accidents.

Except for ARCA (high technological productivity) and SOMANOL (high extraction intensity and recovery rate), the described shortcomings indicate that already in this first productive phase low extraction volume, absence of spatial structuring, and poor cutting techniques restrained raw-material flows and impaired the operational efficiency of subsequent activities.

4.1.2 Operational efficiency in extraction

Logs were skidded from the felling site to the landing at a previously prepared feeder road. Generally smooth terrain with gentle slope gradients, soils with good bearing capacity and absence of climbing vines made access and extraction with farm tractors possible, provided logging had been properly planned and prepared (see Section 4.1.1). However, at ECOSEMA, MITI, and SOMANOL skidtrails were either not cleared at all or were only poorly cleared, thus delaying access to the logs. the travel-unloaded element was therefore subject to frequent interruptions. When the tractor arrived at the pick-up point, the chain was fastened around the log, and the tractor started to travel loaded. Except for ÁLVARO de CASTRO, in most cycles just one single log with a mean volume of 0.66 to 1.32 m^3 was extracted by ground-skidding, without lifting its base. At ÁLVARO de CASTRO, an average of five logs (total volume 0.64 m^3 per cycle) were choked together, starting at the most distant felling site and progressively adding logs to the load along the skidtrail while en route to the landing.

The logs were extracted by 4×2 farm tractors with chains, without hydraulic drag bars or winches. ARCA had a tractor with a hydraulic tong, which during data collection was not operational. The tractor driver was accompanied by an assistant who hooked the log and released it at the landing.

Generally low mean load volume and delays associated with the travel-empty phase limited technological productivity (PT) to between 3.13 and 3.80 m^3/h (Table 4.2). SOMANOL achieved an outstanding PT of 8.27 m^3/h as a result of relatively short skidding distances and a large mean load volume. Inadequate spatial structuring and difficult access to logs caused the tractors to move more slowly during the travel-empty phase than when travelling loaded.

Table 4.2 *Operational efficiency in extraction.*

Variable	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
Skidding distance [m]	265	38	436	90	325
S_s unloaded / loaded [m/min]	108/140	37/40	51/57	46/56	66/82
V_m [m^3/cycle]	0.66	0.64	1.32	0.86	0.72
T_m [min/m·m^3]	0.07	0.42	0.04	0.08	0.05
PT [m^3/h]	3.43	3.80	3.13	8.27	3.58
TP:TI [%]	60:40	95:05	80:20	91:09	95:05

Notes:

Skidding distance = the mean distance from the felling site to the landing
S_s = mean travel speed
V_m = mean volume extracted per cycle
T_m = mean time per metre and per cubic metre
PT = technological productivity as calculated in Eq. (2)
TP = total productive time as defined in Table 3.1
TI = total unproductive time as defined in Table 3.1

Between 60% and 95% of operating time was spent in productive activities, mostly travel loaded and travel unloaded. An extraordinarily large share of time was spent fastening the chain, with 17% at ARCA, 23% at ECOSEMA and 31% at SOMANOL, due to delays recorded when grass and soil beneath the log had to be removed in order to loop the chain around the log. MITI spent only 12% of productive time for this element, since obstacles had been removed before the tractor arrived. At ÁLVARO de CASTRO, the elements “Fasten the Log” and “Manual Traction” consumed 48% of productive time, as the tractor had to stop frequently and numerous small logs had to be dragged and joined to the load. Unproductive time (rest pauses and short technical interruptions) occupied between 5% and 20% of operating time, except for ECOSEMA (40%), where much time was required to remove obstacles or manoeuvre around them when travelling unloaded, as a result of poor skidtrail preparation.

Mean time (T_m) provides an overall measure of operational efficiency. It is determined by the mean volume (V_m) skidded per cycle and the mean travel speed (S_s). V_m varied between 0.64 and 1.32 m^3/cycle. At MITI, SOMANOL, and ARCA, S_s for travelling unloaded and loaded ranged between 51 and 66 m/min and between 57 and 82 m/min, respectively. At ECOSEMA the tractor travelled from the landing to the skid-trail entrance on a feeder road allowing high speed; however, the small mean load volume and the interruptions described above neutralised its positive impact on T_m. At ÁLVARO de CASTRO speed was extremely low, as skidtrails giving access to dense stands were established in curved patterns and the tractor travelled them carefully to avoid damaging residual trees. MITI showed the highest efficiency as measured by T_m, due to the large mean volume extracted per cycle. Except for ÁLVARO de CASTRO, where low volume and low speed resulted in a T_m of 0.42 min/m·m^3, values ranged between 0.04 and 0.08 min/m·m^3.

Skidding distance was predetermined by the extraction intensity and the spatial distribution of landings. Together with T_m it rendered values for PT. Short skidding distances as a result of intensive extraction resulted in superior PT values for SOMANOL and ÁLVARO de CASTRO. Conversely, MITI and ARCA, although showing better efficiency in other measures, had low values of PT because of the long skidding distances.

Observations made during data collection and analysis suggest that an appropriate spatial structuring of blocks with feeder roads, skidtrails, and landings could optimise skidding distance and speed. Furthermore, operational efficiency could be improved by attaching slotted beams or hydraulic tongs to the tractor’s three-point linkage. This would facilitate skidding of multiple logs, which could then also be partially lifted above the ground to reduce dragging friction. To avoid tipping the loaded tractor on the rear wheels, counterweights should then be added to the front of the tractor. The time spent hooking logs could be reduced by having the felling crews prepare logs for extraction by removing obstacles around the logs after crosscutting and by using a metal plate on the tip of the chain so that it would be easier to create a gap between the log and the soil.

4.1.3 Operational efficiency in first loading

First landings were established to accumulate extracted logs along secondary roads. These secondary roads either crossed the logging area in an unstructured pattern (ECOSEMA, MITI), or they systematically surrounded the block being logged (ÁLVARO de CASTRO, SOMANOL, ARCA). Logs were deposited on the landings in rows. Loading crews then prepared the logs for loading and positioned a ramp, made of two stakes 3.5-4.5 m in length, against the bed of the trailer or truck being loaded (see Photo Series 5, Appendix 2). The log to be loaded was rolled with cant hooks to a point near the base of the ramp stakes. Two ropes were then looped around the log and attached to a tractor. The log was then pulled up the ramp by the tractor. At ÁLVARO de CASTRO the small and relatively light logs were loaded manually, without using ramp, rope, or other auxiliary devices. After the logs were loaded, the loading crew rearranged them by hand into a stable position on the truck or trailer, using cant hooks and worn suspension springs as levering devices. Between four and six workers were employed in this activity at each site.

Table 4.3 *Operational efficiency in first loading.*

	ECOSEMA	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
V_m [m³/cycle]	0.49	0.14	1.06	0.91	0.63
PT [m³/h]	3.11	5.36	7.16	8.29	3.5
TP:TI [%]	57:43	60:40	73:27	93:07	*

Notes:

Vm = volume loaded per cycle
PT = technological productivity as calculated in Eq. (2)
TP = total productive time as defined in Table 3.1
TI = total unproductive time as defined in Table 3.1
* Detailed data not available for TP and TI at ARCA/SRZ; mean volume and productivity estimated

Technological productivity (PT), varying between 3.11 and 8.29 m³/h, was determined by mean volume per cycle, log shape and taper, ramp length and slope, the degree in which landings had been prepared for loading, and the share of time spent in unproductive activities.

Productive time occupied between 57% and 93% of operating time. The main loading process, rolling the log up the ramp to the deck, consumed between 13% and 28% of operating time, while more than 50% of productive time was involved in moving the log to the ramp and attaching the ropes. At ECOSEMA and ÁLVARO de CASTRO unproductive time was a large share of operating time. This time was spent mainly in preparing the trailer, along with rest periods and numerous interruptions of short duration.

Analysis of time-study results suggests that the element “Move log to ramp, fix ropes” was extremely time-consuming. This activity could be optimised by arranging logs into lots (according to species, size, and shape), thus creating more consistent loading conditions and improving the stability of loads for subsequent transport.

4.1.4 Operational efficiency in first transport

In this phase the loaded logs were transported either to the technical base (ECOSEMA, MITI, ARCA) or directly to the sawmill (ÁLVARO de CASTRO, SOMANOL)—see Table 2.4. Hauling distances varied between 2.5 and 49 km.

Except at MITI, first transport was done with tractors equipped with one or two semitrailers with capacities of 3-5 t. MITI used flat-deck trucks with capacities of 8 t. Each driver was accompanied by an assistant. Passengers frequently travelled on deck or on top of the load.

Technological productivity (PT) was very low, with values ranging from 0.18 to 1.79 m³/h (Table 4.4). PT was particularly poor at SOMANOL, where slow tractors hauled a low mean volume over a long distance. MITI and ECOSEMA achieved superior PT by using vehicles with load capacities of 6 and 8 tons.

As with extraction, the combined influence of load volume, speed, and unproductive time on operational efficiency was indicated by mean time (T_m), which measures operational efficiency independently of hauling distance. ECOSEMA, MITI, and ÁLVARO de CASTRO had overall efficiencies that were higher than those of SOMANOL and ARCA. The latter two transported low volumes at low speed and, in the case of ARCA, with a large portion of unproductive time. Because of limited load capacities, low speeds, and poor road conditions, none of the companies in this study was able to provide a consistent flow of raw materials.

In addition to low per-km efficiency, long hauling distances at SOMANOL, ÁLVARO de CASTRO, and ECOSEMA resulted in very low levels of PT.

Table 4.4 *Operational efficiency in first transport (with unloading).*

Variable	ECOSEMA	ÁLVARO de CASTRO	MITI	SOMANOL	ARCA/SRZ
Hauling distance [km]	23.4	23.5	14.5	49.0	2.5
S_t unloaded/loaded [km/h]	12.8/11.1	16.4/11.0	11.8/8.3	7.9/6.1	4.7/4.5
V_m [m³/cycle]	6.42	3.97	6.31	2.74	2.52
T_m [min/km·m³]	1.58	2.72	2.31	6.79	15.87
PT [m³/h]	1.62	0.94	1.79	0.18	1.50
TP:TI [%]	96:04	88:12	85:15	94:06	68:32

Notes:

S_t = travel speed
V_m = volume hauled per cycle
T_m = mean time per kilometre and per cubic metre
PT = technological productivity as calculated in Eq. (2)
TP = total productive time as defined in Table 3.1
TI = total unproductive time as defined in Table 3.1

An interesting question is the maximum hauling distance over which first transport could be considered to be at least minimally efficient. Under favourable conditions like those at ECOSEMA (two trailers per tractor and good road conditions), and supposing a required minimum PT of 3.00 m³/h (corresponding to delivery of one load within an eight-hour working day), the maximum limit for hauling distance would be 13 km. For larger distances between first landings and the destination, intermediate landings should be installed where logs would be transferred to trucks with higher capacities and capable of higher speeds. Note that the required PT of 3.00 m³/h in first transport could only be achieved at a distance of 13 km with a load capacity of at least 6 t and roads that are well-graded and well-drained.

4.1.5 Operational efficiency in second loading

This activity occurred in three of the five companies, whereas ÁLVARO de CASTRO and SOMANOL utilised only first transport directly to the sawmill. At MITI, hauling times and their distribution were not recorded; therefore comparative data are not available.

At ECOSEMA and ARCA/SRZ, two different methods were used: semi-manual loading with tractor assistance by the former company and mechanised loading with a front-end loader in the latter case.

Semi-manual loading was carried out at the landing of ECOSEMA's technical base, where sufficient space was available to manoeuvre the tractor. Logs were loaded on one of two semitrailers allocated to a particular truck, while the second semitrailer was travelling with the truck itself. When the truck returned to the landing from a trip, the empty semitrailer was disconnected and left on the landing to be loaded. The loaded semitrailer was coupled to the truck, which immediately began the trip to the final destination. Procedures were similar to first loading, except that the larger, better-graded landing site facilitated rope attachment and tractor work. Logs with a mean volume of 0.49 m³ were lifted as the tractor pulled two ropes looped around the log, rolling it up a ramp composed by two stakes 4.5 m long. To arrange the load, cant hooks and worn suspension springs were used. In this activity two loaders, the driver and an assistant were employed.

Table 4.5 *Operational efficiency in second loading.*

Variable	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
$\mathbf{V_m}$ [m^3/cycle]	0.49	—	*	—	2.20
PT [m^3/h]	4.00	—	*	—	37.34
TP:TI [%]	80:20	—	*	—	92:08

Notes:

V_m = volume loaded per cycle
PT = technological productivity as calculated in Eq. (2)
TP = total productive time as defined in Table 3.1
TI = total unproductive time as defined in Table 3.1
* Activity was not observed
— Activity did not occur

Mechanical loading at ARCA/SRZ required co-ordination between ARCA, which carried out logging and first transport to the central landing in the logging area, and SRZ, which provided the loader and was responsible for second transport to the sawmill. The front-end loader, with a capacity of 3.5 t, was able to handle up to four logs at a time, depending on the average log size. As a result, this method showed an outstanding technological productivity, more than nine times that achieved on the ECOSEMA operation (Table 4.5). However, co-ordination of loader delivery and truck availability made this method most sensitive to bottlenecks in raw-material flow to the sawmill. Although far less productive, semi-manual loading seemed to be better synchronised with second transport and was more capable of sustaining a consistent flow of logs to the final destination.

4.1.6 Operational efficiency in second transport

In second transport, logs were hauled from the second landing to the sawmill or the main log-yard in the provincial capital. Hauling distances ranged between 130 and 279 km. Trucks and semitrailers with load capacities of 25 t were used. An assistant accompanied the truck driver. Except for ECOSEMA, unloading at the destination was included in the time studies.

Technological productivity (PT) of second transport was very low, varying between 0.61 and 2.50 m^3/h (see Table 4.6), particularly for MITI hauling with low speed over a long distance. As a result of a relatively short hauling distance, ECOSEMA presented the highest PT. Without considering the influence of hauling distance, SRZ showed the best operational efficiency, with a medium time of 0.17 min/km·m^3.

The low efficiencies achieved in second transport made it difficult to maintain a consistent material flow from the logging area to the sawmill or sales site. The most important impediments were long hauling distances and, particularly in the case of MITI, extremely poor public-road conditions that forced trucks to travel with reduced load and at low speed.

Assuming favourable conditions such as those experienced by SRZ and a required minimum PT of 3.00 m^3/h (for a roundtrip with a 24 m^3 load within 8 hours), second transport could be operationally efficient up to a hauling distance of 118 km. This supposes that public roads comply with minimum technical standards. Otherwise, as in the case of MITI, the operationally efficient hauling distance shrinks to 57 km.

Table 4.6 *Operational efficiency in second transport.*

	ECOSEMA	ÁLVARO de CASTRO	MITI	SOMANOL	ARCA/SRZ
Hauling distance [km]	130	—	279	—	252
$\mathbf{S_t}$ [km/h]	34.7	—	19.7	—	35.0
$\mathbf{V_m}$ [m^3/cycle]	20.0	—	20.0	—	21.3
$\mathbf{T_m}$ [min/km·m^3]	0.18	—	0.35	—	0.17
PT [m^3/h]	2.50	—	0.61	—	1.39
TP:TI [%]	97:03	—	96:04	—	97:03

Notes:

S_t = travel speed
V_m = volume hauled per cycle
T_m = mean time per kilometre and per cubic metre
PT = technological productivity as calculated in Eq. (2)
TP = total productive time as defined in Table 3.1
TI = total unproductive time as defined in Table 3.1
— Activity did not occur.

4.2 Organisational efficiency

Utilisation rate (UR), labour productivity (P_L) and capital intensity (IC) were selected as indicators for assessing the relative efficiency with which the five companies used machinery, labour and capital during one year of production (see Section 3.2.2). In order to facilitate comparisons, the analysis was restricted to logging and first transport because information on those activities was available for all five companies.

The organisational indicators suggest generally that equipment and personnel were utilised inefficiently by the five companies in this study. Log production was scattered and extensive in terms of production volume, and intensive as to labour and capital, yielding in most cases unfavourable ratios between output (production volume in m^3/year) and input (machine capacity, number of workers and work-months, mean annual investment).

In all studied cases, results suggest that proper harvest planning, spatial structuring and consistent application of logistical principles are prerequisites for making full use of machinery, workforce, and invested capital. Moreover, organisational efficiency can be optimised by increasing extraction intensity, improving road conditions, and reserving road transport exclusively for trucks.

4.2.1 Utilisation rate and production capacity

During the year each was visited, the five companies produced volumes ranging between 150 and 2,400 m^3 of logs. ÁLVARO de CASTRO, SOMANOL, and ECOSEMA operated at very low levels.

In most cases production capacity (CP) was limited by the transport vehicles' low technological productivity as described in Section 4.1.4. Only at MITI, which used a second truck for transport (which was non-operational during data collection), was CP restricted instead by the productivity of the skidding operation. Superior CP was measured in the companies with more favourable equipment configurations (ECOSEMA with two tractors, each of which operated with two trailers; MITI with trucks; ARCA with a short transport distance). In most cases it was not the technological capacity of machinery that limited production but lack of harvest planning, inadequate preparation, and persistent logistical problems. All these had strong negative impacts on production volume and resulted in low utilisation rates (see Table 4.7).

ÁLVARO de CASTRO was troubled by sporadic fuel and spare-parts supplies and ECOSEMA's operations were hampered by scattered, unsystematic logging progress. These problems caused pronounced discrepancies between the two companies' technological capacities and actual production volumes, resulting in utilisation rates of 11% and 13% respectively. SOMANOL made almost full use of the tractor and trailer used in transport and achieved a UR of 92% although producing at very low level with minimum equipment. Facilitated by a short transport distance, ARCA managed to produce a relatively high volume with a well-synchronised set of machines, thus reaching a UR of 79%. Its high UR resulted from efficient use of transport vehicles through rapid loading, and from minimising the first transport distance by locating the main landing at a central site within the logging area rather than outside of it as the other companies did.

Table 4.7 *Utilisation rate (UR), production capacity (CP), labour productivity (P_L) and capital intensity (IC) in logging and first transport.*

Variable	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA**
Total annual production [m3]	600	150	1,600	480	2,400
Year of assessment	1996	1997	1998	1998	1998
UR Crosscut saw or chainsaw[%]	10	09	10	17	12
UR Tractor [%]	12	03	36	04	47
UR Tractor+trailer [%]	13	02	16	04	79
UR Tractor+trailer or truck [%]	13	11	62	92	79
UR Total production [%]	13	11	36	92	79
CP [m^3/year]	4,666	1,354	4,506	520	3,024
P_L [m^3/worker/month]	3.41	1.04	11.11	3.33	17.65
IC [US$/$m^3$]	49.47	40.13	63.03	20.45	25.56

Notes:

UR = utilisation rate of the equipment indicated, calculated as in Eq. (6)
CP = production capacity of the entire combined operation (logging and first transport)
P_L = labour productivity, calculated as in Eq. (7)
IC = capital intensity, calculated as in Eq. (8)

Most of the companies failed to synchronise technological capacity, adapt it to the required production volume, and to coordinate production. Synchronising in this context requires adjusting equipment capacities in logging and transport to one another by attributing a certain number of machines to each activity. Coordinating means to organise production in such a way that the maximum volume can be produced to fully utilise the company's adjusted production capacity.

4.2.2 Labour productivity

In logging and first transport, between 17 (ARCA) and 22 (ECOSEMA) workers were employed (see Section 2.4). Rating annual production volume against the number of workers and working months per year yielded values for labour productivity (P_L) varying between 1.04 and 17.65 m^3/worker-month. Table 4.7 shows that the companies with low annual production volumes were subject to extremely low labour efficiencies. As with equipment utilisation, workforce efficiency can be improved by synchronising the size and number of crews and co-ordinating labour by clearly defining work tasks and production targets, and then by closely supervising the crews and providing regular feedback on performance.

An explicit training program covering efficient working techniques, occupational safety and application of better practices (see Section 5.3) should be addressed to both workers and foremen. Any substantial improvement in operational and organisational efficiency will require a well-developed professional workforce, working and living under adequate conditions. Standards for remuneration, nutrition, and camp facilities are subjects requiring further attention.

4.2.3 Capital intensity

An analysis comparing mean annual investments in machinery (chainsaws, tractors, trucks) with annual production volume indicated capital intensities (IC) between 20.45 and 63.03 US$/m^3 (Table 4.7). At the two extremes, SOMANOL maintained a low production volume with minimum investment, while MITI invested heavily in trucks that were nevertheless subject to frequent breakdowns because of poor road conditions.

4.3 Energy efficiency

Based on fuel consumption, two expressions for energy efficiency were calculated: timber volume produced per 1,000 litres of fuel consumed, and the ratio between calorific values of produced timber and fuel consumed during production (see Section 3.2.3).

Table 4.8 shows that energy efficiency in logging and first transport ranged between 21.56 and 110.91 m^3/1,000 *l*. This was influenced largely by technological productivity, with transport being the most sensitive activity. ECOSEMA's energy efficiency was the highest, since each tractor hauled two trailers and thus spread fuel consumption over a relatively large transported volume. At ARCA the very short hauling distance resulted in a relatively efficient energy use. At MITI, the short distance for first transport with relatively large-capacity vehicles should have made transport energy-efficient. However, poor road conditions prevented the trucks from travelling at sufficient speed to compensate for their relatively high fuel consumption rates. SOMANOL's energy efficiency was extremely low due to the fact that the tractor hauled only one trailer over a long distance.

Subsequent activities were second loading and transport at ECOSEMA, MITI, and SRZ, and processing at ÁLVARO de CASTRO, MITI, and SOMANOL (processing at SRZ was not included in this analysis). Energy efficiency in these activities varied between 50.17 and 76.63 m^3/1,000 *l* where logs were produced (ECOSEMA and ARCA/SRZ), and between 15.56 and 55.19 m^3/1,000 *l* where logs were processed into sawnwood (ÁLVARO de CASTRO, MITI, and SOMANOL). It was particularly low at MITI, where second transport over long distances and processing by mobile band saw resulted in high fuel consumption and low technological productivity. ECOSEMA's efficient energy use was due to relatively high productivity in second transport.

Table 4.8 *Volume produced per 1,000 l fuel (η_e) and energy coefficient (η_c).*

Description	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
Notes on comparisons	†	‡		‡	†
Logging + 1st transport (η_e)	110.91	66.07	74.41	21.56	94.06
Subsequent activities (η_e)	76.63	41.67	15.56*	55.19	50.17
Totals:					
η_e [m^3/1,000 *l*]	45.32	25.55	12.87*	15.50	32.72
η_c [kWh timber/kWh fuel]	0.91	0.51	0.26*	0.31	0.65

Notes:

η_e and η_c were calculated according to Eq. (9) and Eq. (10), respectively

† No processing; products sold as logs only

‡ No second transport

* These figures are for 400 m^3 of logs processed into sawnwood. For 1200 m^3 sold as logs without further processing: η_e = 22.59, η_e Total = 17.33, η_c Total = 0.35

Energy efficiency for total production was on a rather low level, with values for η_e ranging between 17.33 and 45.32 m3/1,000 *l* for log production and between 12.87 and 25.55 m3/1,000 *l* for companies that produced sawnwood. ECOSEMA's relatively high value of 0.91 for η_c was achieved by the favourable configuration of two trailers per tractor in first transport and a relatively short distance for second transport. ARCA/SRZ owed the second-highest ratio to a short hauling distance in first transport and relatively efficient second transport in spite of a long hauling distance. In companies producing sawnwood, energy coefficients ranged from 0.26 (MITI) to 0.51 (ÁLVARO de CASTRO). At SOMANOL energy efficiency was severely reduced by first transport, where a slow vehicle hauled small loads over a long distance. MITI's low energy efficiency was due to high fuel consumption and low productivity in subsequent activities, due in part to poor road conditions for the long second transport and in part to inefficient processing with the mobile sawmill.

4.4 Financial efficiency

Unit costs were used as indicators for financial efficiency as described in Section 3.2.4. Two references were applied: technological productivity as a result of time studies, yielding comparative unit costs, and actual annual production, resulting in effective unit costs. In addition, total effective unit costs were compared to sales revenues in order to assess the relative cost-efficiencies of the companies.

4.4.1 Comparative unit costs (logging and 1st transport)

Dividing cost per machine-hour by technological productivity provides "unit cost," a relative measure of potential financial efficiency which is independent of actual production volume. Total unit costs for logging and first transport ranged between 21.06 US\$/m^3 at ECOSEMA and 32.46 US\$/m^3 at MITI (Table 4.9). Well outside of this range, SOMANOL's total unit cost was astronomically high at 73.55 US\$/m^3, caused largely by an operationally deficient transport system with a unit cost of 61.40 US\$/m^3. MITI and ARCA also generated relatively high unit costs. For MITI this was due to poor road conditions for first transport, and for ARCA the proximate cause was an out-of-balance system that employed too many workers. In general, between 38% and 84% of total unit costs occurred in first transport, followed by loading and extraction. Unit costs for felling and crosscutting were generally less important, but were significantly lower in companies using crosscut saws (see 4.1.1).

Table 4.9 *Comparative unit costs (C_{uc}) in logging and 1st transport.*

Activity	ECOSEMA	ÁLVARO de CASTRO	MITI	SOMANOL	ARCA
	C_{uc} [US$/m^3]				
Felling and crosscutting	1.55	0.71	0.85	0.43	0.81
Extraction	3.25	3.51	6.63	1.34	5.61
1st Loading	4.32	2.89	5.06	1.46	6.84
1st Transport	7.99	15.02	19.22	61.40	14.38
Road maintenance	3.94	1.72	0.70	8.92	0.93
Total	21.06	23.85	32.46	73.55	28.57
$C_{fuc} : C_{vuc} : C_{luc}$* [%]	30 : 61 : 09	09 : 78 : 13	40 : 53 : 07	19 : 65 : 16	39 : 52 : 09

* Distribution of fixed, variable and labour unit costs as percentages of total unit cost

Examination of the results in Table 4.9 suggests that operational costs accounted for most of the unit costs (between 52% and 78%), whereas labour costs did not exceed 16%. Ownership costs ranged between 9% and 40%, depending on how heavily the companies invested in extraction machinery and transport vehicles.

4.4.2 Effective unit costs and margin of profit

Effective unit costs are those associated with an entire year's production, as calculated in Eq. (24). For this study the reference year for each company was the year in which the company's operations were examined. Table 4.10 shows that effective unit costs for felling and crosscutting, extraction, first transport and road maintenance ranged between 25.95 and 73.31 US$/m^3 and occupied between 18% and 33% of total effective unit costs. Low utilisation rates at ECOSEMA, ÁLVARO de CASTRO, and MITI (see Section 4.2.1) drove them to significantly higher effective unit costs for these activities than the other two companies. Only ARCA managed to keep costs low overall, by efficiently employing equipment and hauling over a short distance. SOMANOL's intermediate unit cost for these activities resulted from the lack of second transport and a low unit cost for road maintenance.

Total effective unit costs ranged between 80.40 and 364.14 US$/m^3. Low annual production at SOMANOL and ÁLVARO de CASTRO resulted in exorbitant unit costs, since expensive processing and supervision added to costly logging and first transport. The low production volumes boosted fixed and labour costs to 67% and 69%, for the two companies respectively, of total costs. At ECOSEMA the low annual production level and large inventory of non-operational machinery resulted in a high contribution from fixed costs. MITI's production was subject to high variable costs, caused by low productivity in transport and processing. The only company generating moderate unit costs was ARCA, which employed equipment and personnel in a well synchronised manner, produced a relatively large volume, and minimised hauling distance in first transport. However, subsequent activities performed by SRZ (high fixed costs for second loading with front-end loader and high variable costs caused by low productivity in second transport) more than doubled the unit costs of ARCA's production.

In the companies with low production levels (ECOSEMA, ÁLVARO de CASTRO, SOMANOL) depreciation, interest and insurance costs occurring in the course of annual production resulted in high fixed costs per cubic metre. ÁLVARO de CASTRO, by using obsolete equipment and avoiding second transport by processing close to the logging area, restricted these costs to 30% of total unit costs. However, an excess of personnel in all activities made labour costs prominent. Companies with higher production levels (MITI and ARCA/SRZ) were more affected by variable costs, especially high fuel consumption and low productivity in activities subsequent to logging and first transport.

Table 4.10 *Effective unit costs (C_u), variable costs (C_v), sales details, profit margin (M_p), and break-even point (BEP) in the entire operation for each of the five companies.*

Description	**ECOSEMA**	**ÁLVARO de CASTRO**	**MITI**	**SOMANOL**	**ARCA/SRZ**
Annual production [m^3]	600	150	1,600	480	2,400
Year of assessment	1996	1997	1998	1998	1998
	C_u [US\$/m^3] (% of total)				
Logging+1st Transport	60.31 (33)	73.31 (24)	48.87 (28)	64.84 (18)	25.95 (32)
2nd Loading	11.86 (06)	—	‡	—	19.03 (24)
2nd Transport	27.67 (15)	—	57.96 (33)	—	25.15 (31)
Maintenance	15.75 (09)	32.71 (11)	2.70 (02)	4.91 (01)	2.61 (03)
Non-operating equipment	38.27 (21)	15.58 (05)	6.38 (04)	13.06 (04)	—
Processing	—	74.09 (24)	29.53 (17)	167.17 (46)	—
Supervision	29.82 (16)	109.81 (36)	29.44 (16)	114.16 (31)	7.66 (10)
Total (C_{tu})	183.67	305.51	174.87	364.14	36.22/44.18
$C_{fu} : C_{vu} : C_{lu}$* [%]	56 : 29 : 15	30 : 31 : 39	36 : 56 : 08	49 : 33 : 18	38 : 54 : 08
C_v [US\$/m3]	34.68	50.27	82.74	87.14	14.33/17.45
Product sold	Logs	Parquet scantlings	Logs, lumber	Truck decks	Logs♦
Sale location	Beira	Macuáquà	Pemba	Nampula	Mauela♦
Selling price (US\$/m^3]	75.00	100.00†	130.00	262.50†	50.00♦
M_p [US\$/ m3]	-108.67	-205.51	-44.87	-101.64	13.78♦
BEP [m3/year]	2,217	770	3,119	758	1,473♦

Notes:

* Distribution of fixed, variable and labour unit costs as percentages of total unit cost

† Prices converted to roundwood equivalent (price per cubic metre of logs)

‡ Activity was not recorded

— Activity did not occur

♦ This information is for ARCA alone, rather than ARCA and SRZ combined

Looking at the distribution of unit costs over activities, second loading and transport occupied between 21% and 55% of total unit costs, incurring unit costs of between 39.53 and 57.96 US\$/m3. Where processing was integrated, it generated costs ranging between 29.53 and 167.17 US\$/m3 (17% to 46% of unit costs), depending on production level and productivity as well as on the degree of conversion (sawnwood from 25% of annual log production at MITI, parquet scantlings at ÁLVARO de CASTRO, truck decks at SOMANOL). Costly production at SOMANOL was due not only to the factory's short log supply but also to its high-cost downstream processing.

Taking into account sales revenues from final products, most of the companies generated deficits between 44.87 and 205.51 US\$/m^3, generally as a result of low production levels that caused high fixed costs, and low technological productivity in transport and processing that resulted in high variable costs. ARCA, with the highest overall annual production, was the only company that managed to generate a positive profit margin from its sale of logs at the main landing in the logging area of 13.78 US\$/m^3. These logs were purchased by SRZ for processing at its sawmill in Nicoadala, which was also supplied from other logging areas. Therefore it was not possible to derive an overall profit margin for ARCA/SRZ including processing. However, the purchase price (50.00 US\$/m^3) paid to ARCA plus costs for second loading and transport resulted in raw-material costs at SRZ's sawmill gate of 94.18 US\$/m^3. Assuming a processing recovery rate of 50% and sales revenue for export sawnwood of 400.00 US\$/m^3, SRZ's processing and supervision costs would have to be less than 105.82 US\$/m^3 in order to generate a profit.

4.4.3 Break-even point

As a function of sales revenue and total cost, the break-even point (BEP) indicates the level of annual production required to generate a profit. As indicated in Eq. (26), the calculation of BEP involves rating the annual costs of ownership, repairs, and labour against the gross sales margin (sales revenue minus variable cost). For the five companies in this study, BEP ranged from 758 to 3,119 m^3 of annual production (Table 4.10). Only ARCA produced a volume exceeding its BEP and thus generated a profit.

With the exception of ARCA all of the companies operated at levels well below their break-even points. SOMANOL was closest, with actual production at 63% of its BEP, but operating at the full BEP level would have exceeded its technological capacity (which was restrained by lack of transport vehicles) by 46%. ECOSEMA, ÁLVARO de CASTRO, and MITI could all conceivably have reached their break-even points with better synchronisation and coordination; producing at their break-even points would have required only 48%, 57%, and 69% of the three companies' respective technological capacities. The break-even points could also have been reached, of course, if the three companies had been able to negotiate sufficiently higher prices for their products.

Generally, results of break-even analyses suggest that companies processing sawnwood close to the logging area are able to cover their production costs at lower production levels than those selling unprocessed timber far from the point of origin. As soon as second transport over a long distance is involved it becomes much more difficult to cover production costs.

The cases of ECOSEMA and MITI raise the critical question of whether the BEP can be achieved at all with available timber stocks if they are to be managed on a sustainable basis. ECOSEMA's logging area had been repeatedly exploited and the species in highest demand were in short supply at marketable sizes. Consequently the company was unable to make a profit and eventually was forced to suspend its activities altogether. Although a full analysis of MITI's situation would require more detailed investigation, the sustainable extraction potential of the logging area appears sufficient to permit production at the break-even level if the company were to improve its practices relative to extraction intensity, harvest planning, and transport productivity.

5. CONCLUSIONS AND RECOMMENDATIONS

Efficiency analyses in most cases yielded marginal results for operational and energy efficiency in transport as well as for organisational indicators, thus generating low values for financial efficiency. Only one company, ARCA, achieved a favourable overall result, since the company's logging area was structured spatially for efficiency and the cost of second loading and transport were externalised. Table 5.1 provides an overview of the efficiency results for the companies studied.

Table 5.1 *Configuration of critical properties for efficiency in the analysed companies.*

Property	ECOSEMA	ÁLVARO de CASTRO	MITI	SOMANOL	ARCA/SRZ
Roads and spatial structure	–	+	–	–	+
Extraction intensity	–	+	–	+	–
PT in logging	+	+	+	+	+
PT in transport	+	–	–	–	–
Production volume	–	–	+	–	+
Effective unit costs	–	–	–	–	+
Profit margin/deficit	–	–	–	–	+

+ / – Analysis suggested that the quality or value of the property was relatively favourable / unfavourable.

Results suggest that commercial timber harvesting as it was practised under the observed conditions in these five companies generates no or little benefit and hardly justifies employment of the capital, workforce, and energy required for extraction and processing.

5.1 Main outcomes

In logging, the overall levels of operational efficiency achieved were sufficient, or nearly so, to maintain a consistent flow of raw materials in most of the companies. However, lack of spatial structuring and low recovery rates kept production levels well below the break-even points in most cases. The work studies documented improper working techniques and poor maintenance of felling and crosscutting equipment, problems associated with extraction of scattered and sometimes inaccessible logs, and first landings that were poorly prepared for loading. Technological productivity in transport constituted the main bottleneck, where poor road conditions, low load capacities of vehicles used in first transport, and long hauling distances in second transport impeded raw-material flows and restrained annual production volumes.

Two different strategies were observed relative to organisational efficiency. ÁLVARO de CASTRO and SOMANOL used obsolete equipment with low technological capacities in an effort to minimise capital inputs. This resulted in low production volumes and low labour productivity. The other three companies used more productive equipment in an effort to maximise production. ECOSEMA and MITI were unable to achieve this goal at a level that would make them profitable. At ECOSEMA, low stocking of commercially valuable trees in the repeatedly logged-over forest restricted extraction potential and resulted in low log prices. At MITI, a poor road network in the logging area hampered truck utilisation. Only ARCA was able to achieve good results in all organisational indicators.

Energy efficiency in logging and first transport was, except for SOMANOL, achieved at indicator levels greater than 1.0, indicating that the estimated energy value of logs recovered exceeded the energy value of fuel consumed during the operation. However, high fuel consumption and low productivity in second transport and processing reduced the energy balance for the complete operation in all cases below 1.0 (in most cases far below), indicating inefficient energy use overall.

Financial efficiency varied as a function of production volume, the degree of final-product conversion, and the distance between the logging area and the processing plant or point of sale. In four of five cases, total effective unit costs were exorbitant. While only 18 to 33% of these costs were incurred in logging and first transport, second transport and processing were extremely high-cost operations in nearly all cases. Most companies generated pronounced deficits at low annual production levels which prevented them from covering their fixed costs, and with low levels of technological productivity in transport and processing that made it impossible for them to cover high variable costs. Only ARCA managed to limit unit costs and attain a profit by efficiently employing equipment and personnel, thus producing on a relatively high level. ARCA also was able to externalise costs for second loading and transport to the sawmill that bought the logs (but at the cost of a low price for its logs). The break-even point, varying as a function of sales revenue and cost structure, was far beyond the actual production volume for four of the five companies although within the limit of technological capacity for three of those four. Results suggest that companies producing processed timber close to the logging area would have attained their break-even point with lower production volumes than those selling logs far from their origin.

5.2 Impediments

Being subject to operational, organisational, and institutional constraints, logging efficiency was limited by low production levels and high unit costs. The main shortcomings found in the study were low extraction intensity, lack of harvest planning and preparation, and low productivity in transport and processing.

5.2.1 Low extraction intensity

In the logging areas visited for this study, commercial species of the sizes required for harvest occurred in a scattered distribution. Demand was concentrated on a small number of species and maximum diameters. The working techniques employed in felling and crosscutting converted only a small fraction of the available tree volume into logs prepared for extraction. All this contributed to low extraction volumes per hectare. In addition, government inspection practices, requiring not the trees harvested but rather the logs passing road checkpoints to comply with minimum diameter limits, had the effect of encouraging the poor recovery rate. Moreover, buyers' scaling practices excluded sapwood entirely, thus reducing log volumes significantly at the point of sale.

5.2.2 Lack of harvest planning and preparation

Scattered timber resources call for systematic harvest planning and preparation. Establishing and maintaining a road network and spatially structuring the logging blocks facilitates access, survey, felling, and extraction and thus helps to organise operations so that raw material flows can be maintained at the required level. Most of the companies in this study were unable to cope with these requirements. The practice of granting cutting licenses based on the volume extracted provided little in the way of incentives to invest in infrastructure, spatial organisation of logging, or sustainable resource management in order to optimise extraction intensity. Instead, logging was carried out in an ad-hoc, largely unplanned way.

5.2.3 Low productivity in transport and processing

Transport operations, already hampered by the scattered distribution of first landings, also suffered from insufficient road networks and poor road conditions. Hauling equipment often travelled with small loads at low speed. Long hauling distances, particularly in second transport, increased operating time and restricted technological productivity to an extremely low level. This in turn impaired raw-material flows, thus affecting log supply and machine utilisation in subsequent processing. The detrimental influence of poor road conditions and long hauling distances suggests that beyond 15 km in first transport and 120 km in second transport, log hauling under the conditions observed in this study is unlikely to achieve a satisfactory level of efficiency and maintain a consistent flow of raw materials.

5.2.4 Impacts of impediments to production

A typical small-scale logging enterprise starts production on the basis of a cutting license granted for 500-2,000 m^3 without investing in a management plan, road network, or spatial structuring. Scattered timber resources strangle raw-material flows right from the beginning. Extraction and transport bring high unit costs for fuel, lubricants, tyres, and wages, which internal accounting perceives as production costs. Sales revenues hardly cover the expenses of current production. In order to save the apparent profit (according to internal accounting, sales revenues minus the cost of consumables and wages), the company reduces expenses for fuel and spare parts by slowing down current production rather than taking positive action. ECOSEMA, ÁLVARO de CASTRO, and SOMANOL were all entangled in this spiral of progressive efficiency that finally forced them to suspend their activities.

5.3 Proposals for improving efficiency

In order to improve efficiency, annual production should be raised to a level that will cover both fixed and variable costs, and efforts should be made to increase technological productivity in critical phases, particularly in transport. A set of guidelines that might help to achieve this goal are summarised in Table 5.2.

Of paramount importance for improving efficiency in commercial logging is the need to increase productivity by harvesting a larger number of commercial species and by recovering a greater volume per tree felled. In addition, it is essential to increase the volume per load and speed of extraction and transport, and to reduce hauling distances by locating processing units as close as possible to logging areas. Improving the efficiency of logging practices will require minimum annual production levels of around 2,000 m^3 in order to cover costs. Whether industrial enterprises are willing to invest in decentralised, integrated production under these conditions depends on the logging area’s long-term potential for commercial timber. It must be sufficient to avoid short-supply situations with negative impacts on production costs as well as resource degradation caused by over-exploiting certain species. These aspects have to be clarified by applying appropriate planning instruments. Regarding the constraints imposed by dispersion and low increment of commercial species, efficient and sustainable logging should be confined to areas rich in diversity and abundant in commercial tree species.

The practices suggested in Table 5.2 must be implemented in the context of sustainable forest management, which implies that the area under management must be well delimited and demarcated, with land-use rights clearly defined and granted on long term. Without legal security, companies are unlikely to invest in the necessary road networks, to establish permanent processing and maintenance facilities, or to make the considerable effort needed to optimise extraction intensity.

Table 5.2 *Recommended practices for improving efficiency.*

Objectives	**Practices**
Better use of timber resource potential	**Harvest planning and preparation**
• Improved conditions for access, survey, and systematic forest management. Controlled achievement of required production volume.	• Elaborate a stock map of the logging area and divide it into marked and numbered management blocks; install and maintain a network of main and secondary roads.
• Reduced distances and increased speed of extraction; optimised pre-accumulation of logs; reduced damage to residual stand.	• Establish crews for surveying and spatial structuring of blocks to be logged: select, measure, and register trees to be felled and mark the direction of fall; mark skidtrails; determine landing sites; and elaborate detailed sketches of planned extraction.
• Increased extraction volume per hectare.	• Extract logs of all commercial species within the limits of sustainability.
More efficient and safer logging	**Applying better equipment, working techniques and procedures**
• Increased recovery rate and extraction intensity; reduced damage to residual stand.	• Introduce directional felling, cutting as close as possible to the ground, and crosscutting the maximum volume per tree prepared for extraction.
• Improved efficiency and safety in felling and crosscutting.	• Use crosscut saws or chainsaws with all safety devices, and wedges for directional felling; provide maintenance tools for crews to use.
• Fewer delays in hooking and increased loads per extraction cycle; reduced soil disturbance.	• Introduce chains with tip plate for hooking and hydraulic notch beam fixed to three-point linkage of tractor for hauling multiple logs partially suspended.
• Fewer interruptions during loading.	• Improve organisation of first landings and position the logs according to loading sequence.
More efficient 1st transport	**Investing in machinery and road network**
• Increased load capacity and speed of vehicles used in 1st transport.	• Employ trucks with capacities of at least 6 t.
• Increased average speed in 1st transport.	• Invest in grading and drainage of roads used for 1st transport.
More consistent raw-material flows	**Configuring logging area, landing and processing facility or point of sale**
• Improved efficiency in transport.	• Limit hauling distances to 15 km in 1st transport and to 120 km in 2nd transport.
• Optimised log supply and utilisation rate in processing.	• Decentralise processing by locating sawmills as close as possible to the logging areas.
Better logistics and equipment	**Investing in permanent maintenance facilities**
• Increased technical availability of vehicles. Improved performance of crosscut saws and chainsaws.	• Develop a well-equipped maintenance workshop with fuel and oil tanks at the main landing in the logging area.
Better workforce performance	**Developing training program and task descriptions**
• Improved efficiency and safety in all operations.	• Implement training programs in recommended practices and in occupational safety.
• Improved synchronicity of operations.	• Establish task descriptions for each crew, including quantitative and qualitative production targets.
• Improved working and living conditions for workers.	• Provide adequate remuneration, nutrition, camp facilities, transport, and health assistance.

The efficient and sustainable use of timber resources must render benefits for the local population, establish a nucleus of skilled professional workers, and invest in appropriate equipment, occupational safety, health, and housing (JOHANSSON & STREHLKE 1996). Enterprises committed to efficiency and sustainability must make sure that workers are properly remunerated and live in adequate conditions. In addition, it is essential to conduct training courses in working techniques and occupational safety on a regular basis, and to optimise the ergonomic features of applied technologies and operations.

Whether these recommended practices improve efficiency in commercial timber harvesting and the degree to which more efficient practices would conform to standards on reduced environmental impacts and socio-economic sustainability deserves further attention through field research.

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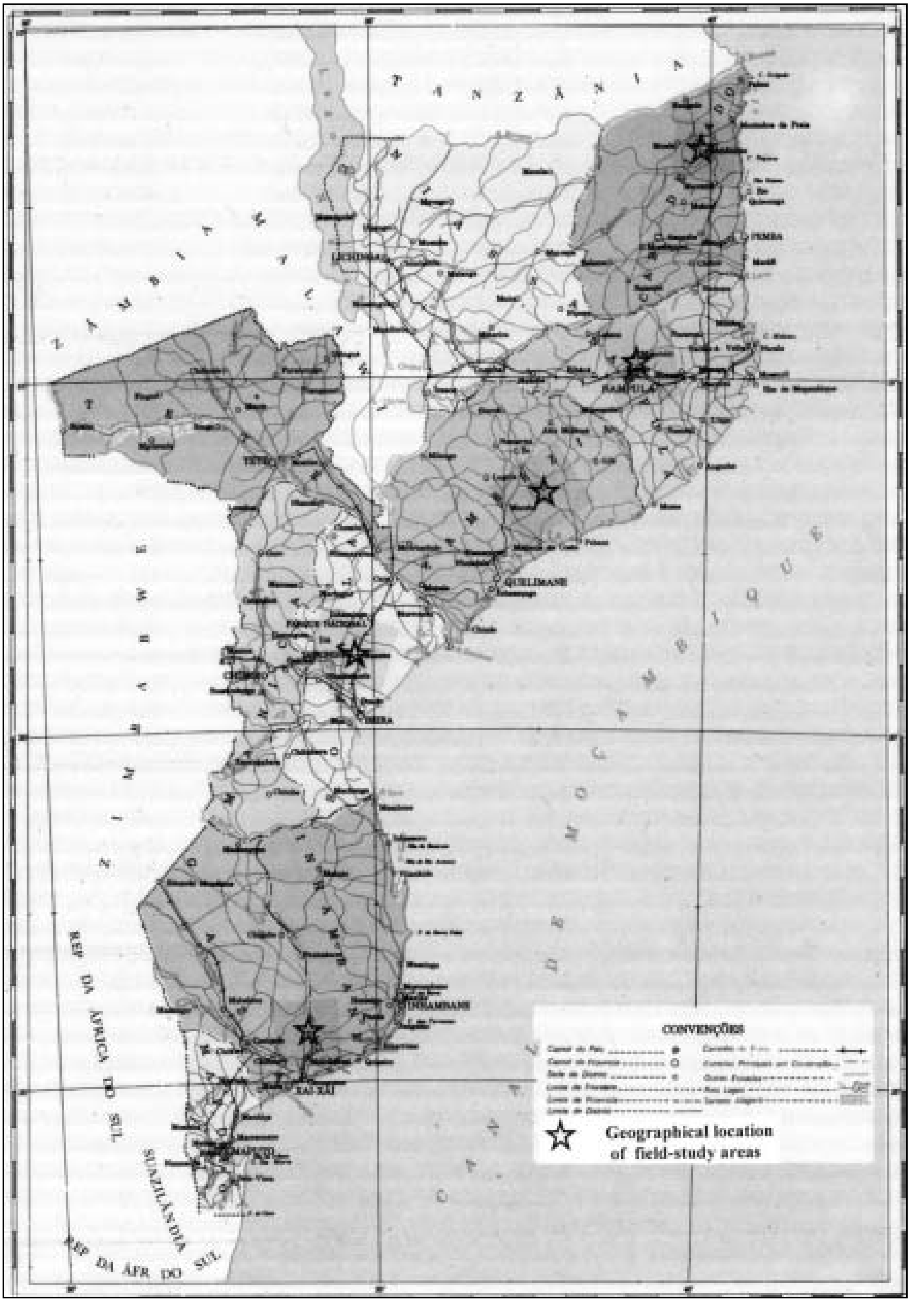
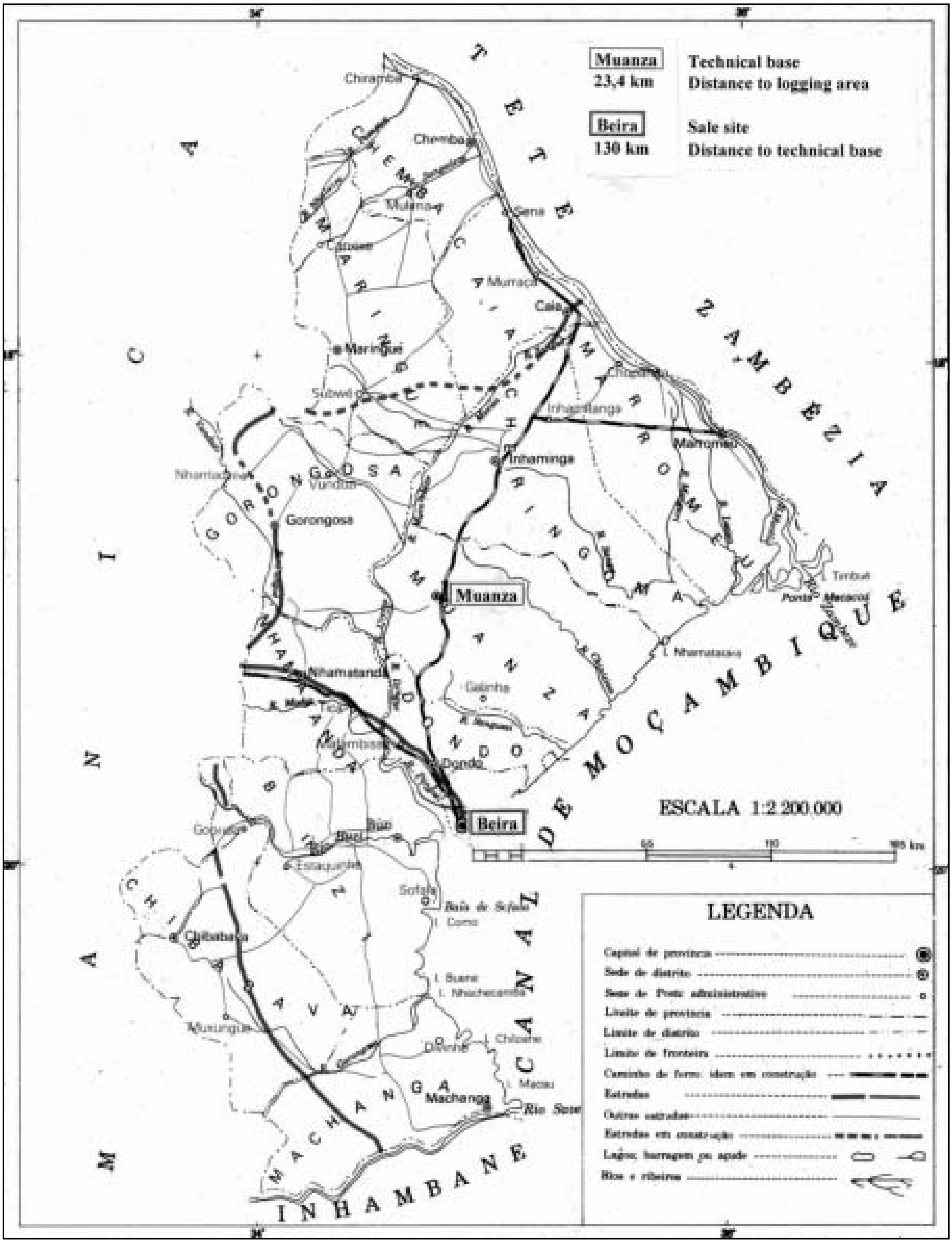
Appendix 1. Maps

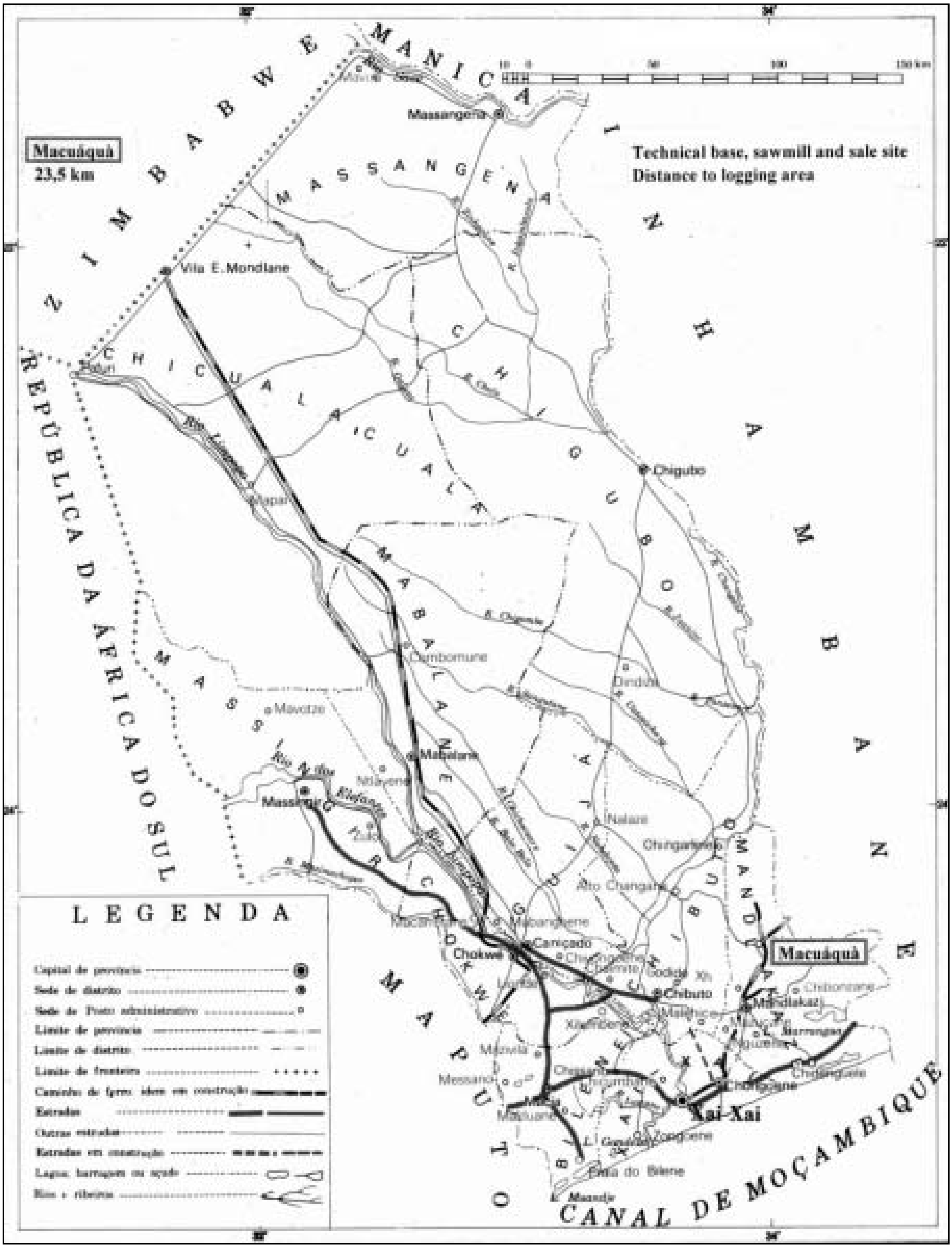
Map 1. *Map of Mozambique showing the five field-study sites.*



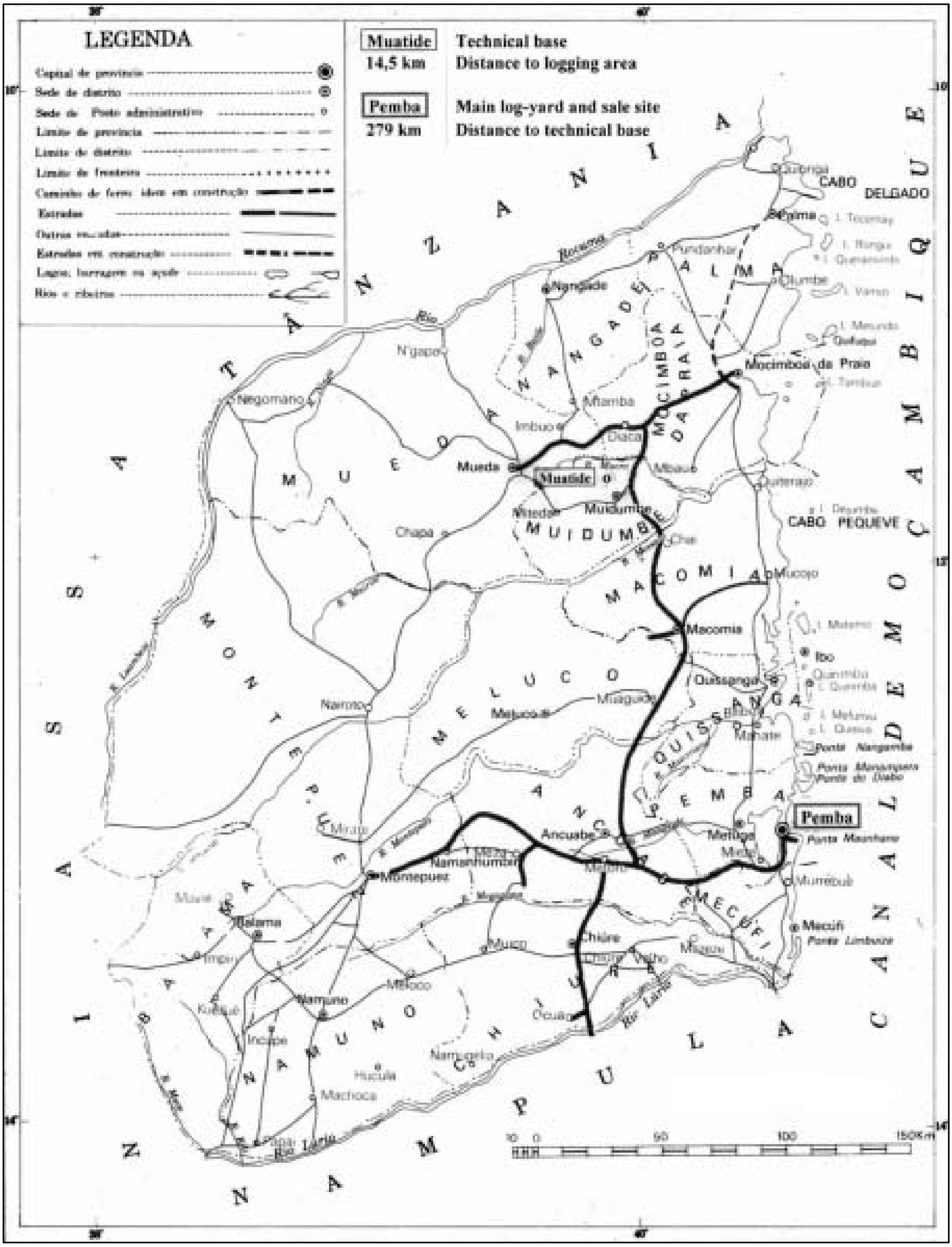
Map 2. *Province of Sofala, site of the ECOSEMA operation.*



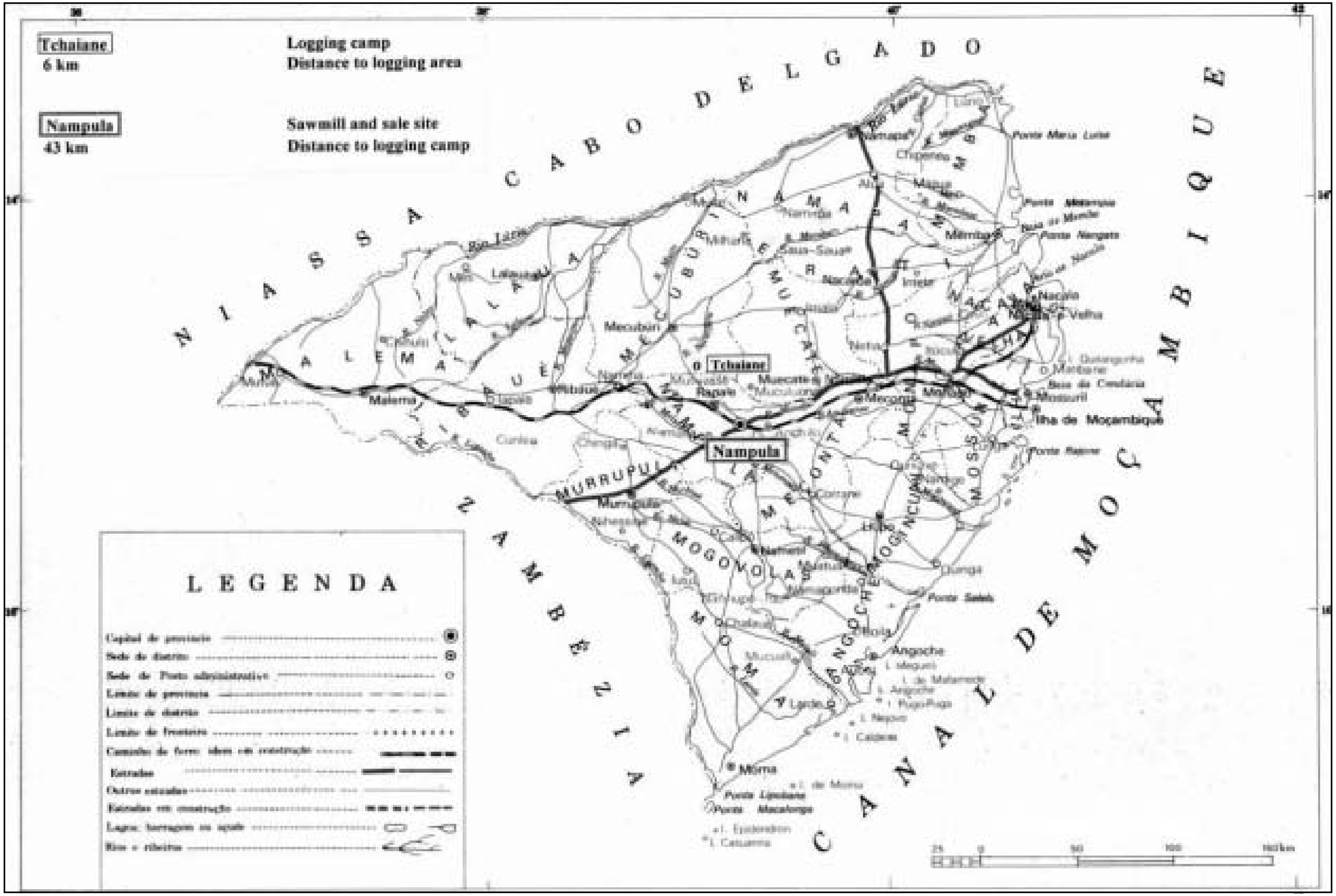
Map 3. *Province of Gaza, site of the ÁLVARO de CASTRO operation.*



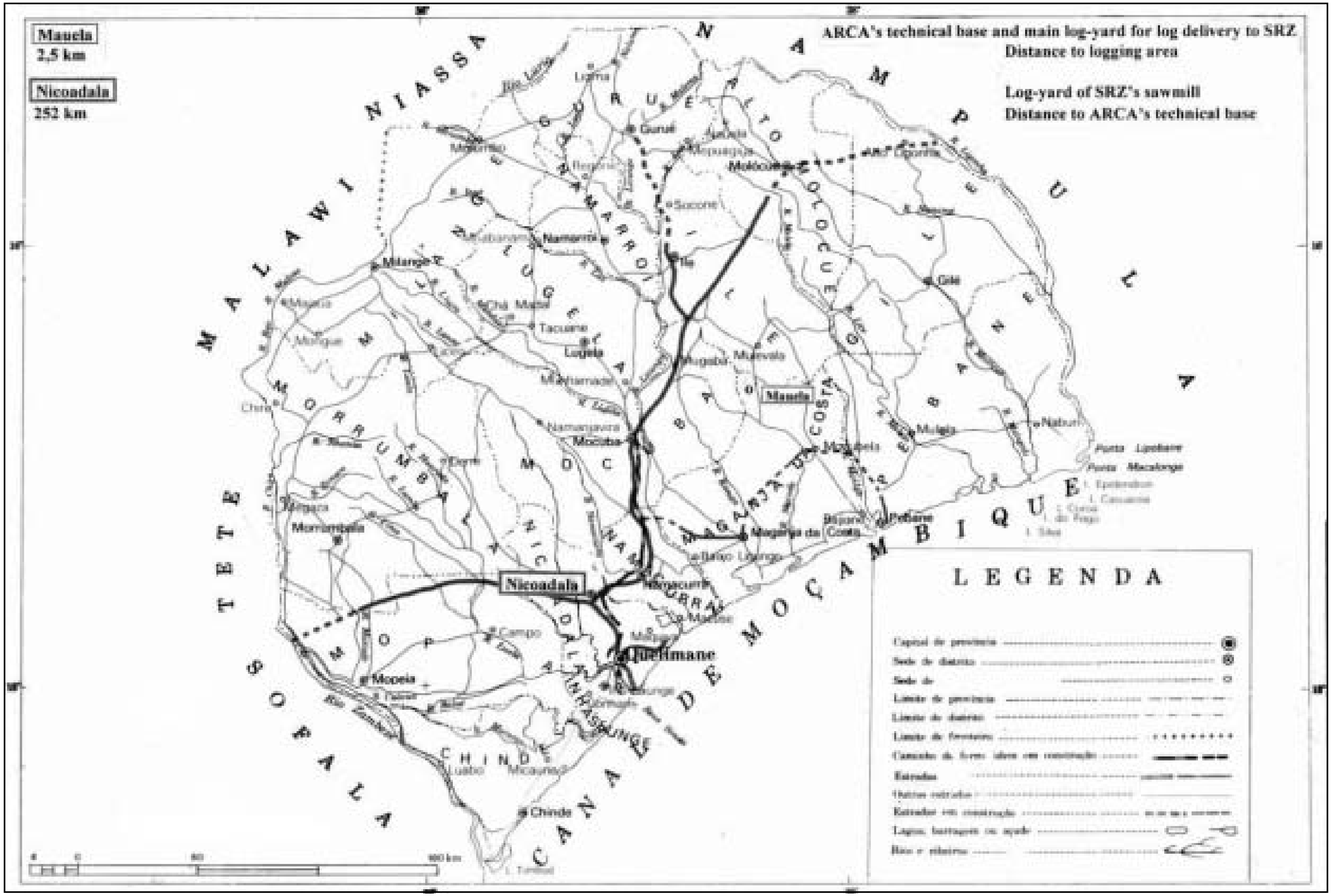
Map 4. *Province of Cabo Delgado, site of the MITI operation.*



Map 5. *Province of Nampula, site of the SOMANOL operation.*



Map 6. *Province of Zambézia, site of the ARCA operation and SRZ sawmill.*



Appendix 2. Photographs

Photo Series 1.

Non-directional felling (right) and its impact on the residual stand at ECOSEMA (below).

Photo Series 2.

Right: felling and crosscutting with crosscut saw.

Left: bringing down a lodged tree with dangerous working technique at ÁLVARO de CASTRO

Photo Series 3.

Use of a poorly sharpened and improperly set crosscut saw for felling at SOMANOL (top), and its effect on timber recovery (bottom). Note the pulled fibres in the stump in the lower photo.

Photo Series 4.

Hooking and ground skidding of one log per cycle with agricultural tractor at SOMANOL.

Photo Series 5.

Tractor-assisted first loading of logs onto a semitrailer at SOMANOL (top) and a flatbed truck at MITI (bottom).

Photo Series 6.

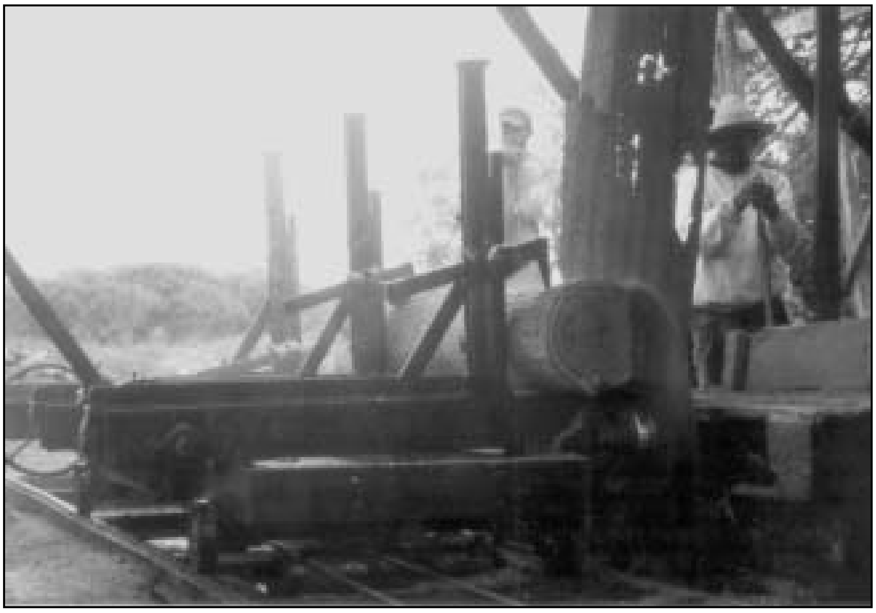
First transport with farm tractor and semitrailer at ÁLVARO de CASTRO (top) and with a flatbed truck at MITI (bottom).

Photo Series 7.

Second transport with truck and 25 t semitrailer at MITI (top) and ARCA/SRZ (bottom).

Photo Series 8.

Processing logs with a circular saw at ÁLVARO de CASTRO (top) and with a bandsaw at SOMANOL (bottom).



FOREST HARVESTING CASE STUDIES

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Plastic Log Chute in Steep Terrain Thinning Operations by K. Leppänen. FOPH Publication 1989. 30 pp. Country: Republic of Korea. Language: English.

Integrated Small-scale Forest Harvesting and Wood Processing Operations by O. Eeronheimo. FOPH Publication 1990. 27 pp. Country: Zimbabwe. Language: English.

Forest Harvesting with Small-scale Mobile Cable System by O. Eeronheimo. FOPH Publication 1991. 16 pp. Country: Republic of Korea. Language: English.

1. Reduction of Wood Waste by Small-scale Log Production and Conversion in Tropical High Forest by Risto Kilkki. FOPH Publication 1992. 33 pp. Country: Papua New Guinea. Language: English.

2. Cosecha de Hongos en la VII Región de Chile by Juan E. Donoso y Risto Kilkki. FOPH Publication 1992. 37 pp. Country: Chile. Language: Spanish.

3. Uso de Bueyes en Operaciones de Aprovechamiento Forestal en Areas Rurales de Costa Rica by William Cordero. FOPH Publication 1994. 44 pp. Country: Costa Rica. Language: Spanish.

4. Use of the Construction Crane for Wood Extraction on Mountainous Terrain by Norbert Winkler. FOPH Publication 1995. 38 pp. Country: Austria. Language: English.

5. Elephants in Logging Operations in Sri Lanka by Palitha Jayasekera and Shelton Atapattu. FOPH Publication 1995. 36 pp. Country: Sri Lanka. Language: English

6. Impacto ambiental de las prácticas de cosecha forestal y construcción de caminos en bosques nativos siempreverdes de la X Region de Chile by Jorge Gayoso Aguilar. FOPH Publication 1995. 169 pp. Country: Chile. Language: Spanish.

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12. Environmentally Sound Forest Infrastructure Development and Harvesting in Bhutan by Norbert Winkler. FOPH Publication 1999. 75 pp. Country: Bhutan. Language: English.

13. Logging Impacts on the Training and Model Forest (TMF) of the National University of Lao P.D.R. Being printed.

14. Rural Road Infrastructure as Introduced in Nepal: The Green Road Concept Being printed.

15. Forest Harvesting Operations in Papua New Guinea: the PNG Logging Code of Practice by Norbert Winkler. FOPH Publication 2001. 72 pp. Country: Papua New Guinea. Language: English.

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17. Financial and Economic Assessment of Timber Harvesting Operations in Sarawak, Malaysia by Frank Richter. FOPH Publication 2001. 57 pp. Country: Malaysia. Language: English