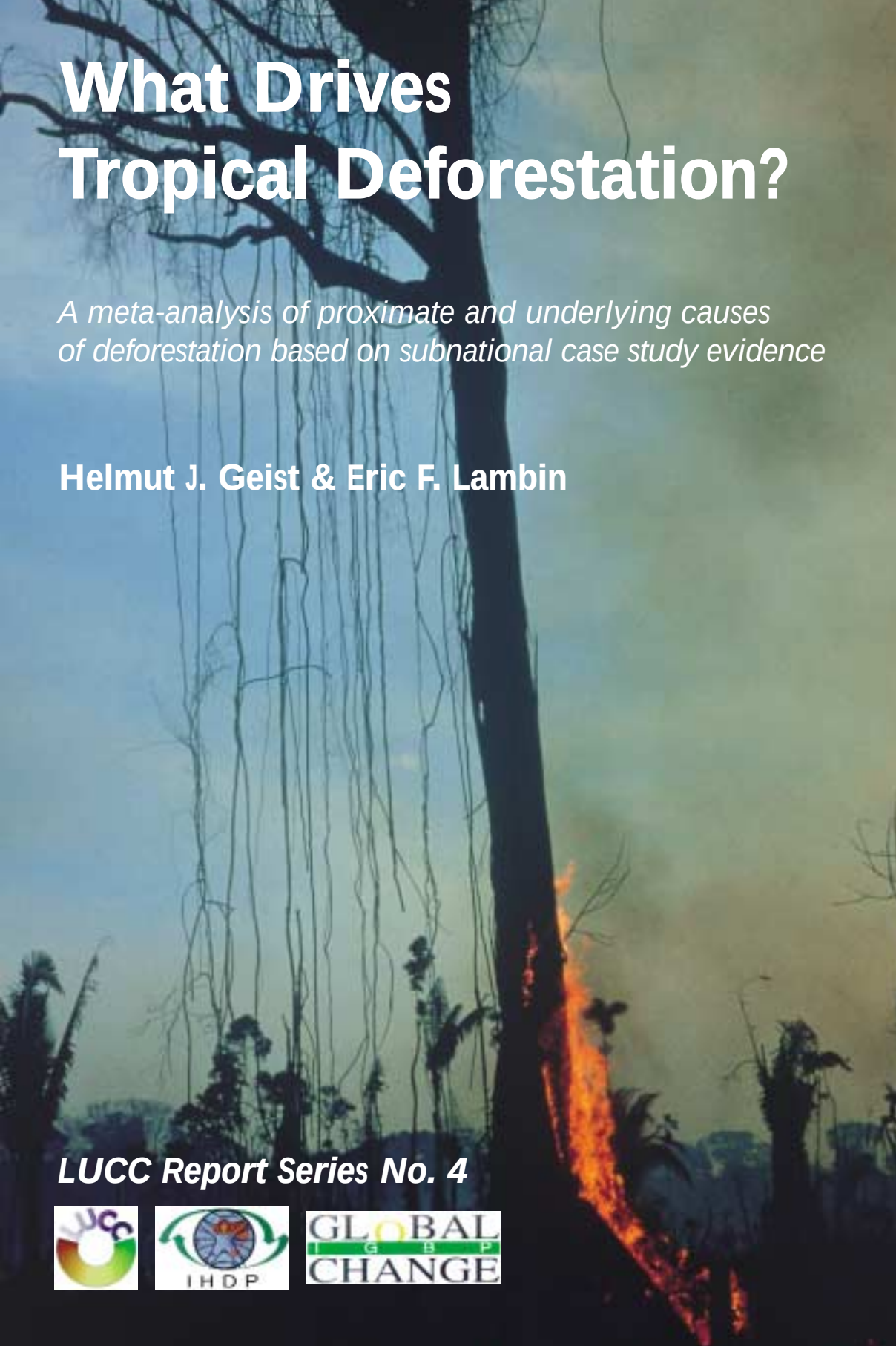

What Drives Tropical Deforestation?

A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence

Helmut J. Geist & Eric F. Lambin

LUCC Report Series No. 4

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Foreword

This section aims at guiding the reader through the rather voluminous work. One way to read the meta-analysis is, of course, from the beginning to the end. Another way is to focus on subchapters and/or certain variable explorations as explained in the following.

In the first, introductory chapter, a brief rationale is given why subnational – and not country-wide – case study evidence constitutes an important tool to comparatively investigate causes and drivers of change in the form of a meta-analysis as adopted here.

In the second chapter, we outline the analytical concept of proximate and underlying causes of land change used in land use/cover change research. Only a few broad proximate and underlying clusters had been adopted to explore, identify and quantify causes and drivers inherent to the subnational cases. It was our intention to work, as much as possible, along the lines of the conceptual framework as given in the LUCC Science/Research Plan (Turner et al. 1995, pp. 20-22).

In the third chapter, we attempt to generalize results across regions or broad geographical entities (Africa, Asia, Latin America). Results are presented in a threefold manner. The first section (3.1) presents the frequency of occurrence of broad clusters of causes and more specific activities (or actor-driven processes) associated with tropical deforestation. The second section (3.2) presents patterns of causality (interlinkages) both at the proximate and underlying levels (and between them), in terms of the mode of connection of causes, i.e., single factor causation, concomitant occurrence, and chain-logical connection. The frequency analysis of causalities only considers chain-logical connections in their most simple form, i.e., as two-factor chain or tandem. The third section (3.3) shows variations of results other than by broad geographical entities – i.e., by forest type, area size, topography, spatial pattern and process at work, deforestation rate, and poverty- versus capital-driven deforestation. We recommend the reader either to browse or to go into certain variable clusters that touch his/her fields of interest. Especially in the causality and variation sections (3.2, 3.3), the reader will find cross-references at several points to guide him/her to subchapter 3.1, where proximate and underlying causes are laid down in more detail. We consider the results to be the first attempt relating underlying to proximate causes in a systematised manner. This means a significant step forward compared to previous studies that identified, for example, road extension, cattle ranching and population growth being associated with deforestation in a blurring manner. To the best of our knowledge, this part of the study is the first which quantifies the impact of cultural or socio-political driving forces upon deforestation (3.1.2, 3.2.2, 3.2.3), the feedbacks from the proximate upon the underlying level (3.2.4), and underlying driver tandems (3.2.2).

In the fourth chapter, we hold our findings against other empirical evidence on tropical deforestation. The discussion items we selected, i.e., shifting cultivation, population growth, indebtedness and IPAT, are not meant to be exhaustive. Rather, we hope that results from this meta-analysis will help to proceed incrementally towards a platform for further explorations of tropical deforestation guided by theories.

In the fifth chapter, conclusions are drawn with view on empirical results as compared to prevailing explanations of tropical forest decline, concerning future modelling of the process of deforestation, concerning policy implications, and concerning the future design of case study comparisons.

Acknowledgements

Grateful support is acknowledged from the Services of the Prime Minister of Belgium, Office for Scientific, Technical and Cultural Affairs (OSTC) which enabled case study compilation and data evaluation on a post-doc research contract. We owe special thanks to Arild Angelsen, Agricultural University of Norway, and Jianchu Xu as well as Andy Wilkes, Chinese Academy of Sciences, for carefully reviewing an earlier version of this report. Nonetheless, reviewers should not be held responsible for any remaining inaccuracies. Further support is acknowledged from the International Human Dimensions Programme on Global Environmental Change (IHDP) for printing the publication. We owe dinner to William McConnell, LUCC Focus 1 Office at Indiana University, for continuously providing valuable comments, and wish to thank John Bellamy from the International Geosphere-Biosphere Programme (IGBP) as well as Herman van Rooy from Ciaco Printshop for their technical support.

1 Introduction

Understanding the dynamics of land-use and land-cover has increasingly been recognized as one of the key research imperatives in global environmental change research (e.g., Turner et al. 1990, Turner and Meyer 1994, Lambin et al. 1999, Geist 1999, Lambin et al. 2001). A major focus, especially of human dimensions research, has been characterized by the U.S. National Research Council (1999, p. 297) as "explaining pattern and changes in the rates of environmental transformation in terms of driving forces that act globally, regionally, and at the level of responsible decision makers". In this context, understanding the causes of tropical deforestation has been identified to remain one of the key contentious (or even unanswered) questions in global environmental change research (pp. 302-7). It relates to one of the fundamental science questions asked by the Land-Use and Land-Cover Change (LUCC) project of IGBP and IHDP: "What are the major human causes of land-cover change in different geographical and historical contexts?" (Lambin et al. 1999, p. 12).

Since the 1980s, numerous attempts have been made to explain the causative pattern of tropical deforestation (e.g., Tucker and Richards 1983; Allen and Barnes 1985; Walker 1987; Richards and Tucker 1988; Rudel 1989; Burns et al. 1994; Williams 1990, 1994; Kimsey 1991; Stern, Young and Druckman 1992; Amelung and Diehl 1992; Brown and Pearce 1994; Bilsborrow 1994; Krutilla et al. 1994; Lambin 1994, 1997; Capistrano and Kiker 1995; Painter and Durham 1995; Bernard and Koninck 1996; Sponsel et al. 1996; Bawa and Dayanandan 1997, 1998; Rudel and Roper 1996, 1997; Kant and Redantz 1997; Murali and Hedge 1997; Amsberg 1998; Ehrhardt-Martinez 1998; Kaimowitz and Angelsen 1998; Mather et al. 1998; Palo and Uusivuori 1999; Wibowo and Byron 1999; Angelsen and Kaimowitz 1999; Wunder 2000; Mather and Needle 2000). The intellectual efforts, however, of especially social scientists have typically taken the form of matching cross-national socio-economic and deforestation data, with the latter being collected by agencies – such as the FAO – charged with monitoring deforestation. Theories have produced rich arguments, especially coming from the neoclassical, impoverishment and political ecology schools of thinking (cf Wunder 2000, pp. 26-55), but empirical evidence continues to suffer from cross-national statistical analyses, in some cases linked to debatable rates of forest cover change.[1]

Broadly speaking, two major and divergent pathways of explanation have emerged: single factor causation *versus* irreducible complexity. On the one hand, shifting cultivation (e.g., Amelung and Diehl 1992; Myers 1993; Rerkasem 1996; Ranjan and Upadhyay 1999) and population growth (e.g., Allen and Barnes 1985, Amelung and Diehl 1992; Cropper and Griffiths 1994; Ehrhardt-Martinez 1998) have been viewed as primary causes, and only "few other variables have emerged as possible causes for deforestation" (Rudel and Roper 1996, p. 160). On the other hand, correlates of deforestation and causative variables are stated to be many and varied, revealing no distinct pattern (Rudel and Roper 1996; Bawa and Dayanandan 1997; Mather et al. 1998; Angelsen and Kaimowitz 1999). On the latter view, some widely held statements read as follows:

> Deforestation results from complex socio-economic processes, and in many situations it is impossible to isolate a single cause (Walker 1987, p. 19).
>
> There is no clear definition of „deforestation", neither are there reliable estimates of its extent nor its primary causes, and – partly – as reflection of these – there is no consensus on the underlying causes (Angelsen 1995, p. 1713).
>
> Reports of tropical deforestation indicate that it occurs in diverse circumstances which obscure underlying patterns of deforestation [...] [D]eforestation has multiple causes with the particular mix of causes varying from place to place (Rudel and Roper 1996, p. 160).
>
> A rich crop of explanations for deforestations have appeared, none of which, however, are definitive (Bernard and Koninck 1996, p. 9).
>
> [T]he factors influencing deforestation are different in different continents. It may be difficult to generalise that one or several factors are the most important (Murali and Hedge 1997, p. 475).
>
> [F]indings generally support the view that processes of deforestation vary by place (Rudel and Roper 1997, p. 62).
>
> The study of the causality of trends in forest cover ... does not readily yield the simplicity and elegance of explanation that would reward the ideal scientific endeavour. In the real word of human-driven change in land and land cover, there are numerous problems and difficulties that confound such an endeavour. The field cannot be successfully tilled as a disciplinary preserve, and neither reductionism nor holism alone seems to offer the approach necessary for success (Mather et al. 1998, p. 1992f).

In general, uncovering the possible underlying human driving forces of land-use/cover change has been viewed as "a formidable task" (Meyer and Turner 1992, p. 52). Despite such warnings, we ran a frequency analysis of the occurrence of underlying driving forces and direct causes of tropical deforestation and their interlinkages as reported in 152 subnational case studies. We show that tropical deforestation is driven by identifiable regional variations of synergetic cause/driver combinations in which economic factors, institutions, national policies and remote influences are prominent. Our findings reveal that too much emphasis has been given to population growth and shifting cultivation as primary and direct causative variables at the decadal time scale. We further show that region-specific patterns of causation can be identified in addition to the more "robust" proximate and underlying causes (or cause connections) showing low regional variations, if subnational rather than country-wide evidence is taken. The results have implications for modelling the process of deforestation, for policy intervention and future case study analyses aimed at identifying causality behind land-use and land-cover change.

Notwithstanding formidable tasks and confounded endeavours, we thus recognize a need both for comparative analyses of the main processes of land cover change and for advanced methods to monitor and model land-cover changes at regional scales (Lambin 1997; Lohnert and Geist 1999; Petschel-Held, Lüdeke and Reusswig 1999). We are aware, however, that there are several biases inherent in this meta-analysis. First, author bias could be inherent in the case studies themselves (selection and interpretation of real and perceived causes and drivers) as well as, second, our own bias of variable grouping, data exploration and interpretation. Needless to say that case study evidence does not prove that results can attain full global, regional or even local validity. These caveats

notwithstanding, it is hoped that the exercise can contribute to – and, thus, enrich – the discussion of tropical deforestation and lead to a better understanding of its proximate and underlying causes.

2 Conceptual framework

From abundant – and sometimes contradictory notions of what precisely constitutes a driver of environmental change –, the usually complex set of actions, factors and rationales involved in tropical deforestation is broken down here by a limited number of three aggregate proximate causes (agricultural expansion, wood extraction, expansion of infrastructure) and five broad categories of underlying driving forces (demographic, economic, technological, policy/institutional, and cultural or socio-political factors). In addition to these clusters, a group of variables associated with deforestation has been introduced (at the proximate level) which comprises pre-disposing environmental factors (land characteristics or features of the biophyiscal environment), so-called biophysical drivers and social trigger events. All these broad, aggregate variables are composed of specific activities, mostly related to specific actors – see list of variables in Tables 1 to 4. In order to come up with assessments which can be generalized, the relative impact of different causes, drivers and other factors upon tropical deforestation has been analysed in terms of their frequency of occurrence in the case studies and in terms of their type and frequency of causality patterns. In doing so, we adhere to the notion – as put forward by Stern, Young and Druckman (1992, p. 92) on human causes of global environmental change in general – that:

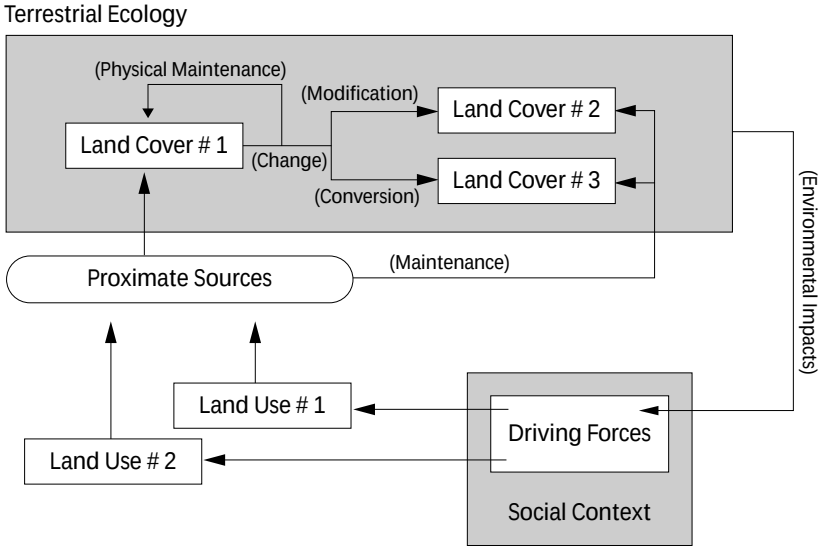
> [t]he task is relatively simple in the sense that the initital accounts need not have great precision. For social scientific work to begin, it will be sufficient to know whether a particular human activity contributes on the order of 20 percent, 2 percent, or 0.2 percent of humanity's total contribution to a global change. Such knowledge will allow ... to set worthwhile research priorities until more precision is available.

2.1 Proximate, underlying and other causes of tropical deforestation

The links between proximate causes, (social) underlying driving forces, land-use and land-cover change have been conceptualized, for example, by Meyer and Turner (1992), Turner et al. (1993), Ojima et al. (1994) and Lambin et al. (1999) – see Figure 1. Proximate causes are human activities (land uses) that directly affect the environment and thus constitute proximate sources of change. They connect the changes in land cover (biophysical attributes of the earth's surface) and land use (human purpose or intent applied to human activities that directly alter the physical environment). These activities reflect human goals which constitute underyling social driving forces. Proximate causes change land cover – in this case, conversion of forest to other cover types –, with further environmental consequences that may ultimately feedback to affect land use (or even underlying forces). Instead of using the so-called proximate/ultimate divide[2], more sophisticated conceptualizations could have been applied such as the interplay of agency and structure in processes of change (*cf* Leach et al. 1999; Leach and Fairhead 2000). However, we wanted to be practical (reduce case study information to a format to be

managed), start at a proper scale (use existing LUCC approaches), and proceed incrementally (use this work to develop a better understanding of drivers and causes in general) (*cf* NRC 1995, pp. 10-11; Lambin et al. 2001).

Figure 1: Links between human activities and land use and land cover



Source: Ojima et al. 1994, p. 301 (after Turner et al. 1993).

2.1.1. Proximate Causes

Proximate causes of deforestation are seen here to constitute (near-final or final) human activities that directly affect environment (Turner et al. 1990, 1993). Different from structural, systemic or initial conditions, they can be interpreted as the more immediate, direct factors which originate from land-use and directly impact upon forest cover (Ojima et al. 1994). In terms of scale, proximate causes are seen to operate at the local level (i.e., sites of the respective case studies).

In the deforestation literature (e.g., Ledec 1985; Lambin 1994; Mainardi 1998; Kaimowitz and Angelsen 1998; Contreras-Hermosilla 2000), proximate causes are commonly grouped into three broad categories: expansion of cropped land and pasture (agricultural expansion), harvesting or extraction of wood (wood extraction), and expansion of infrastructure. In the cases analysed, these broad groups were found to be further composed of specific variables (activities): for example, forest to pasture conversion for large-scale cattle ranching, clear-cutting of trees for food (subsistence) farming, or forest removal due to the establishment of agro-industrial plantations. However, some activities as drawn from case studies still remain broad, aggregate entities, since authors occasionally specified cattle ranching or commercial wood extraction, for example, as proximate causes, but gave no mention of specific actors or agents behind these activities – see Table 1.

Table 1: List of variables (proximate causes) – I

Proximate causes		
Agricultural expansion (AGRO)	Shifting cultivation	Traditional shifting cultivation
		Colonist shifting cultivation
	Permanent cultivation	Subsistence (food, smallholder) agriculture
		Commercial agriculture (large-scale, smallholder)
		Agricultural (Integr. Rural) Development Projects
	Cattle ranching	Smallholder cattle ranching (pasture creation)
		Large-scale cattle ranching (pasture creation)
		Unspecified
	Colonization, transmigration, resettlement	Spontaneous transmigration
		Local transmigration (resettlement)
		Military transmigration (penal settlements)
		Estate settlement (agricultural, nucleus)
		Industrial forestry plantation settlement
		Unspecified
Wood extraction (WOOD)	Commercial wood extraction (clear-cutting, selective harvesting)	State-run logging (selective, clear-cutting)
		Private company logging (selective, clear-cutting)
		"Growth coalition"-led logging
		Illegal (illicit, undeclared) logging
		Unspecified
	Fuelwood extraction	Domestic uses (rural, urban)
		Industrial uses (rural, urban)
		Unspecified
	Polewood extraction	Domestic uses (rural, urban)
		Industrial uses (rural, urban)
		Unspecified
	Charcoal production	Domestic uses (rural, urban)
		Industrial uses (rural, urban)
		Unspecified
Infrastructure extension (INFRA)	Transport infrastructure	Roads (public, military, logging, mining, etc.)
		Railroads
		Rivers & tributaries
	Market infrastructure	Public infrastructure (food markets, storage, etc.)
		Private infrastructure (sawmills, food markets, etc.)
	Public services	Water & sanitation facilities, electrical grids, etc.
		Unspecified
	Settlement expansion	(Semi-)urban settlements
		Rural settlements
		Military defense villages
		Unspecified
	Private entreprise infrastructure	Hydropower development
		Oil exploration
		Mining (gold, coal, tin ore, etc.)

Most of the subdivisions of proximate variables are assumed to be evident, some might not. The aggregation, for example, of agricultural expansion into colonization

agriculture, transmigration and (re)settlement projects, and the further subdivision into specific activities such as local transmigraton (resettlement), agricultural (estate, nucleus) settlement, and "spontaneous" transmigration follows, by large, the categories used by Brookfield and Byron (1990) in cases from Borneo and Malay peninsula. In wood extraction, the specific activity of growth coalition-led logging has been borrowed from Rudel (1993), who applied it in the context of the Ecuadorian Amazon. We identified this activity as occurring in several cases from other regions, and, thus, coded it using the term. It is not only different from, for example, pure state-run or private company logging, or fuelwood harvesting by private households, but rather linked to an institutional model (and, therefore, explained in more detail in the next subchapter on underlying forces). Given the prominent ranking of shifting cultivation as an assumed primary cause of deforestation (e.g., Amelung and Diehl 1992; Myers 1993; Rerkasem 1996; Ranjan and Upadhyay 1999), we established a difference between two modes of farming, though much of the writing on causes of deforestation beyond the case studies used here does not (e.g., Amelung and Diehl 1992). The two modes are traditional shifting cultivation (or swidden-fallow farming practiced by indigenous people; Russell 1988), and colonist shifting cultivation (or slash-and-burn agriculture practiced by migrant settlers). It might be argued that the expansion of transport infrastructure, especially road construction, is not a land use and, thus, a proximate cause of deforestation (due to its limited direct impact upon forest cover). However, given the many direct and indirect impacts reported in the cases, we felt that infrastructure expansion, mainly road extension, deserves to be coded as a proximate cause. Underpinning the view upon road construction as an immediate or direct cause is the recent, forestry-related statement (ITTTA and FAO 1999, p. 7) that

> [r]oad construction represents the most harmful aspect of forestry activities. The forest has to be cleared for them and they are thus a direct cause of deforestation.

2.1.3. Underlying causes

Underlying driving forces (or social processes) are seen to be fundamental forces that underpin the more obvious or proximate causes of tropical deforestation.[2] They can be seen as a complex of social, political, economic, technological, and cultural variables that constitute initial conditions in the human-environmental relations that are structural (or systemic) in nature. In terms of spatial scale, underlying drivers may operate directly at the local level, or indirectly from the national or even global level. Kaimowitz and Angelsen (1998, p. 95) point out that "[i]t is more difficult to establish clear links between underlying factors and deforestation than between immediate causes (…) and deforestation [since the] causal relationships are less direct".

Fundamental explanations, as taken from deforestation literature (e.g., Ledec 1985; Lambin 1994; Kaimowitz and Angelsen 1998; Mainardi 1998; Contreras-Hermosilla 2000), are broadly grouped here into five categories (*cf* Turner 1989; Stern et al. 1992; Lohnert and Geist 1999; NRC 1999). These are demographic factors (human population dynamics, sometimes referred to as population "pressure"), economic factors (commercialisation, development, economic growth or change), technological factors (technological change or progress), policy and institutional factors (change or impact of political-economic institutions, institutional change), and a complex of socio-political or

cultural factors (values, public attitudes, beliefs, and individual or household behaviour). These broad groups are composed of specific forces or human activities – see list of underlying variables in Tables 2 to 3. Again, we felt a need to work as much as possible along the lines of the LUCC framework (Turner et al. 1995, pp. 20-22), while recognizing that further developments might also conceptualize, for example, underlying biophysical driving forces (*cf* Brookfield 1999).

Table 2: List of variables (underlying causes) - II

Underlying causes (I)		
Economic factors (economic growth, change or development, commercialisation)	Market growth & commercialisation	Unspecified: rapid market growth (especially of the export-oriented sector), rise of cash economy, increasing commercialisation, incorporation into (world) economy
		Increased market accessibility (esp. of semi-urban and urban markets)
		Growth of sectoral industries (wood-related, agriculture-related, mineral-related, others)
		Lucrative foreign exchange earnings
		Growth of demand for consumer goods and services procured with cash due to a rise in well-being (unspecified, wood-related, agriculture-related, housing & transport)
	Specific economic structures	Unspecified
		Large individual (mostly) speculative gains
		Poverty & related factors (lack of income opportunities, joblessness, resource poverty, low living standard, etc.)
		Economic downturn, crisis conditions
		Indebtedness, heavy foreign debt
	Urbanization & industrialization	Urbanization: growth of urban markets
		Industrialization: rapid built-up of new basic, heavy and forest-based or –related industries
	Special economic parameters	Comparative advantages due to cheap, abundant production factors in resource extraction & use
		Special, mainly artificially low kept production conditions
		Price (value) increases (of fuel, land, cash crops)
		Price decreases (of cash crops)
Policy and institutional factors (change of political economy institutions)	Formal policies	On taxation, charges, tariffs, prices
		On credits, subsidies, licenses, concessions, (logging) bans
		On economic development (agriculture, infrastructure)
		On finance, legislation, investment, trade
		On population (migration)
		On land
		Other pro-deforestation policy (unspecified)
	Informal policies (policy climate)	Corruption, lawlessness
		Growth or development coalitions at work
		Poor performance, mismanagement
		Clientelism, vested (private) interests
		Redefinition of (forestry) policy goals
	Property rights regimes	Insecure ownership, land tenure insecurity (unspec.)
		Land race, race for property rights
		Titling, legalization, consolidation (of individual titles)
		Malfunct customary rights
		Low empowerment, deprivation, marginality
		Open access conditions

Table 3 : List of variables (underlying causes) – III

Underlying causes (II)		
Technological factors (technological change or progress)	Agro-technological change	Land-use intensification
		Land-use extensification
		Agricultural involution
		Other changes (landholding, production orientation, etc.)
	Technological applications in the wood sector	Damage & wastage due to poor logging performance
		Wastage in wood processing, poor industry performance
		Lack of cheap, technological alternatives to woodfuel; poor domestic & industrial furnace performance
	Other production factors in agriculture	Low level of technological inputs (unspecified)
		Land-related factors (landlessness, land scarcity)
		Labour –related factors (limited labour availability)
		Capital-related factors (no credits, limited irrigation)
Cultural (or socio-political) factors	Public attitudes, values, beliefs	Public unconcern or lack of (public, political) support for forest protection and sustainable use: low morale or education, frontier mentality, and dominance of other public attitudes (modernization, development, nation-building, etc.)
		Unconcern about the welfare of others and future generations, or disregard of the "sacredness of nature"
		Beliefs about how environmental conditions affect those things which individual values
	Individual and household behaviour	Unconcern by individuals about the environment as reflected in increasing levels of demands, aspirations, materials and energy consumption, commonly associated with commercialisation and increased income
		Situation-specific behaviour of actors: rent-seeking, non-profit orientation, tradition/imitation/continuation of inherited modes of resource use
Demographic factors (human population dynamics)	"Population pressure" (unspecified)	
	Population growth (unspecified)	
	Natural increment (fertility, mortality)	
	In-migration	
	Population density	
	(uneven) spatial population distribution	
	Life cycle features	

Individual, specific variables are directly interpreted from case studies and grouped under the five broad categories. Most of the broad groups and individual variables are easy to identify. Some, however, might not. The sorting of individual variables to fit broader groups follows the driver information in the cases studied rather than any superimposed systematics, e.g., the four general deforestation mechanisms as suggested by Wibowo and Byron (1999), the list of variables included in economic models of deforestation as compiled by Kaimowitz and Angelsen (1998, pp. 129-34), or the broad categorisation in poverty- or capital-driven deforestation as suggested by Rudel and Roper (1997). Selected examples of variable groupings debated in the deforestation literature are given in the following, i.e., the impact of demographic factors, political economy factors, and poverty.

Demographic factors: A widespread belief exists that population growth (or "pressure") is a significant driver of deforestation, often even the primary underlying cause of deforestation (e.g., Wibowo and Byron 1999; Sandler 1993; Vanclay 1993). Demographic factors were coded here to capture the impact of natural increment, in-migration/outmigration, population density, spatial distribution, and life cycle features, thus avoiding the blurred notion of "pressure". Our broader understanding of population-based approaches, however, is that they should be linked to more realistic market-driven approaches (*cf* Angelsen 1996, 1999). Kaimowitz and Angelsen (1998, p. 95) outlined how the population variable can affect deforestation in a broader understanding.

> Theoretically, population can affect deforestation through (1) changes in the number of rural families seeking land to cultivate, fuelwood or timber; (2) population's indirect effects on labour markets; (3) demand for agricultural and forest products; and (4) induced technological or institutional change.

Thus, the demographic impact coded as such – see Table 3 – comprises only one facet of how population theoretically can affect deforestation. In the meta-analysis, other facets are therefore subsumed, or appear, as economic factors (market growth, e.g., growth of demand) and technological factors (agricultural intensification and extensification, labour availability in agriculture). Not in the result section, but in subchapter 4.3, the various population aspects are brought together and the broader defined population impact is discussed.

Political economy factors: Economic factors include four broad groups, i.e., market growth/commercialisation, specific economic structures, urbanization/industrialization, and special economic parameters (some of them overlapping), while policy and institutional factors are subdivided into formal policies, informal policies (policy climate), and factors related to property rights regimes.

The categorisation of "government (or policy) failure" refers to, "first, misdirected policies that result in unintended deforestation, and second, inability to preclude preventable deforestation due to the failure of government institutions to function effectively" (Wibowo and Byron 1999, p. 458). From the deforestation literature, one could assume that policy failures are better elaborated than formal (normal, standard) state or international policies leading to intended deforestation (Deacon 1995). Therefore, we preferred and, thus, introduced the term informal policies instead of failures to hold informal policies (or policy climate) apart from formal policies that result in intended deforestation (pro-deforestation policies).

In doing so, suggested systematics such as Wibowo and Byron's (1999) "deforestation mechanisms" are not fully followed. For example, corruption (and greed) underlying unsustainable logging practices at the proximate level was coded as part of informal policies or policy climate (policy/institutional factor), while timber prices were coded as special economic factors (and not as informal policies). Another example are protectionist national policies of developing countries, in particular, timber export bans and taxes. Though "[l]og export bans are probably the most commonly cited ‚misdirected' policies" (ibd. 1999, p. 458), we consider them to be mainly formal (pro-deforestation) policies and coded them accordingly: developing countries impose the bans as a means to promote the development of their export-oriented processing industries. The policy is thought to have led to large-scale deforestation because it forces domestic timber prices

to fall, and lower prices are associated with wasteful logging, diminished processing efficiency and, as a result, increased deforestation. This coding scheme differs from, for example, Repetto and Gillis (1988) and a number of World Bank reports cited by Amsberg (1994, 1998).

The operation of so-called growth (or development) coalitions associated with deforestation was not coded as an economic (or development) factor, but as an informal policy outcome due to an informal symbiosis of actors, either intended or unintended, which could be related to an institutional model. The term growth coalition implies that no single actor but specific social arrangements develop to facilitate access to frontier land. Growth coalitions mean social organizations, whose objective is to pool resources, including political, economic, or administrative support needed for settlement and land aquisition. Lead institutions commonly take unilateral actions to open up a region for deforestation, and potential settlers take advantage of these. Such cases were described, for example, by Rudel (1993) and Sierra and Stallings (1998) in the Ecuadorian Amazon. We found that these cases – i.e., resource-endowed agents (state, logging firms, rich individuals) intentionally or unintentionally facilitating the advance of poor peasants into the frontier – could be identified in other regions as well, and coded the process accordingly. We even adopted a broader understanding of growth coalitions by coding similar cases such as an informal symbiosis of various agents involved in logging, regional development, agricultural colonization, etc.

As specific economic structures, we coded (i) large, individual, mostly speculative gains – related to what Hecht (1993) called "speculative deforestation" –, (ii) poverty in relation to economic factors, (iii) collapse of economic systems (crisis conditions), and (iv) foreign debts. Again, this differs from the categorisation, for example, of Sandler (1993), or from what Wibowo and Byron (1999, pp. 462-463) subsume under the so-called microeconomic approach which

> attempts to provide explanations on how, under various forms of market failure, an agent's economic behaviours lead to deforestation [with] frequently cited forms of market failure [being] poorly defined property rights, poorly designed logging contracts and undervaluation of forest benefits.

In our understanding, poorly designed logging contracts are better understood as policy/institutional factors (informal policies, policy climate), and the undervaluation of forest benefits – i.e., putting greater emphasis on direct-use values such as timber logging and fuelwood extraction, thus ranking other values low – clearly relates to cultural or socio-political factors. Therefore, the latter is subsumed there under attitudes, values, beliefs and behaviour. Similarly, poorly defined property rights seem to us not part of the microeconomic factor set, but just one aspect of a wider range of factors associated with land tenure or property right arrangements, i.e. a policy or institutional factor (*cf* Ostrom 1990; Ostrom et al. 1994, 1999).

Many point to (poorly-defined) property rights as one of the main policy and institutional causes of deforestation, sometimes related and reduced to "tragedy of the commons" or "open access" in a simplified form (Barbier et al. 1991; Barbier and Burgess 1997; Deacon 1994, 1999; Mendelsohn 1994; Mendelsohn and Balick 1995; Tietenberg 1992; *cf* Geist 1999, pp. 165-167). In coding, we adopt the view as put forward by NRC (1999) that it is essential to consider the relations of state, individual, and group property,

while open access might often be created through specific interlinkages between the three. Therefore, we prefer the term "quasi open acess" and use it alongside other policy/institutional factors such as insecure ownership, "land races" (for property rights), malfunct customary rights, low empowerment (deprivation, marginalization) of local users, and titling (i.e., legalization, consolidation of individual titles). It might surprise some to see titling related to deforestation. Parts of the deforestation literature, however, emphasize that (especially frontier) agricultural systems are characterised – among others – by quasi open access where forest clearing gives farmers land rights. Deforestation, therefore, becomes a title establishment strategy, and land titling (plus credit programmes) may increase deforestation (Rudel 1995; Angelsen 1996, 1999)

Though policies could be added to other boxes as well, political factors are taken together here with institutional causes. We are aware that, in particular, the distinction between formal and informal policies was not always obvious, and probably constitutes an interpretation bias. We are further aware that one should probably better distinguish between three sets of political factors held apart from other broad clusters: (i) policies directly related to land use (e.g., forest regulation, settlement programmes, etc.), (ii) policies which have side-effects on deforestation (intended, or not), originating from other fields such as road development and agricultural pricing policy, and (iii) politics, i.e., the political environment, corruption, dominance of interest groups, and the like. Nonetheless, we believe that our choice for grouping policy and institutional causes reflects a broadly defined change of political economy institutions as related to tropical deforestation.

Poverty: In their categorization of driving forces, Wibowo and Byron (1999) treat poverty as an economic variable and relate it to foreign debt (macroeconomic approach) and to the undervaluation of the full benefits of forests (microeconomic approach). In contrast, Rudel and Roper (1997) took "immiserization" as one of two main, broad generalisations or fundamental explanations of deforestation (besides capital-driven deforestation). In this study, we decided to code poverty not as a separate, underlying category, since - from the cases analysed – poverty turned out to be a cross-cutting underlying theme rather than a single variable or cluster. It was reported to bear demographic, economic, technological, policy and institutional meanings, namely: resource-poor farming, survival economies, insufficient food production, chronic food deficit, displacement, limited land endowment, growing land scarcity, landlessness, land division, creation of poor landholdings, low living standard, joblessness, extremely low income levels, social deprivation, marginalization, and low empowerment of local user groups. In subchapter 3.3.2, we pull together the various aspects of poverty and discuss whether impoverishment (or "capital") does matter as a driving force of tropical deforestation.

2.1.3. Other factors

The group of other factors associated with deforestation – see Table 4 – is composed of pre-disposing environmental factors (land characteristics, features of the biophysical environment), biophysical drivers and social trigger events. Land characteristics such as soil quality, topography, and forest fragmentation are increasingly recognized – not to drive, but rather – to shape deforestation (e.g., Rudel and Roper 1997). Biophysical

drivers (triggers) and social trigger events have been introduced to identify such forces or events that often work as catalytic factors leading to sudden shifts in the human-environment condition. These shifts could be of social nature (such as wars, abrupt economic changes or policy interventions), or operate in the form of biophysical drivers (such as droughts or forest fires), while the difference between the social and natural sphere cannot always be clearly drawn. Some of the factors exert an immediate and direct impact upon forest cover change, and may thus be attributed to proximate causes of change (e.g., forest fires, war), while others work as slow processes (e.g., droughts, land degradation), or even have an underlying character that becomes a catalytic force only if related to land-use (e.g., flat, fertile valley bottom land being deforested first).

Table 4: List of variables (other factors) – IV

Other factors		
Land characteristics (biophysical environment)	Soil-related	Good/bad soil quality
	Slope & topography-related	Flat areas
		Gently sloping areas
		Lowlying areas
	Water-related	Location next to water resources
	Vegetation-related	Forest size & fragmentation
		Vegetation density (high, of marketable woods)
Biophysical drivers (triggers)	Soil-related	Soil compaction
		Soil fertility decline
		Land degradation (unspecified)
	Water-related	Drought conditions (aridity)
		Wet conditions (high humidity)
		Floods
	Vegetation-related	Weed intrusion
		Forest fires
Social trigger events	(Civil) war, rebellion, revolution, social unrest & disorder	
	Health & economic crisis conditions (e.g., epidemics, economic collapse)	
	Abrupt (& violent) population displacements (refugee movements)	
	Government policy failures (e.g., abrupt shifts in macro-policies)	

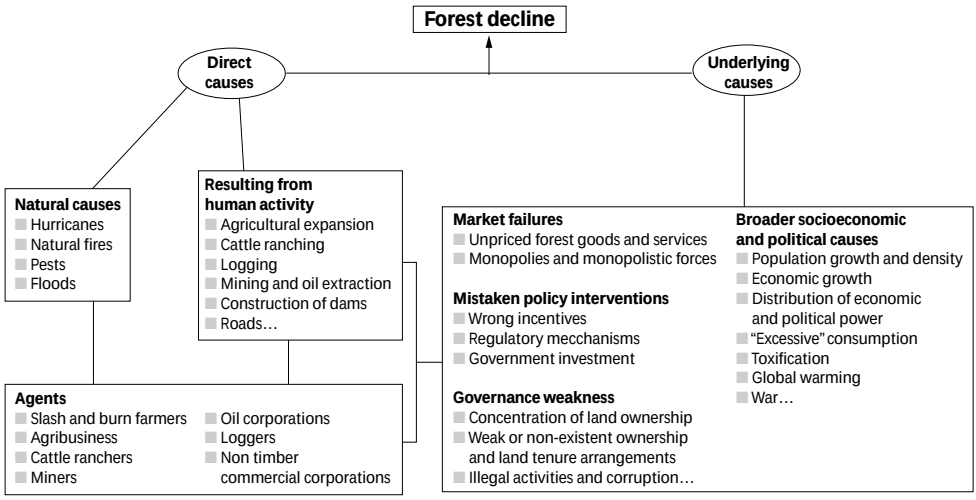
We coded all of the other factors as proximate causes. Only if sudden events impacting upon deforestation (e.g., abrupt price changes) could be related to certain underlying policies such as structural adjustment programmes, the proximate social trigger event was double-coded, i.e., linked to and coded as driven by a policy/institutional factor, for example. Similarly, differences between proximate biophysical triggers and underlying biophysical forces could be established, but are not considered here. Brookfield (1999), mainly relating to the work of Blaikie and Brookfield (1987), has just begun to establish differences between direct and underlying geophysical causes. In contrast, Contreras-Hermosilla (2000, p. 5) still treats what he calls natural causes of forest decline (hurricanes, fires, pests and floods) as part of the direct factors which are not related, however, to underlying forces – see Figure 2.

In summary, the group of other factors collects rather heterogenous variables concerning the temporal (and spatial) dynamics of land use and land cover change: while land characteristics entail a more static perspective, social as well as biophysical trigger events point to dynamic change. With view on what we called pre-disposing environmental factors, it could be argued that more precise results could be expected from identifying shaping factors (or modifiers), filter or context variables, and the like – rather than coding land characteristics at the proximate level. In addition, all of these factors need to be better conceptualized in terms of feedbacks between themselves (interlinkages) and between the proximate and underlying levels, as well as in terms of the interplay of (human, biophysical) agency and structure in processes of change (Leach et al. 1999, Leach and Fairhead 2000). If we are to justify the conceptual framework used here, then it is to "proceed incrementally" (NRC 1995, p.11), i.e., to use this work in order to develop a better framed understanding of causes and drivers.

2.1.4. Summary

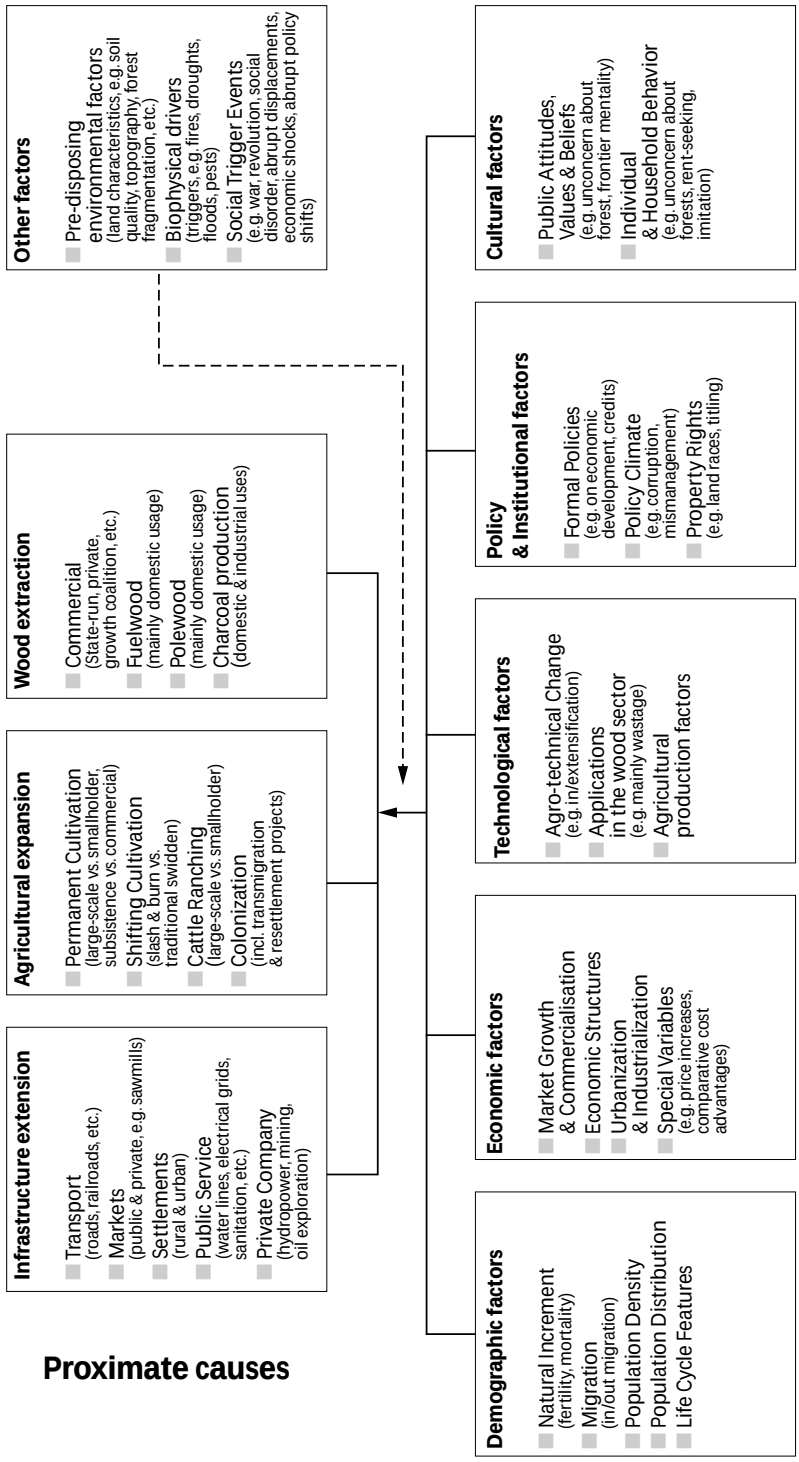
To conclude this overview on proximate, underlying and other causes associated with tropical deforestation, we developed a preliminary scheme which depicts the relations between proximate and underlying causes as translated from the meta-analysis of subnational cases in a descriptive manner. Compared to another, most recent descriptive (but not quantified) scheme, striking similarities (e.g., grouping of natural causes at the proximate or direct level) and minor differences (e.g., formatting of cultural and technological factors) are obvious – *cf* Figures 2 and 3. Considering our meta-anlysis to be the first study which relates underlying to proximate causes in a systematised manner, a summarisation of the quantified scheme of Figure 3 is provided in Figure 9 (inlay).

Figure 2: The causes of forest decline – I



Source: After Contreras-Hermosilla (2000), Underlying causes, CIFOR, p. 5.

Figure 3: The causes of forest decline - II



2.2 Meta-analysing cases of tropical deforestation

In this section, we discuss what is meant by a case of deforestation selected from the case study, what type of bias might be inherent in the meta-analysis, and, finally, how results were categorized.

2.2.1. What is a case of deforestation?

A total of 152 cases of tropical deforestation have been taken from 95 articles published in 40 scientific journals which are included in the Citation Index of the Institute for Scientific Information (ISI) – see annex for the full list of articles. One article (or case study) could comprise several cases, and several cases could relate to the same study area. Articles were considered suitable for analysis if net losses of forest cover (between two time points, at least) were related both to proximate causes and underlying factors. Thus, the meta-analysis does not include cases in which forest increases or only single time point observations of forest cover were available.

Only cases from the subnational scale were considered. Thus, no country-wide analysis was used. Rather, the analysis was limited to deforestation processes reported in case study areas ranging from small villages to large multi-province regions (such as the Brazilian Amazon). Cases were located in Asia (55 or 36% of all cases, in 10 countries), Africa (19 or 13%, in 8 countries), and Latin America (78 or 51%, in 11 countries) – see Figure 4, 5 and 6.[3]

The term deforestation bears a variety of meanings that have not yet been standardized in global change studies. Here, we adopt a broad and inclusive definition "in the sense that it highlights not only forest conversion (…) but also different types of degradation (…)" (Wunder 2000, p. 10). We are aware that this choice of deforestation criteria has repercussions on the subsequent analysis of its causes. For example, selective harvesting of wood thus became coded as a proximate cause of deforestation – *cf* Table 1.

Results on causes, drivers and other factors associated with deforestation are called "robust", if they were identified to occur in cases that are (almost) equally widespread among regions (continents). Thus, robustness of factors is estimated in terms of the statistical frequency of occurrence of factors per continent by comparison to the frequency of factors found in all cases.

Further, cases in which rates of deforestation – regardless of methodologies used – were specified had been analysed in terms of low *versus* high (rates of) deforestation. Similarly, other variations of factor and causality frequencies include dry *versus* humid forest cases, cases of small *versus* large (case study) areas, cases that show varying spatial patterns associated with characteristic deforestation processes (geometric, corridor, etc.), and cases in which poverty or capital are reportedly specified as main forces of change (subchapter 3.3).

With view on methodologies used in the case studies to generate driver information, we consider a case of deforestation as a specific environmental and social context that is spatially defined by the subnational unit of the case study area, regardless of how results are gained methodologically. A reported case of deforestation can entail a simple and easy

to code observation (process) such as: road construction driven by frontier development followed by transmigration of landless settlers which - in combination with large-scale ranching and follow-on commercial timber logging – leads to deforestation. Such narratives make up for 36% of the cases evaluated. In 40% of all cases, driver-specific information is gained through qualitative interpretation of secondary data and/or documents published otherwise. In the remaining 24% of all cases, reported information is derived from quantitative empirical analysis in the form of structured household surveys or secondary data exploration, mainly through correlation and regression analysis. Thus, our acquisition of understanding of the cases is based upon two main methods, i.e., qualitative interpretation and quantitative analysis. They are treated as non-exclusive (i.e., the same way) and, thus, lead to a single type of presentation of results. This implies that, in our understanding, all cases are comparable.

Figure 4: Location of case study areas (Africa) – I

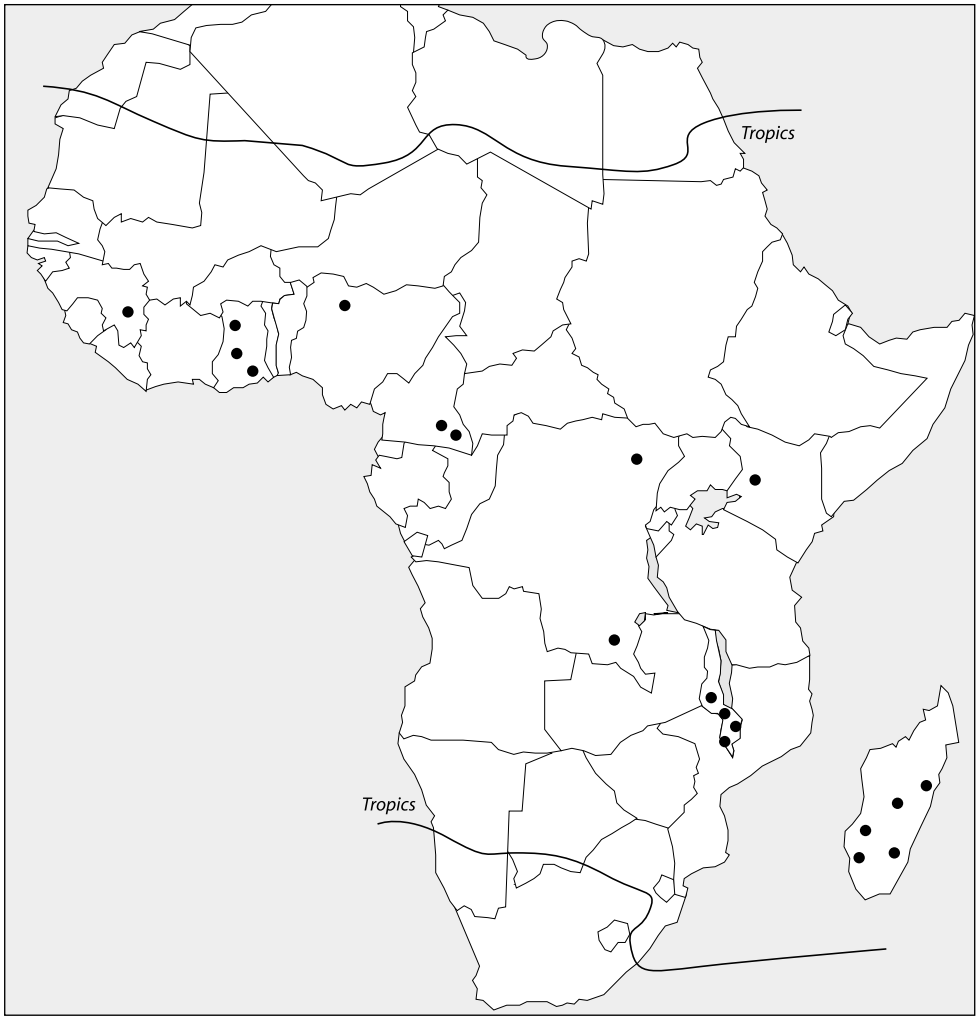
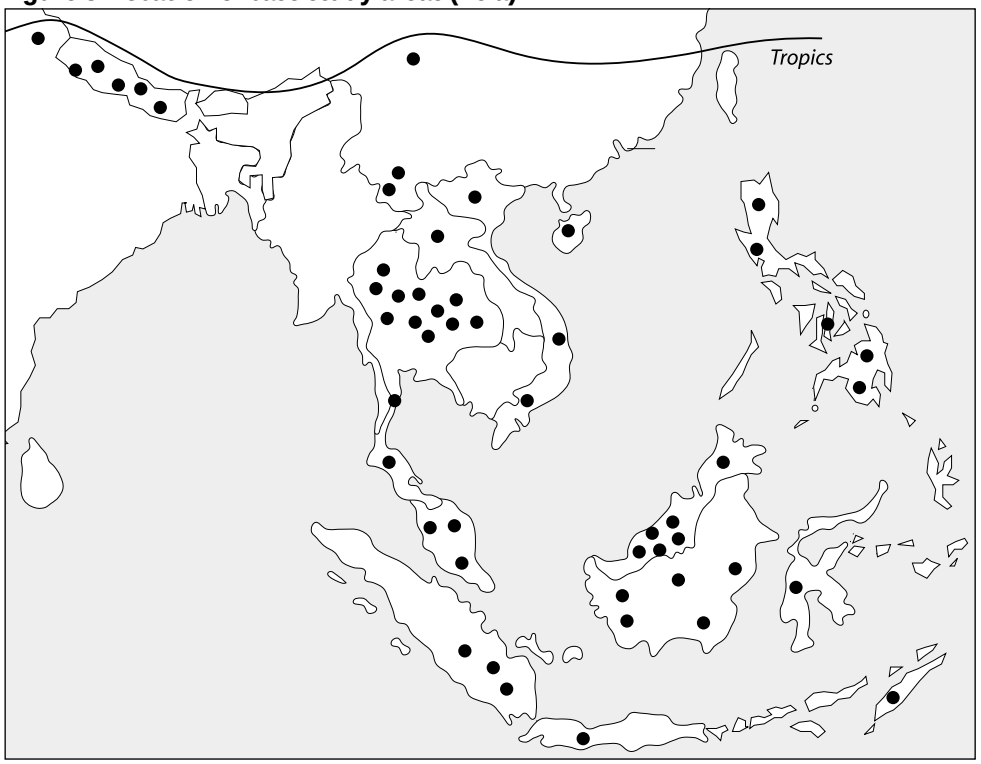
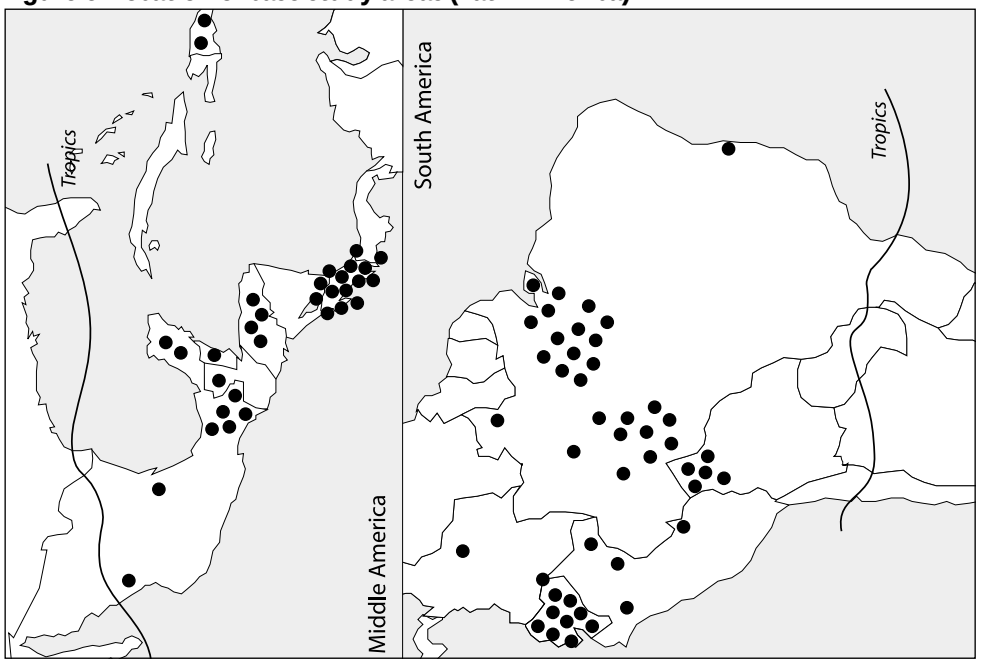


Figure 5: Location of case study areas (Asia)* – II



** With two Asian cases not depicted here, i.e., Western Samoa Islands and Irian Jaya.*

Figure 6: Location of case study areas (Latin America) – III



The time horizon covers the period from 1880 (n=63) to 1996 (n=70), with the mean total time span being 25 years (median: 21, mode: 43, minimum: 5, maximum: 100, range: 95). The most frequently covered period comprises 1940 to 1990 (mode), with the post-colonial years 1960 to 1984 being the average period (mean).

2.2.2. Discussion of possible methodological bias

The selection of cases might represent biased sampling in terms of author bias and weighting bias in the selection of case study areas and agents. Concerning potential author bias, we tested our results against the disciplinary background of the author(s), and concluded that author bias is minimal and does not contaminate the results of the study (for specific results, see subchapter 4.6).

Table 5: Selected cases measured against the dynamics of forest cover change

	Losses in forest cover								Selected cases	
	1880-1990		1940-1990		1960-1980/90		1990-2000			
	10^6 km^2	%	10^6 km^2	%	10^6 km^2	%	000 ha	%	abs.	%
Africa	0.18[1]	6	0.13[1]	8	0.06[1]	8	5264	51	19	13
Asia	1.83[2]	65	0.93[2]	60	0.41[2]	54	454[3]	4	55	36
Latin America	0.80	29	0.49	32	0.29	38	4588	45	78	51
TOTAL	2.81	100	1.55	100	0.76	100	10306	100	152	100

1 Tropical Africa; 2 Including China, but not Oceania; 3 Including China and Oceania.
Sources: Ramankutty and Foley (1999), pp.1018-19; FAO Global Forest Resources Assessment 2000 (1990-2000).[4]

Concerning potential weighting bias in the selection of case study areas, it is obvious from the information above – *cf* subchapter 2.2.1 – that Asian cases (36%) and Latin American (especially Amazonian) cases (51%) are more frequently represented than African cases (13%). Does this constitute, for example, a Latin American bias? Ideally, the proportion of cases from a region should be (more or less) equal to the proportion the total area deforested which is located in that region. Thus, weighting bias was estimated according to varying time scales applied (range, mode, mean) and compared to the total forest cover removed in broad geographical regions – see Table 5. If the total time span covered by the cases is taken (range: 1880-1996) and compared to forest/woodlands removed in 1880 to 1990, one could conclude that the results from especially the Latin American cases might dominate the overall causative pattern found, with Asian – and to a lesser degree, African – cases less frequently reported. If the period most frequently covered by the cases is taken (mode: 1940-1990) and compared to forest/woodlands removed in the same period, African cases feature quite well, while the Latin American bias continues. If the average period is taken (mean: 1960-1984) and compared to forest/woodlands removed in 1960 to 1985, African cases continue to feature fairly well, while the share of Latin American cases decreases and the share of Asian cases increases.

Most recent data on forest cover change from FAO's Global Forest Resources Assessment 2000 (FRA 2000)[4] suggest that an assumed Latin American bias is minimal, but that more frequently reported Asian cases might dominate the general picture of causes, especially if compared to less frequently reported African cases. In summary, for the mean period considered, bias in terms of selection of (regional) case study areas is limited.

Concerning potential weighting bias in the selection of agents of deforestation, there is, indeed, some reason to assume that information is easier to get from farmers (or on farming communities) than from logging companies, and that for this reason fewer studies on logging company behaviour (or industrial forestry plantations) were produced. Thus, the results gained cannot aspire global or regional validity, but, strictly speaking, are only valid for the set of case studies analyzed here.

2.2.2. Categorization of results

The information on proximate causes, underlying drivers and other factors associated with deforestation is analysed in terms of single factor causation, chain logical connection of several factors, and concomitant occurrence of factors involved – see Figure 7.

Single factor causation: Single factor causation at the proximate level means that one individual proximate factor (traditional shifting cultivation, for example) is reported to lead to deforestation, and, thus, is coded as such. Consequently, any single individual factor at the underlying level (in-migration, for instance), that is reported to drive one or more proximate factors, was coded as such.

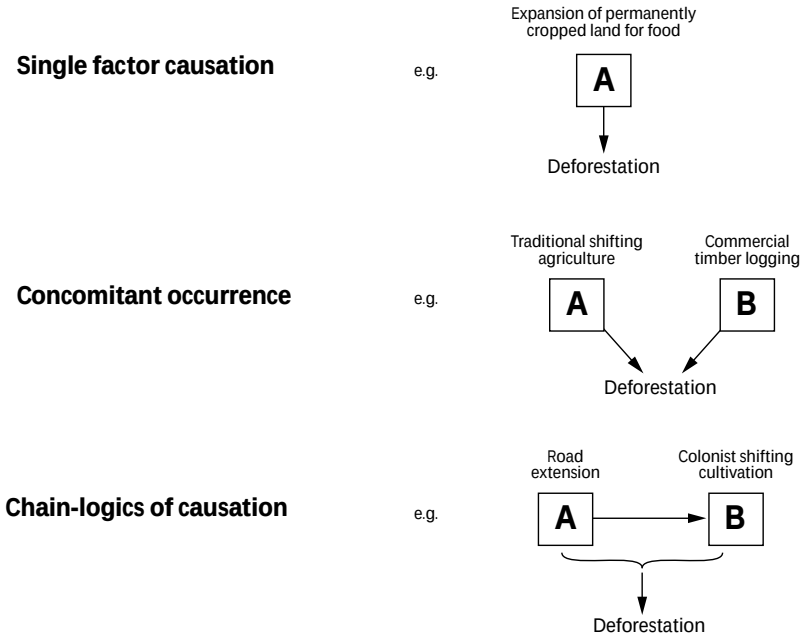
Chain-logical causation: Chain-logical causation has been observed at both the proximate and undelying levels, and, of course, between the two levels, i.e., one or several underlying factors driving one or several proximate factors. In order to reduce complexity inherent to chain-logical connections, we have chosen to consider only two-factor relations or tandems.[5] This enables us to compare our results with tandems as they are already dealt with in the deforestation literature. Underlying tandems, e.g., socio-political (or cultural) factors underlying national policies or institutional arrangements leading to deforestation, have less frequently been described than proximate tandems. Walker (1987, p. 19), for example, has been among the first to depict and model the so-called logging-agriculture tandem, fully operating at the proximate level.

> Deforestation often occurs in a two-step fashion: First, loggers build roads into primeval forest in order to cut trees. Generally, they clearcut their plots rather than harvest selectively, and they do not reseed. The loggers move on to where mature trees stand and continue to cut, doing little if anything to preserve the forest they have already passed through. Once the loggers have abandoned their plots, forest farmers move in and occupy the land, using it for agricultural production so that the forest stands little chance of regenerating. Although the loggers ultimately leave, the farmers do not, and the agricultural production persists.

Concomitant occurrence: Different from single factor causation and chain-logical connections, concomitant occurrence of factors means the independent, separate operation of factors at both the proximate and underlying levels.

Following this categorization, we found a similar pattern at both the proximate and underlying levels. Single factor causation occurs in 9 (or 6% of all) cases at the proximate, and in 17 (or 12% of all cases) at the underlying level (*cf* Tables 6 and 11). In contrast, concomitant occurrence features more cases, i.e., 45 (or 30% of all) cases at the proximate, and 36 (or 24% of all) cases at the underlying level. Pure chain-logical connections are low, i.e., they occur in 9 (or 6% of all) cases at the proximate, and in 7 (or 5% of all) cases at the underlying level. However, chain-logical causation in combination with concomitant factors drives 89 (or 59% of all) cases at the proximate level, and 92 (or 61% of all) cases at the underlying level. Thus, chain-logical causation is inherent to a total of 65% of all cases.

Figure 7: Modes of causation in tropical deforestation case studies



2.2.4. Summary

To conclude the discussion of strengths and weaknesses of the methodology used (which certainly has implications for the conclusions drawn from the statistical results), we are aware of own interpretation bias (variable grouping, coding, data exploration), while original author bias is minimal and selection bias (case study areas, not so agents) is limited. As compared to the methodological foundations of other case study comparisons – see subchapters 1 and 2.1 –, we feel that our standard criteria, i.e., to choose only ISI covered journal articles and to try a middle way between fine-scale local studies and cross-national data explorations, is unique and timely. This meta-analysis is the first study which, in a systematised manner, relates underlying to proximate causes for a very large number of case studies – and, first time, quantifies the causative linkages (*cf* Figure 9).

3 Results

Results are presented in a threefold manner. First, a frequency distribution of factors involved in tropical deforestation is provided for proximate causes, underlying driving forces, and other factors involved (land characteristics, biophysical drivers, trigger events). In quantifying the occurrence of factors, we attempted to capture the broad as well as more specific pictures of activities, actors and processes involved – see subchapter 3.1. Second, an analysis of causalities between broad as well as detailed proximate causes and underlying driving forces is undertaken, by focussing on two-factor chains or tandems – see subchapter 3.2. Third, several variations of frequency distribution and causality patterns are analysed in terms, for example, of spatial patterns and deforestation processes, low *versus* high deforestation, small *versus* large (case study) areas, and poverty- *versus* capital-driven deforestation – see subchapter 3.3.

3.1 Frequency analysis of the occurrence of causes

A simple frequency distribution is provided for broad, aggregate proximate causes, underlying driving forces and other factors related to deforestation (land characteristics, biophysical drivers, social trigger events). The frequency analysis further entails more specific causes, i.e., detailed activities, actors and social processes directly leading to, underlying or associated with tropical deforestation. In both the aggregate and detailed analysis, multiple counts occur since several factors are reported to be commonly interlocked in one case (and fuzzy boundaries exist in some cases – see subchapter 2.2.2).

3.1.1. Proximate causes

At the broad aggregate level of three proximate causes (including other factors related to deforestation), it is a striking feature of reported cases that not causation by single variables, but rather synergetic factor combinations are important – see Table 6. Single proximate causes reportedly explain just 6% of all deforestation cases, whereas next to all cases (96%) are caused by multi-factorial terms. In particular, agricultural expansion, in combination with one up to three other causes or factors, contributes to most of the variable combinations. Thus, the expansion of cropped land and pasture is the most frequently reported proximate cause of tropical deforestation. – What are the specific causes in more detail?

Table 6: Frequency of broad proximate causes*

	All cases (N=152)			Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	cum	abs	rel	abs	rel	abs	rel
Single factor causation									
AGRO	6	4%	4%	2	4%	1	5%	3	4%
WOOD	2	1%	5%	0	-	2	11%	0	-
INFRA	1	1%	6%	0	-	0	-	1	1%
OTHER	0	-	-	0	-	0	-	0	-
2-factor term of causation									
AGRO-WOOD	22	15%	20%	12	22%	2	11%	8	10%
AGRO-INFRA	30	20%	40%	3	6%	2	11%	25	32%
AGRO-OTHER	5	3%	43%	1	2%	3	16%	1	1%
WOOD-INFRA	1	1%	44%	0	-	0	-	1	1%
WOOD-OTHER	1	1%	45%	0	-	1	6%	0	-
3-factor term of causation									
AGRO-WOOD-INFRA	38	25%	70%	21	38%	2	11%	15	19%
AGRO-WOOD-OTHER	6	4%	74%	4	7%	1	5%	1	1%
AGRO-INFRA-OTHER	8	5%	79%	0	-	0	-	8	10%
WOOD-INFRA-OTHER	1	1%	80%	0	-	0	-	1	1%
4-factor term of causation									
All	31	20%	100%	12	22%	5	26%	14	18%
Total	152	100%	-	55	100%	19	100%	78	100%

* AGRO = agricultural expansion, WOOD = wood extraction, INFRA = infrastructure extension, OTHER = land characteristics, biophysical drivers and social trigger events.

Agricultural expansion

The expansion of cropped land and pasture is, by far, the leading proximate cause of tropical deforestation. It was found to lead to deforestation in 146 out of 152 cases (96%) – see Table 7. In next to all cases, agricultural expansion does not operate alone, but in combination with other proximate causes. Permanent cropping, pasture creation for cattle ranching, shifting cultivation and colonization (transmigration, resettlement) hold simi-

larly high shares (40 to 48%). As a broad group, agricultural activities tend to be equally widespread among regional cases, but cattle ranching and colonization are important in certain regions, and only permanent cultivation and shifting cultivation are robust proximate causes.

Table 7: Frequency of specific agricultural activities causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Permanent cultivation								
Total	**73**	**48%**	**24**	**44%**	**10**	**53%**	**39**	**50%**
• subsistence agriculture[1]	61	40%	20	36%	10	53%	31	40%
• commercial agriculture	22	15%	5	9%	4	21%	13	17%
(smallholder)	(17)	(11%)	(3)	(6%)	(4)	(21%)	(10)	(13%)
(large-scale)	(9)	(6%)	(4)	(7%)	(1)	(5%)	(4)	(5%)
• agricultural projects[2]	6	4%	1	2%	3	16%	2	3%
Cattle ranching (pasture creation)								
Total	**70**	**46%**	**3**	**6%**	**3**	**16%**	**64**	**82%**
• unspecified	38	25%	1	2%	2	11%	35	45%
• smallholder	28	18%	2	4%	1	5%	25	32%
• large-scale	15	10%	0	-	0	-	15	19%
Shifting cultivation								
Total	**63**	**41%**	**24**	**44%**	**8**	**42%**	**31**	**40%**
• traditional shifting cultivation	46	30%	24	44%	7	37%	15	19%
• colonist shifting cultivation	26	17%	5	9%	3	16%	18	23%
Colonization, transmigration, (re)settlement								
Total	**61**	**40%**	**23**	**42%**	**4**	**21%**	**34**	**44%**
• unspecified	51	34%	21	38%	1	5%	29	37%
• "spontaneous"	21	14%	8	15%	2	11%	11	14%
• local transmigration[3]	8	5%	4	7%	2	11%	2	3%
• military transmigration[4]	5	3%	5	9%	0	-	0	-
• estate settlement[5]	6	4%	6	11%	0	-	0	-
• forestry settlement[6]	2	1%	2	4%	0	-	0	-
Agricultural expansion (unspecified)								
Total	7	5%	6	11%	0	-	1	1%
All activities	146	96%	55	100%	16	84%	75	96%

* Multiple counts possible; percentages relate to the total of all cases (N=152).

1 In the sense of a predominantly smallholder food production.

2 Agricultural (Integrated, Rural) Development Projects.

3 i.e., resettlement of displaced persons.

4 i.e., establishment of defense villages and military penal settlements.

5 i.e., agricultural nucleus (estate) settlements.

6 i.e., industrial forestry plantation settlement.

Permanent cultivation: All variants of the expansion of permanently cropped land, be it smallholder subsistence or large-scale commercial farming, show comparatively low regional variations across the cases. Thus, permanent cultivation tends to be a robust cause of deforestation, being about three times more often associated with the expansion of food cropped areas (mainly for smallholder subsistence) than with commercial agricultural activities. And, even in commercial agriculture, smallholder activities are more often reported than large-scale farming such as plantation agriculture or agro-enterprise activities.

Cattle ranching: Pasture creation for cattle is a striking factor of deforestation predominantly in 64 cases from Latin America. In two thirds of these pasture-driven cases from mainland South America, humid lowlands are affected such as the coastal zones of southern Belize and Costa Rica (north, south), the Yucatán, Chiapas, Campeche and Quintana Roo parts of Mexico, and the Amazon lowlands of Peru, Ecuador, Bolivia and Brazil. The remaining third of the cases falls under uplands and foothill zones, again mainly dominated by humid climates. Given uncertainties due to the high share of unspecified cattle ranching activities, data indicate that smallholder activities outweigh large-scale cattle ranching.

Shifting cultivation: Shifting cultivation comprises two main modes, i.e., activities of mostly indigenous people that practice a traditional mode of swidden-fallow farming, called traditional shifting cultivation in the study (30% of all cases) and slash-and-burn agriculture as practiced by colonizing settlers or immigrants, called colonist shifting cultivation in the study (17% of all cases). Regional variations across the cases are considerable. It appears that cases of swidden-driven deforestation are more widespread in Asia than elsewhere. Nearly all of these cases are located in upland and foothill zones under humid climates, be it in the insular parts – such as Western Samoa Islands, Cebu Island and Luzon (Philippines), Sumatra and Kalimantan/Borneo (Malaysia, Indonesia) – or in the mainland parts of Northern Laos, Northeastern Thailand, peninsular Malaysia, China (Yunnan), Nepal (Siwalik Hills), and Vietnam (highland, midland and foothill areas). Except for two cases, traditional shifting cultivation always operates in combination with wood extraction. Differently, slash-and-burn agriculture by migrants appears to occur mainly in cases from Latin American humid lowlands (Brazil, Bolovia, Ecuador, Mexico, Dominican Republic, Honduras, Guatemala). Reported evidence suggests that between two thirds and four fifths of the cases also involve (i.e., are concomitantly caused by) wood extraction (commercial timber logging, mainly) and the expansion of infrastructure (in particular, road construction). Three fifths of the cases are related to agricultural colonization as being driven by poverty. Conditions of poverty do best capture the underlying factors of migration to the frontier and forest conversion into agricultural land: landlessness or growing land scarcity, insufficient food production, and, especially social deprivation or marginalization (in the sense of low empowerment).

Colonization, transmigration, (re)settlement: Most of the colonization, settlement, transmigration and resettlement activities leading to deforestation are reported from Asia and Latin America, where they almost exclusively occur in humid forest zones. Given uncertainties due to the large share of activities that were not specified in sufficient detail (in the Asian and Latin American cases), there is indication only that "spontaneous" transmigration probably is the most important form (in 14% of all cases). In Asia, colonization, transmigration and (re)settlement frontiers turn out to be equally wide-

spread among upland, lowland and transitional or foothill zone locations (cases from Indonesia, Malaysia, Thailand and Vietnam), while in Latin America four fifths of the cases are located in the humid lowlands of Honduras, Costa Rica, Mexico and, in particular, the Amazon lowlands of Brazil, Peru, Bolivia, Ecuador and Colombia. Nearly all Asian cases are concomitantly caused by wood extraction as another proximate factor of deforestation. This is reportedly not the case in Latin America where – not wood extraction, but rather – the expansion of road infrastructure works in a synergetic cause combination in almost all cases. The impact of special activities – such as the establishment of defense villages and penal settlements, agricultural nucleus estate settlements, and of industrial forestry plantation settlements (causing deforestation, too) – is limited to the Outer Islands of Indonesia as reported from various independent sources.

Table 8: Frequency of specific infrastructure impacts causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Transport infrastructure								
Total	**97**	**64%**	**26**	**47%**	**9**	**47%**	**62**	**80%**
• **roads**[1]	93	61%	25	46%	9	47%	59	76%
• **railroads**	17	11%	2	4%	1	5%	14	18%
• **rivers & tributaries**	13	9%	2	4%	0	-	11	14%
Market & settlement infrastructure								
Total	**41**	**27%**	**12**	**22%**	**3**	**16%**	**26**	**33%**
• **settlement expansion**	24	16%	10	18%	1	5%	13	17%
• **sawmills, food markets**	5	3%	0	-	1	5%	4	5%
• **public services**[2]	8	5%	0	-	0	-	8	10%
• **improvements (unspec.)**	17	11%	7	13%	2	11%	8	10%
Private enterprise infrastructure								
Total	**25**	**16%**	**12**	**22%**	**1**	**5%**	**12**	**15%**
• **mining (gold, coal, tin ore)**	13	9%	6	11%	1	5%	6	8%
• **hydropower development**	7	5%	6	11%	0	-	1	1%
• **oil exploration**	5	3%	0	-	0	-	5	6%
All activities	110	72%	36	66%	9	47%	65	83%

* Multiple counts possible; percentages relate to the total of all cases (N=152).

1 Any type of road, i.e., public roads (including strategic military highways and unfinished penetration or feeder roads), logging roads, oil and mining company roads.

2 Water, sanitation, electrical grids, other public services.

Infrastructure extension

The extension of infrastructure, in combination with other proximate causes, explains 110 out of 152 cases of deforestation (72%). Overland transport infrastructure, especially road extension, was found in nearly two thirds of all cases. Market or settlement expansion as well as the extension of private enterprise infrastructure is reportedly less associated with deforestation – see Table 8.

Transport infrastructure: The extension of overland and river transport infrastructure, contributing to deforestation in 64% of all cases, is most pronounced in Latin American cases. Railroad construction, river transport and, in particular, road network extension are reported as prominent proximate causes of forest losses there. Road construction is reportedly associated with half of all cases in Asia (from altogether eight countries, but mainly Thailand, Indonesia and Malaysia) and in Africa (from altogether five countries). Thus, road extension is one of the main specific proximate causes of tropical deforestation. It is associated with deforestation especially in three quarters of the Latin American cases located in all countries there (where cases are reported from).

Market & settlement expansion: The expansion of rural, semi-urban and urban settlements plus accompanying market infrastructure, such as public services and private or public food markets, reportedly contributes to deforestation in slightly more than one fourth of all cases (27%). Settlement expansion together with other, infrastructural improvements (that were not further specified in more detail) hold the largest single shares. They do not vary across regional cases to a considerable degree.

Private enterprise infrastructure: The extension of private enterprise infrastructure appears as a minor proximate cause of deforestation only, since it is associated with deforestation in just 16% of all cases (with next to none reported from Africa). The impact of mining gold, coal or tin ore is equally spread among cases in Asia (southern Thailand, upland Philippines and, especially, several cases from China, i.e., coal mining in combination with pig iron production on the basis of charcoal inputs) and Latin America (especially Pará and, to a lesser degree, Rondônia State in the Amazon Basin of Brazil). In contrast, hydropower development associated with deforestation is more often found in Asian cases than elsewhere (inland Sarawak of Malaysian Borneo, southern Kalimantan of Indonesia, several cases from Vietnam and central Thailand). The impact of oil development upon deforestation, especially during the exploration phase, is only reported from Amazon lowland locations in the so-called Napo Region of Peru, Ecuador and Colombia.

Wood extraction

The extraction of wood or timber, in combination with other proximate causes and factors, is reported to lead to deforestation in 102 out of 152 cases (67%). Commercial wood extraction, be it clear-cutting or selective timber logging, occurs in more than half of all cases (52%), while the impact of fuelwood extraction (28%), polewood extraction (20%), and charcoal production (10%) tend to be lower. Variations across regional cases are considerable – see Table 9.

Table 9: Frequency of wood extraction causing tropical deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Commercial wood extraction[1]								
Total	**79**	**52%**	**43**	**78%**	**5**	**26%**	**31**	**40%**
• **unspecified**	48	32%	22	40%	4	21%	22	28%
• **illegal (illicit, undeclared)**	18	12%	12	22%	0	-	6	8%
• **state-run**	17	11%	15	27%	1	5%	1	1%
• **private-run**	9	6%	6	11%	1	5%	2	3%
• **growth coalition-led**	5	3%	0	-	1	5%	4	5%
Fuelwood extraction								
Total	**42**	**28%**	**18**	**33%**	**10**	**53%**	**14**	**18%**
• **for domestic uses[2]**	33	22%	14	26%	7	37%	12	15%
• **for industrial uses[2,3]**	17	11%	6	11%	7	37%	4	5%
Polewood extraction								
Total	**31**	**20%**	**15**	**27%**	**8**	**42%**	**8**	**10%**
• **for domestic uses[2]**	21	14%	11	20%	4	21%	6	8%
• **for industrial uses[2,3]**	16	11%	6	11%	6	32%	4	5%
Charcoal production								
Total	15	10%	8	15%	4	21%	3	4%
All activities	102	67%	49	89%	13	68%	40	51%

* Multiple counts possible; percentages relate to the total of all cases (N=152).
1 Clear-cutting and selective timber logging for export/trade.
2 Rural and urban uses.
3 For direct input into the industrial production process, i.e., not traded (commercially); e.g., artisans and micro-scale enterprises (carpentry, house equipment production).

Commercial wood extraction: The commercial extraction of timber – mainly destined for export to foreign markets[6] – was found to occur both in the form of clear-cutting or selective logging. It was reportedly associated with more than three quarters of the Asian cases, and, thus, constitutes a significant proximate cause of deforestation there. The Asian cases are widespread among nine countries in both the insular and continental parts (western Samoa Islands, northern Laos and India, upland Philippines, and various parts in Vietnam, China, Malaysia, Thailand, Indonesia). Wood extraction was always reported to occur together with agricultural expansion, mainly of shifting cultivation, and in three quarters of the cases together with the extension of roads. Given uncertainties due to the high share of extractional activities not specified in further detail, data indicate that state-run activities are more widespread than private company activities. It is also noteworthy that illegal (illicit, undeclared) logging plays a major role in 12% of all – and especially in one fifth of the Asian – cases.

Fuelwood, polewood, charcoal extraction: Cases of fuelwood harvesting, polewood extraction and charcoal production for rural as well as urban (domestic and industrial) uses – other than destined for trade or export – are most frequently reported to be associated in

Africa, though they also occur in Asia and, to a lesser degree, in Latin America. Domestic and industrial uses are fairly balanced in the African cases (from Guinea, Ghana, Nigeria, Cameroon, Congo-Zaire, Malawi, Kenya, and Madagascar). In all other regional cases, the use of poles and fuelwood for domestic uses tends to be the more prevalent proximate cause of deforestation as compared to industrial uses.[6]

Other factors

Other factors associated with deforestation such as land characteristics, biophysical drivers and social trigger events, are reported in 52 out of 152 (or 34% of all) cases – see Table 10. None of these factors reportedly operates alone. A fairly equal distribution exists between the broad categories of land features, biophysical drivers and social triggers being involved in deforestation in the range of 14 to 18% of all cases each. In the African cases, these factors seem to play a more powerful role (53%) compared to cases from other continents. Further, it seems that certain attributes of the biophysical environment (especially, soil-related factors) are associated with deforestation more strongly in the Latin American cases, while biophysical drivers (especially forest fires) and social trigger events (such as civil wars and rebellions) operate more frequently in African cases.

Land characteristics: Among the pre-disposing environmental factors (or features of the biophysical environment), soil-related features are most frequently cited, but do not operate at all in African cases. In more than two thirds of the cases where soil features are associated with deforestation, forests on fertile soils located on mainly flat grounds are reported to undergo exceptionally high deforestation. On the other hand, poor soil quality is also reported to lead to relatively high deforestation, since meagre soil endowment fuels accelerated clearing, as it is reported in the remaining third of the cases. Except for one case (from the outer islands of Indonesia), all cases driven by soil quality are located in mainland South America: in various parts of the Amazon Basin of Brazil, in the Oriente of Ecuador, in the Atlantic belts of Costa Rica or Honduras, and in the Yucatán and Lacandonia Provinces of Southern Mexico, soil quality-driven cases are less related to crop cultivation but more so to pasture creation, mainly for smallholder cattle ranching. The combination of cattle ranching and soil quality appears to drive exceptionally high deforestation. Indeed, the mean annual deforestation rate (2.0%) in soil feature-driven cases (n=8) has been found to range above the mean deforestation rate (1.5%) in all cases where rates of deforestation were specified (n=108).

Table 10: Frequency of specific other factors associated with deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Land characteristics (features of the biophysical environment)								
Total	**21**	**14%**	**2**	**4%**	**2**	**11%**	**17**	**22%**
• **soil quality**	12	8%	1	2%	0	-	11	14%
• **slope & topography**[1]	7	5%	0	-	2	11%	5	6%
• **water location**	6	4%	0	-	0	-	6	8%
• **vegetation**[2]	4	3%	1	2%	0	-	3	4%
Biophysical drivers (triggers)								
Total	**27**	**18%**	**11**	**20%**	**6**	**32%**	**10**	**13%**
• **soil-related**[3]	7	5%	4	7%	2	11%	1	1%
• **water & climate**[4]	10	7%	3	6%	2	11%	5	6%
• **vegetation-related**[5]	18	12%	9	16%	4	21%	5	6%
Social trigger events								
Total	**24**	**16%**	**10**	**18%**	**6**	**32%**	**8**	**10%**
• **social disorder**[6]	15	10%	8	15%	3	16%	4	5%
• **crisis conditions**[7]	5	3%	1	2%	2	11%	2	3%
• **pop. displacement**[8]	3	2%	0	-	2	11%	1	1%
• **policy failures**[9]	5	3%	1	2%	3	16%	1	1%
Total	52	34%	17	31%	10	53%	25	32%

* Multiple counts possible; percentages relate to the total of all cases (N=152).
1 Flat and gently sloping areas, lowlying areas.
2 Forest size and fragmentation, high vegetation density (especially of marketable woods).
3 Soil compaction, soil fertility decline, soil or land degradation.
4 Drought conditions (aridity), wet conditions (high humidity), floods.
5 Forest fires, weed intrusion.
6 War, civil war, rebellion, revolution, social unrest.
7 Health and economic crisis conditions (e.g., epidemics, economic collapse).
8 Abrupt, partly violent population displacements (e.g., refugee movements).
9 Government policy failures (e.g., abrupt shifts in price or macro policies).

Biophysical factors: Among the biophysical drivers or triggers, vegetation-related factors, especially forest fires, are the most frequently cited (n=16). Except for forest fire cases that were not specified in sufficient detail (n=8), the remaing half is equally split into cases of intentional, partly repeated burning or fires ignited on agricultural or forest land, and in cases of accidental, uncontrolled fires due to burning for land clearance (mostly in combination with increasingly arid conditions). The impact of forest fires tends to vary across regional cases. It is more frequently reported in Asian cases (from Northern Laos, the Siwalik Hills of Nepal, and several areas in China and Indonesian Kalimantan) and in African cases (South Central and Southeast Ghana, Eastern Cameroon, East/Central Highland Madagascar), compared to cases from Latin America (Parâ State of Brazil, Peruvian Northern Andes, Volcanic Highland

of Southern Honduras). Unexpectedly, no forest fires are reported from dry forests, but more so from humid and – to a lesser degree – transitional forest zones (humid savannas).

Social trigger events: Among social trigger events, factors that are related to social disorder or unrest are the most frequently cited. Impacting upon deforestation at exceptionally high rates are wars, civil wars, and revolutions. These cases imply the collapse of state control, periods of insecure ownership, and races for land claims, but also the direct impact of warfare on forest destruction and the creation of military defense settlements in forest zones. Disorder-driven deforestation seems to be more important in African and Asian cases compared to cases from Latin America. Examples include, among others, the occupation and subsequent revolution in Indonesian Java from 1942 into the 1970s; the 17-year civil war in Mozambique (ending in 1994) which triggered off refugee movements to neighboring Malawi adding to widespread deforestation there in the south; large-scale clearing and burning of forests during the Vietnam war, especially in the southern Highlands and the Eastern Nam Bo foothill zone; the Zapatista rebellion, as reported in several cases from the Lancandonia Province of Southern Mexico, weakening the establishment of rationale forestry rules there; and periods of lawlessness following the Revolution in China in 1949 and during the Cultural Revolution, with both state-run and private, illegal logging and marketing of timber on a large scale.[7]

3.1.2. Underlying causes

At the broad aggregate level, it is striking that synergetic driver combinations rather than single variables are associated with tropical deforestation – see Table 11. Single underlying forces, mainly economic factors, reportedly explain only 12% of all deforestation cases. Most of the cases (88%) are driven by multi-factor terms of causation. The more complex the combination, the higher the degree of explanation. More than one third of the cases is driven even by the full interplay of all underlying forces. Economic factors are most prevalent in (some) single and multi-factorial combinations (81%) as compared to policy and institutional (63%), technological (59%), socio-political or cultural (56%), and demographic factors (51%). The dominance of economic factors found here relates to their frequency of occurrence, i.e., as single, chain-logically connected or concomitant cause (when considering chain-logical connections only between the underlying and proximate levels, it appears that policy and institutional factors are more important).

Table 11: Frequency of broad underlying driving forces*

	All cases (N=152)			Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	cum	abs	rel	abs	rel	abs	rel
Single factor causation									
ECON	13	9%	9%	0	-	0	-	13	17%
INST	4	3%	12%	0	-	1	5%	3	4%
TECH	0	-	-	0	-	0	-	0	-
CULT	0	-	-	0	-	0	-	0	-
POP	0	-	-	0	-	0	-	0	-
2-factor term of causation									
POP-ECON	5	3%	15%	0	-	3	16%	2	3%
POP-TECH	4	3%	17%	2	4%	1	6%	1	1%
POP-INST	1	1%	18%	0	-	0	-	1	1%
POP-CULT	1	1%	18%	0	-	0	-	1	1%
ECON-TECH	1	1%	19%	0	-	0	-	1	1%
ECON-INST	5	3%	22%	0	-	0	-	5	6%
INST-CULT	5	3%	26%	4	7%	0	-	1	1%
3-factor term of causation									
POP-ECON-TECH	5	3%	29%	0	-	4	21%	1	1%
POP-ECON-INST	1	1%	30%	1	2%	0	-	0	-
POP-ECON-CULT	2	1%	31%	0	-	1	5%	1	1%
POP-TECH-INST	4	3%	34%	1	2%	1	5%	2	3%
ECON-TECH-CULT	1	1%	34%	0	-	0	-	1	1%
ECON-INST-CULT	6	4%	38%	0	-	0	-	6	8%
TECH-INST-CULT	5	3%	42%	5	9%	0	-	0	-
4-factor term of causation									
POP-ECON-TECH-INST	8	5%	47%	5	9%	2	11%	1	1%
POP-ECON-TECH-CULT	1	1%	47%	0	-	1	5%	0	-
POP-ECON-INST-CULT	2	1%	49%	1	2%	0	-	1	1%
POP-TECH-INST-CULT	5	3%	52%	4	7%	0	-	1	1%
ECON-TECH-INST-CULT	19	13%	64%	12	22%	0	-	7	9%
5-factor term of causation									
All	54	36%	100%	20	36%	5	26%	29	37%
Total	152	100%	-	55	100%	19	100%	78	100%

* POP = Human population dynamics, ECON = Economic growth or change, commercialisation, development, TECH = Technological change, INST = Policy and institutional factors, or change of political-economy institutions, CULT = Cultural or socio-political factors.

Table 12: Frequency of specific economic factors causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Market growth and commercialisation								
Total	**103**	**68%**	**30**	**55%**	**15**	**79%**	**58**	**74%**
Rapid market growth (unspec.)[1]	38	25%	13	24%	3	16%	22	28%
Increased market accessibility[2]	27	18%	9	16%	5	26%	13	17%
Growth of sectoral industries	78	51%	23	42%	13	68%	42	54%
... (wood-related)[3]	(44)	(29%)	(16)	(29%)	(5)	(26%)	(23)	(30%)
... (agriculture-related)[4]	(44)	(29%)	(9)	(16%)	(10)	(53%)	(25)	(32%)
... (mineral-related)[5]	(22)	(15%)	(9)	(16%)	(0)	(-)	(13)	(17%)
... (others)[6]	(8)	(5%)	(2)	(4%)	(1)	(5%)	(5)	(6%)
Lucrative forex earnings	38	25%	16	29%	5	26%	17	22%
Demand, consumption[7]	69	45%	24	44%	13	68%	32	41%
... (unspecified)	(14)	(9%)	(9)	(16%)	(2)	(11%)	(3)	(4%)
... (wood-related)[3]	(48)	(32%)	(16)	(29%)	(7)	(37%)	(25)	(32%)
... (agriculture-related)[4]	(28)	(18%)	(7)	(13%)	(7)	(37%)	(14)	(18%)
... (housing, transport)	(7)	(5%)	(2)	(4%)	(1)	(5%)	(4)	(5%)
Specific economic structures								
Total	**52**	**34%**	**22**	**40%**	**6**	**32%**	**24**	**31%**
Unspecified[8]	12	8%	5	9%	0	-	7	9%
Large individual gains[9]	14	9%	4	7%	0	-	10	13%
Poverty & related factors[10]	23	15%	14	26%	1	5%	8	10%
Economic downturn, crisis	11	7%	0	-	3	16%	8	10%
Indebtedness, foreign debt	10	7%	2	4%	4	21%	4	5%
Urbanization and industrialization								
Total	**58**	**38%**	**23**	**42%**	**5**	**26%**	**30**	**39%**
Urbanization, urban mkt. growth	26	17%	8	15%	5	26%	13	17%
Industrialization[11]	43	28%	21	38%	1	5%	21	27%
Special economic variables								
Total	**48**	**32%**	**9**	**16%**	**5**	**26%**	**34**	**44%**
cheap, abundant prod. factors[12]	9	6%	1	2%	0	-	8	10%
special low cost conditions[13]	11	7%	2	4%	0	-	9	12%
price (value) increases[14]	25	16%	6	11%	2	11%	17	22%
price decreases (cash crops)	9	6%	0	-	3	16%	6	8%
All factors	123	81%	39	71%	16	84%	68	87%

* Multiple counts possible; percentages relate to the total of all cases (N=152).

Table 12 (continued)

1 Economic growth (especially of the export-oriented sector), rise of cash economy and prosperity, increasing commercialisation and incorporation into world economy.
2 Especially of urban and semi-urban markets.
3 Charcoal, wood processing, furniture, house equipment and construction, paper, other timber and wood products (fuelwood, polewood).
4 Agricultural food (including smoked fish) and non-food (coca, opium) products, especially as cash crops and for export; including animal nutrition.
5 Energy industry (oil, gas, petrochemical), coal mining, iron production.
6 Transport and transport equipment industry, house equipment and construction industry, rural banking service economy.
7 Growth of demand for consumer goods and services procured with cash due a rise in well-being.
8 Rapid and uneven growth; competitive overexploitation of especially natural resources.
9 Especially through land speculation.
10 Mainly rural poverty, i.e., resource poverty, low living standard, displaced and deprived livelihoods, joblessness; lack of alternative, non-agrarian income opportunities and revenues; joblessness; lack of basic infrastructure and services.
11 Rapid built-up of new basic and heavy industries, domestic forest based industrialization (substituting imports, protecting national economy).
12 Comparative advantages in natural resource extraction and forest based production.
13 Low domestic prices for land, labour, fuel, or timber (kept low artificially, in parts).
14 Especially of fuel, land and cash crops.

Economic factors

Underlying factors related to economic growth (or, similarly, to economic change, commercialisation or economic development) underlie 123 out of 152 cases (81%), mainly in combination with other drivers – see Table 12. In just 9% of all cases, economic factors operate as single underlying forces as reported from several cases in mainland South America. In the majority of all cases (91%), however, economic factors work in driver combinations, mainly as interplay of four or even all underlying factors. If grouped by factors of (positive, successful) market growth and commercialisation versus specific economic structures, by urbanization and industrialization, and by special economic variables, market growth and commercialisation drive 68% of all cases, while other other economic variable clusters underlie tropical deforestation in the range of 32 to 38% of the cases. There is not significant variation across regional cases, and economic factors could, thus, be labelled as the most important and robust underlying forces of tropical deforestation.[8]

Market growth & commercialisation: In the broad group of market growth and commercialisation, the most dominant individual variables are the growth of specific sectoral production industries (51%) together with the growth of demand for consumer goods and services (45%), both underlying about two thirds of all cases. On the demand side, the consumption of wood or wood-based products (such as fuelwood, polewood, charcoal, paper, plywood, sawn wood, and furniture) is more often cited than, i.e., the consumption of agricultural goods (such as food and non-food products or animal fodder). On the production side, both the growth of wood- and agriculture-related industries underlie deforestation with about the same frequency (29%). The growth of mineral and fossil fuel industries, such as oil, gas, coal mining and iron production, underlies 15% of all cases (none in Africa). Among other individual factors, the increased accessibility of urban and semi-urban markets, mainly achieved through the development of tranport infrastructure, is noteworthy since it underlies about a fifth of all cases (18%). Lucrative foreign exchange earnings, gained from timber extraction and agricultural production on formerly forested land, constitute another considerable force that drives 25% of all cases. Another quarter of all cases (25%) is driven by market growth and commercialisation in the broad sense, i.e., given no further specification in the case studies. In 9% of the cases, market growth and commercialisation are associated with a

rise in general well-being and operate as single factors in several cases from mainland South America (Costa Rica, Amazon lowlands of Bolivia and Brazil): at the proximate level, deforestation is associated here with the expansion of cropped land and cattle ranching (in combination with the extension of overland transport infrastructure, i.e., roads and railroads), while the specific underlying forces comprise the country-wide unfolding of economic development in the form of a rising cash economy, growing commercialisation and prosperity, partly driven by the lending practice of international financial institutions to promote economic development.

Specific economic structures: Not only successful market expansion but also specific economic structures (in some cases related to so-called market failures) are reported to drive deforestation. Individual factors such as indebtedness, poverty or economic crisis conditions reportedly underlie only 7 to 15% of all cases each. However, regional variations across the cases indicate that some factors are more important in certain cases than others.

For example, poverty - defined here in purely economic terms (i.e., deprived livelihoods, poor economic resources, poor living standard, high unemployment, lack of alternative non-agrarian income, and lack of basic infrastructure and services) – is a more frequent driver of deforestation in cases from Asia (northern Laos, upland Philippines, several cases from Vietnam, Thailand, Indonesia, China and Malaysia) and Latin America (southern Belize, several cases from Honduras, Peru and the Brazilian Amazon) than, unexpectedly, in Africa. Apart from poverty, speculative deforestation through large individual gains from land speculation has not been found in African, but more so in Latin American cases (Atlantic belt of Honduras, Amazon lowlands of Ecuador and Brazil, in particular, Acre, Rondônia and Pará States), and to a lesser degree in Asian cases (Eastern Borneo, various cases from Thailand). Conditions of economic crisis and downturn are not reported to be driving forces in Asian but rather in other regional cases. The impact of national indebtedness or heavy foreign debts drives more cases in Africa than elsewhere.

Urbanization and industrialization: Stronger than the expansion of urban markets in 17% of all cases (demand, consumption, production necessities) is the process of industrialization. It is reported to play a role in more than one quarter of tropical deforestation cases (28%). The rapid built-up of new (basic, heavy) industries on the basis of domestic forest resources (e.g., iron, steel, and petrochemicals) is enhanced by national policies of import substitution and domestic economy protection. These factors are most frequently cited in 21 cases settled in emerging market economies in Asia (in specific, China, Thailand, Indonesia, Malaysia, and Vietnam), and in 21 Latin America cases from seven (out of a total of 11) countries), but considerably less so in Africa.

Special economic variables: Special economic factors underlie about one third of all deforestation cases. They are composed of individual decision factors and are associated with only 6% to 16% of the cases, especially in Latin America. Price increases of land, fuel and cash crops tend to impact more strongly on deforestation than price decreases, for example, in the cash crop sector (often together with economic downturn). Though not very common, "subsidizing deforestation" (Barbier 1993) in the form of domestic prices for land, labour, timber or fuel – kept artificially low and, thus, subsidizing hin-

terland colonization – is reported in less than 10% of the cases. The same holds true for comparative advantages in natural resource extraction and forest-based production through the availability of cheap, abundant production factors.

Policy and institutional factors

Policy and institutional factors (or changes in political economy institutions) were found in 119 out of 152 (or 78% of all) cases, predominantly in combination with other drivers – see Table 13. They, thus, emerge as the second most important underlying force of tropical deforestation (in terms of their frequency of occurrence). If grouped into broad categories such as formal and informal policies, and matters of property rights regimes, formal pro-deforestation policies underlie considerably more of the cases (69%) than informal policies or policy climate (42%), while certain features related to property rights institutions are associated with 44% of all cases. From variations across regional cases, it could be derived that especially policy climate (e.g., corruption and mismanagement) and issues related to property rights (such as land titling and quasi open access) are most pronounced in Asian and Latin American cases.

Formal policies: Formal pro-deforestation policies constitute the most important group of instutional factors, driving tropical deforestation in more than two thirds of all cases. Among them, policy measures that relate to land matters (40% of all cases) and economic development (34%) constitute the leading individual variables.

Specific policy measures such as taxation, charges, prices, tariffs and other measures (such as – favourable – credits, subsidies and – liberally granted – licenses and logging concessions) are also reported to be of importance. They underlie one fifth or, respectively, one quarter of all cases, mainly in Latin America. Another quarter of the cases is driven by special finance, trade, and investment policies that mainly originate from the international level and are translated into national policies. In the order of decreasing importance, these are practices of international financial lending institutions interested in the promotion of economic development (such as sectoral World Bank policies promoting cash crop and infrastructure development), national laws encouraging foreign investment (often accompanied by public spending), the impact of Structural Adjustment Programmes, and timber import barriers in developed nations (driving import substituting and domestic forest-based industrialization strategies of developing nations). Further contributing to deforestation in 8% of all cases are (inter)national population policies, mostly in the Asian cases (except for a single case from the Brazilian Amazon). In these cases from Vietnam, northern Thailand, and Kalimantan, Sumatra and the Outer Islands of Indonesia, restrictions on migration to urban areas and the exclusion of highland ethnic minorities from population control programs are reported to indirectly drive rural land pressure and agricultural expansion plus wood extraction. Further, violent expulsion by the army has reportedly led to the relocation of displaced people into forested areas in Asian cases which were partly funded by transmigration programs of international institutions and national governments.

Table 13: Frequency of specific policy and institutional factors causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Formal policies								
Total	**105**	**69%**	**46**	**84%**	**7**	**37%**	**52**	**67%**
Taxation, charges, prices, tariffs	27	18%	5	9%	2	11%	20	26%
Credits, subsidies, concessions	39	26%	11	20%	1	5%	27	35%
Economic development[1]	51	34%	22	40%	5	26%	24	31%
Finance, investment, trade	32	21%	12	22%	2	11%	18	23%
Population (migration)	12	8%	10	8%	0	-	2	3%
Land	60	40%	28	51%	5	26%	27	35%
Unspecified	2	1%	0	-	0	-	2	3%
Informal policies, policy climate								
Total	**64**	**42%**	**31**	**56%**	**1**	**5%**	**32**	**41%**
Corruption, lawlessness	18	12%	17	31%	0	-	1	1%
Growth (development) coalitions	24	16%	9	16%	0	-	15	19%
Poor performance, mismanagemt.	38	25%	13	24%	1	5%	24	31%
Clientelism, vested interests	22	15%	17	31%	0	-	5	6%
Redefintion of policy goals	5	3%	2	4%	0	-	3	4%
Property rights regimes								
Total	**67**	**44%**	**33**	**60%**	**5**	**26%**	**29**	**37%**
Land tenure insecurity (unspec.)[2]	22	15%	18	33%	3	16%	1	1%
(Land) Race for property rights	19	13%	6	11%	1	5%	12	15%
Titling, legalization[3]	19	13%	7	13%	2	11%	10	13%
Malfunct customary rights	6	4%	5	9%	1	5%	0	-
Deprivation, marginality[4]	28	18%	17	31%	3	16%	8	10%
Quasi open access conditions	29	19%	18	33%	0	-	11	14%
All factors	119	78%	53	96%	9	47%	57	73%

* Multiple counts possible; percentages relate to the total of all cases (N=152).
1 Especially agricultural and infrastructure development.
2 Including insecure (private) ownership.
3 Consolidation of individual land titles.
4 Low empowerment.

On land development, next to all policy decisions leading to deforestation – such as colonization and (re)distribution of forest land – are reportedly made at the national level. Some of these policies are common to all regions (especially in Asian and Latin American cases), while others are not. Common characteristics are government decisions to distribute public forest land to marginal people, as reported from several cases in Thailand as well as from Costa Rica, Ecuador and Brazil, and to establish colonization settlements as reported from cases in Nepal, Indonesia, Malaysia and Thailand as well as from Bolivia, Peru, Ecuador, Colombia and the Brazilian Amazon. A special feature,

mostly in the Asian cases, are government land claims for logging (institutionalized logging) and the establishment of state agricultural and forestry plantations such as in northern Laos, upland Philippines, central and southern Thailand, in Kalimantan (Borneo), peninsular Malaysia and on the Outer Islands of Indonesia. In constrast, land policies in the Latin American cases seem to be more strongly shaped by the liberalization of land markets, an easy legal transfer of public forest land for private uses, and state regulations in favour of large individual holdings.

Economic development policies underlie about one third of all deforestation cases, regardless of regional variations. In about half of these cases, national policies drive most of the expansion of cropped land and pasture together with the expansion of infrastructure, mostly through national development plans and, to a considerably lesser degree, through specific growth-oriented agricultural and infrastructure policies. National development plans focus the international policy impact – such as development aid, World Bank policies on cash crop, timber and road development, and Structural Adjustment Programs – and direct it to the local level where deforestation results. However, about one third of the cases driven by economic policies have no backward linkages to the global level. In these cases, national policies directly impact local economies through nationally enforced food production (China), the encouragement for high intensive agriculture through rural extension services, and through government efforts towards sedentary agriculture.

Informal policies, policy climate: Informal policies (or policy climate) are reported to contribute to deforestation in 42% of all cases. In specific, these are mainly poor forest management, the impact of growth coalitions, patron-client relations, vested private interests in state regulation, and corruption.

Poor performance of government institutions to protect forests underlies one quarter of all cases, though not so much in Africa. In specific, these are poor logistics (due to lots of bureaucratic red tape), inadequate allocation of funds and staff in forest management, weak, low or no control of the state's forest patrimony, and weak, low or no environmental protection regulation. In fewer of these cases, the poor management of state forests goes hand in hand with poor agricultural extension services that indirectly induce local farmers to expand cropped land and pasture into forested areas.

In 16% of all cases, so-called growth or development coalitions associated with deforestation are at work. This relates to strong political support for development projects from the local, national and even international level (e.g., local populations, powerful public work departments, and developers, all pushing infrastructure projects in forested areas). Also, reportedly at work are growth coalitions or an informal symbiosis of outside loggers and local population groups. The pattern is reiterated at the national level by policy coalitions of agricultural colonization and timber logging, mainly in the Asian cases.

In 15% of all cases, deforestation is associated with clientelism (patron-client relations) and vested interests (of influential private persons or, even, foreign powers) in forest legislation and natural resource use, again mostly in the Asian cases. These are, in specific, ruling coalitions of (rapacious) elite interests, vested private interests in forest legislation (access to logging concessions and licenses), and unequal power relations due to which much of the political decisions on forest use are concentrated in a clan elite.

In 12% of all cases, corruption as a form of bureaucratic capitalism is associated with deforestation mostly due to unsustainable timber logging. Corruption, as any other form of lawlessness, makes bureaucrats and government institutions unable to perform their supervisory duties effectively, and, thus, occurs together with most of the cases of forest mismanagement. Such cases are next to exclusively found in Asia.

Property rights issues: Issues related to property rights institutions are reportedly associated with deforestation in 44% of all cases. In specific, these are land tenure insecurity, land races, conditions of quasi open access, malfunct customary rights, low empowerment of local user groups, and, even, legal land titling procedures.

In about one fifth of all cases (19%), conditions of so-called open access underlie cases of deforestation in Asia and Latin America (not so in Africa). In actual terms, the cases are dominated by quasi open access situations where mainly invasion and squatting of government forest patrimony (forest reserves, national parks) occurs by loggers and farmers – such as in Northern Laos, various parts of Thailand, insular Malaysia (Sarawak), in the Xingu Basin of Para State in the Brazilian Amazon, in the Samana Bay area of the Dominican Republic and in the Rico Bonito National Park of northern Honduras.

In 18% of all cases, situations of low empowerment of local user groups, social deprivation and marginality are reported to underlie deforestation. Partly, they explain squatting of protected forest land, low technolocial inputs and cropped land expansion, or operate as push factors of in-migration into (and spontaneous colonization of) forested land.

Land tenure insecurity reportedly underlies 15% of all cases, mainly in Asia and Africa (less so in Latin America). In specific, these cases comprise insecure private ownership, the lack of secure titles and the intentional or unintended consequences of informal policies or policy failures (forest mismanagement) such as the unclear delineation of forest/agriculture boundaries.

Land races in the sense of races for property rights underlie 13% of all cases of deforestation. Most of them occur concomitantly with insecure (private) land tenure situations and spontaneous colonization where formal government policies require a proof of occupation before legal titling is provided. Different from mentality-driven deforestation (“clear before anyone else does“), these cases follow the rule “clear (half) claim before legal“. They are most widespread in Latin America, e.g., Costa Rica (various regions), Ecuador (Sierra, Costa), in parts of the Amazon lowlands of Brazil (Rondônia State), Ecuador (Oriente) and Bolivia, but also in Asian cases such as in China (Yunnan), Nepal (Eastern Hill Region), Indonesia (Sumatra, western Kalimantan/Borneo), and on western Samoa Islands.

Taken properly, malfunct customary rights could be subsumed either under land tenure insecurity or quasi open access conditions. They are taken here separately to document that the collapse or malfunction of group property rights does not necessarily establish a “tragedy“ of open access. Malfunct customary land tenure is reported to underlie just a few cases of deforestation (4%).

Technological factors

Various technological factors in the wood and agriculture sectors, in combination with other driving forces, underlie 107 out of 152 deforestation cases (70%). They, thus, constitute the third most important underlying driver – see Table 14. If grouped into broad categories such as agro-technological change (in/extensification and other changes) and technological applications in the wood sector (mainly logging and wood processing technologies), both groups of factors account for slightly less than half of all cases. Since in the agricultural sector not all factors could be related to agro-technnological change alone, certain production factors reported to be associated with deforestation (in 28% of all cases) are considered separately.

Table 14: Frequency of specific technological factors causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Production factors in agriculture								
Total	**42**	**28%**	**22**	**40%**	**4**	**21%**	**16**	**21%**
low technological level (unspec.)	16	11%	9	16%	1	5%	6	8%
land-related factors[1]	27	18%	11	20%	4	21%	12	15%
labour-related factors	3	2%	2	4%	0	-	1	1%
Capital-related factors	8	5%	7	13%	0	-	1	1%
Technological factors in the wood sector								
Total	**69**	**45%**	**39**	**71%**	**8**	**42%**	**22**	**28%**
Poor logging performance	24	16%	14	26%	2	11%	8	10%
Wastage in processing	17	11%	12	22%	2	11%	3	4%
Consumption[2]	10	7%	6	11%	4	21%	0	-
Agro-technological change								
Total	**70**	**46%**	**28**	**51%**	**8**	**42%**	**34**	**44%**
Land-use intensification	28	18%	11	20%	6	32%	11	14%
Land-use extensification	19	13%	9	16%	1	5%	9	12%
Agricultural involution	7	5%	3	6%	1	5%	3	4%
Other changes[3]	50	33%	17	31%	5	26%	28	36%
All factors	107	70%	49	89%	14	74%	44	56%

* Multiple counts possible; percentages relate to the total of all cases (N=152).
1 Landlessness, land scarcity, limited amount of productive land.
2 Lack of cheap alternative technologies to woodfuel; poor domestic and industrial furnace performance.
3 Changes in landholding size, market versus subsistence production orientation, and intensity of labour and capital used.

Agro-technological change: Technological factors, as related to agrarian change and reportedly associated with deforestation, underlie 46% of all cases. Regional variations across the continents are low, thus, making the broad group as well as individual factors robust driving forces. However, the more detailed picture of agro-technological change behind deforestation is complex, and does not provide an easy-to-generalize pattern.

For example, cases of land-use intensification (18%), that are reportedly associated with deforestation – and in which local farmers reduce fallow, adopt new crop rotations, high-yielding crop varieties, commercial crops, and agro-chemical inputs like fertilizer, herbicides and pesticides –, are balanced by cases of land-use extensification (13%), especially, if taken together with cases of agricultural involution (7%) – in which farmers extend agricultural land under low levels of technological inputs. In some instances, there seem to be repeated shifts between intensification and extensification (disintensification), mainly induced in rural areas by external economic shocks or trigger events such as abrupt price collapses and sectoral market shifts (from food to cash cropping, and vice versa). However, the number of cases following this pattern is too low to be generalized.

One third of the cases (33%) is underlain by changes other than modification of farming systems through intensification and extensification. These changes relate to landholding sizes, broad orientations in production (for commercial market, or subsistence), and to labour as well as capital intensity. With regard to landholding patterns, two contrasting developments of division and consolidation occur in about one fifth of all cases each: shifts both from small to large landholdings and from small to very small holding sizes. Cases of land division behind deforestation mostly occur outside the areas affected by deforestation, and work as push factors of in-migration into forested, agricultural frontier zones. In production orientation of local farmers, two major trends are about equally represented, and tend to supplement each other: the shift towards commercial (tree, crop) production and the drive away from shifting cultivation (in about 15% of all cases each). About one fifth of all cases is further characterized by shifts from labour-intensive to capital-intensive modes of farming (mechanization). This trend is associated with deforestation both directly at the local level and indirectly at the national level. In the latter case, large-scale mechanization operates as a push factor of migration, i.e., shifting resource-poor farmers and jobless land labourers to the forest frontier as reported from various regional cases.

Technological factors in the wood sector: Technological factors involved in timber logging (e.g., use of chainsaws or heavy equipment), in wood processing (mainly, poor timber processing technology) and in the industrial and domestic consumption of wood (e.g., poor performance of domestic or industrial furnace technology) are reported to be associated with deforestation in nearly half of all cases (45%). The main impact arises in cases from Asia (Thailand, Indonesia, Malaysia, Philippines) where inappropriate technologies in logging appear more widespread than are poor, wasteful technologies in processing and inefficient consumption equipments. In logging, the increasing use of chainsaws – often together with the use of heavy equipment such as trucks, tractors and bulldozers – contributes to deforestation in the form of damage and wastage due to poor (logging) performance. Wastage, indirectly contributing to deforestation, also occurs in the processing sector due to poor timber processing technologies, and, partly, due to poor industry performance, in general. In the consumption sector, both the lack of cheap, technological alternatives to domestic woodfuel and the poor performance of wood-based, mainly domestic – but also industrial – furnaces is reported as another technological factor contributing indirectly to deforestation (in Asian as well as African, but less so in Latin American cases).

Production factors in agriculture: Production factors, which are mainly related to the agro-technological production process (i.e., land, labour, and capital), occur across all regional cases. Noteworthy among them are land-related production factors and low technological levels which coincide with cases of land-use extensification. Not so much limited labour or capital (in the form of fertilizer, irrigation techniques, etc.), but more so insufficient land resources are reported to drive deforestation in 18% of all cases. In specific, landlessness, existing or growing land scarcity and limited amounts of productive land underlie directly local deforestation processes or, indirectly, pull or shift farmers from their areas of origin to the forest frontier.

Cultural factors

Cultural (or socio-political) factors, in combination with other drivers, are found to be involved in 101 out of 152 (or 66% of all) cases of deforestation – see Table 15. These forces could, thus, be considered as the fourth most important underlying driving force. If broadly grouped by public attitudes, values and beliefs (for example, about forests, forest protection and development) on the one hand, and individual and household behaviour on the other hand, both groups of variables underlie deforestation in more than half of all cases (63% and 53% of the cases, respectively). More pronounced than in the African cases, cultural factors tend to impact Latin American and, especially, Asian cases.

Public attitudes, values, beliefs: Public attitudes – such as unconcern for forests due to low morale and frontier mentalities – and other unconcern or lack of basic psychological values – such as disregard for "nature" –, and, to a lesser degree, beliefs or disregards about the environment are associated with nearly two thirds of all deforestation cases, especially those from Asia and Latin America.

With regard to public attitudes, a specific frontier mentality shapes human agency, especially government action, at the national and local level in several cases from Asia (north and northeast Thailand, Sarawak/Malaysian Borneo, and various areas in Indonesia) and Latin America (Amazon lowlands of Bolivia, Peru, Ecuador and Brazil, northern Petén region of Guatemala, and various areas in Costa Rica). In all these regional cases, forest colonization is (or has been) viewed as important for national land consolidation, security, unity, integrity, and military defense. Not in the Asian, but in the Latin American cases only, two main public notions of deforestation prevail such as: the establishment of human frontiers will be achieved not through social development, but through road construction; forest frontiers are useful as escape velvets to remedy country-wide social conflicts. Besides frontier mentality, low morale or lacking public education are reported to be associated with deforestation in nearly 20% of all cases, but were not further specified. Among other public attitudes shaping government actions are those of modernization, development and post-colonial nation building. Mainly located at the state level, a strong desire is reported from mainly Asian and Latin American cases for market economy development and political stability, together with the view that forest conversion is the best way to promote national economic growth and also meet local demands. Across all regional cases, including those from Africa, attitudes associated with deforestation are reported such as: forest conversion is the best method for promoting agricultural modernization and raising living standards. There are two minor variants of it. At the local level, a dominant attitude prevails among farmers that it is desirable to take advantage of market opportunities. And, certain public notions domi-

nate, for example, the colonization of the Bolivian Amazon lowlands and in cases from China and insular Malaysia: make the country compatible with others in terms of modernization; catch up with others (i.e., reach similar levels of national economic development); political stability can be restored through infrastructure – instead of human capital – development.

Table 15: Frequency of specific cultural factors causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Public attitudes, values and beliefs								
Total	**96**	**63%**	**45**	**82%**	**5**	**26%**	**46**	**59%**
Public (un)concern, no support[1]	66	43%	25	46%	3	16%	38	49%
... (low morale/education, unspec.)	(27)	(18%)	(12)	(22%)	(1)	(5%)	(14)	(18%)
... (dominant frontier mentality)	(37)	(24%)	(10)	(18%)	(0)	(-)	(27)	(35%)
... (other public attitudes)[2]	(31)	(20%)	(16)	(29%)	(2)	(11%)	(13)	(17%)
Other unconcern or disregard[3]	55	36%	33	60%	2	11%	20	26%
Beliefs about forest values[4]	32	21%	20	36%	3	16%	9	12%
Individual and household behaviour								
Total	**80**	**53%**	**38**	**69%**	**6**	**32%**	**36**	**46%**
Unconcern by individuals[5]	48	32%	20	36%	4	21%	24	31%
Situation-specific behaviour	74	49%	36	66%	5	26%	33	42%
... (rent seeking behaviour)[6]	(53)	(35%)	(26)	(47%)	(4)	(21%)	(23)	(30%)
... (non-profit orientation)[7]	(22)	(15%)	(9)	(16%)	(2)	(11%)	(11)	(14%)
... (tradition, imitation)	(34)	(22%)	(18)	(33%)	(3)	(16%)	(13)	(17%)
All factors	101	66%	46	84%	7	37%	48	62%

* Multiple counts possible; percentages relate to the total of all cases (N=152).

1 Lack of support for forest protection and quality (sustainability).
2 Prevailing attitudes of modernization, development, nation-building, etc.
3 Lack of basic values such as the concern with welfare of others and future generations, or belief in the "sacredness of nature".
4 Beliefs about how environmental conditions may affect those things that an individual values in the case of forests.
5 Unconcern by individuals about the environment as reflected in increasing levels of demands, aspirations, materials and energy consumption, commonly associated with increased income.
6 Profit and cash orientated behaviour.
7 Behaviour aimed at emancipation, independent livelihood, etc.

Unconcern about the welfare of others and future generations, or lack of belief in the "sacredness of nature" underlie more than one third of all deforestation cases both at the local and national level (less so, however, in Africa). In specific, these are low recognition of customary rights from outsiders (creditors, loggers) and low recognition from local people of legal procedures such as area protection (for nature conservation, state forest, etc.). Disregards for the environment and welfare of others – such as the refusal of personal responsibilty under collective leadership and insecure ownership, and a general view upon forests as a "free good" for quick cash – are reported mainly from Asian cases. Crops and cattle tend to be viewed as rural capital or bank for fast cash in cases of cash crop expansion in Asia and pasture creation for ranching in Latin America. Especially in

the humid lowlands of mainland South America, pasture creation is often reported as an unproductive, profit-seeking activity to add value to land and, thus, raises the value of land for speculation purposes (speculative deforestation). The private capture of economic surplus, not re-invested in land-use, together with competition in capturing social status, power and prestige are often reported to occur concomitantly in both traditional and modern rural societies across the regional cases.

Beliefs about how environmental conditions may affect those things that individuals value are reported to underlie one fifth of all cases. Besides traditions shaping individual behaviour ("follow others", "imitate others"), these are, in specific, beliefs that forest conversion is inevitable to meet local demand and promote growth, since deforestation "will happen anyway", and that it is advisable to "clear before anyone else does". These beliefs go hand in hand with notions on forests as "free goods", and that traditional shifting cultivation is a "destructive practice" that has to be replaced by sedentary agriculture.

Individual and household behaviour: A group of variables related to individual and household behaviour is reported to be associated with deforestation in more than half of all cases. Variations across regional cases tend to be lower than with variables related to public attitudes, values and beliefs, thus, making behavioral factors a rather robust force. Situation-specific behaviour (49% of all cases) appears to outweigh the more fundamental unconcerns of individuals about the the environment (32%).

With regard to situation-specific behaviour, the profit or cash-orientation of actors of deforestation (rent-seeking behaviour) is reported to underlie more than one third of all cases. In more than half of these cases, actors are rooted in the local level (mainly as farming households), while other actors also come from outside (cattle ranchers, cash crop developers, loggers). In both groups, rational responses to increased profitability, private capture of economic surplus and the readiness to take advantage of market opportunities (short-term rent-seeking) are reported to be as dominant as the inclination towards land speculation through unproductive rent-seeking behaviour. In contrast, about one third of the deforestaton cases associated with situation-specific factors of behaviour are driven by the desire – of, especially, young actors – to establish their own families, to secure independent livelihoods, and to attain emancipation from wage work (through forest clearance for cash crops).

Tradition, imitation and the continuation of inherited modes of production are reported to be associated with deforestation in more than one fifth of all cases. This relates to the widespread notion to "follow others", as practiced mainly by impoverished farming households migrating to the forest frontier, and by local shifting cultivation households copying timber harvesting practices of outside loggers (i.e., selling wood to them). Low government morale in forest protection and the continued, self-reinforcing lack of personal responsibility under insecure ownership or collective leadership are further reported to contribute to modes of agricultural land expansion and wood extraction that result in deforestation. "Clear before anyone else does" is another widespread individual and household behaviour that reportedly holds true across all regional cases.

Demographic factors

Human population dynamics, in combination with other drivers, is reported to underlie 93 out of 152 (or 61% of all) cases of deforestation – see Table 16. It, thus, appears to be the fifth most important underlying force of tropical deforestation, still impacting at high level. Most of its explanatory power tends to be derived from interlinkages with other underlying forces, especially in the full interplay of all five major drivers, since single factor causation is nil. Considerable variations across regional cases indicate that demographic factors in tropical deforestaton are more important in Africa as compared to other regional cases.

Table 16 Frequency of specific demographic factors causing deforestation*

	All cases (N=152)		Asia (n=55)		Africa (n=19)		L. America (n=78)	
	abs	rel	abs	rel	abs	rel	abs	rel
Population pressure (unspec.)	6	7%	5	9%	1	5%	0	-
Population growth (unspec.)	58[1]	38%	28	51%	15	79%	17	22%
Natural increment	12[2]	8%	6	11%	1	5%	5	6%
In-migration	58	38%	12	22%	9	47%	37	47%
Population density	38	25%	12	22%	6	32%	20	26%
Uneven spatial distribution	4	3%	0	-	1	5%	3	4%
Life cycle features	2	1%	0	-	0	-	2	3%
All factors	93	61%	34	62%	18	95%	41	53%

* Multiple counts possible; percentages relate to the total of all cases (N=152).
1 Occurring at and impacting from the national level in 11 cases.
2 Occurring at and impacting from the national level in 2 cases.

Given uncertainties due to the frequent mention of vague notions of population pressure and growth, which were not further specified in the cases, there is indication to assume that most of the human population dynamics driving deforestation could be related to in-migration of farmers and other actors into the areas affected by deforestation (38% of all cases). In one quarter of all cases, population pressure upon forests materializes in already existing or increasing population density values (25%), while natural increment explains only less than 10% of all cases. It seems noteworthy that there are cases of population-driven deforestation, in which outmigration is reported and/or even rural depopulation, such as in the East coast and highland areas of Madagascar, in the Sierra and Costa regions of Ecuador, and in the Petén region of Guatemala (n=4).

3.2 Frequency analysis of cause connections

The analysis of causality patterns falls into four parts: first, interlinkages between proximate causes only; second, interlinkages between underlying forces only; third, underlying forces driving proximate causes, and fourth, proximate factors having a feedback upon underlying forces.

3.2.1. Interlinkages between proximate causes

Proximate factor interlinkages are made up of factors that occur concomitantly (in 30% of the cases) or concomitantly together with chain-logically connected factors (in 59% of the cases). Pure chain-logical connection is low (6%). If causative (chain-logical) connections, inherent to altogether 65% of the cases, are broken down by their most simple form which is a tandem[5] or two-factor chain (e.g., expansion of road infrastructure causing agricultural expansion), a total of 120 causative factor interlinkages emerges at the broad aggregate level – see Table 17. Two main tandems relate to agriculture-driven deforestation: the expansion of infrastructure as a strong cause of agricultural expansion (and, to a far lesser degree, of wood extraction) in 37% of all cases, and wood extraction impacting upon agricultural expansion in 10% of all cases. These two main interlinkages at the proximate level are labelled infrastructure-agriculture tandem and logging-agriculture tandem in the following.

Table 17: Chain-logical connection of broad proximate causes (N=98)*

	Agricultural expansion	Wood extraction	Extension of infrastructure	Other factors[1]	Total row
Agricultural expansion	5	5	2	0	(12)
	3%	3%	1%	-	
Wood extraction	15	4	2	1	(22)
	10%	3%	1%	1%	
Extension of infrastructure	56	7	2	0	(65)
	37%	5%	1%	-	
Other factors[1]	12	2	1	6	(21)
	8%	1%	1%	4%	
Total column	(88)	(18)	(7)	(7)	(120)

* Row causes column; percentages relate to all cases of deforestation (N=152).
1 Land characteristiscs (or features of the biophysical environment), biophysical drivers, and social trigger events.

Infrastructure-agriculture tandem

The infrastructure-agriculture tandem explains more than one third of all cases of deforestation (37%), and is a robust linkage widespread across regional cases. In 90% of these cases, the extension of road networks caused the expansion of permanently cropped land – both for food and commercial crops – and pasture for cattle, resulting in deforestation. Considerably less shifting cultivation and colonization activities – except for spontaneous transmigration – are driven by road development. The tandem has been identified in 15 (out of 55) cases from six (out of 10) Asian countries and in 5 (out of 19)

cases from 4 (out of 19) African countries. It is most widespread in 36 (out of 78) cases from 9 (out of 11) countries in mainland South America (Mexico, Belize, Honduras, Costa Rica, Brazil, Ecuador, Colombia, Bolivia, Peru).

Logging-agriculture tandem

The logging-agriculture tandem explains merely 10% of all cases of deforestation. Except for two cases in Mexico (Yucatán) and Cameroon (East), the impact of wood extraction upon the expansion of agricultural activities is a phenomenon of predominantly Asian cases. These are cases from Indonesia (Java, Kalimantan/Borneo, Iran Jaya, East Timor), China (Yunnan, Heilongjiang, Sichuan, Hainan Island), and Thailand (central plains, northeastern part), as well as from upland Philippines and insular Malaysia. The leading specific cause in the Asian cases is uniformly reported to be commercial, chiefly state-run timber logging leading to the expansion of cropped land. In only half of these cases, logging induces shifting cultivation, and in all of these cases, no other proximate causes (not even road development) are reported to be important concomitant or causative factors associated with – what Angelsen (1995, p. 1718) called – the "logging-shifting cultivation tandem". Rather, logging-induced agricultural activities emerge as strongly driven by underlying social factors which, in most cases, are factors related to policy climate, namely, corruption, weak, low or no enforcement of forestry laws and rules, and conditions of general lawlessness.

3.2.2. Interlinkages between underlying causes

The interlinkages between underlying causes include factors that simply occur concomitantly (24% of all cases), or along with chain-logically connected factors (61%). Pure chain-logical connection of underlying factors (5%) as well as single factor causation (11%) is very low. Drawn from all cases, a total of 342 causative factor interlinkages was identified at the broad aggregate level, if causative connections in altogether 66% of the cases are broken down by their most simple form which is a two-factor chain or tandem[5] – see Table 18. With view on the main interlinkages, economic as well as policy and institutional factors appear to be strong drivers of all other underlying forces, while cultural, demographic and technological factors are less so. As a striking feature, some factors belonging to the same group of variables are reported to strongly impact upon each other, thus establishing – what can be called – internal driver qualities. Economic and policy/institutional factors, in particular, tend to be strongly interrelated.

Table 18: Chain-logical connection of broad underlying causes (N=152)*

	POP	ECON	TECH	INST	CULT	Total (row)
Demographic Factors (POP)	3	10	16	4	0	(33)
	2%	7%	11%	3%	-	
Economic Factors (ECON)	17	33	16	23	15	(104)
	11%	22%	11%	15%	10%	
Technological Factors (TECH)	17	5	12	5	4	(43)
	11%	3%	8%	3%	3%	
Policy & institutional Factors (INST)	13	12	29	38	9	(101)
	9%	8%	19%	25%	6%	
Cultural Factors (CULT)	4	9	19	23	6	(61)
	3%	6%	13%	15%	4%	
Total (column)	(54)	(69)	(92)	(93)	(34)	(342)

* Row causes column; percentages relate to all cases of deforestation (N=152).

Economy-driven tandems

Among economic factors, market growth/commercialisation, specific economic structures and variables are the most important and robust forces of tropical deforestation. They impact upon demographic, technological, policy/institutional and cultural (socio-political) factors in 10 to 15% of all cases each. Also, they turn out to be strongly interrelated, too, i.e., establishing cases in which multiple and interactive economic factors are at work in the form of internal drivers at varying scales (22%).

Internally driven economic tandems: The strong internal driver qualities of economic factors, eminent in more than one fifth of all cases (22%), do relate to the demand and supply (or production) side of market growth and commercialisation as related to increased income and raised standards of living or well-being. Both demand and supply vary considerably across spatial scales. The increases in demand for mainly wood-based and agricultural consumer goods (such as fuelwood, raw and sawn timber, furniture, food and cash crops) translates into the growth of the respective sectoral industries (such as timber and charcoal processing, food and non-food agricultural markets), finally leading to forest losses at the local level due to timber logging and land clearance for agriculture.

Concerning the local to global demand side, it is noteworthy, that wood-related demand in the African cases is reported to arise only at the local level (Ghana, Malawi, Congo-Zaire, Cameroon, Madagascar), while in cases from Asia and Latin America, especially the demand for timber originates at the national level mainly (occassionally even at the international level). In Latin American cases (from Mexico, Brazil, Honduras, Ecuador, and Costa Rica), demand for timber and agricultural products originates from local and national levels in about half of the cases each. Differently, demand in the Asian cases is reported to arise at all scales, including the international level (in cases from Indonesia, Malaysia, and Thailand, in particular).

Concerning the local to global supply side, production or sectoral industry growth associated with deforestation occurs at all scales, with strong regional variations though. In the African cases, more of the sectoral growth of wood-related and agricultural industries is located at the local level. In the Latin American cases, industry growth-driven deforestation, especially if it relates to the growth of cash crop produce and timber markets, originates from local and national levels. Differently, less than half of the Asian cases are driven by production for international cash crop and timber markets. Most of the industry growth impacting upon deforestation in these cases stems from the national level. World timber markets exert considerable impact, unmatched by cases from other regions.

Economy-policy/institution tandems: In 15% of all cases, economic factors are reported to induce policy and institutional factors becoming associated with deforestation, regardless of the region. Market growth and commercialisation (especially, the growth of sectoral industries) as well as various specific economic structures and variables are involved in next to all of the cases. Similarly, on the policy and institutional side, formal pro-deforestation policies (mainly on land matters), informal policies or policy climate (mainly poor performance and the operation of growth coalitions), and property rights (especially the creation of quasi-open access conditions) are equally involved. However, next to each case has a unique specific factor combination. For example, cases are reported from various logging sites in Pará State of the Brazilian Amazon where colonization (by slash-and-burn subsistence farmers and cattle ranchers) is driven by low prices for agricultural produce and by a booming logging sector (wood market). Colonists join growth coalitons of loggers, sales agents and sub-contractors. Thus, institutionally they become provider peasants in roadside frontier areas where - in the absence of high value species - selective, low-intensity logging contributes to most of deforestation in unclaimed areas. Other cases are similarly reported from rural Ghana and the Brazilian Amazon: economic dependence on revenues from natural resources, needs to generate foreign exchange earnings, and needs to escape national indebtedness (especially in periods of economic decline or recession), induce state policies and project planning in favour of export-oriented cash crop development. Partly associated with lending practices of international donours, such state policies promote the expansion of commercial smallholder and plantation agriculture resulting in deforestation.

Economy-demography tandems: In 11% of the cases, economic factors are reported to drive demographic factors being associated with deforestation. In specific, these are frontier cases from eight Latin American countries (Dominican Republic, Costa Rica, Honduras, Bolivia, Brazil, Peru, Colombia, Ecuador) where in-migration of colonizing settlers into forested areas – and, to a small degree only, associated with local growth and rising population density - is reported to contribute to deforestation. In particular, the growth of modern, mechanized cash crop agriculture for export - and the related decline of traditional smallholder farming, joblessness and rural poverty - are reported to operate as push factors of migration to the frontier. Only in the foothill and lowland zones of Bolivia and in the so-called Napo region of Peru, Colombia and Ecuador, international demand for cocain attracts migrants and leads to deforestation - however, to a lesser degree than pasture creation for ranching and other cropped land expansion. Additionally, some local industrial growth, such as oil exploration or commerical logging, are further reported to induce in-migration, as are low land prices, in particular.

Economy-technology tandems: In 11% of the cases, economic factors are reported to drive technological factors associated with deforestation. In these cases, the need for foreign exchange earnings and the growth of sectoral, especially agriculture-related industries – rather independent from demand - are the main underlying economic processes accounting for three quarters of these cases. Neither specific economic structures nor special economic variables are involved in a significant manner. These economic forces establish causative factors for agrotechnological change, finally ending up in deforestation: land-use intensification and modifications of farming systems. The latter mainly imply the creation of large, consolidated holdings, partly together with the shift from small, traditional family farms to large, modern and mechanized agricultural enterprises. About half of these cases are reported from the local level, while another half of the cases originates at the national level, thus, indirectly causing deprived small farmers to migrate to the frontier. Purely market-driven cases guiding agro-technological change are reported from various regions such as mainland South America (Mexico, Honduras, and Bolivia – but not the Brazilian Amazon) and Africa (Cameroon, Congo-Zaire, Madagascar). In Asia, only one case is reported from the Middle Mountain Zone of Nepal. Cases which are driven by the need to capture foreign exchange earnings stem from Malaysia (Borneo), Cameroon, Bolivia, Mexico and Honduras – but not the Brazilian Amazon or Indonesia, for example.

Economy-culture tandems: In 10% of the cases, economic factors reportedly underlie cultural or socio-political factors being associated with deforestation. Different from other interlinkages, a highly complex picture emerges. On the one hand, economic factors comprise demand-driven industry growth (timber, agriculture) as well as rapid (and uneven) economic growth, increased market accessibility (especially of urban markets), urbanization, the hunt for foreign exchange earnings, and specific economic structures (large, individual gains, in particular) as well as special economic factors (price decreases and increases). On the other hand, almost all categories of cultural or socio-political factors are involved: all variants of public attitudes, unconcerns or disregards, beliefs and individual or household behaviour – except for non-profit oriented behaviour. Thus, each of these cases from Thailand, Philippines, Indonesia, Kenya, Cameroon, Congo-Zaire, Honduras and Brazil has ist own and very specific type of interlinkage, and no generalisations are possible.

Policy- and institution-driven tandems

Less than economic factors, policy and institutional factors such as formal, pro-deforestation policies, government failures and property rights arrangements impact mainly upon technological factors (in 19% of all cases) and, more so, have strong internal driver qualities (in 25% of all cases). All of these cases are regionally widespread. In one quarter of all cases, policy and institutional factors impact each other, particularly in Asia and Latin America. A closer look at Asian and Latin American cases shows that internal policy and institutional drivers, i.e., multiple and interactive policy and institutional factors, operate in a fairly comparable manner.

Internally driven policy/institution tandems (Asian cases): Variables involved in almost all Asian cases, driven by internal policy/institution tandems, are formal policies and property rights regimes, but less so informal policies (or policy climate). In specific, these are state policies on economic and land development, on finance, trade, investment (and the

like), insecure ownership and quasi open access conditions. Cases of quasi open access relate to the squatting of public forest land by locals or in-migrants which can directly be enhanced through the distribution of forest land to marginal people or unclear delineation of the forest/agriculture boundary (as in several cases from Thailand). It can indirectly be triggered or amplified through land claims by the state for commercial plantations, protected areas and state-run logging which undermines local customary rights and fosters, in reverse, the individual appropriation of, for example, public forest land (as in the case of Malaysian Borneo). The establishment of colonization settlements is another causative factor associated with state policies. It can directly, and in a planned manner, be driven by the implementation of agrarian reforms (such as in south Sumatra) or by the implementation of national development plans and by the state's encouragement for intensive agriculture through extension services (such as on peninsular Malaysia). It can also indirectly be driven by the state's incapacity to control public forest land and, thus, enhance spontaneous colonization (such as in upland Philippines). Land races, or races for property rights, occur in several cases reported from Indonesia (Sumatra, West Kalimantan) where institutionalized logging, state claims of forest plantations and large-scale funding of transmigration combine with property right changes such as shifts from traditional law to individual rights or legalization of unofficial land titles which triggers off races for property rights resulting in deforestation. Other cases of internally driven policy and institutional factors relate to commercial wood extraction, such as reported from Indonesia and Malaysia: international timber market arrangements and national protective economic measures push rapid domestic, forest based industrialization which easily leads to conditons of insecure ownership and quasi open access.

Internally driven policy/institution tandems (Latin American cases): Variables involved in the Latin American cases, driven by internal policy/institution tandems, are formal policies (especially on taxation, credits, subsidies, land and economic development), property right issues (especially titling), and – by far stronger than in Asian cases – informal policies (or policy climate) such as weak law enforcement, poor performance and mismanagement. Both poor control or weak monitoring of forests and redefinition of state policies on forests impact upon each other and result in uncontrolled wood extraction and agricultural expansion. While this is particularly widespread in periods of uncertain market/policy conditions such as in the Chiapas highlands of Mexico, national development planning (such as in other parts of Mexico) or agrarian reforms (as in Bolvia) enhance the promotion of export-oriented commodity production and liberalized land markets which is linked to increasingly individualized land titles, all reportedly associated with deforestation. There are even cases in which specific policy measures, originally designed to control deforestation (such as bans on logging concessions), turn into the reverse and foster policy coalitions of loggers and colonizers driving deforestation, as reported from several cases in Ecuador (and some cases in Asia, too). Marginality in terms of low institutional empowerment underlies some cases of colonization settlement in the Brazilian Amazon (as well as one case from Madagascar), while other processes of colonization are driven by state regulations in favour of large, individual holdings that implies low charges and taxes for land use. Only in few cases are international policy measures such as Structural Adjustment Programmes reported to bear the consequence that

changes in agricultural policies (such as the removal of price control, currency devaluation and fiscal incentives for export commodity production) underlie deforestation – what is also reported from one case in Ghana and, slightly different, in Cameroon.

Policy/institution-technology tandems: In about one fifth of all cases, policy and institutional factors are reported to drive technological factors resulting in deforestation. About one third of these cases are characterized by policy measures that are directed towards commercial logging and invariably imply the use of chainsaws and/or heavy equipment such as tractors, trucks and bulldozers. Even among growth coalitions of loggers and local farmers, the application of chainsaws instead of axes, in particular by local users, reportedly drives deforestation. Another variant of this interlinkage is poor performance and wastage in timber processing that indirectly fuels logging, with both activities being driven by pro-logging government policies. Similary, policy measures which explicitly address the expansion of modern mechanized, capital-intensive farming – through agricultural extension services or by means of agrarian reforms – are reported to imply the creation of large holdings, partly enhanced by lack of control over state forest patrimony. Government subsidies, fiscal incentives and encouragement through rural extension agents for more intensified production, often in combination with insecure land tenure arrangments, are reported to drive a shift from low-intensity modes of production to, for example, fallow reduction, the increased use of new crop rotations and agro-technological inputs.

Culture-driven tandems

Only two tandems, driven by cultural or socio-political factors, are noteworthy to report. In 15% of all cases, cultural factors have a causative connection to policy and institutional forces, especially state policies on land-use, policy failures (such as corruption and poor state performance), and marginality (i.e., low institutional empowerment). In 13% of all cases, socio-political factors are reported to shape technological factors to result in deforestation, what tends to be a special feature of cases reported only from a limited number of Asian countries.

Culture-institution tandems: Cultural factors underlie policy and institutional factors in 15% of all cases. Public attitudes and behavioural aspects - but not values – are involved in about half of these cases. In specific, cultural driving forces are the lack of support for forest protection (or sustainable use) such as low morale of government employees (in the forestry sector), dominant frontier mentalities and prevailing attitudes of modernization and economic growth (public attitudes). Further, individual and household behaviour are associated with policy and institutional arrangements driving deforestation in about half of the cases. Chiefly, this is profit-oriented behaviour besides the unconcern by individuals about the environment, commonly associated with increased income. Such cases appear to be widespread among all regions, but tend to originate from Asia mainly. They relate to unsustainable logging practices which appear to be symptoms only of deeper rooted problems such as corruption and greed (*cf* Vanclay 1993), but can also be related to broader ideologies. In several cases, for example from post-1950 China, it is reported that logging (and black marketeering of wood) on a large-scale are driven, among others, by the needs of a rapidly industrializing society to make the country compatible with – or even catch up with the economic development level of – others (The Great Leap Forward). The respective impact on forestry policies was that law enforcement was weak and almost no sanctions applied. Comparatively, much of

institutionalized logging – such as in the Chiapas highlands of Mexico or in upland Phillipines (under Marcos) – tends to be driven by the ideology that forest conversion is the best way to promote national or regional economic growth, or to privately capture excessive economic surplus not reinvested in social or economic structures. The concept of forest frontiers – i.e., frontiers that work as escape velvet for the remedy of social conflicts and for the sake of national integration, defense, unity and security – bears manyfold policy and institutional implications reported to be associated with agriculture-related deforestation in Indonesian Sumatra as well as in the Brazilian Amazon: establishment of colonization settlements, weak or no control of the forest patrimony, and titling (i.e., consolidation of individual land rights) giving birth to speculative deforestation. Profit-oriented individual behaviour as well as public beliefs (e.g., forest resources are "free goods") drive state land claims for plantations as well as the expansion of commercially cropped land by smallholders in various cases. Minor variants of the culture-institution interlinkage are cases where state bias against indigenous hillside people promotes policies of military attack, violent expulsion and the establishment of defense villages, penal settlements or other colonization activities by migrants from low-lying areas (mainly reported from the Outer islands of Indonesia). Other variants include the desire for agricultural modernization and raised living standards that leads governments, especially their Agricultural Departments, to provide subsidies, fiscal tax incentives, and especially rural extension service for the promotion of intensive, export-oriented cash crop agriculture.

Culture-technology tandem: The culture-technology tandem occurs in 13% of all cases which next to all originate from three countries in Asia (Thailand, China, Indonesia). In particular, the unconcern about the welfare of others and future generations are related to certain agro-technological production factors. From West Kalimantan, both growing aspirations and demands ("wish to live better") at the local level in combination with growing needs of goods and services procured with cash (including the need of foreign exchange and state revenues at the national level) are reported to transform shifting cultivators into commercial crop producers. Farmers reportedly eliminate fallows for tree crops and expand rice into forests. This occurs against the background that selective loggers and industrial timber plantation forestry induce competition for land, since the Indonesian law states that unmananged fallows are not in use and may thus be expropriated ("claim land by planting rubber"). In various cases from Thailand it is reported that low or no recognition of customary rights from outsiders (loggers, creditors, speculators) causes division of landholdings and accumulation of land by a minority, while attitudes by locals prevail such as: "Why not cut down trees ourselves, when those capitalists from town will definitely do that?". Several cases from China are reported where the overarching concept of the Cultural Revolution (The Great Leap Forward) through rapid industrialization, led to the application of several inappropriate technologies such as charcoal burning in primitive furnaces for the production of pig iron.

Land-migration tandem

The land-migration tandem, actually, is a specific variant of the broader technology-demography interlinkage. In 11% of all cases, technological factors – especially agricultural production factors related to land and the modification of farming systems – reportedly cause in-migration associated with deforestation. Most of these cases (i.e., 13

out of 17) are located in Latin America where they mainly concentrate in various lowlying, humid frontier areas of the Amazon Basin of Brazil, Peru, Ecuador, and Colombia. In specific, the availability of land or soils for agricultural production emerges as the main agro-technological driver. There are indications that, outside the areas affected by deforestation, landlessness or growing land scarcity on customary land push small, deprived farmers or landless workers to the forest frontier, for example, from the Andean highlands, from drought-stricken Northeast Brazil, or from areas of modern mechanized production such as in the south of Brazil. This correlates with land availability at the frontier which is the main pull factor of in-migration in these cases. This further correlates with changes of farming systems, which - rather than population growth - cause land scarcity or landlessness outside the case study areas. Shifts from labour- to capital-intensive farming and the creation of large consolidated holdings induce land division, i.e., the creation of very small (poor) landholdings. The land-migration tandem, and some minor variants of it, operate most frrequently in Latin American cases especially of the Amazon lowland frontier. To a far lesser degree, the tandem also occurs in cases of deforestation which are reported from upland Philippines, from peripheral Sangthong District in Northern Laos, from the surroundings of Blantyre town in southern Malawi, and from the Ndelele area in East Cameroon.

Population growth-intensification tandem

The population growth-intensification tandem is a specific variant of the demography-technology interlinkage. In another 11% of all cases, demographic factors – mainly high local population growth and increasing population densities due to in-migration – are reported to impact upon technological factors – mainly land-use intensification and modification of farming systems –, being associated with deforestation. Cases are regionally widespread, but primarily found in Asia (East Kalimantan, Middle Mountains and Siwalik Hills of Nepal, Yunnan highlands in China, various highland, midland and foothill sites in Vietnam) and in Africa (various sites in north and south central Ghana, Mwanza District of southern Malawi, southwestern Madagascar). Except for the Ecuadorian Costa and Indonesian Kalimantan case, growth-driven intensification leading to deforestation is a characteristic feature of upland or foothill zones, even in the case of Latin America (Cordillera Central of the Dominican Republic). Different from the land-migration tandem, which underlies deforestation cases in the Amazon Basin, population growth-driven cases resulting in intensification and leading to deforestation are not reported from the Amazon Basin at all. More so, they are a feature of mainly food cropping areas outside colonization frontiers. The main process is reported as follows: increasing population densities lead to situations of reduced per capita land area in which the main reaction of local farmers is to reduce fallow land. In cases where density values were specified, they increased from 45 to 61 and 88 inhabitants per km^2 over time. The main driver behind rising densities was high population growth (up to 5.2%), mainly driven by in-migration (as compared to all other cases in which population growth ranks between 1.8 and 2.8% annually). Decreases in fallow go hand in hand with in-migration, ending up in land clearance through deforestation. In about one third of the cases, division of landholdings occurs, which means the transformation of farm land into increasingly smaller units.

3.2.3 Underlying forces driving proximate causes

Chain-logical connection pervades the causative pattern of all interlinkages between the proximate and underlying levels, i.e., one or more underlying factors driving one or more proximate causes (interlinkages in the form of feedbacks from the proximate level upon underlying forces are considered later). Again, interlinkages are considered as broken down by simple two-factor relations (tandems).[5] When relating all underlying forces to proximate causes as reported in the cases studies, a total of 683 interlinkages emerges. This implies that, on average, each case of tropical deforestation is driven by 4 to 5 tandems – see Table 19.

Table 19: Chain-logical connection of broad underlying causes driving broad proximate factors*

	Agricultural expansion	Wood extraction	Extension of infrastructure	Other factors[1]	Total row
Policy and institutional factors	98	62	29	6	(195)
	65%	41%	19%	4%	
Economic factors	58	63	33	3	(157)
	38%	41%	22%	2%	
Cultural factors	62	48	22	0	(132)
	41%	32%	15%	-	
Technological factors	65	42	3	3	(113)
	43%	28%	2%	2%	
Demographic factors	72	9	4	1	(86)
	47%	6%	3%	1%	
Total column	(355)	(224)	(91)	(13)	(683)

* Row drives column; percentages relate to all cases of deforestation (N=152).

1 Land characteristics (features of the biophysical environment), biophysical drivers, and social trigger events.

In the order of decreasing importance, policy and institutional factors exert the highest impact upon the proximate level. They drive, in particular, agricultural expansion (in 65% of all cases), wood extraction (41%), and the expansion of infrastructure (19%). Similarly, economic and cultural (or socio-political) factors underlie agricultural expansion (in 38 and 41% of the cases, respectively), wood extraction (41 and 32%, respectively), and the expansion of infrastructure (22 and 15%, respectively). To a lesser degree, technological factors exert impact upon proximate causes, especially agricultural expansion (in 43% of all cases) and wood extraction (28%). Human population dynamics drives only agricultural expansion to an extent worth to be considered (in 47% of all cases). The most important specific chain-logical cause connections between the underlying and proximate levels are described in the following in more detail.

Policy and institutional factors driving agricultural expansion, wood extraction and road extension

Policy and institutional factors – such as formal state policies, informal policies (policy climate) or land tenure arrangements – exert by far the strongest impact upon proximate causes, however, to varying degrees (consider that economic factors dominate the overall frequency of occurrence of causes, including single and concominant factors, but that policy and institutional factors dominate the causative pattern or chain logics of proximate/underlying interlinkages).[8] More cases of agricultural expansion turn out to be driven by broadly defined policy and institutional factors (65%) than cases of wood extraction (41%) or expansion of infrastructure – *cf* Table 19.

Institution-driven agricultural expansion: About two thirds of all cases (65%) are agriculture-driven and underlain by policy and institutional factors. In specific, these are mainly state policies on land and economic development, and – to a lesser degree – uncertain property right arrangements. With a view on specific agricultural activities, not so much permanent cultivation by smallholder subsistence farmers but more so commercial cropping, shifting cultivation, cattle ranching and agricultural colonization are shaped by policy and institutional factors. In commercial cropping, pro-deforestation policies – especially, low taxation, favourable credits, and land development for export crops – turn out to be most important. These formal policies are more significant than informal policies or policy climate (i.e., no impact of corruption, low clientelism, etc.). About half of the institution-driven cases of commercial land expansion are reportedly associated with land tenure arrangements. Here, the main specific drivers are low institutional empowerment of (marginal, socially deprived) local users – who are eager, but hardly entitled to enter the formal cash crop sector –, and the impact of legal titling procedures that allow the individual appropriation of land which has formerly been under traditional law and has now become devoted to cash crops. It seems noteworthy, though, that land races, quasi open access conditions and malfunct customary rights do not emerge as essential for the expansion of commercially cropped areas, finally associated with deforestation.

In shifting cultivation, mainly formal government policies on land and economic development – such as the distribution of public forest land to settlers, planned colonization, agrarian reforms, and liberalization of land markets – are associated with about half of the cases. Here, policy and institutional arrangements underlie cases of predominantly colonist shifting cultivation. Land tenure uncertainties underlie another half of mainly tradtional shifting cultivation cases. The specific drivers in the latter situation are destabilized indigenous property right institutions which are related to the marginal, weakly empowered position of local swidden farmers, and quasi-open access conditions that have been created externally through the intrusion of outsiders (creditors, loggers, farmers, landless settlers). Conditions of insecure ownership and the widespread shift from traditional to individual law – rather than malfunct indigenous customary rights per se – are reported to underlie these cases of deforestation. Among informal policies or policy climate, only poor performance of forestry rules and laws is noteworthy to report as a specific cause that further leads shifting cultivation to contribute to deforestation.

In cattle ranching, as it is in the cases of commercial cropping, the most important specific drivers turn out to be formal pro-deforestation policies of the state, e.g., credits, subsidies, low taxation, economic development funding, and land development for

pasture creation. In contrast, informal policies or policy climate – with the exception, probably, of poor forestry management – do not impact upon pasture-driven deforestation in a significant manner. The same is true for land tenure arrangements since neither insecure ownership nor quasi open access conditions are reported as being essential for cattle-driven deforestation.

In agricultural colonization (settlement, transmigration), formal state policies clearly dominate next to all of these cases. In particular, policies (and projects) on land and economic development are reported to be among the most important specific drivers. These could be state decisions to open up the agricultural frontier in low populated and heavy forested hinterlands, or public decisions to distribute forest patrimony to marginalized settlers. A special feature of only the Asian cases is the establishment of state agricultural and forestry plantations reportedly associated with deforestation. Differently, land policies prevail in the Latin American cases where measures are directed towards deregulation of land access, easy transfers from public forest land to private holdings, and state regulations in favour of large, individual holdings. Further contributing to deforestation through colonization are specific measures of economic and development policies: national and regional development plans and specific growth-oriented policy measures on infrastructure, timber and cash crop development. The latter were occasionally promoted by international agencies and translated into national laws, regional programmes and local projects. Policy and institutional uncertainties as related to land tenure – e.g., insecure ownership, land race conditions and quasi open access situations – are involved in about one fifth of these cases. Thus, they are not as dominant for agricultural colonization as are formal state policies.

Policy/institution-driven wood extraction: Policy and institutional factors underlie 41% of all cases in which wood extraction is reported to be a proximate cause of deforestation, among others. From the various types of wood extraction associated with deforestation, more cases of commercial wood extraction are reported to be driven by instutional factors (four fifths) than are cases of fuel- and polewood harvesting for domestic and industrial uses (about one third). Formal state policies, government failures and land tenure arrangements are involved to varying degrees.

In commercial timber logging, the underlying policy and institutional factors vary according to the specific commercial activities carried out. Cases of state-run logging associated with deforestation, mainly located in Asia, are nearly all driven by the liberal granting of state concessions, donour-driven projects, and state claims for logging areas. This means that formal pro-deforestation policies are decisive (institutionalized logging). Among government failures, corruption as a form of bureaucratic capitalism and poor, weak or no performance of forestry rules pervade about two thirds of these cases (while property right institutions do not matter in state-run logging). Private commercial logging activities are similarly underlain by formal policies such as the liberal granting of concessions, low stumpage charges, fees, taxes (for forest use), and tariff exemption for the import of capital-intensive (heavy) logging equipment. Formal policies underlying logging-caused deforestation are further reported to include national and donour policies on land and economic policies, in which timber development is promoted as prominent free enterprise development. Informal policies or policy climate such as growth coalitions between loggers, mill agents and local farmers occur in next to all of the private-run cases.

More than half of them are further associated with client-patron networks and weak or no enforcement of forestry laws (while the impact of corruption is reportedly low). Different from private and government logging, more than half of the cases of illicit or undeclared commercial logging are related to global policy and institutional factors: Structural Adjustment Programmes which tend to generate undeclared timber logging for the generation of revenues, and global trade restrictions (or timber import barriers in developed nations). The latter factor, in specific, is the tariff escalation between raw log and processed timber products blocking efficient forest-based industrialisation (in cases reported from Malaysia and Indonesia, only). About one third of the cases of illicit commercial logging is reportedly related to patron-client relations (clientelism), weak forestry law enforcement and land policies creating quasi-open access conditions.

Cases in which the extraction of fuelwood and polewood for domestic uses is reportedly associated with deforestation are underlain by both formal policies (for example, low collection fees), policy climate (poor law enforcement, no or weak monitoring, no or weak sanctioning, corruption), and property right aspects (quasi open acess, marginality of local users, malfunct customary rights). In cases of industrial uses for both rural and urban enterprises, formal as well as informal policy measures which promote unsustainable wood harvesting are involved. However, the main specific underlying processes are reported to be patron-client relations and growth coalitions operating and driving deforestation in various cases from Africa (rural Ghana, Malawi, Nigeria, Madagascar), Asia (Nepal, Philippines, Malaysia, Indonesia), and Latin America (Brazil, Honduras, Costa Rica).

Institution-driven infrastructure extension: Cases which are caused, among other proximate factors, by the expansion of infrastructure (mainly roads) and underlain by policy and institutional factors occur in 19% of all cases of deforestation. No impact of policy climate and, in only one third of these cases, property right arrangements – such as quasi-open access conditions and low empowerment of local users – are associated with road extension, but more so formal (pro-deforestation) policies that are directed towards economic growth, modernization and development (especially of the infrastructure and agriculture sector). In less than half of these policy-driven cases, the infrastructure-agriculture tandem is a strong driver at the proximate level. This is especially true for South American cases of frontier colonization (Bolivia, Brazil, Peru) and for some Asian cases (Laos, Indonesia, Thailand), but less so for African cases (Cameroon, only). No significant pattern emerges besides the ones already explored – *cf* subchapters 3.1.1 (infrastructure extension), 3.1.2 (policy and institutional factors), 3.2.1 (infrastructure/agriculture tandem), and 3.2.2 (institution-driven tandems).

Economic factors driving wood extraction, agricultural expansion, and road extension

Various economic factors such as market growth/commercialisation, urbanization/industrialisation, specific economic structures and some special economic variables are reported to underlie agricultural expansion (in 38% of all cases) and wood extraction (in 41% of all cases). To a far lesser degree, they are causative for the expansion of infrastructure (22%), and other factors (2%) – *cf* Table 19.

Economy-driven wood extraction: About two fifths of all cases (41%) are caused by several variants of wood extraction as underlain by economic factors. Mainly, these are demand-driven growth of wood-related industries, and industrialization (in tropical countries). In

12 out of 63 cases, the growth of wood markets and timber industries is related to forest-based national, regional and local industrialisation. Except for a single case from Africa (Ghana), the built-up of new basic and heavy industries on the basis of domestic forest resources appears to be a special feature of Asian cases only, i.e., cases from emerging market economies or NICs (Newly Industrializing Countries) such as China, Indonesia, Malaysia, and Thailand. Other cases of economy-driven wood extraction show various underlying factor combinations and tend to be widespread among the continents, with Asia, however, concentrating half of all cases – *cf* subchapters 3.1.1 (wood extraction), 3.1.2 (economic factors), and 3.2.2 (economy-driven tandems).

Economy-driven agricultural expansion: Another two fifths of all cases (38%) are caused by the expansion of cropped land and pasture as underlain by economic factors, mainly demand-driven growth of agriculture-related industries and lucrative foreign exchange earnings gained from agricultural production on formerly forested land. Cases tend to be robust in terms of regional variations. No significant pattern emerges besides the ones already explored – *cf* subchapters 3.1.1 (agricultural expansion), 3.1.2 (economic factors), and 3.2.2 (economy-driven tandems).

Economy-driven infrastructure extension: Slightly more than one fifth of all cases of deforestation (22%) are caused – among other proximate impacts – by the extension of infrastructure as underlain by economic factors. The latter are reported to be mainly rapid (and partly uneven) economic growth, urbanisation and industrialisation (neither specific economic structures nor certain economic variables appear to be important). In two thirds of these cases, the infrastructure-agriculture tandem is a strong causative factor at the proximate level. Almost three quarters of all road-driven deforestation, as related to economic driving forces, originate from cases in mainland South America (Costa Rica, Guatemala, Ecuador, Peru, Colombia, Brazil). No significant pattern emerges besides the ones already explored – *cf* subchapters 3.1.1 (infrastructure extension), 3.1.2 (economic factors), 3.2.1 (infrastructure-agriculture tandem), and 3.2.2 (economy-driven tandems).

Cultural factors driving agricultural expansion, wood extraction and road extension

Cultural (or socio-political factors) such as attitudes, values, beliefs and behaviour underlie agricultural expansion in 41%, wood extraction in 32%, and the expansion of infrastructure in 15% of all cases – *cf* Table 19.

Culture-driven agricultural expansion: Cultural factors such as public attitudes, values, beliefs and individual and household behaviour, reportedly associated with agriculture-driven deforestation, are broken down in the following by specific agricultural activities.

In cases of traditional shifting cultivation (n=18), most of them originate from Asia and are associated with wood extraction, too. Various cultural factors are involved, and hardly any generalisation appears – besides the two following. First, the national perception of forests as "free source" or "free good", and imitating behaviours by locals ("follow others", especially loggers and in-migrants) are reported to be associated with one third of these cases. Second, stronger drivers than in other cases are the wish to live better, to establish an own family and independent livelihood, and rationale responses to the increased profitability of growing cash crops.

Cases of colonist shifting cultivation (n=14) are driven by varying socio-political factors that hardly allow for broad generalisations, besides the following: national concepts of frontier colonization and low morale of local government employees to adequately protect forests go hand in hand with about half of these cases.

Cases of permanent food cropping by smallholders mainly for subsistence (n=20) are similarly shaped by complex cultural factors. Very weak to no impact at all originates from certain public attitudes such as colonizing the frontier and national desires for modern agricultural development. Instead, lack of public or political support for forest conservation and the farmers' personal wish to live better (growing aspirations and demands) tends to be more widespread in these cases as compared to others.

Cases of permanent commercial cropping (n=15), driven by complex underlying cultural factors, are – more strongly than other cases – associated with the view upon forests as "free goods" and public attitudes of frontier colonization. Further noteworthy are the desire for modern agricultural development, mostly located among (inter)national development planning agencies, and the nation-wide as well as local belief that forest conversion is the best way to promote economic growth and meet local human needs.

Cases of pasture creation for cattle ranching (n=35) are predominantly driven by the profit-oriented behaviour of actors (in about two thirds of these cases). The latter are not only local cattle ranchers but also outside, town-based creditors or absentee owners. Rent-seeking behaviour as such – besides simple short-term rent-seeking through overexploitation of forest and land resources – implies unproductive profit-seeking behaviour. This means that cattle land is taken for land speculation: "improvements" for pasture (such as the establishment of watering points and fences) are done to add value to land, to raise land prices, and sell off land if appropriate. Thus, behaviour-driven cattle ranching is the most pronounced type of what Hecht (1993) has called "speculative deforestation".

Cases of spontaneous transmigration, probably the most important form of colonization (n=15), are not driven at all by public attitudes or values directed towards agricultural modernization or even frontier colonization. Rather, beliefs about how environmental conditions may affect those things that individuals value are reported to underlie more than two thirds of these cases ("follow, imitate others", view forests as "free goods"). Similarly, cases of spontaneous transmigration are not driven by profit-oriented behaviour or general unconcern by individuals about the environment. Rather, situation-specific behaviour in the form of imitation underlies about two thirds of the cases.

Cases of agricultural colonization (n=34) – other than spontaneous transmigration – emerge as strongly driven by public notions of frontier settlement, unconcerns or disregards, and rent-seeking behaviour. While profit-oriented behaviour clearly appears only in cases of cattle-driven colonization, state notions of opening the frontier and lacking basic values tend to be inherent to all other forms of colonization. Clearly, state decisions to open up the frontier guide most of agricultural colonization (besides few cases of colonization motivated by military strategic goals). Colonization has to be seen against a cultural or socio-political background (frontier mentality) such as: human frontiers can be established though road construction; frontiers serve to stimulate export commodity production; frontiers can be used as an escape velvet (to remedy national conflicts of rapid, uneven

growth, social injustice, marginality, etc.); frontier colonization is good for national security, territorial sovereignity, military security, unity and defense. Among values (or disregards), the most prominent disregards are views upon forests as a free source for quick cash and views upon land as sources for indirectly profit-seeking activities (i.e., land speculation rather than productive land-uses). Almost all value-based colonizing activities relate to pasture creation for cattle ranching. Other value-oriented disregards, that are noteworthy to report, comprise cultural biases against indigenous hillside people and low (or no) recognition of customary rights by outsiders (loggers, creditors).

Culture-driven wood extraction: Cultural factors are reported to underlie, among other causes, wood extraction in 32% of all cases. These are, in particular, public attitudes of unconcern towards forest protection and sustainable use, low morale of government officials (in the forestry sector), and low formal education or lacking knowledge of predominantly local users. Value-based factors underlie three fifths of these cases. They emanate from the national level as well as from the local level. At the state level, a widespread value, set by policymakers, is that economic growth, especially to catch up with modern sector developments, has to be higher valued than conservation ethics or sustainable uses in forestry. At the local level, a widespread, value-led behaviour is that legal procedures (for example, of forest product harvesting and recognition of protected areas) are not well recognized by local people. Also, private capture of economic surplus is reported as a value-led behaviour of especially ruling elites in illicit logging (through patron-client networks and growth coalitions). Public attitudes and value-based factors often go hand in hand with rent-seeking behaviour in about three fifths of the cases. In two fifths of the cases, traditional and imitating behaviour are reported to underlie wood extraction. This relates both to state- or private-run logging companies that continue a colonial mode of forest resource extraction (overexploitation), and to local people copying or imitating logging activities as shown by outsiders (i.e., felling trees and selling wood to outside loggers or agents).

Culture-driven extension of road infrastructure: The expansion of infrastructure, mainly road extension, is underlain by socio-political factors in 15% of all cases. Different from culture-driven agricultural expansion or wood extraction, the factors clearly point to public attitudes among which lacking support for forest protection is most frequent: state mentalities of forested hinterland colonization and attitudes of modernization, development and nation-building clearly dominate over conservation ethics or sustainable forest uses. In specific, culture-driven road extension implies that the transport infrastructure is seen as the main means for establishing human frontiers (as in the case of colonizing the Ecuadorian Oriente), and that political stability is seen to be restored through infrastructure development rather than through human or social development (as in the case of colonizing the Bolivian lowlands). As a typical feature of socio-political factors underlying road extension as a proximate cause of deforestation, most of these cases are found in Latin America – *cf* subchapter 3.1.1 (infrastructure extension).

Technological factors driving agricultural expansion and wood extraction

Technological factors are, among other underlying forces, reported to be associated with deforestation in 43% of all cases where agricultural expansion has been specified as a proximate cause, and in 28% of all cases where wood extraction is a proximate cause of deforestation – *cf* Table 9. Cases of agricultural expansion as driven by agro-techno-

logical change or agricultural production factors have been reported elsewhere, as it is with cases of wood extraction that are reportedly driven by technological applications in the logging, wood processing and, even, consumption sector – *cf* subchapter 3.1.2 (technological factors).

Population-driven agricultural expansion

Human population dynamics is reported to directly underlie the expansion of cropped land and pasture in about half (47%) of all cases – *cf* Table 19. It appears that no single demographic factor drives any of the agricultural activities resulting in deforestation alone. Rather, population dynamics operates in concomitant occurrence (57% of all population-driven cases) or in a causative connection with other underlying forces (33% of all population-driven cases). All agricultural activities which were identified as proximate causes of deforestation are invariably underlain by population dynamics in half of these cases. Invariably, in most of these cases, in-migration and, to a lesser degree only, growing population densities (due to high population growth) drive the expansion of cropped land and pasture.

With a view on the population-driven expansion of permanently cropped land, more cases of subsistence farming in Africa tend to be driven by in-migration and local population growth than cases in other regions (various sites in East Cameroon and Madagascar, southern Malawi, and in the Fouta Djallon Highlands of Guinea). One tenth of the population-driven cases of agricultural expansion only are associated with land-use intensification, mainly in Asian and African highlands, midlands, and foothill zones, but not at all in lowlying, humid frontier areas of the Amazon Basin - *cf* subchapter 3.2.2 (population growth-intensification tandem).

Half of the pasture-driven cases of deforestation, 32 out of 35 of them being located in mainland South America, are reported to be mainly underlain by in-migration. Similarly, agricultural colonization is in half of all cases driven by population movements to the frontier, though some regional variations appear. Only a minority of the Asian cases has been related to demography (but even more so to economic and policy/institutional factors) while, especially in the Latin American cases, in-migration is the major driving force of colonization. This holds especially true for the spontaneous settlement of humid, lowlying areas in mainland South America where 9 out of 14 reported cases were located.

As a remarkable and important feature, all types of shifting cultivation – i.e., indigenous swidden-fallow farming (traditional mode) as well as slash-and-burn agriculture by migrant settlers (colonist mode) – turn out to driven by in-migration rather than by fertility increases. Except for one case of deforestation in the Eastern Hill Region of Nepal (driven by growing population density and overall growth), colonist shifting cultivation turns out to be driven by in-migration, and seems to be a phenomenon of especially humid lowland areas in Latin American frontier regions (where 13 out of 18 of these cases have been found). Also, in almost all cases of traditional shifting cultivation, mainly reported from Asia and Africa, in-migration (partly in combination with national population growth that works as a push factor for (impoverished) migrant settlers) turns out to be the major driving force associated with deforestation. There are only two out of 26

cases of traditional shifting cultivation in which either natural increment (Western Samoa Islands) or high poulation densities (Eastern Rainforest zone of Madagascar) are reported to underlie deforestation.

3.2.4. Feedbacks of proximate upon underlying causes

As a striking feature of the interlinkages between the proximate and underlying levels, feedbacks from the proximate level upon underlying causes do reportedly occur in 43 out of 152 (or in 28% of all) cases – see Table 20.

Table 20: Chain-logical connection of broad proximate causes having a feedback upon broad underlying factors*

	Demographic factors	Economic factors	Technological factors	Policy/ institutional factors	Cultural factors	row
Agricultural expansion	0	0	1	1	1	(3)
	-	-	1%	1%	1%	
Infrastructure extension	9	18	1	1	3	(32)
	6%	12%	1%	1%	2%	
Wood extraction	3	0	0	1	3	(7)
	2%	-	-	1%	2%	
Other factors[1]	8	4	3	7	6	(28)
	5%	3%	2%	5%	4%	
Column	(20)	(22)	(5)	(10)	(13)	(70)

*Row drives column; percentages relate to all cases of deforestation (N=152).
1 Pre-disposing environmental factors (or land characteristics), biophysical drivers (or triggers), and social trigger events.

Each of the proximate factors – i.e., agricultural expansion, wood extraction, infrastructure extension and other factors associated with deforestatoin (land characteristics, biophysical drivers, social trigger events) – having a feedback upon the underlying level, exerts impact on at least two of the underlying forces. If causative connections are broken down by their most simple form (tandem), a total of 70 interlinkages emerges. However, noteworthy in terms of quantification is only the feedback from infrastructure (mainly road extension) upon underlying economic factors. Since only tandems were analysed, the reality of feedbacks from the proximate upon the underlying level might be more complex than found here.

Infrastructure(road)-market tandem

In 18 out of 152 (or 12% of all) cases, the expansion of infrastructure, i.e. road extension mostly in combination with market and settlement expansion, has a feedback upon or affects economic factors such as market growth and commercialisation, thus accentuating deforestation. Cases which are driven purely by the road-market tandem (n=5) can be separated from other cases (n=13).

In five out of 18 cases where the road-market tandem was found, road construction is reported to drive the growth of wood markets (timber industry), the growth of agricultural markets (for food, especially beef), and to induce agricultural modernization in the form of growing cash crop production. These cases (from northern Thailand, south-

ern Belize, and various sites in Costa Rica) share common features such as humid climate conditions, medium sized areas (ranging between 6,000 and 13,000 km^2), absence of timber logging, traditional shifting cultivators turning into sedentary cash croppers and permanently settled subsistence (and/or cash) croppers (rather than spontaneous colonization), and the interplay of three up to five underlying factors. At the underlying level, all the road/market-driven cases turn out to be fully underlain (i.e., originally driven) by the growth of agricultural cash crop markets, geared for the generation of foreign exchange earnings (namely, beef, tea, sugar, opium, taro, rice, fruits, vegetables).

In most of the cases where infrastructure extension exerts a feedback upon economic factors (13 out of 18 cases), road extension works in combination with market and settlement expansion, and reportedly affects market growth and commercialisation. This occurs mainly in frontier cases from the Amazon lowlands (Brazil, Ecuador, Peru), and to a lesser degree in Asian cases (Indonesian Sumatra, Dehra Dun valley of northern India), but not in cases from Africa. Common features of these cases are consistently poor, fragile and weak soils, frontier situations with growing urban populations, and the interplay of four to five underlying forces. At the underlying level, human population dynamics is not the main driver, while in-migration – induced by market growth, especially wood or agriculture markets – is reported to be invariably high (while population densities are low). Important in these cases are formal pro-deforestation policies and the situation-specific behaviour of local populations (and outside creditors, absentee landlords, and loggers) that is shaped by rent-seeking and profit-orientation. Rural farming populations dynamically respond to signals coming from the market.

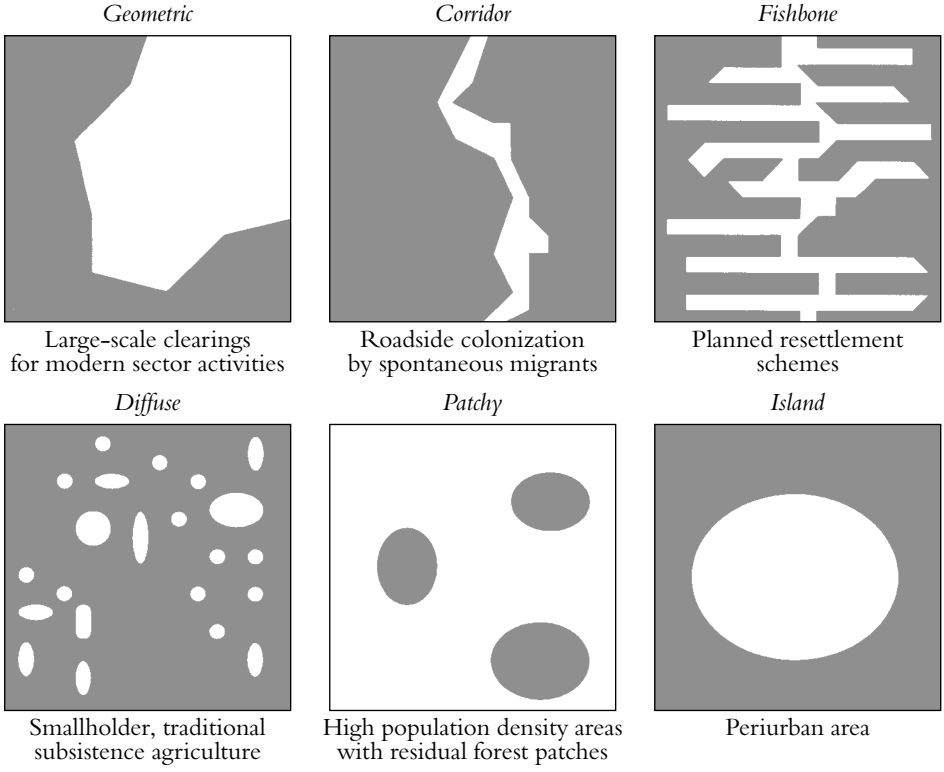
3.3 Variations of cause frequencies and causality patterns

Variations of frequencies and causality patterns as outlined above, in total and by regions or continents, are related here to deforestation processes as a function of spatial patterns, poverty *vs.* capital-driven deforestation cases, low *vs.* high deforestation cases, dry *vs.* humid forest cases, lowland *vs.* upland cases, and small *vs.* large case study areas.

3.3.1. Deforestation processes and spatial patterns

Specific sequences of events leading to deforestation (deforestation processes) are commonly assumed to leave unmistakable footprints. Processes such as agricultural expansion by subsistence farmers, cattle ranchers, agro-enterprises, etc., wood extraction by local users, outside logging companies, etc., or infrastructure expansion in the form of roadside clearing, river-bound colonization, etc. are associated with spatial patterns of the forest-nonforest interface (Lambin 1994). Across the tropical belt, a few characteristic spatial deforestation patterns were recognised and categorised in terms of geometric, corridor, fishbone, diffuse, patchy and island patterns (Husson et al. 1995; Mertens and Lambin 1999) – see Figure 8.

Figure 8: Typology of the forest-nonforest spatial patterns and their interpretation in terms of deforestation processes



Source: Mertens and Lambin (1997), Spatial modelling of deforestation, p. 149.

Cartographic evidence in the form of maps, aerial views and satellite imagery has been used to verify these patterns in (some of) the case studies. It appears that diffuse, patchy and geometric patterns are comparatively more frequent among the cases (11 or 12% of all cases each) than corridor and island patterns (9%), while fishbone patterns are fewer in numbers (7% of all cases) and regionally limited to the Brazilian Amazon (any demographic data given in the following have to be treated cautiously since number of cases were low).

Fishbone pattern of deforestation

The fishbone pattern of deforestation, commonly associated with planned resettlement schemes, is related here to cases of colonization, transmigration and (re)settlement. A total of 10 cases has been found (i.e., 7% of all cases) which all originate from the Amazon lowland of Brazil: Pará State (Xingu River Basin, Tailândia and Altamira towns and surrounding areas), Rondônia State (Theobroma area, central parts), and Acre State (Pedro Peixoto area).

Proximate level: At the proximate level, fishbone cases represent processes of roadside frontier colonization, with colonist shifting cultivation and cattle-ranching being the dominant modes of land-use associated with deforestation. Though being roadside cases, the infrastructure (road)-agriculture tandem is not a powerful proximate cause (as it is in the corridor cases, for example). Similarly, half of the cases are associated with wood extraction (mainly for local, regional and national industrial uses), but the logging-agriculture tandem does not establish a powerful interlinkage.

Underlying level: Half of the fishbone cases are associated with human population dynamics, with high in-migration being involved in all of them. Policy and institutional factors involved are formal, pro-deforestation state decisions to establish the colonization settlements. The shift from quasi-open access to individual property does best characterize the land tenure situation. Economic factors relate to the demand for timber and to the growth of local wood markets (sawmills), which reportedly drive half of the cases (in which wood extraction is reported to be a proximate cause of deforestation). Among socio-political factors, state objectives of colonizing the frontier shape policy decisions to open up forested areas for other uses, while among local land users, in more than half of these cases, values of unconcern with the environment and rent-seeking behaviour are widespread. About one third of these cases are driven by rural poverty, i.e., colonizing settlers of marginal position and being displaced from their area of origin.

Geometric pattern of deforestation

The geometric pattern of deforestation, commonly associated with large-scale clearings for modern sector activities, is related here to activities such as large-scale commercial (plantation) agriculture, large-scale pasture creation for cattle ranching, estate settlement agriculture, and industrial forestry plantation settlements (i.e., no cases of commercial timber logging). A total of 17 geometric cases has been found (11% of all cases). Regionally, they tend to concentrate in Southeast Asia (Indonesia, Malaysia) and in mainland South America (Brazilian Amazon, Mexico and the Napo Region of Ecuador, Peru and Colombia).

Proximate level: At the proximate level, none of the geometric cases appears to be a unique, individual case of large-scale clearing for a single modern sector activity alone. Rather, some of the modern activities occur concomitantly (e.g., cases of agricultural estate establishment together with industrial forestry plantation settlements, large-scale commercial cropping together with cattle ranching). Similarly, all large-scale activites are reported to occur concomitantly with small-scale agricultural activities to varying degrees (shifting cultivation, permanent cultivation, ranching, spontaneous transmigration). Further, geometric cases can additionally be caused or shaped by wood extraction, expansion of infrastructure, trigger events or biophysical features. The infrastructure (road)-agriculture tandem turns out to be most frequent.

Underlying level: Economic factors (mainly, urban market growth, export-oriented cash crop and timber market growth, and generation of foreign exchange earnings) are causative to technological factors, which drive land-use intensification and the growth of modern, mechanized large holdings. The impact of certain policy/institutional, economic and socio-political factors appears to be considerable: formal pro-deforestation policies (such as state subsidies and favourable credits), agricultural modernization or growth of export produce (in combination with rising land prices and land speculation, public attitudes of frontier colonization, public and individual views upon forests as "free goods"), and a tendency towards rent-seeking through unproductive speculation rather than productive uses, especially in pasture-based beef raising.

Corridor pattern of deforestation

The corridor pattern of deforestation, commonly associated with roadside colonization by spontaneous migrants, is related here to cases in which spontaneous colonization coincides with roadside deforestation (n=14, or 9% of all cases). Corridor cases were found to be regionally widespread in Latin America (Amazon lowlands of Brazil, Bolivia, and Ecuador, coastal sites of both the Dominican Republic and Honduras, various frontier regions in Costa Rica), in Asia (North and East Thailand, Indonesian Kalimantan, and various sites in upland Vietnam), and in Africa (East Cameroon, southern Malawi).

Proximate level: At the proximate level, none of the cases is uniquely driven by road extension and spontaneous colonization alone. Rather, between one third and one half of the cases are further associated with traditional shifting cultivation and permanent subsistence food cropping as concomitant proximate causes of deforestation. Trigger events (mainly social disorder due to war, rebellion, etc.), land characteristics (mainly good soil quality) and biophysical drivers (especially forest fires) are powerful drivers of deforestation in these cases.

Underlying level: The full interplay of all forces underlies three fifths of the corridor cases. As a consequence, especially demographic factors impact more frequently than in other cases: population densities are reported to have increased from 37 to 72 to 108 inhabitants per km^2 over time, due to high population growth (5.5% on average per year) which can mainly be attributed to high in-migration. Policy and institutional factors impact considerably in the form of pro-deforestation policies: distribution of public forest land to marginal people, establishment of colonization settlements, regional development plans focussing on infrastructure extension, promotion of plantations for export commodity production, and government efforts towards sedentary agriculture. In one

third of these cases, state policies are associated with property right aspects such as marginality of in-migrating settlers and quasi open acess conditions in the area of arrival. Further, technological factors are most prevalent: low levels of technological input, both land-use intensification and extensification (with no dominant trend in agro-technical change). Similarly, economic factors drive corridor cases in a considerable manner: local, but even more so national and international growth of export-oriented agricultural markets (food, animal nutrition, non-food produce), and the built-up of new basic and heavy industries (in specific: oil, gas and petrochemical complexes). Finally, cultural or socio-political factors impact more strongly than in other cases.

Diffuse pattern of deforestation

The diffuse pattern of deforestation, commonly associated with traditional, smallholder subsistence agriculture, is related here to cases of traditional shifting cultivation and permanent cultivation by smallholders for predominantly subsistence needs (i.e., no slash-and-burn-agriculture practiced by colonizing settlers). A total of 18 cases of traditional small-scale agriculture have been found (12% of all cases). They are widespread among all continents, originating from Latin American countries (Honduras, Ecuador, and – especially - Mexico and Peru), from Asian countries (Nepal, China, Indonesia, Malaysia, Samoa Islands, and the Philippines), and from Africa (Madagascar, Cameroon), with next to all of them under humid climates.

Proximate level: At the proximate level, between one third and one half of the cases are caused concomitantly by commercial cropping, cattle ranching, roadside deforestation and logging (commercial wood extration as well as fuel and polewood harvesting for domestic uses) – besides two peri-urban and three protected areas cases only. The road-agriculture tandem operates in one third of the cases only. Impacts from the logging-agriculture tandem are poor.

Underlying level: Human population dynamics underlies more than half of the diffuse cases. Population growth is reported to be mainly driven by high in-migration which constitutes the most important demographic factor. Indications of demographic pressure, however, are low: both annual growth rates (1.1%, on average) and human population densities of diffuse cases (7 inhabitants/km^2, as a mean value) turn out to be far below the median of all cases (2.8% and 31 inhabitants/km^2, respectively). Consequently, no interlinkages exist between population as a driver of technological developments such as land-use intensification. Rather, population increases directly induce the expansion of cropped land, mainly. Economic, policy/institutional, technological, and cultural factors impact upon deforestation more strongly than demographic factors in about three quarters of the cases each. However, individual variable impacts vary considerably, and no dominant picture emerges. Farming systems are characterized by low technological level and show a tendency towards land-use extensification rather than intensification in about half of the cases. With view on agricultural production functions, profit-maximizing behaviour is extremely low, wheras target income achievment clearly dominates (i.e., fulfillment of immediate, mainly pure subsistence needs, risk aversion and risk minimizing behaviour). Among policy and institutional factors, mainly policy failures - such as poor law enforcement and mismanagement of forestry services – are associated with almost one third of the cases.

Patchy pattern of deforestation

The patchy pattern of deforestation, commonly related to high population density areas with residual forest patches, is associated here to cases of exceptionally high population density, which is different from island or corridor cases – see Table 21. A total of 18 (or 12% of all) cases has been found. Cases show wide distribution among the continents (in Asia: Thailand, India, Nepal, Philippines; in Latin America: Mexico, Honduras, Guatemala, Dominican Republic, Brazil, Colombia; and in Africa: southern Malawi, upland Kenya, southern Congo-Zaire). Except for two, all patchy cases are located in midland, highland and foothill zones under varying climates and types of forest (dry, humid, transitional).

Table 21: Demographic features related to spatial patterns of deforestation

	Mean rate of annual population growth	Mean population density (inhabitants/km²)	Mean rate of annual deforestation
Patchy cases (n=18)	2.9%	101	1.4%
	(n=4)	(n=9)	(n=16)
Geometric cases (n=17)	4.4%	19	1.5%
	(n=2)	(n=3)	(n=8)
Diffuse cases (n=18)	1.1%	13	1.7%
	(n=2)	(n=7)	(n=13)
Corridor cases (n=14)	6.6%	21	2.0%
	(n=2)	(n=4)	(n=9)
Fishbone cases (n=10)	NA	(3)	1.4%
	(-)	(n=1)	(n=9)
Island cases (n=13)	2.4%	225	1.7%
	(n=1)	(n=2)	(n=10)
All cases (N=152)	Mean: 3.3%	Mean: 57	Mean: 1.5%
	Median: 2.8%	Median: 31	Median: 1.2%
	Min.: 0.1%	Min.: 2	Min.: 0.1%
	Max.: 8.9%	Max.: 250	Max.: 5.7%
	Mode: 2.2%	Mode: 4	Mode*: 0.5%
	(n=15)	(n=35)	(n=108)

*Multiple modes exist. The smallest value is shown.

Proximate level: At the proximate level, patchy cases are related to processes of permanent cultivation for food, predominantly, - and to a lesser degree – for cash crop production, in two thirds of the cases. Similarly, wood extraction is reported to be a concomitant cause of deforestation in two thirds of the cases: mainly, fuelwood extraction for

predominantly domestic usages. The expansion of infrastructure, mainly road extension, impacts in about half of the cases (while the road-agriculture and logging-agriculture tandems are far less frequent than among corridor or geometric cases).

Underlying level: Demographic and economic factors dominate the underlying pattern of deforestation in almost all cases. The demographic impact of especially human population density upon the expansion of food cropped land is a direct and immediate one. Population "pressure" arises in the form of high annual growth (2.9%, on average) and high, already existing and increasing densities (around 100 inhabitants/km^2 as a mean value) – including two cases, even, where outmigration occurs – in more than four quarters of the patchy cases – *cf* Table 21. About one third of the cases of population increase are specifically related to in-migration, what in reverse could imply that most of the population increase is due to natural increment of local populations rather than migration (though most of the causes of growth were not specified in sufficient detail). Among economic factors, market growth and commercialisation – especially, the demand-driven growth of agricultural (food) markets, urbanisation, industrialisation, increased market access and price increases of agricultural produce – turn out to be most important. Economically defined poverty is inherent to slightly less than half of the cases. Consequently, agricultural production functions of local farming groups comprise income maximisation strategies (mainly, simple profit-maximising behaviour) as well as strategies aimed at target income achievment (mainly, fullfillment of immediate subsistence needs and of additional cash). In about one third of the cases, land division and excessive resource usage are reported to underlie deforestation. Among policy and institutional factors, more of the cases (two thirds) are driven by formal pro-deforestation policies (credit, investment, land development and agrocultural growth policies). Land tenure arrangements underlie about one quarter of the patchy cases (mainly, insecure ownership and marginality of land users). Characteristic shifts in state and group property arrangements underlie about half of the patchy cases. This means that communal lands were increasingly being appropriated by the state (e.g., for state forests and nature reserves), and state as well as communal land turned into situations of quasi open acess (e.g., squatting of forest patrimony by locals). As a consequence, mainly unconcern by individuals about forest protection and sustainable forest use is associated with about half of the patchy cases.

Island pattern of deforestation

The island pattern of deforestation, commonly associated with periurban areas, has been related here to cases of deforestation occurring around (semi)urban settlements and not associated with other spatial patterns (also including peri-urban situations). A total of 13 (or 9% of all) cases are characterized by this pattern. They are regionally widespread among all continents: Africa (northern Nigeria, southern Malawi, southern Madagascar), Asia (Indonesian Java, Cebu Island of the Philippines, Sarawak of Malaysian Borneo) and Latin America (central Costa Rica, southern Mexico, Tucuma and Paragominas town areas in Pará State of the Brazilian Amazon).

Proximate level: At the proximate level, island cases are concomitantly caused by agricultural expansion, wood extraction and the extension of infrastructure in more than half of the cases. Wood extraction alone is reported to cause deforestation in two African cases (from Kano close Settled Zone in Northern Nigeria and from a cluster of villages

located within Lake Malawi National Park in southern Malawi). Land characteristics (mainly soil quality), biophysical drivers (forest fires) and social trigger events (social disorder) are associated with about half of the cases, always in combination with other proximate causes. No dominant agricultural activities are inherent to island patterns. In about half of the island cases, road network extension and extending settlements and/or market infrastructure constitute proximate causes of deforestation. Fuelwood and polewood extraction for domestic uses as well as commercial timber logging are most strongly associated with deforestation (in about half of the cases).

Underlying level: Demographic, socio-political, policy/institutional, technological and, especially, economic factors interact in various combinations and drive between three fifths and three quarters of the cases. This implies that, in particular, the impact of human population dynamics is stronger than in non-island cases: higher than usual annual population growth (1.7%, on average) in combination with high densities (of more than 200 inhabitants/km^2 as a mean value) due to in-migration and natural increment. Demographic factors impact directly and have few interlinkages with other underlying causes. Among economic forces, demand-driven growth of agricultural and, especially, wood markets are the most important factors. Agricultural production functions of local users comprise dynamic responses from farmers to secure market signals and increased needs for additional income ("spontaneous" cash cropping). Among technological factors, intensification measures and agricultural involution are reported to occur in about one third of the cases. Here, agro-technical (or farming systems) change means that shifting cultivators turn to commercial crop production, and that landholding sizes get increasingly smaller. Though market growth and commercialisation are important drivers of peri-urban deforestation, (economically defined) poverty is at work in one third of the island cases.

3.3.2. Poverty- *versus* capital-driven deforestation

Poverty- and capital-driven deforestation make up two general "paths to rain forest destruction" (Rudel and Roper 1997). One of the major set of explanations, with Malthusian overtones, arises from "immiserization theory". It attributes most deforestation, especially in countries with small forests, to expanding poor peasant and shifting cultivator populations who have few other economic opportunities and therefore decide to clear additional land for agriculture (Myers 1993; Walker 1993; Rock 1996; Rudel and Roper 1997). Another set of explanations arises from "frontier theory" (or models). It identifies entrepreneurs, companies, and small farmers, working in concert, as the chief agents of deforestation. Sometimes, these actors form "growth coalitions" (Molotch 1976; Rudel 1993). In other instances, they benefit from each others' activities, but do not work together – though being organized participants of networks using private capital and state assistance to open up regions for exploitation, settlement and deforestation, especially in places with large forests (Plumwood and Routley 1983; Hecht 1985; Walker 1987, 1993; Rudel and Roper 1997).

Poverty-driven deforestation

Poverty, in combination with other factors, has been reported as an underlying social process of deforestation in 64 out of 152 (or 42% of all) cases. It was specified in terms of several demographic, economic, technological and policy/institutional factors (resource-poor farming, survival economies, insufficient food production, chronic food deficits, displacement, limited amount of land, growing land scarcity, landlessness, land division and creation of poor landholdings, low living standard, joblessness, extremely low income levels, social deprivation, marginalization, low empowerment of local user groups). Cases originate from all continents, i.e., Africa (Cameroon, Madagascar, Ghana and Malawi), Latin America (Mexico, Bolivia, Brazil, Dominican Republic, Honduras, Ecuador and Costa Rica), and Asia where relatively more cases are found than elsewhere (Laos, Samoa Island, Indonesia, Malaysia, China, Nepal, Philippines, Vietnam and, especially, Thailand). Conditions of poverty are more frequent in cases with corridor, patchy or geometric spatial patterns than in cases having a fishbone, island or diffuse pattern. Noteworthy, that two fifhts of the poverty-driven cases (n=26) are associated with capital-driven (frontier) cases.

Proximate level: At the proximate level, about half of the poverty-driven cases are associated, in various combinations, with traditional as well as colonist shifting cultivation, permanent smallholder subsistence farming, cattle ranching and colonization (far less with commercial cropping). Associations with other proximate factors turn out to be low. Consequently, pure subsistence and the fulfillment of immediate needs – rather than income maximisation or, even, survival strategies – characterize most of the poverty-driven cases.

Underlying level: At the underlying level, four fifths of the poverty-driven cases are related to human population dynamics, among other underlying forces. Population presssure arises in the form of high population growth (mean rate of 3.8% annually; n=16) and high densities (80 inhabitants/km^2, on average; n=10) due to in-migration and natural increment (non poverty-driven cases, in contrast, are characterized by 2.5%, and 37 inhabitants/km^2, respectively). With view on policy and institutional factors, almost all cases are associated with formal pro-deforestation policies, especially on land and economic development. Two thirds of the cases are further underlain by aspects related to property right arrangements. These are mainly insecure ownership, quasi open access, and low empowerment of local user groups (marginality, social deprivation). Similarly, specific economic structures (in about half of the cases), but even more so market growth and commercialisation underlie poverty-driven deforestation. All cases are underlain by public attitudes, values and beliefs – especially, unconcern towards the forest environment –, whereas behavioural aspects – namely, the desire to raise incomes and gain profits – appear in two thirds of the cases. With view on technological factors, slightly more than half of the cases could be related to situations where landlessness as push factor of migration, growing land scarcity on communal land (under customary tenure), and land division or the creation of poor landholdings operate at the underlying level.

Capital-driven deforestation

Cases of capital-driven deforestation are related here to cases in which typical frontier situations were specified (n=64). Noteworthy, that growth coalitions or informal symbiosis of actors, which reportedly occur in 24 (or 16% of all) cases, do not only coincide with frontier cases (n=13). They also operate in cases of deforestation that are associated with subsistence as well as commercial farming, peri-urban, logging and, especially, roadside developments (n=11). Further noteworthy, that slightly less than half of the capital-driven cases (n=26) are concomitantly associated with poverty conditions. Capital-driven frontier cases tend to appear predominantly (two thirds of them) in Latin America under humid climates (Amazon lowlands of Brazil, Ecuador, Bolivia, Peru and Colombia, but also in Guatemala, Honduras, Costa Rica and the Dominican Republic). They go hand in hand with geometric, fishbone, corridor and patchy spatial patterns, mainly.

Proximate level: At the proximate level, activities of colonization – centered around mainly colonist shifting cultivation and cattle ranching – are the most common causes leading to deforestation (in about three fifths of the cases). Three quarters of the cases are associated with road extension, and commercial timber logging is associated with three fifths of the cases.

Underlying level: Demographic factors in the form of high in-migration (including even cases of medium to high outmigration) tend to be characteristic for almost all cases. Consequently, annual growth rates of population (n=4) are higher than in non-frontier cases (3.8% as compared to 3.2%, as an annual average; n=11), but density values are as low as 14 inhabitants/km^2 (mean value; n=12), when held against non-frontier cases (79; n=23). Various forms of demand-driven market growth and commercialisation (mainly in the agriculture and wood sector) are the main economic drivers in next to all cases. Among technological changes associated with frontier deforestation, cases of land-use intensification are more or less balanced by cases of extensification (in one third to one quarter of the cases each). With view on policy impacts, pro-deforestation policies (mainly credits, subsidies, finance and investment measures, land and economic development projects) drive next to all of the frontier cases. Quasi open access conditons and some policy failures underlie half of these cases (with the latter, mainly, being poor performance of forestry laws, operation of growth coalitions and patron-client relations). Underlying two thirds of the cases are public attitudes of unconcern such as explicit frontier mentalities and concepts (less so values and beliefs), and situation-specific behaviour of actors (best characterized as profit-seeking behaviour).

Poverty-capital relations

The notion exists that there is a sequence of poverty- and capital-driven processes in the form of a "curvilinear relationship between economic development and deforestation" (Rudel and Roper 1997, p. 61):

> Rates of deforestation are high in impoverished places; they increase with an initial surge of economic growth, and they decline when additional wealth creates other economic opportunities.

The type of poverty-capital relation described paraphrases much of an environmental Kuznets curve for deforestation (*cf* Koop and Tole 1999; *cf* Mather et al. 1999). It appears, indeed, that annual rates of deforestation in poverty-driven cases (with the latter used as

an equivalent to impoverished places) amount to 1.4% (as an annual average), remain stable at 1.4% in cases that are both poverty- and capital-driven, and increase to 1.7% in capital-driven frontier cases, whereas deforestation rates fall back to 1.4% in all remaining cases – see Table 22. Further, rates of population growth in poverty-driven cases tend to be as high as 3.5% (annual average), lower in capital-driven frontier cases (3.1%), and – probably – decrease (to around 1.5%) in remaining cases (though data evidence is not strong due to low number of cases). However, better data evidence suggests that, indeed, poverty-driven cases are characterized by population densities as high as 94 inhabitants/km^2 (as a mean value), while this is not the case in capital-driven frontier cases where density values decrease to 12 inhabitants/km^2 (they remain high in all other cases).

Table 22: Selected features of poverty/capital-driven deforestation

	Mean rate of annual population growth	Mean population density (inhabitants/km^2)	Mean rate of annual deforestation
Poverty-driven cases only	3.5% (n=9)	94 (n=13)	1.4% (n=30)
Capital-driven* cases only	3.1% (n=3)	12.1 (n=9)	1.7% (n=27)
Both types	NA	18 (n=3)	1.4% (n=17)
Remaining cases	1.5% (n=2)	59 (n=10)	1.4% (n=34)

* Identical with frontier cases.

3.3.3 Low *versus* high deforestation cases

In 108 cases, annual rates of deforestation were specified (mean= 1.57%), and the median of 1.2% was taken to separate cases of low deforestation (n=57) from cases of high deforestation (n=51). – Do low and high deforestation cases differ in terms of their frequency of proximate and underlying causes involved? And, are there distinct or similar patterns of causality behind cases of low and high deforestation?

Proximate causes: At the proximate level, cases of low deforestation are mainly driven by the combination of agricultural expansion – except for spontaneous transmigration, smallholder cattle ranching and commercial cropping –, wood extraction (especially commercial timber logging) and infrastructure expansion (especially road network extension). In contrast, certain features of the biophysical environment and social trigger events appear to be mostly associated with cases of high deforestation. What are the specific causes leading to different deforestation outcomes in more detail ?

With view on the frequency of causes at the aggregate level, it emerges that only in infrastructure-driven cases of deforestation (n=83) a difference can be observed between cases of low and high deforestation, i.e., low rates of deforestation tend to be slightly more widespread (n=48) than high rates (n=35) – see Table 23. Cases of low deforestation, ranking between 0.5 and 0.7% annually, tend to occur where transport infrastructure (especiallly, roads and railroads, less so rivers), private enterprise infrastructure (mining, hydropower, less so oil exploration), and market or settlement infrastructure (especially, the expansion of rural, urban and semi-urban settlement) are reportedly associated with deforestation.

Table 23: Infrastructure extension and mean annual deforestation*

	Abs.(rel.)	Rate (%)
Cases of low deforestation (n=57)		
Transport infrastructure	41 (72%)	0.6
... roads	... 38 (67%)	(0.6)
... railroads	... 11 (19%)	(0.7)
Company infrastructure	12 (21%)	0.5
... hydropower	... 3 (5%)	(0.6)
... mining	... 8 (14%)	(0.5)
... oil exploration	... 1 (2%)	(0.6)
Other infrastructure[1]	18 (32%)	0.6
... settlement expansion	... 12 (21%)	(0.7)
Cases of high deforestation (n=51)		
Transport infrastructure	32 (63%)	2.5
... roads	... 31 (61%)	(2.5)
... railroads	... 6 (12%)	(2.4)
Company infrastructure	7 (14%)	2.8
... hydropower	... 0 (-)	(-)
... mining	... 4 (8%)	(2.9)
... oil exploration	... 3 (6%)	(2.7)
Other infrastructure[1]	14 (28%)	2.6
... settlement expansion	... 9 (18%)	(2.8)

* Multiple counts possible.

1 Market and settlement extension.

In agriculture-driven deforestation, the difference between cases of low and high deforestation appears to be negligible, if agricultural expansion is considered as an aggregate entity. A breakdown, however, by specific agricultural activities indicates that more of the smallholder actitivites and spontaneous colonization tend to produce higher deforestation than other forms of colonization or large-scale agriculture – see Table 24.

Table 24: Agricultural expansion and mean annual deforestation*

	Abs.(rel.)	Rate (%)
Cases of low deforestation (n=57)		
Spontaneous transmigration	3 (5%)	0.6
Smallholder agriculture		
... commercial cropping	2 (4%)	0.7
... cattle ranching	7 (12%)	0.5
Large-scale agriculture		
... commercial cropping	3 (5%)	0.4
... cattle ranching	7 (12%)	0.3
Cases of high deforestation (n=51)		
Spontaneous transmigration	7 (15%)	2.5
Smallholder agriculture		
... commercial cropping	6 (12%)	1.9
... cattle ranching	14 (28%)	2.3
Large-scale agriculture		
... commercial cropping	1 (2%)	1.9
... cattle ranching	3 (6%)	2.8

* Multiple counts possible.

There is further indication that in cases where commercial timber logging was reported as a proximate cause of deforestation – and in which deforestation rates were given (n=51) –, cases of low deforestation (n=29) tend to slightly outweigh cases of high deforestation (n=22), especially with regard to state-run and illicit wood extraction. Differences in the impact of polewood and fuelwood collection are not as pronounced. If types of deforestation processes are considered, indicative results support this observation. Low deforestation is a characteristic feature of logging areas only (n=27), where in two thirds of the logging-caused forest losses (n=18) the mean annual rate of deforestation is 0.6% as compared to the remaining third (n=9) of these cases (3.2%). In deforestation areas where subsistence food production, commercial cropping, frontier colonization, road and periurban developments are characteristic, the distinction between low and high deforestation is not as pronounced as in logging areas.

With view on features of the biophysical environment and trigger events, more cases, in which biophysical features and triggers have an influence on the deforestation process, are associated with higher deforestation than others – see Table 25. Biophysical features such as good quality, gentle slopes, flat topography, low elevation, and sufficient water provision are reported to be associated with mean annual deforestation rates as high as 2.4% in 14 cases (mainly located in mainland South America). Most of the cases are related to frontier colonization, colonist shifting cultivation and pasture creation for cattle. Mainly flat plots of good soil quality in lowlying areas that are adjacent to rivers and tributaries were deforested first and at exceptionally high rates. Prominent cases are the flat lands of Yucatán Peninsula, the Norte, Atlantico and Pacific Sur frontier regions of Costa Rica, the Atlantic lowlands of Northern Honduras, Rondônia State in the Amazon Basin of Brazil, and several Provinces in Northwestern and Northeastern

(Amazon lowland) Ecuador. Only a few cases are reported in which poor, degraded pasture soils, partly created through overgrazing and located on flat or moderately sloping land, also fuel accelerated deforestation, if wet season accessibility is high. In addition, flat and lowlying areas tend to be prone to commercial timber logging. High deforestation, shaped by slope, soil, water and relief (or topography), could also be associated with traditional as well as colonist shifting cultivation, permanent subsistence smallholder cultivation and commercial agriculture. In summary, features of (low) relief or (flat) topography seem to shape high deforestaton, especially if they combine with good soil quality and high water availability as well as wet season accessibility. It seems further noteworthy, though the number of cases is rather low, that social trigger events such as rebellions, wars, civil wars and social upheavals are invariably more associated with high rates of deforestation.

Table 25 : Other factors and mean annual deforestation*

	All cases		Asia		Africa		Latin America	
	Abs. (rel.)	Rate (%)	Abs. (rel.)	Rate (%)	Abs. (rel.)	Rate (%)	Abs. (rel.)	Rate (%)
Cases of low deforestation (n=57)								
Biophysical factors	**3 (5%)**	**0.4**	**0**	**-**	**0**	**-**	**3**	**0.4**
... Soil quality	1 (2%)	0.3	0	-	0	-	1	0.3
... Slope & topography[1]	0 (-)	-	0	-	0	-	0	-
... Water location	1 (2%)	0.6	0	-	0	-	1	0.6
... Vegetation[2]	2 (4%)	0.3	0	-	0	-	2	0.3
Social triggers	**6 (11%)**	**0.6**	**5**	**0.6**	**1**	**0.6**	**0**	**-**
... Social disorder[3]	4 (7%)	0.6	3	0.6	1	0.6	0	-
Cases of high deforestation (n=51)								
Biophysical factors	**14 (28%)**	**2.4**	**1**	**2.4**	**2**	**1.9**	**11**	**2.6**
... Soil quality	7 (14%)	2.2	0	-	0	-	7	2.2
... Slope & topography[1]	7 (14%)	2.2	0	-	2	1.9	5	2.8
... Water location	5 (10%)	2.1	0	-	0	-	5	2.1
... Vegetation[2]	1 (2%)	2.4	1	2.4	0	-	0	-
Social triggers	**11 (22%)**	**2.3**	**2**	**2.4**	**2**	**2.0**	**7**	**2.4**
... Social disorder[3]	7 (14%)	2.4	1	2.4	1	1.8	4	2.6

* Multiple counts possible.
1 Flat and gently sloping areas, lowlying areas.
2 Forest size and fragmentation, high vegetation density (especially of marketable woods).
3 War, civil war, rebellion, revolution, social unrest.

Underlying causes: The pattern of various combinations of specific proximate causes and biophysical features associated with either low or high rates of deforestation has no equivalent at the broad, aggregate underlying level. This means that all five underlying driving forces (economic, policy/institutional, technological, cultural, and demographic factors) are equally well represented in either low or high deforestation cases.

3.3.4. Dry *versus* humid forest cases

In terms of broad forest types, the total of 152 deforestation cases can be subdivided into two broad categories: humid (or wet and moist) forests in 119 (or 78% of all) cases, and dry forests or woodlands, including transitional forest types located at the dry/humid forest contact zone (tree savannas, woodlands) in 33 (or 22% of all) cases. – Do forest categories differ in terms of frequency of proximate and underlying causes behind deforestation? And, are there distinct or similar patterns of causality behind the cases?

Proximate causes

At the proximate level, the expansion of infrastructure (which is mainly road extension) and, consequently, the road-agriculture tandem turn out to be more widespread in humid than dry forest zones (whereas no difference exists with regard to other broad proximate causes). Relatively more cases of shifting cultivation are found in humid forests, especially traditional shifting cultivation (34% of the humid *versus* 18% of the dry forest cases). The reverse seems to be true for permanent cultivation. In specific, smallholder food production for subsistence is more frequent in 70% of the dry forest cases as compared to 32% of the humid forest cases (while no difference appears if commercial cropping is broken down by dry *versus* humid forests). Cattle ranching, both small- and large-scale, and agricultural colonization tend to be stronger proximate causes of deforestation in humid than in dry forests. In colonization, this holds especially true for planned colonization (in the form of agricultural nucleus settlements, industrial forestry plantation settlements, and military transmigration) rather than for local transmigration (i.e., resettlement of displaced persons) and spontaneous colonization. Subsequently, the geometric spatial pattern of deforestation (associated with large-scale, modern activities), the fishbone pattern (planned resettlement schemes), and the diffuse pattern (traditional smallholder agriculture) are more strongly related to humid forest cases. In contrast, the patchy pattern (associated with high population density areas) is observed in 24% of the dry forest and in just 8% of the humid forest cases – see Table 26.

Table 26: Selected features in dry *versus* humid forest cases

	Dry forests (n=33)	Humid forests (n=119)
Smallholder food production for subsistence (permanent cultivation)	23 (70%)	38 (32%)
Patchy spatial pattern	8 (24%)	10 (8%)
Mean population density (inh./km²)	74 (n=12)	47 (n=23)
Mean rate of annual population growth	2.9% (n=4)	3.5% (n=11)
Mean rate of annual deforestation	1.6% (n=26)	1.4% (n=82)

Underlying causes

At the underlying level, no difference exists concerning economic and technological factors driving deforestation. In contrast, more of the dry forest cases are underlain by demographic factors (70%) than humid forest cases (59%), and more of the humid forest cases are driven by policy and institutional factors (83%, as compared to 61% of the dry

forest cases) and cultural or socio-political factors (71%, as compared to 49% of the dry forest cases). The high impact of demographic factors upon deforestation in dry forests goes hand in hand with the expansion of smallholder food production areas (mainly for subsistence) in already high population density areas due to increases in population number driven by in-migration. In humid forests, policy and institutional factors impacting upon deforestation are found among formal as well as informal policies and property right arrangements. What makes humid forest cases fundamentally different from dry forest cases, are, in specific, state policies on land and population (for example, distribution of public forests to marginal people and establishment of colonization settlements), the operation of growth coalitions and patron-client relations, races for property rights, and the creation of quasi open access conditions. Among the cultural or socio-political factors associated with deforestation, public attitudes, values, beliefs and behaviour all impact at higher level than in dry forest cases. What makes humid forest cases fundamentally different are, in specific, frontier mentalities (of national governments) in combination with unconcern by individuals about the forest environment. The main difference could, thus, be viewed in terms of capital-driven frontier processes that dominate half of all humid forest cases, but only one quarter of the dry forest cases.

3.3.5. Lowland *versus* upland cases

In terms of topography, the total of 152 deforestation cases falls into three broad categories: uplands (midlands, highlands, mountains) in 44 (or 29% of all) cases, lowlands in 66 (or 43% of all) cases, and transitional (or foothill) zones in 42 (or 28% of all) cases. – Do cases of different topography vary in terms of frequency of proximate and underlying causes behind deforestation? And, are there distinct or similar patterns of causality behind cases from uplands, lowlands and foothill zones?

At the proximate level, broad causes such as wood extraction or agricultural expansion impact invariably in different topographical situations, but specific activities tend to vary. Further, analysts have argued that rates of tropical deforestation should begin to decline because growing proportions of remaining forests become increasingly inaccessible in rugged, upland locations (Myers 1993; Rudel and Roper 1997). Indeed, it appears that foothill zones and uplands show slightly lower mean annual rates of deforestation compared to cases from low lying areas – see Table 27.

In the following, only variations of broad proximate causes are given. For the respective underling driving forces, see subchapters 3.1.2 (underlying causes) and 3.2.3 (underlying factors driving proxiamte causes).

Table 27: Selected features in upland, lowland and foothill zone cases

	Uplands (n=44)	Transition zone (n=42)	Lowlands (n=66)
Mean population density (inh./km²)	102 (n=11)	40 (n=12)	31 (n=12)
Mean rate of annual population growth	3.8% (n=8)	3.1% (n=4)	2.3% (n=3)
Mean rate of annual deforestation	1.4% (n=34)	1.4% (n=31)	1.6% (n=43)

Agricultural expansion

First, the expansion of traditional smallholder agriculture associated with deforestation appears to be a phenomenon of mainly upland and foothill zones. Indigenous swidden-fallow farming and small-scale permanent cutlivation for subsistence occurs each in 41% and 55%, respectively, of the upland cases, and in 31% and 50%, respectively, of the foothill zone cases. As for comparion, the respective percentages of the lowland cases are 24% and 23%, respectively. Different from traditional shifting cultivation, the colonist mode of shifting cultivation tends to be a striking feature of lowlands mainly. This observation goes hand in hand with the almost exclusive distribution of diffuse and patchy spatial patterns in transitional and upland areas only. Consequently, population growth and population densities – but not rates of deforestation – are higher in uplands and foothills than in lowlands – *cf* Table 27.

Second, other agricultural activities such as cattle ranching and colonization appear to be phenomena of lowlands mainly. Cases of pasture creation for cattle occur in 65% and colonization in 56% of the lowland cases as compared to uplands and foothill zones (around 30% each). Forest conversion for large-scale cattle ranching turns out to be a marked feature only of the humid Amazon lowland cases of Brazil, Ecuador and Bolivia (n=15). This goes hand in hand with geometric and fishbone patterns of deforestation which are mainly found in humid lowlands.

Infrastructure extension, wood extraction, and other factors

The impact of transport infrastructure tends to be stronger in lowland and foothill cases than in uplands, what is especially true for road extension (occurring in 71% of the lowland as compared to 48% of the upland cases) and river-bound deforestation. Differences with regard to private enterprise infrastructure exist only at the level of specific activities, i.e., hydropower activities (mainly in uplands), mining activities (in foothill zones), and oil exploration (not at all in uplands). Specific activities related to the extension of market and settlement infrastructure tend to be more concentrated in lowlands (i.e., sawmills, food markets, water and sanitation).

Concerning commercial timber logging as a proximate cause of deforestation, state-run and undeclared (illegal, illicit) extractional activities do markedly occur in foothill zones and uplands rather than in lowlying areas. Similarly, fuelwood/polewood harvesting and charcoal production associated with deforestation are more common in foothill and, especially, upland cases than elsewhere.

Land characteristics (or features of the biophysical environment) associated with deforestation tend to equally matter in various topographical situations, except for two features. Good quality soils converted to cropped land and pasture appear to be more common in lowland than in other cases. And, vegetational features – such as forest size and fragmentation, or high density of especially marketable woods – seem to be absent in foothill zones. No significant observations can be made on biophysical drivers and social trigger events.

3.3.6. Small *versus* large case study areas

The mean size of case study areas as specified in 78 cases (or 51% of all), never comprising the whole of a nation state, ranges from 10 km², as in the case of a multi-village area in the Ituri Forest Zone of northeastern Congo-Zaïre, to 5,000,000 km², as in the case of the so called Legal Amazon of Brazil. The mean size amounts to 172,633 km², with a median of 3,420 km² and the mode being 6,000 km². If the median is taken to subdivide cases into large and small areas, a total of 40 cases of small areas and 38 cases of large areas has been identified. – Is there a distinct or similar pattern of causes and drivers behind deforestation dependent upon aereal size? What can be said on the scale-dependency of drivers?

At the broad proximate level, agricultural expansion causes deforestation in all cases, regardless of the size of area under study. However, marked differences emerge if specific activities are considered. Differently, wood extraction and other factors such as biophysical drivers and social trigger events are far more often reported from small area cases. In contrast, almost all large areas are reportedly impacted by road (or infrastructure) extension as compared to three fifths of the small area cases. Similarly, land characteristics associated with deforestation impact more strongly in cases reported from large areas – *cf* subchapters 3.1.2 (underlying causes) and 3.2.3 (underlying factors driving proximate causes) for the respective and varying impact of underlying forces.

Agricultural expansion

Though impacting at an invariably high level, specific agricultural activities vary across area size. First, more of small area cases are characterized by traditional smallholder agriculture in the form of subsistence farming (on a permanent basis) and, especially, traditional as well as colonist shifting cultivation in three fifths of these cases (compared to one quarter of the large area cases). The finding coincides with the observation that considerably more of the diffuse and patchy patterns of deforestation correlate with small areas. Second, and differently, more of the cases in which (especially large-scale, aerea extensive) cattle ranching and (modern, large-scale) colonizing actitivities are reported as proximate causes of deforestation correlate with large areas. This is supported by geometric and fishbone spatial patterns of deforestation that chiefly coincide with large areas (while corridor and island cases emerge as indifferent). The difference is further summarized in terms of demographic features and deforestation rates – see Table 28.

Table 28: Selected features in small *versus* large case study areas

	Small areas (n=40)	Large areas (n=38)
Traditional smallholder agriculture (permanent & shifting cultivation)		
Shifting cultivation	25 (63%)	10 (26%)
Subsistence farming	21 (53%)	15 (40%)
Mean population density (inh./km²)	54 (n=12)	32 (n=4)
Mean rate of annual population growth	2.4% (n=6)	NA
Mean rate of annual deforestation	1.6% (n=28)	1.1% (n=23)
Cattle ranching & colonization		
Cattle ranching	19 (48%)	25 (66%)
Colonization	11 (28%)	23 (61%)
Mean population density (inh./km²)	34 (n=7)	32 (n=4)
Mean rate of annual population growth	2.8% (n=6)	NA
Mean rate of annual deforestation	1.4% (n=23)	1.3% (n=31)

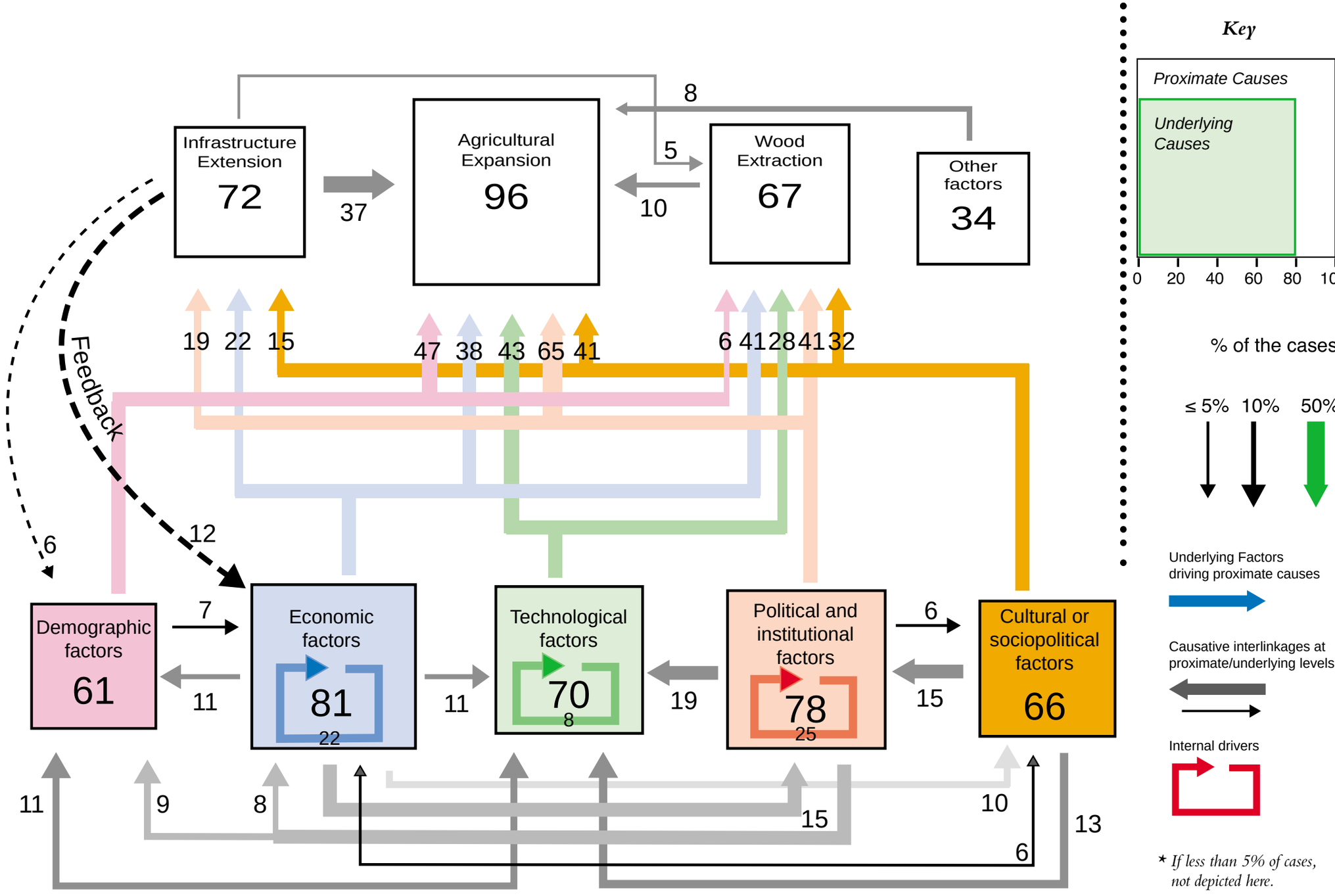
Infrastructure extension, wood extraction, and other factors

Public infrastructure in the form of roads, settlement expansion, provision of water and sanitation facilities, etc. reportedly impacts far more in large areas (while no marked differences appear with regard to other infrastructures).

Concerning wood extraction, first, commercial logging activities turn out to be indifferent with view on the size of area considered. Second, and in contrast, cases of fuelwood collection and polewood harvesting, associated with deforestation, are characteristic of small areas – regardless of domestic versus industrial end uses: 18 cases of fuelwood collection (polewood harvesting: 10) are reported from small areas as compared to just 2 cases of fuelwood collection and polewood harvesting reported each from large areas. Third, cases of charcoal production are merely reported from small areas.

First, features of the biophysical environment that relate to deforestation are more frequently reported from large than small area cases. This implies mainly soil quality (i.e., good soils fueling high and poor soils fueling accelerated clearing) and nearby locations of water (i.e., alluvial valley bottoms and areas of good wet season access deforested first). Second, among biophysical drivers it is noteworthy that all cases of forest fires could be related to small areas only (n=9), while the low counts of other drivers do not allow for generalisations. Third, the impact of social trigger events – in particular, wars, revolutions, etc. and sudden population displacements associated with deforestation – are predominantly reported in small area cases.

Figure 9 **A systemic and generalized view upon the causative pattern of tropical deforestation (N = 152 cases)***



4 Discussion

4.1 Does shifting cultivation matter?

Challenging the notion of principal agents

Agricultural encroachment by traditional smallholder agriculture occupies a central position in the debate on tropical deforestation, and shifting cultivators have since long been viewed as the primary agents of deforestation in tropical developing countries. Overall estimates of their share, based on cross-national statistical analyses, range as high as 45% (UNEP 1992) to 60% (Myers 1992), with peak values ranking as high as 79% (Amelung and Diehl 1992, p. 118) to 95% (FAO/UNEP 1981) for individual countries. Agent-based modelling efforts focus on shifting cultivators (e.g., Walker 1999), and, similarly, heuristic methods to estimate the extent of forest land converted to food production are based upon traditional shifting agriculture (e.g., Döös 2000). This implies that agricultural expansion is assumed to be the leading source of tropical deforestation, and that shifting cultivators are viewed as being the main agents responsible for forest losses. From our findings, we confirm the first hypothesis, but question and reject the second one. An overestimation of the role of shifting cultivation (or traditional smallholder agriculture) in tropical deforestation may be due to unclear definitions of what precisely constitutes shifting cultivators or "shifted cultivators", to uncertain estimates and potential political biases (Angelsen 1995; Bryant and Bailey 1997). Consequently, the exaggerated emphasis on shifting cultivation should be challenged.

Amelung and Diehl (1992), among others, provide percentages of various economic activities in deforestation for up to 40 tropical countries. They state that the agricultural sector recorded the highest share in all tropical deforestation, ranging between 80 and 100 percent of activities contributing to deforestation. This is in agreement with our findings that the expansion of cropped land and pasture, mostly in combination with other proximate factors, accounts for 96% of all cases studied. Further, a review of 150 economic models of deforestation concluded that "[a] broad consensus exists that expansion of cropped area and pasture constitutes a major source of deforestation" (Kaimowitz and Angelsen 1998, p. 89). Thus, we confirm that agricultural expansion apparently is the most important proximate source of tropical deforestation, and we add that it is mainly operating in synergetic ways (cause connections) with other proximate factors such as wood extraction and infrastructure extension.

About half of tropical deforestation is commonly explained by the expansion of traditional agriculture, focussing explicitly on shifting cultivation. Amelung and Diehl (1992), for example, state that "[w]ithin the agricultural sector the shifting cultivators accounted for the largest share of deforestation [...] on average for all tropical countries" (p. 117). In contrast, our case study evidence – taking into account that multiple counts of agricultural acitivities occur in nearly each case of deforestation – suggests that activities such as permanent cultivation (both for food subsistence and commercial

requirements) and cattle ranching, inherent to 48% and, respectively, 46% of all cases, slightly outweigh cases in which shifting cultivation is reported to be a proximate activity associated with deforestation (41%). Further, not a single case has been identified in which shifting cultivation alone was reported to cause deforestation. Rather, shifting cultivation concomitantly occurs with other, competing agricultural activities (including colonization) and other proximate causes (wood extraction, expansion of infrastructure).

Making a difference between shifting and shifted cultivators

If the rather broad and unclearly defined term (shifting cultivation) is broken down by more specific and related modes of farming, it emerges that colonist shifting cultivation (or slash-and-burn agricultural activities as practised by migrant settlers pushed to or otherwise attracted by forest frontiers) are associated with just 17% of the cases analysed, while traditional shifting cultivation (or swidden-fallow farming as practised by mainly indigenous, hillside people) accounts for 30% of the cases, mostly in conjunction with other factors. Thus, empirical case study evidence does not assign responsibility to (traditional) shifting cultivators as the primary agents of deforestation.

With view on traditional shifting cultivators contributing to deforestation (in 46 out of 152, or 30% of all cases), empirical evidence suggests that these cases are much more common in foothill and upland locations of island and mainland Asia than elsewhere. Thus, any generalization across regional cases tends to be unjustified. Further, almost all cases of traditional shifting cultivation operate in conjunction with (mainly, commercial) wood extraction as concomitant cause of deforestation.

With view on colonist shifting cultivation, which contributes to deforestation in 17% of all cases, empirical evidence suggests that more than two thirds of these cases are concomitantly – directly or indirectly – caused by wood extraction (chiefly, commercial timber logging) and the expansion of infrastructure (in particular, road construction). Different from cases of traditional shifting cultivators, the activities of shifted agriculturalists appear to occur mainly in cases from Latin America (Brazil, Bolovia, Ecuador, Mexico, Dominican Republic, Honduras, Guatemala). Three fifths of these cases are related to agricultural colonization with poverty as an underlying driving force. Conditions of poverty do best capture the underlying factors of migration to the frontier and conversion of forests into agricultural land: landlessness or growing land scarcity, insufficient food production, and, especially social deprivation or marginalization (low empowerment to promote own interests).

4.2 Which tandem matters ?

From case study evidence, we identified several tandems (simple two-factor cause connections) leading to deforestation.[5] At the proximate level, two main connections are reported to be the most important, i.e., the infrastructure-agriculture and the logging-agriculture tandem.

Logging-agriculture tandem

The logging-agriculture tandem – specified, chiefly, as logging-shifting cultivation tandem – has frequently been used to explain deforestation. Walker (1987, p. 19), for example, argues that the "process is a consistent behavioral explanation for the finding of Allen and Barnes (1985) that deforestation is correlated with the intensity of logging operations and population growth". He suggests econometric modelling that clarifies the conditions under which it occurs (ibd.; *cf* Walker and Smith 1993; Wibowo and Byron 1999, p. 464f). Grainger (1993), among others, argues that agricultural expansion following the logging frontier has been one of the main vehicles of deforestation in Asia, and Myers (1980) estimated that the combination of commercial loggers and follow-on cultivators accounts for 80% of the overall conversion rate.

Empirical support from case studies, however, suggests that the logging-agriculture tandem explains just 10% of all cases, while in just half of these cases commercial timber logging induces follow-on shifting cultivation (i.e., with other agricultural activities involved, too). Though the tandem has lower explanatory power than commonly claimed, it has been found to impact predominantly in Asian cases only. To be more specific, mainly state-run timber logging induces follow-on cultivation, with policy impacts involved such as corruption, poor enforcement of forestry laws and periods of general lawlessness or social disorder as main underlying social processes. Further, the statement of Angelsen (1995), that the logging-agriculture tandem "contrasts with the situation in Amazonia, where logging follows the farming frontier" (p. 1718), can be confirmed in so far as four out of five cases, in which the agriculture-logging tandem is reported, are settled in the Brazilian Amazon (cases from Pará, Rondonia and Roraima States). Nevertheless, both the logging-agriculture tandem and its reverse variant are seen to be of comparatively weak importance, if held against empirical case study evidence. Thus, modelling efforts could be, in particular, challenged if they are, for example, solely directed towards optimal logging contracts lengths or follow-on cultivation, while they implicitly assume to have addressed the whole deforestation process.

Infrastructure-agriculture tandem

Stronger than the logging-agriculture tandem, the infrastructure-agriculture tandem – predominantly, a road-agriculture tandem – is a robust, causative connection at the proximate level. Though concentrated in mainland South America, reported cases are not limited to this region, but are widespread among all continents. The tandem has been found to explain 37% of all cases, in which it is mainly associated with the expansion of cattle ranching and permanently cultivated land (both food and commercial cropping). With a view on the road-forestry connection, it was recognized in a recent statement, that "road construction represents the most harmful aspect of forestry activities [since the] forest has to be cleared for them and they are thus a direct cause of deforestation" (ITTTA and FAO 1999, p. 7). Thus, the road-agriculture connection deserves to be more highlighted and, henceforth, modelled in a similar manner as it was done with the logging-agriculture linkage.

Underlying and internal driver tandems

Compared to proximate connections, tandems which are composed of underlying driving forces are seemingly not treated in the deforestation literature at all. From our case study evidence, however, we found that several of these tandems are at work – see subchapter 3.2.2 (interlinkages between underlying causes). These are five tandems driven by economic factors, two tandems driven each by policy/institutional and cultural (or socio-political) factors, one technology-demography (or land-migration) tandem, and one demography-technology (or population growth-intensification) tandem.[5]

Similarly, not well recognized in the deforestation literature are internal driver combinations, i.e., tandems made up of factors from the same group and strongly impacting upon each other (for example, the demand-production linkage of economic explanation). We found that especially economic and policy/institutional factors establish strong internal driver combinations accounting for 25% of all cases, and 22%, respectively - *cf* subchapter 3.2.2 (interlinkages between underlying causes).

Tandems at the proximate/underlying divide

Noteworthy, that each chain-logical connection between the underlying and proximate levels establishes a tandem (if causative connections are reduced to two-factor connections). In the order of decreasing importance, these are the institution-agriculture tandem (accounting for 65% of all cases), the demography-agriculture tandem (47%), the technology-agriculture tandem (43%), the culture-agriculture, institution-logging and economy-logging tandems (41% each), the economy-agriculture tandem (38%), the culture-logging tandem (32%), the technology-logging tandem (28%), the economy-infrastructure (road) tandem (22%), the institution-infrastructure (road) tandem (19%), and the culture-infrastructure (road) tandem (15%). Any other proximate-underlying interlinkages account for just less than 10% of all cases each - *cf* subchapter 3.2.3 (underlying factors driving proximate causes). Among proximate factors having a feedback upon the underlying level, only the infrastructure (road)-economy tandem, operating in 12% of all cases, deserves a mention - *cf* subchapter 3.2.4 (feedbacks of proximate causes upon underlying causes).

By emphasizing the operation of tandems in tropical deforestation, we are aware that the reality of causative connections is more complex and, probably, deserves a still more complex breakdown of interlinkages. However, even when reducing complexity to simple two-factor chains, it becomes evident that much of the tandems found in case studies are not well recognised, especially in modelling literature. Thus, empirical results gained here on tandems from subnational cases might be useful as a platform to proceed incrementally towards explorations guided by sound theories.

4.3 Does population matter ?

Explaining about half of the deforestation cases, but not as single factor

Population in the form of human agency is undoubtedly related to all cases of tropical deforestation (this holds even true for reported cases of "natural" hazards such as accidental, uncontrolled forest fires some of which occur under conditions of drought, in most cases related to burning for land clearance by human actors). However, if only increases in population number are considered and held against subnational case study evidence, there is indication that human population dynamics is only the fifth most important among five directly underlying driving forces considered (chiefly, driving agricultural expansion and – less so – other proximate factors). From the cases surveyed, we found that 61% of all deforestation cases could be related to human population dynamics. In about half of all cases (47%), demographic factors – especially in-migration of farmers into forested frontier zones – directly underlie the expansion of cropped land and pasture. Therefore, we might, by large, confirm the notion that "approximately half of the variation in extent of deforestation is explained in statistical terms by variation in population" (Mather et al. 1998, p. 1987). However, the notion – as put forward, for example, by Allen and Barnes (1985) – that population growth is "the" primary cause of deforestation can be rejected against empirical evidence from subnational cases: among five underlying driving forces, human population dynamics is reported less frequently than, for example, economic, policy and institutional factors.

In none of the population-driven cases does human population dynamics operate as a single and direct causative factor over the temporal scale of a few decades that is inherent to most of the case studies reveiwed here (for contrary views, see Sandler 1993 and Vanclay 1993). More so, demographic factors are related to other underlying causes, mainly in the full interplay of all underlying drivers. In these driver combinations, demographic variables either operate concomitantly with other factors (57% of the population-driven cases), or are driven themselves by other, mainly economic, policy, institutional and cultural factors (in more than one third of the remaining cases).

Indirect effects of population variables

Kaimowitz and Angelsen (1998, p. 95) pointed out that, theoretically, population – besides increases in number – can also impact indirectly through effects on labour markets, demand for agricultural and forest products, and induced technological or policy/institutional change. With regard to the first point, we found that cheap, abundant production factors (including labour) accounted for 6% of all cases, and special cost conditions (mainly low labour costs) for 7% of all cases of deforestation. Given cases in which both conditions overlap, a total of 18 (or 12% of all) cases is found. With regard to the second point, we found that demand for wood products underlies considerably more of the cases (32%) than the demand for agricultural products (18%). Given cases in which both demands overlap, a total of 62 (or 41% of all) cases have been identified. With regard to the third point, we found that in 20 (or 13% of all) cases, demographic factors underlie technological and/or policy/institutional changes. In total, this wider population impact accounts for 82 (or 54% of all) cases. Considering the wider impact

in relation to the impact of population increases, we found that 24 (or 16% of all) cases are driven solely by the wider impact of population (among other factors), that more of the cases, i.e., 34 (or 22% of all) cases are driven by increases in population number (among other factors), and that most of the cases, i.e., 58 (or 38% of all) cases are driven by both. This means that the theoretically full population impact – as defined by Kaimowitz and Angelsen (1998) - underlies 116 out of 152 (or 76% of all) cases. Thus, only less than a quarter of all cases of deforestation are driven by underlying factor combinations in which direct human population dynamics does not matter.

4.4 Does debt matter ?

The direct link between foreign debt and deforestation has been suggested as a full "macroeconomic approach" (Wibowo and Byron 1999). The hypothesis that heavy foreign debt causes high rates of tropical deforestation has been examined, among others, by Angelsen and Culars (1996), who found that empirical evidence indicates that no universally valid link exists between debt and deforestation. In contrast, Kahn and McDonald (1994, 1995), Capistrano (1994) as well as Capistrano and Kiker (1995) found positive links. However, since their results were correlative rather than causative, they raise more questions than they answer. In the case of Latin American countries, Gullison and Losos (1993) found a very strong correlation between the two factors, but, after data were corrected by population level, the correlation disappeared. Further, it was suggested by Rudel and Roper (1997, p. 61) that debt could be a strong driver in already settled areas only. As a variant of the debt argument, Hansen (1989) has shown that, because debt payments reduce capital investments, they could actually lower the level of deforestation.

Given these contradictions, under what mechanisms or contexts does debt lead to (increased) deforestation as derived from subnational case study evidence? We found that foreign debts underlie cases of deforestation in just 7% of all cases. Comparatively more cases in Africa are affected. Deforestation in debt-driven cases tend to show higher rates of deforestation (2.0% as an annual average; n=7) than cases in which debt has not been specified as one of the underlying economic driving forces (1.4%; n=82). Subsistence farming areas turn out to be affected as well as commercial cropping, peri-urban, roadside and frontier areas. In next to all debt-driven cases, important concomitant drivers are at work such as poverty (except for just two cases) and population pressure caused by in-migration (except for just one). This might, indeed, suggest indirect links between debt and deforestation – i.e., a debt-poverty-deforestation connexus – as brought forward, for example, by the World Resources Institute (1992).

4.5 Does IPAT matter ?

IPAT has been considered to be "[t]he single comprehensive approach to the question of driving forces" (Meyer and Turner 1992, p. 51). The equation I = PAT has been used by Ehrlich and Ehrlich (1990) and Commoner (1972, 1990), where I represents environmental impact, taken to be the product of P (population), A (affluence), and T

(technology). If population is only to comprise increases in number, and if affluence is seen to constitute an economic factor, we found that the underlying driver combination exactly made up of these three factors (population-economy-technology) underlies just 5 (or 3% of all) cases. The three-factor term further appears in 63 (or 42% of all) cases, however, with policy/institutional, cultural or both factors operating as concomitant drivers. Thus, the isolated environmental impact of PAT is rather low (3% of the cases), but increases if other than PAT factors would be considered, too (42% of the cases).

A variant of the IPAT explanation, however, could read as follows. We identified 116 out of 152 (or 76% of all) cases in which population either directly (through increases in number) or indirectly (through labour markets and demands) underlies proximate causes of deforestation. We further identified 69 out of 152 (or 45% of all) cases in which the growth of demand for mainly consumer goods (forest and agricultural products) procured with cash due to a rise in general well-being was reported as an underlying economic factor, suitable to be approached in terms of "affluence" (or consumption). We further found that in 48 (or 32% of all) cases unconcern by individuals and/or households operates as an underlying cultural factor that could also be related to consumption (or "affluence"), since by definition it was unconcern by individuals about the environment reflecting increasing levels of demands, aspirations, material and energy consumption (commonly associated with increased income or "affluence"). Given cases in which these variants of affluence coincide, a total of 88 consumption-driven cases (58%) have been identified. If all consumption- and (directly plus indirectly) population-driven cases are related to technology-driven cases (70% of all cases), a total of 70 out of 152 (or 46% of all) cases emerges, in which P, A, and T, very broadly speaking, operate together in a synergetic driver combination. However, it has been found again that in only 5 (or 7% of the IPAT, or 3% of all) cases demographic, economic, cultural and technological factors are involved alone and best approach PAT. This means, that in 93% of the IPAT-driven cases (or in 97% of all cases) policy and institutional factors are reported to operate concomitantly (along) with or are even causative of PAT variables.

In summary, the simplicity and elegance often ascribed to the IPAT formula does not appear to capture adequately the interplay of factors inherent to tropical deforestation. The approach mainly fails to account for policy impact or – to be more specific – the impact of non-demand driven market forces as shaped by policy and institutional factors. This fits with the findings on deforestation in the Philippines which was analysed and described by Kummer and Turner (1994) in terms of large-scale logging for exports (driven by international market demands for tropical wood as mediated by corrupt political domestic structures) followed by agricultural expansion (enhanced by road building and rural population increases). Population pressure, however, turned out to be insignificant, and the authors stated "the IPAT variables do not correlate strongly with land-use and land-cover change, but economic and institutional causes do" (ibd., p. 324).

4.6 Does the disciplinary background of case study authors influence findings?

Is there a shared understanding of the various factors driving tropical deforestation among various academic disciplines? Or, is there a bias inherent to the identification of driving forces due to the disciplinary background or institutional affiliation of the respective authors? To explore the assumption that an author's disciplinary background may have an impact upon drivers and causes perceived and, thus, reported in the cases (for example, economists would predominantly report economic factors driving cases of deforestation), we limit ourselves to underlying causes only – *cf* subchapter 2.2.2 (discussion of methodological bias).

Several factors will have to be taken into account, when it comes to draw conclusions from measuring an author's disciplinary background in terms of his institutional affiliation as specified in the journal article – see Table 29. First, an institution made up of several disciplines – history, for example, under one umbrella with political economy and political sience – was coded as by the first-named discipline (history in this case). Second, multi-author teams with individual contributors having varying disciplinary background (and institutional affiliation) were made explicit as "mixed teams". This was meant not to blur the difference between disciplines such as soil science, social analysis and remote sensing. Third, due to lack of other information in the article, authors working for the World Bank were coded as economists, though this could be a major bias concerning their actual academic background. Fourth, the background of authors attached to non-governmental organizations, (inter)national research groups or others (such as the Center for South-East Asian Studies) had to be coded as "unkown" concerning their actual academic background.

Among the nine categories of institutional or academic background identified, four fifths of the cases (80%) were dealt with under four academic perspectives only: an eco-cological perspective was applied in about one fourth of the cases (24%), an economic view was used in about the same number of cases (23%), a geographical view was applied in about one fifth of the cases (18%), and multiple research perspectives were applied in "mixed teams" (15%). Purely anthropological, historical, sociological and political science approaches turned out to be considerably less used.

An obvious bias seems inherent to cases analysed by political scientists, since policy and institutional factors are related to all of the cases reported, while considerably less other factors were reported to allegedly drive tropical deforestation. In particular, political scientists seem to disregard purely economic and cultural variables. In cases where natural science (ecological) approaches are applied, it is striking that single and two-factor cause combinations do prevail. Ecologists often tend to ignore demographic and technological factors. Cases analysed from an anthropological, historical, geographical or sociological perspective – but also cases following a political ecology research design and classified as „unknown" here, since authors had no distinct institutional affiliation – prove to have a broader understanding of multiple drivers involved than cases following other research designs. This understanding is a predominantly complex, multi-factor causation (the reverse is true for cases in which ecological and political science approaches were applied,

and driver combinations are reportedly less complex). Although applied in just 15% of all cases, it is striking that integrated research perspectives, which combine natural as well as social science views (frequently including remote sensing technology) in "mixed teams", do best parallel the overall frequency pattern of underlying causes (i.e., predominantly economic, policy and institutional factors inherent to four fifths of the deforestation cases, with technological, cultural and demographic factors found in less, but still far more than half of the cases). Thus, author bias can be considered to be neglibile if various research perspectives were combined in the analysis of drivers.

Table 29: Underlying causes of deforestation as measured against the author's disciplinary background*

	1	2	3	4	5	6	7	8	9	Total
Frequency of occurrence of broad underlying causes										
Demographic Factors	6 75%	28 80%	11 31%	16 57%	4 100%	2 100%	2 50%	14 61%	10 83%	93 61%
Economic Factors	7 88%	31 89%	26 72%	23 82%	4 100%	2 100%	1 25%	17 74%	12 100%	123 81%
Technological Factors	7 88%	27 77%	15 42%	25 89%	3 75%	2 100%	2 50%	14 61%	12 100%	107 70%
Policy and Institutional factors	7 88%	30 86%	19 53%	24 86%	4 100%	2 100%	4 100%	17 74%	12 100%	119 78%
Cultural or socio-Political factors	7 88%	21 60%	17 47%	23 82%	3 75%	2 100%	1 25%	15 65%	12 100%	101 66%
Total (row) **% (row)**	8 5%	35 23%	36 24%	28 18%	4 3%	2 1%	4 3%	23 15%	12 8%	152 100%
Type of factor causation										
Single factor Causation	0	1	13	0	0	0	2	1	0	17
2-factor causation	0	6	8	2	0	0	0	6	0	22
3-factor causation	1	4	5	7	1	0	1	5	0	24
4-factor causation	4	8	6	9	0	0	0	6	2	35
5-factor causation	3	16	4	10	3	2	1	5	10	54
Total (row) **% (row)**	8 5%	35 23%	36 24%	28 18%	4 3%	2 1%	4 3%	23 15%	12 8%	152 100%

* Percentages in (1) to (9) are column percentages; total (column) values specify the frequency of occurrence of underlying causes in all cases, with multiple counts possible.

1 Anthropology.

2 Economy (forest economy, agricultural economy, resource economy, environmental economy, (international) development economy, regional science, (spatial) planning science, international and public affairs.

3 Ecology (biology, environmental science, forest ecology, mathematical ecology, forestry and wildlife management, botany, zoology).

4 Geography (regional, physical and human geography).

5 History (regional and environmental history).

6 Sociology (in combination with human ecology).

7 Political science (development studies, political economy, human rights).

8 "Mixed teams" (namely, soil science-ecology-geography-remote sensing, anthropology-economy-political science, agronomy-earth science, soil science-agricultural economy-geography, botany-biology-anthropology, anthropology-forest economy, anthropolgy-geography-political science, ecology-forest economy, ecology-geography-forest economy, agricultural economy-anthropology, geography-resource management, ecology-earth science-remote sensing, anthropology-geography, demography-ethnobotany-geography, ecology-economy-remote sensing.

9 Unknown (mainly political ecologists having no distinct institutional affiliation).

In summary, author bias in the meta-analysis is minimal and does not contaminate the results of the study, and conclusions to be drawn in the following.

5 Conclusions

Conclusions from the meta-analysis of 152 subnational cases of tropical deforestation are drawn in a fourfold manner. First, empirical findings are held against prevailing explanations of tropical forest decline. Second, implications are outlined with view on the future modelling of the process of deforestation, and, third, the same is done with view on policies designed to control deforestation. Fourth, we conclude with a short outlook on the future design of case study comparisons exploring the causes of land use and land cover change.

Empirical findings *versus* prevailing explanations

Looking upon empirical results from the meta-analysis as the first study which relates underlying to proximate causes in a systematised manner – see Figure 9 (inlay) which graphically summarises the results –, our main findings are compared to prevailing explanations of forest decline in the tropics as follows:

- Causes and drivers of tropical deforestation cannot be reduced to a single variable, or to a few variables even. Rather, the interplay of several proximate as well as underlying factors drive deforestation in a synergetic way. We found that mainly 3- and 4-factor terms of underlying causation are related to 2- and 3-factor terms of proximate causation. Among the most frequently found factor combinations are the agriculture-wood-road connexus (mainly driven by economic, policy, institutional and cultural factors), the agriculture-wood connexus (mainly driven by technological factors), and population-driven agricultural expansion. Regional variations of synergetic cause connections turned out to be considerable, with the agriculture-wood connexus featuring mainly Asian cases, and the road-agriculture connexus featuring mainly Latin American cases, for example.
- While the expansion of cropped land and pasture is clearly the most important proximate cause of tropical deforestation, shifting cultivators are not always the key agents of deforestation: shifting cultivation is often associated with timber logging and road construction as concomitant causes; traditional shifting cultivation (swidden-fallow farming) mainly characterises upland and foothill Asian cases, while colonist shifting cultivation (slash-and-burn agriculture by in-migrants) is limited mostly to humid lowland cases in Latin America, with many of the latter cases driven by conditions of poverty. Rather than shifting cultivation, the expansion of permanently cropped land for food by smallholders dominates agricultural expansion leading to deforestation.
- Chain-logical causation in the form of simple tandems (or 2-factor chains) underlies about two thirds of the proximate as well as underlying causes. It provides insight in all underlying/proximate factor interlinkages. On average, 4 to 5 tandems are associated with each case of tropical deforestation (since only tandems were considered, the actual pattern might be more complex even). At the proximate level, the infrastructure (road)-agriculture tandem seems to be the key causative connection. At the

underlying level, policy and institutional factors – such as formal state policies, policy climate (or informal policies) and property right arrangements (or issues) – exert the strongest impact upon proximate causes, while economic factors dominate the overall frequency pattern of cause occurrence (i.e., including single factor, concomitant and chain-logical causation).

- Rather than single or direct fundamental causes, underlying driver tandems were identified to be most important. These are mainly economy-, policy and institution-, and culture-driven tandems impacting upon the proximate level (especially the latter tandem is not treated well in the deforestation literature). However, next to each case has its own and very specific type of interlinkage, and hardly any generalisations are possible on the underlying tandems. There are only few exceptions: the land-migration tandem dominates Latin American cases, while the population growth-intensification tandem was found to prevail in African and Asian cases. Among broad, aggregate economic and policy/institutional causes, multiple and interactive factors were found to drive cases of tropical deforestation.
- Population pressure in the form of natural increases in number of population due to high fertility is clearly not the major underlying driving force at the scale of a few decades, when taken as a direct cause in isolation from other factors. Rather, in-migration into forested (not natural increase in densely populated) areas plays an important role in cases of frontier colonization. In all cases, however, population does not operate as a single force but is interlinked with other underlying factors. In underlying driver combinations, policy/institutional, economic, socio-political (or cultural) and technological factors play the major part.
- With view on variations of cause frequencies and causality patterns, there is empirical indication that in cases with high rates of annual deforestation pre-disposing biophysical factors are at work or shape the pattern of deforestation. Namely, these are low relief and flat topography in combination with good soil quality and high water availability. In contrast, proximate causes that cannot be assimilated to biophysical conditions are more associated with cases featuring considerably lower rates of annual deforestation (no such equivalent was found at the underlying level).
- The explanatory power of PAT variables (population, affluence, technology) is astonishingly poor. This model obviously fails to consider policy and institutional factors shaping market opportunities as powerful explanatory factors of tropical deforestation.
- Though difficult to code, we consider the meta-analysis to be the first study – not only to relate underlying driving forces to proximate causes in a systematised manner, but also – to quantify the impact of cultural or socio-political factors upon the process of tropical deforestation. It has contributed to sharpen and partly revise the six broad patterns commonly associated with certain deforestation processes, which are agricultural expansion, wood extraction and infrastructure extension at the proximate level, and economic, policy and institutional, cultural, technological and demographic factors at the underlying level. Feedbacks from the proximate upon the

underlying level turned out to be fairly weak (and only mattered in the case of infrastructure extension inducing in-migration and fostering the economic valorisation of areas affected by road construction).

- The multiple factors intervening in tropical deforestation also make it particularly difficult to develop generic and widely applicable policies that best attempt to control the process. Many land-use policies are underlain by simplifications on the drivers of change. Such simplification suggest simple technical solutions and sometimes may serve the interests of critical groups (Lambin et al., 2001). From the results of the meta-analysis it is clear that any universal policy or global attempt to control deforestation (e.g., through poverty alleviation) is doomed to failure.

Implications for modelling and controlling deforestation

Implications from our our empirical findings for both the future modelling of the process of deforestation and for policies to control deforestation are as follows:

- Deforestation is a complex, multiform process which cannot be represented by a mechanistic approach. This has implications for modelling as many of the simulation models of land-use change tend to be mechanistic. Mechanistic models are built on the belief that we know the processes by which a system operates (Elston and Buckland, 1993) and that individual processes can be modelled using scientific laws, or rules, described by simple equations. Given the large number of interacting factors driving deforestation, and given interactions at different levels of causality – underlying forces, trigger events, mediating factors, proximate causes – only a system approach seems to be appropriate. System models are mathematical descriptions of several complex, interacting processes. They emphasise the interactions among all components within an ecosystem by implementing the "whole system" concept. System models sometime sacrifice parsimony and abstraction in favour of an apparent attempt to simulate the socio-natural system in its entirety (ibd., 1993).
- Do we understand with a sufficient level of generality and clarity the causes of deforestation to be able to represent these in a system model? The case study evidence examined in this meta-analysis clearly suggests that we still lack an overarching theory to encompass the different factors which intervene in the processes of deforestation. The role of a theory is to explain experimental findings and to predict new results. Specific relationships underlying deforestation and the processes involved have been effectively addressed through theories of particular components of a land use system. These include, but are not limited to, household economics, smallholder and peasant behaviour, land allocation, technological innovation, fertility change, policy/institutional regimes associated with land resource management, national markets, and international accords (Brown and Pearce 1994; Kasperson et al. 1995; Palo and Mery 1990). The complex and multidimensional character of deforestation processes requires understanding and modelling that incorporates the principles from such theories. However, the variability in how these principles come together in a place or region at particular times is not conducive to research strategies aimed at a test of simple hypotheses that might equate deforestation to population, economic struc-

tures, technology, political structures, or biophysical attributes (Lambin et al. 2001). These and other drivers of deforestation are always present but interact differently according to the temporal and spatial dynamics of particular regional or local situations. A thorough understanding of these complex interactions is a prerequisite to generate realistic projections of land-cover changes based on simulation models.

- Empirical evidence shows that the complexity and diversity of driving factors of deforestation is reduced when looking at specific processes – e.g., subsistence agriculture, commercial agriculture, colonisation activities or logging activities – and specific geographic situations – i.e., frontier areas, roadside areas, peri-urban areas. Thus, while the development of a "universal" model of deforestation is probably out of reach, a collection of specific models which represent the particular interactions between a reduced set of dominant driving forces for a given process of deforestation, in a given geographic situation, is a feasible approach. While the essence of modelling land-use change processes is "[...] to transcend the complexity of context, seeking to identify broad and universally applicable forces of change that crosscut the circumstances of place and period" (Turner and Meyer 1991, p. 672), one should also recognise the importance of that very complexity and the uniqueness of particular cause-impact relationships in specific situations (Turner and Meyer, 1991). Thus, models must recognize the variability by region or place of the human activities driving land-cover changes (Turner et al. 1990). This can best be achieved by applying different models to regions which are relatively homogeneous with respect to the phenomenon being modelled.
- The overall dominance of the broad cluster of agricultural expansion is well perceived in the modelling of tropical deforestation (e.g., Kendall and Pimentel 1994; UNEP 1997). However, this is not always the case when it comes more specific agricultural uses and other than agricultural land uses such as logging (e.g., Hamilton 1997). This meta-analysis provides indicative values for these proportions causing deforestation. For example, the emphasis given to traditional shifting cultivators in agent-based modelling (e.g., Walker 1999) or heuristic methods (e.g., Amelung and Diehl 1992; Döös 2000) certainly has to be revised in favour of modelling the gradual expansion of permanently cultivated land for both commercial and subsistence needs, or in favour of infrastructure extension and wood extraction. In addition, chain-logical modelling along the lines of the logging-shifting agriculture tandem is less fruitful than considering the more dominant infrastructure (road)-agriculture tandem. Further, any effort to apply, for example, cattle development as a major variable in global models attaining scenario development is likely to be misleading, since forest conversion for pasture creation almost exclusively concerns lowland cases under humid climates in mainland South America.

Implications for future case study comparisons

We conclude that any future case study, aimed at understanding the causes of tropical deforestation in any particular place, should follow a standard protocol to allow for improved comparisons in the future.

- The LUCC research framework (Turner et al. 1995, pp. 20-22; Lambin et al. 1999) proved to be a fruitful platform from which to proceed to develop a general understanding of the drivers of land use and land cover change, and from which to conduct a systematic comparison of a large number of subnational case studies. Theorizing, for example, of proximate as well as underlying biophysical causes has started, and the typification of certain proximate and underlying variables as filter variables, modifiers, contextual factors or triggers (catalytic factors) will certainly help to improve the conceptual understanding. Probably, the proximate/underlying divide will have to be overcome, so as to allow for more complex interplays of human agency and structure in processes of land change.
- Concerning regional representation of case studies in future comprehensive comparisons, we found that weighting bias in our meta-analysis was low, but we also found indication that future work will have to include considerably more African cases and reduce, by far, the proportion of Asian cases (given most recent forest cover dynamics in these regions). Latin American cases, holding about half of all cases, probably continue to feature quite well.
- Concerning weighting bias in terms of agents involved in the process of deforestation, one needs to have a better understanding of logging company behaviour and/or industrial forestry plantation activities (as compared to farming communities) – given the considerable role of wood extraction involved in many synergetic driver combinations, and given that especially state-run and illegal (illicit or undeclared) commerical logging activities were found to play a major role.
- Finally, we believe that a systematic comparison of local-scale case studies is an extremely productive methodology to extract generalities on the causes and processes of land-use change at multiple scales. It is labour-intensive and requires a high level of rigour in its implementation, but the insights it reveals are much more realistic and richer than cross-national statistical analyses, and more representative and general than research on single cases. Global change research, thus, needs more of such synthesis activities based on case study comparisons.

Notes

1 For cross-national statistical analyses, see Kahn and McDonald 1995, Capistrano and Kiker 1995, Shafik 1994, Palo 1994, Cropper and Griffiths 1994, Rudel 1989, Rudel and Roper 1997.

2 Ultimate and underlying causes (or driving forces) are often used in an identical manner. In this study, we avoided the first and favoured the second term, for several reasons. The most important was that ultimate tends to imply the end of a causal chain, while, in the course of data exploration, most of these fundamental causes turned out to be functions of others.

3 With the exception of four case studies, all cases of deforestation are settled in different regions (or areas). Only four regions (areas) are covered by two cases, i.e., the so called Legal Amazon of Brazil, the upland zone of the Philippines, the Playa de Oro Community in Esmeralda Province of northwestern Ecuador (Costa), and Napo/Sucumbio Provinces of northeastern Ecuador (Oriente).

4 The summary of the forest resource assessment can be downloaded at: ftp://ftp.fao.org/ unfao/ bodies/ cofo/cofo15/X9835e.pdf, and a free electronical copy can be obtained from a.liano@cgiar.org (Ambar Liano). The home page of the FAO forest resource assessment is: http://www.fao.org/forestry/fo/fra/index.jsp.

5 Two-factor terms of causation leading to deforestation – *cf* Tables 6 and 11 – do not necessarily imply that they are interlinked in a causative manner to qualify them as tandem (or as a two-factor chain of causation). The two factors could also occur concomitantly.

6 A difference was made between wood extraction for commercial purposes (i.e., traded wood, mainly for export to foreign markets) and industrial polewood extraction. The latter means that harvested wood has been directly used for input into the industrial production process (i.e., not traded), by artisans or other micro-scale enterprises (carpentry, house equipment producers, etc.), for example; *cf* also notes 1 and 3 in Table 9.

7 Though fuzzy boundaries exist between social trigger events and social underlying causes, we tried to identify those catalytic forces that should be held apart from "standard" social factors (thus, admitting interpretation bias). These events were also (double)coded at the underlying level.

8 This relates to the frequency of occurrence of economic factors, independent of their mode of operation, i.e., single factor, concomitant cause, or chain-logically connected; when it comes to consider chain-logical connections only (between the underlying and proximate level), policy and institutional factors appear to be more dominant, i.e., drive more factors than economic causes.

9 A broader version of T.S. Brothers (1997): Rapid Destruction of a Lowland Tropical Forest, Los Haitises, Dominican Republic. – Ambio. Vol. 26 (8). pp. 551-552.

10 Similarly, see G.S. Dei (1990): Deforestation in a Ghanaian rural community. – Anthropologica. Vol. 32, pp. 3-27.

11 All information has been drawn from N.L. Peluso (1992): Rich Forests, Poor People. Resource Control and Resistance in Java. – University of California Press: Berkeley.

12 A broader and updated version of S.B. Hecht (1985): Environment, Development and Politics. Capital Accumulation and the Livestock Sector in Eastern Amazonia. - World Development. Vol. 13 (6), pp. 663-684.

13 Similarly, see P. Hirsch (1987): Deforestation and development in Thailand. – Singapore Journal of Tropical Geography. Vol. 8 (2), pp. 129-138.

14 Draws mainly from G.M. Green (1993): Remotely sensed determination of deforestation history and topopgraphic controls. Manatady National Park and surroundings. – Duke University, Center for Resource and Environmental Policy Research: Durham, NC.

15 Reduced versions of (i) D.M. Kummer (1991): Deforestation in the postwar Philippines (= Geography Research Paper; 234). - University of Chicago Press: Chicago, London; (ii) D. M. Kummer & C.H. Sham (1994): The causes of tropical deforestation. A quantitative analysis and case study from the Philippines. – in: K. Brown & D.W. Pearce (Eds): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London, pp. 146-158.

16 Similarly, see B. Mertens & E.F. Lambin (1997): Spatial modeling of deforestation in southern Cameroon. Spatial disaggragation of diverse deforestation processes. – Applied Geography. Vol. 17 (2), pp. 143-162.

17 Identical with E.F. Moran, A. Packer, E. Brondizio & J. Tucker (1996): Restoration of vegetation cover in the eastern Amazon. – Ecological Economics. Vol. 18, pp. 41-54.

18 Drawn from A.S.P. Pfaff (1997): What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data (= Policy Research Working Paper; 1772). – The World Bank/Policy Research Department/Environment, Infrastructure, and Agriculture Division.

19 Similarly, see (i) D. Skole & C. Tucker (1993): Tropical deforestation and habitat fragmentation in the Amazon. Satellite data from 1978 to 1988. – Science. Vol. 260, pp. 1905-1910 ; (ii) D.L. Skole (1994): Data on Global Land-Cover Change. Acquisition, Assessment, and Analysis. – in: W. B. Meyer & B. L. Turner II (Eds): Changes in Land Use and Land Cover. A Global Perspective. – Cambridge University Press: Cambridge, pp. 437-471.

20 On the eastern part, information is drawn from G.M. Green & R.W. Sussman (1990): Deforestation history of the eastern rain forests of Madagascar from satellite images. – Science. Vol. 248, pp. 212-215.

References

ALLEN, J. & D.F. BARNES (1985): The causes of deforestation in developing countries. – Annals of the Association of American Geographers. Vol. 75 (2), pp. 163-184.

AMELUNG, T. & M. DIEHL (1992): Deforestation of Tropical Rain Forests. Economic Causes and Impact on Development (=Kieler Studien; 241). – J.C.B. Mohr: Tübingen.

AMSBERG, J.v. (1994): Economic parameters of deforestation (= Policy Research Working Paper; 1350). – World Bank: Washington, D.C.

AMSBERG, J.v. (1998): Economic Parameters of Deforestation. – The World Bank Economic Review. Vol. 12 (1), pp. 133-153.

ANGELSEN, A. (1995): Shifting Cultivation and „Deforestation". A Study from Indonesia. – World Development. Vol. 23 (10), pp. 1713-1729.

ANGELSEN, A. (1996): Deforestation. Population or market driven? Different approaches in modelling agricultural expansion (= Working-Paper; 9). – Christian Michelsen Institute: Fantoft, Bergen.

ANGELSEN, A. (1999): Agricultural expansion and deforestation. Modelling the impact of population, market forces and property rights. – Journal of Development Economics. Vol. 58 (1), pp. 185-218.

ANGELSEN, A. & R. CULAS (1996): Debt and deforestation. A tenuous link (=Working Paper; 10). – Christian Michelsen Institute: Fantoft, Bergen.

ANGELSEN, A. & D. KAIMOWITZ (1999): Rethinking the Causes of Deforestation. Lessons from Economic Models. – The World Bank Research Observer. Vol. 14 (1), pp. 73-98.

BARBIER, E. (1993): Economic aspects of tropical deforestation in Southeast Asia. – Global Ecology and Biogeography Letters. Vol. 3, pp. 215-234.

BARBIER, E.B. & J.C. BURGESS (1997): The Economics of Tropical Forest Land Use Options. – Land Economics. Vol 73 (2), pp. 174-195.

BARBIER, E.B., BURGESS, J.C. & A. MARKANDYA (1991): The economics of tropical deforestation. – Ambio. Vol. 24 (5), pp. 286-296.

BAWA, K.S. & S. DAYANANDAN (1997): Socioeconomic factors and tropical deforestation. – Nature. Vol. 386 (6625), pp. 562-563.

BAWA, K.S. & S. DAYANANDAN (1998): Causes of tropical deforestation and institutional constraints to conservation. – in: G.T. PRANCE, N. BROWN, B. SHARPE, M.J. EDEN, S.M. ROSS, Kamaljit S. BAWA, S. BASS, A. GRAINGER, C. CLUBBE, A. JUNIPER & F.B. GOLDSMITH (Eds): Tropical Rain Forests. A wider Perspective. – Chapman & Hall: London, pp. 175-198.

BERNARD, S. & R. de KONINCK (1996): The retreat of the forest in Southeast Asia. A cartographic assessment. – Singapore Journal of Tropical Geography. Vol. 17 (1). pp. 1-14.

BILSBORROW, R. (1994): Population, development and deforestation. Some recent evidence. – in: Population, Environment, and Development. – Department of Economic and Social Information and Policy Analysis, United Nations, pp. 117-134.

BLAIKIE, P. & H. BROOKFIELD (1987): Land Degradation and Society. – Routledge: London, New York.

BROOKFIELD, H. (1999): Environmental damage. Distinguishing human from geophysical causes. – Environmental Hazards. Vol. 1, pp. 3-11.

BROOKFIELD, H. & Y. BYRON (1990): Deforestation and timber extraction in Borneo and the Malay Peninsula. The record since 1965. – Global Environmental Change. Vol. 1, pp. 42-56.

BROWN, K. & D.W. PEARCE (Eds; 1994): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London.

BRYANT, R. L. & S. BAILEY (1997): Third world political ecology. - Routledge: London, New York.

BURNS, T., KICK, E.L., MURRAY, D.A. & D.A. MURRAY (1994): Demography, development and deforestation in a world-system perspective. – International Journal of Comparative Sociology. Vol. 35 (3/4), pp. 221-239.

CAPISTRANO, A.D. (1994): Tropical forest depletion and the changing macroeconomy. – In: K. BROWN & D.W. PEARCE (Eds): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London, pp. 68-85.

CAPISTRANO, A.D. & C.F. KIKER (1995): Macroscale economic influences on tropical forest depletion. – Ecological Economics. Vol. 14 (1), pp. 21-29.

COMMONER, B. (1972): The Closing Circle. – Knopf : New York.

COMMONER, B. (1990): Making Peace with the Planet. – Pantheon: New York.

CONTRERAS-HERMOSILLA, A. (2000): The Underlying Causes of Forest Decline. – (= CIFOR Occasional Paper; 30). – Center for International Forestry Research: Bogor.

CROPPER, M. & C. GRIFFITHS (1994): The interaction of population growth and environmental quality. – American Economic Review. Vol. 84 (2), pp. 250-254.

DEACON, R.T. (1994): Deforestation and the Rule of Law in a Cross-Section of Countries. – Land Economics. Vol. 70 (4), pp. 414-430.

DEACON, R.T. (1995): Assessing the Relationship between Government Policy and Deforestation. – Journal of Environmental Economics and Management. Vol. 28, pp. 1-18.

DEACON, R.T. (1999): Deforestation and Ownership. Evidence from Historical Accounts and Contemporary Data. – Land Economics. Vol. 75 (3), pp. 341-359.

DÖÖS, B.R. (2000): Increasing food production at the expense of tropical forests. – Integrated Assessment. Vol. 1, pp. 189-202.

EHRHARDT-MARTINEZ, K. (1998): Social Determinants of Deforestation in Developing Countries. A Cross-National Study. – Social Forces. Vol. 77 (2), pp. 567-586.

EHRLICH, P.R. & A.H. EHRLICH (1990): The Population Explosion. – Simon & Schuster: New York.

ELSTON, D.A. & S.T. BUCKLAND (1993): Statistical modeling of regional GIS data. An overview. – Ecological Modelling. Vol. 67 (1), pp. 81-102.

FAIRHEAD, J. & M. LEACH (1998): Reframing deforestation. Global analyses and local realities: studies in West Africa (= Global Environmental Change Series). – Routledge: London.

FAO/UNEP (1981): Tropical Forest Resources Assessment Project (= Technical Report; 1-3). – Food and Agriculture Organization of the United Nations & The United Nations Environment Programme: Rome, Nairobi.

GEIST, H. (1999): Exploring the Entry Points for Political Ecology in the International Research Agenda on Global Environmental Change. – Zeitschrift für Wirtschaftsgeographie. Vol. 43 (3/4), pp. 158-168.

GRAINGER, A. (1993): Controlling tropical deforestation. – Earthscan: London.

GULLISON, R.E. & E.C. LOSOS (1993): The role of foreign debt in deforestation in Latin America. – Conservation Biology. Vol. 7 (1), pp. 140-147.

HAMILTON, L.S. (1997): Current human impacts on forests. – in: BRUNE, D., CHAPMAN, D. V., GWYNNE, M.D. & J.M. PACYNA (Eds): The Global Environment. Vol. 1. – Scandinavian Science Publisher: Oslo, VCH: Weinheim, pp. 225-252.

HANSEN, S. (1989): Debt for nature swaps. Overview and discussion of key issues. – Ecological Economics. Vol. 1, pp. 77-93.

HECHT, S.B. (1985): Environment, Development and Politics. Capital Accumulation and the Livestock Sector in Eastern Amazonia. – World Development. Vol. 13 (6), pp. 663-84.

HECHT, S.B. (1993): The Logic of Livestock and Deforestation in Amazonia. Considering land markets, value of ancillaries, the larger macroeconomic context, and individual economic strategies. – BioScience. Vol. 43 (10), pp. 687-695.

HUSSON, A., FONTÉS, J., JEANJEAN, H., MIQUEL, C., PUIG, H. & C. SOLIER (1995): Study of forest non-forest interface. Typology of fragmentation of tropical forest (= TREES series B: Research Report EUR 16291 EN; 2). – European Commission.

INTERNATIONAL TECHNICAL TROPICAL TIMBER ASSOCIATION (ITTTA) & FAO (1999): Road infrastructures in tropical forests. Road to development or road to destruction? – Food and Agriculture Organisation of the United Nations: Rome.

KAHN, J. & J. McDONALD (1994): International debt and deforestation. – In: BROWN, K. & D.W. PEARCE (Eds): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London, pp. 57-67.

KAHN, J.R. & J.A. McDONALD (1995): Third-World Debt and Tropical Deforestation. – Ecological Economics. Vol. 12 (2), pp. 107-123.

KAIMOWITZ, D. & A. ANGELSEN (1998): Economic Models of Tropical Deforestation. A Review. - Centre for International Forestry Research: Jakarta.

KANT, S. & A. REDANTZ (1997): An econometric model of tropical deforestation. – Journal of Forest Economics. Vol. 3 (1), pp. 51-86.

KASPERSON, J.X., KASPERSON, R.E. & B.L. TURNER (1995; Eds): Regions at risk. Comparisons of threatened environments. - United Nations University Press: Tokyo, New York & Paris.

KENDALL, H.W. & D. PIMENTEL (1994): Constraints on the expansion of the global food supply. – Ambio. Vol. 23, pp. 198-205.

KIMSEY, M. (1991): A spatial analysis of the causes of tropical deforestation. – University of Georgia, Department of Geography (Ph.D. Thesis).

KOOP, G. & L. TOLE (1999): Is there an environmental Kuznets curve for deforestation ? – Journal of Development Economics. Vol. 58, pp. 231-244.

KRUTILLA, K., HYDE, W.F. & D. BARNES (1995): Periurban deforestation in developing countries. – Forest Ecology and Management. Vol. 74, pp. 181-195.

KUMMER, D.M. & B.L. TURNER II (1994): The Human Causes of Deforestation in Southeast Asia. The recurrent pattern is that of large-scale logging for exports, followed by agricultural expansion. – BioSience. Vol. 44 (5), pp. 323-328.

LAMBIN, E.F. (1994): Modelling deforestation processes. A review (= TREES Series B: Research Report; 1). – Office of Official Publications of the European Community: Luxembourg.

LAMBIN, E.F. (1997): Modelling and monitoring land-cover change processes in tropical regions. – Progress in Physical Geography. Vol. 21 (3), pp. 375-393.

LAMBIN, E.F., BAULIES, X., BOCKSTAEL, N., FISCHER, G., KRUG, T., LEEMANS, R., MORAN, E.F., RINDFUSS, R.R., SATO, Y., SKOLE, D., TURNER, B.L. II & C. VOGEL (1999): Land-Use and Land-Cover Change (LUCC) – Implementation Strategy. A core project of the International Geosphere-Biosphere Programme and the International Human Dimensions Programme on Global Environmental Change (= IGBP Report; 48/IHDP Report; 10). – IGBP Secretariat: Stockholm & IHDP Secretariat: Bonn.

LAMBIN, E.F., TURNER, B.L. II, GEIST, H.J., AGBOLA, S.B., ANGELSEN, A., BRUCE, J.W., COOMES, O., DIRZO, R., FISCHER, G., FOLKE, C., GEORGE, P.S., HOMEWODD, K., IMBERNON, J., LEEMANS, R., LI, X., MORAN, E.F., MORTIMORE, M., RAMAKRISHNAN, P.S., RICHARDS, J.F., SKÅNES, H., STEFFEN, W., STONE, G.D., SVEDIN, U., VELDKAMP, T.A., VOGEL, C. & J. XU (2001): The Causes of Land-Use and Land-Cover Change. Moving Beyond the Myths. – Global Environmental Change: Human and Policy Dimensions. Vol. 4 [in print].

LEACH, M. & J. FAIRHEAD (2000): Challenging neo-Malthusian deforestation analyses in West Africa's dynamic forest landscapes. – Population and Development Review. Vol. 26 (1), pp. 17-41.

LEACH, M., MEARNS, R. & I. SCOONES (1999): Environmental entitlements. Dynamics and institutions in community-based natural resource management. – World Development. Vol. 27 (2), pp. 225-247.

LEDEC, G. (1985): The political economy of tropical deforestation. – In: J.H. LEONARD (Ed): Diverting Nature's Capital. The Political Economy of Environmental Abuse in the Third World. – Holmes & Maier: New York, London, pp. 179-226.

LOHNERT, B. & H. GEIST (1999): Endangered Ecosystems and Coping Strategies. Towards a Conceptualization of Environmental Change in the Developing World. – In: Ibd. (Eds): Coping with Changing Environments. Social Dimensions of Endangered Ecosystems in the Developing World. – Ashgate: Aldershot, Brookfield, Singapore, Sydney, pp. 1-53.

MAINARDI, S. (1998): An econometric analysis of factors affecting tropical and subtropical deforestation. – Agrekon. Vol. 37 (1), pp. 23-62.

MATHER, A.S., NEEDLE, C.L. & J. FAIRBAIRN (1998): The human drivers of global land cover change. The case of forests. – Hydrological Processes. Vol. 12 (13/14). pp. 1983-1994.

MATHER, A.S., NEEDLE, C.L. & J. FAIRBAIRN (1999): Environmental kuznets curves and forest trends. – Geography. Vol. 84 (362), pp. 55-65.

MATHER, A.S. & C.L. NEEDLE (2000): The relationships of population and forest trends. – The Geographical Journal. Vol. 166 (1), pp. 2-13.

MENDELSOHN, R. (1994): Property Rights and Tropical Deforestation. - Oxford Economic Papers. Vol. 46 (5), pp. 750-756.

MENDELSOHN, R. & M. BALICK (1995) : Private property and rainforest conservation. – Conservation Biology. Vol. 9 (5), pp. 1322-1323.

MERTENS, B. & E. F. LAMBIN (1997): Spatial modelling of deforestation in southern Cameroon. Spatial disaggragation of diverse deforestation processes. – Applied Geography. Vol. 17 (2), pp. 143-162.

MEYER, W.B. & B.L. TURNER II (1992): Human population growth and global land-use/land-cover change. - Annual Review of Ecology and Systematics. Vol. 23, pp. 39-61.

MOLOTCH, H. (1976) : The city as a growth machine. Toward a political economy of place. – American Journal of Sociology. Vol. 82 (2), pp. 309-332.

MURALI, K.S. & R. HEDGE (1997): Patterns of tropical deforestation. – Journal of Tropical Forest Science. Vol. 9 (4), pp. 465-476.

MYERS, N. (1980): The Present Status and Future Prospects of Tropical Moist Forests. – Environmental Conservation. Vol. 7 (2), pp. 101-114.

MYERS, N. (1992): Tropical forests. The policy challenge. – Environmentalist. Vol. 12 (1), pp. 15-27.

MYERS, N. (1993): Tropical forests. The main deforestation fronts. – Environmental Conservation. Vol. 20 (1), pp. 9-16.

MYERS, N. (1994): Tropical deforestation: rates and patterns. – in: BROWN, K. & D.W. PEARCE (Eds): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London, pp. 27-40.

NATIONAL RESEARCH COUNCIL (1995): Finding the Forest in the Trees – The Challenge of Combining Diverse Environmental Data. Selected Case Studies. – National Academy Press: Washington, D.C.

NATIONAL RESEARCH COUNCIL (1999): Global Environmental Change. Research Patchways for the Next Decade. – National Academy Press: Washington, DC.

OJIMA, D.S., GALVIN, K.A. & B.L. TURNER II (1994): The Global Impact of Land-use Change. – BioScience. Vol. 44 (5), pp. 300-304.

OSTROM, E. (1990): Governing the Commons. The Evolution of Institution for Collective Action. – Cambridge University Press: Cambridge.

OSTROM, E., GARDNER, R. & J. WALKER (1994): Rules, Games, and Common-Pool Resources. – University of Michigan Press: Ann Arbor.

OSTROM, E., BURGER, J., FIELD, C.B., NORGAARD, R.B. & D. POLICANSKY (1999): Revisiting the Commons. Local Lessons, Global Challenges. – Science. Vol. 284, pp. 278-282.

PAINTER, M. & W.H. DURHAM (Eds; 1995): The Social Causes of Environmental Destruction in Latin America. – The University of Michigan Press: Ann Arbor.

PALO, M. (1994): Population and deforestation. – in: BROWN, K. & D. W. PEARCE (Eds): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London, pp. 42-56.

PALO, M. & G. MERY (Eds; 1995): Sustainable Forestry Challenges for Developing Countries (= Environmental Science and Technology Library; 10). – Kluwer Academic Publishers: Dordrecht, Boston, London.

PALO, M. & J. UUSIVUORI (Eds; 1999): World Forests, Society and Environment. – Kluwer Academic Publishers: Dordrecht, London, Boston.

PETSCHEL-HELD, G., LÜDEKE, M. & F. REUSSWIG (1999): Actors, Structures and Environments. A comparative and transdisciplinary view on regional case studies of global environmental change. – In: B. LOHNERT & H. GEIST (Eds.): Coping with Changing Environments. Social Dimensions of Endangered Ecosystems in the Developing World. – Ashgate: Aldershot, Brookfield, Singapore, Sydney, pp. 255-292.

PLUMWOOD, V. & R. ROUTLEY (1983): World rainforest destruction. The social factors. – The Ecologist. Vol. 3 (2), pp. 199-217.

RANJAN, R. & V.P. UPADHYAY (1999): Ecological problems due to shifting cultivation. – Current Science. Vol. 77 (10), pp. 1246-1250.

REPETTO, R. & M. GILLIS (1988): Public Policies and the Misuse of Forest Resources. – Cambridge University Press : Cambridge.

RERKASEM, B. (1996): Montane Mainland Southeast Asia in Transition. – Chiang Mai University Consortium: Chiang Mai.

RICHARDS, J.F. & R.P. TUCKER (Eds; 1988): World Deforestation in the Twentieth Century. – Duke University Press : Durham.

ROCK, M.T. (1996): The Stork, the Plow, Rural Social Structure and Tropical Deforestation in Poor Countries? – Ecological Economics. Vol. 18 (2), pp. 113-131.

RUDEL, T.K. (1989): Population, development, and tropical deforestation. A cross national study. – Rural Sociology. Vol. 54, pp. 327-338.

RUDEL, T. (1993): Tropical deforestation, Small Farmers and Land Clearing in the Ecudorian Amazon. – Columbia University Press: New York.

RUDEL, T.K. (1995): When Do Property Rights Matter? Open Acces, Informal Social Controls and Deforestation in the Ecuadorian Amazon. – Human Organization. Vol 54 (2), pp. 187-194.

RUDEL, T. & J. ROPER (1996): Regional Patterns and Historical Trends in Tropical Deforestation, 1976-1990. A Qualitative Comparative Analysis. – Ambio. Vol. 25 (3), pp. 160-166.

RUDEL, T. & J. ROPER (1997): The Paths to Rain Forest Destruction. Crossnational Patterns of Tropical Deforestation, 1975-90. – World Development. Vol. 25 (1), pp. 53-65.

SANDLER, T. (1993): Tropical deforestation. Markets and market failures. – Land Economics. Vol. 69 (3), pp. 225-233.

SHAFIK, N. (1994): Macroeconomic causes of deforestation. Barking up the wrong tree? – in: K. BROWN & D. W. PEARCE (Eds): The Causes of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forests. – University College London Press Ltd.: London, pp. 86-95.

SIERRA, R. & J. STALLINGS (1998): The dynamics and social organization of tropical deforestation in Northwest Ecuador, 1983-1995. – Human Ecology. Vol. 26 (1), pp. 135-161.

SPONSEL, L.E., HEADLAND, T.N. & R. BAILEY (Eds; 1996): Tropical Deforestation. The Human Dimension. - Columbia University Press: New York.

STERN, P.C., YOUNG, O.R. & D. DRUCKMAN (Eds; 1992): Global environmental change. Understanding the human dimensions. - National Academy Press: Washington, D.C.

TIETENBERG, T. (1992): Environmental and Natural Resource Economics. – HarperCollins: New York.

TUCKER, R.P. & J.F. RICHARDS (Eds; 1983): Global Deforestation and the Nineteenth Century World Economy. – Duke University Press: Durham.

TURNER, B. (1989): The Human Causes of Global Environmental Change. – in : R.S. DeFRIES & T.F. MALONE (Eds) : Global Change and Our Common Future. Papers from a Forum. – National Academy of Sciences : Washington, D.C.

TURNER, B.L. II & W.B. MEYER (1994): Global Land-Use and Land-Cover Change: An Overview. – in: MEYER, W.B. & B.L. TURNER II (Eds): Changes in Land Use and Land Cover: A Global Perspective. – University of Cambridge: Cambridge, New York, Melbourne, pp. 3-10.

TURNER, B.L. II, CLARK, W.C., KATES, R.W., RICHARDS, J.F., MATHEWS, J.T. & W.B. MEYER (Eds; 1990): The earth as transformed by human action. Global and regonal changes in the biosphere over the past 300 years. - Cambridge University Press (with Clark University): Cambridge, New York, Port Chester, Melbourne & Sydney.

TURNER, B.L., MOSS, R.H. & D.L. SKOLE (1993): Relating land use and global land-cover change. A proposal for IGBP-HDP core project (= IGBP Report; 24/HDP Report; 5).

TURNER, B.L. II, SKOLE, D., SANDERSON, S., FISCHER, G., FRESCO, C. & R. LEEMANS (1995): Land-use and Land-cover Change. Science/Research Plan (= IGBP Report; 35/HDP Report; 7).

UNEP (1992): The World Environment 1972-1992. – The United Nations Environment Programme: Nairobi.

UNEP (1997): Global Environment Outlook. – The United Nations Environment Programme, Oxford University Press: Oxford.

VANCLAY, J.K. (1993): Saving the tropical forest. Needs and prognosis. – Ambio. Vol. 22 (4), pp. 225-31.

WALKER, R.T. (1987): Land Use Transition and Deforestation in Developing Countries. – Geographical Analysis. Vol. 19 (1), pp. 18-30.

WALKER, R. (1993): Deforestation and Economic Development. – Canadian Journal of Regional Science/Revue canadienne des sciences régionales. Vol. 16 (3), pp. 481-197.

WALKER, R. (1999): The structure of uncultivated wilderness. Land use beyond the extensive margin. – Journal of Regional Science. Vol. 39 (2), pp. 387-409.

WALKER, R. & T.E. SMITH (1993): Tropical Deforestation and Forest Management under the System of Concession Logging. A Decision-Theoretic Analysis. – Journal of Regional Science. Vol. 33 (3), pp. 387 - 419.

WIBOWO, D.H. & R.N. BYRON (1999): Deforestation Mechanisms. A Survey. – International Journal of Social Economics. Vol. 26 (1/2/3), pp. 455-474.

WILLIAMS, M. (1990): Forests. - in: B.L. Turner II et al. (Eds): The earth as transformed by human action. Global and regonal changes in the biosphere over the past 300 years. - Cambridge University Press: Cambridge, pp. 179-202.

WILLIAMS, M. (1994): Forests and Tree Cover. - in: MEYER, W.B. & B.L. TURNER II (Eds): Changes in Land Use and Land Cover. A Global Perspective. – Press Syndicate of the University of Cambridge: Cambridge, New York, Melbourne, pp. 97-124.

WORLD RESOURCES INSTITUTE (1992): World Resources 1992-1993. – Oxford University Press.

WUNDER, S. (2000): The Economics of Deforestation. The Example of Ecuador. – Macmillan Press Ltd.: Houndmills, London; St. Martin's Press: New York.

Annex

List of case studies

ABBOT, Joanne I.O. & Katherine HOMEWOOD (1999): A history of change. Causes of miombo woodland decline in a protected area in Malawi. – Journal of Applied Ecology. Vol. 36 (3), pp. 422-433.

ANGELSEN, Arild (1995): Shifting Cultivation and „Deforestation". A Study from Indonesia. – World Development. Vol. 23 (10), pp. 1713-1729.

BAJRACHARYA, Deepak (1983): Fuel, Food or Forest? Dilemmas in a Nepali Village. – World Development. Vol. 11 (12), pp. 1057-1074.

BARBIER, Edward (1993): Economic aspects of tropical deforestation in Southeast Asia. – Global Ecology and Biogeography Letters. Vol. 3, pp. 215-234.

BARROS, Ana Cristina & Christopher UHL (1995): Logging along the Amazon River and estuary. Patterns, problems and potential. – Forest Ecology and Management. Vol. 77, pp. 87-105.

BERESFORD, Melanie & Lyn FRASER (1992): Political economy of the environment in Vietnam. – Journal of Contemporary Asia. Vol. 22 (1), pp. 3-19.

BLUFFSTONE, R.A. (1995): The effect of labor-market performance on deforestation in developing countries under open access. An example from rural Nepal. – Journal of Environmental Economics and Management. Vol. 29 (1), pp. 42-63.

BROOKFIELD, Harold & Yvonne BYRON (1990): Deforestation and timber extraction in Borneo and the Malay Peninsula. The record since 1965. – Global Environmental Change. Vol. 1, pp. 42-56.

BROTHERS, Timothy S. (1997): Deforestation in the Dominican Republic. A village-level view. – Environmental Conservation. Vol. 24 (3), pp. 213-223.[9]

CHOMITZ, Kenneth M. & David A. GRAY (1996): Roads, Land Use, and Deforestation. A Spatial Model Applied to Belize. – The World Bank Economic Review. Vol. 10 (3), pp. 487-512.

CHUAN, Goh Kim (1982): Environmental impact of economic development in Peninsular Malaysia. A review. – Applied Geography. Vol. 2, pp. 3-16.

CLINE-COLE, R.A., MAIN, H.A.C. & J.E. NICHOL (1990): On Fuelwood Consumption, Population Dynamics and Deforstation in Africa. – World Development. Vol. 18 (4), pp. 513-527.

COLCHESTER, Marcus (1993): Pirates, squatters and poachers. The political ecology of dispossession of the native peoples of Sarawak. – Global Ecology and Biogegraphy Letters. Vol. 3, pp. 158-179.

CROPPER, Maureen, GRIFFITHS, Charles & Muthukumara MANI (1999): Roads, Population Pressures, and Deforestation in Thailand, 1976-1989. – Land Economics. Vol. 75 (1), pp. 58-73.

DALE, Virginia H., O'NEILL, Robert V., PEDLOWSKI, Marcos & Frank SOUTHWORTH (1997): Causes and Effects of Land-Use Change in Central Rondônia, Brazil. – Photogrammetric Engineering & Remote Sensing. Vol. 59 (6), pp. 997-1005.

DEACON, Robert T. (1999): Deforestation and Ownership. Evidence from Historical Accounts and Contemporary Data. – Land Economics. Vol. 75 (3), pp. 341-359.[11]

DEI, George S. (1992): A Forest Beyond the Trees. Tree Cutting in Rural Ghana. – Human Ecology. Vol. 20 (1), pp. 57-88.[10]

DEININGER, Klaus W. & Bart MINTEN (1999): Poverty, Policies, and Deforestation. The Case of Mexico. – Economic Development and Cultural Change. Vol. 47 (2), pp. 313-344.

FEARNSIDE, P.M. (1993): Deforestation in Brazilian Amzonia. The Effect of Population and Land Tenure. – Ambio. Vol. 22 (8). pp. 537-545.

FEARNSIDE, P.M. (1997): Transmigration in Indonesia. Lessons from its environmental and social impacts. – Environmental Management. Vol. 21 (4). pp. 553-570.

FOX, Jefferson, KRUMMEL, John, YARNASARN, Sanay, EKASINGH, Methi & Nancy PODGER (1995): Land Use and Landscape Dynamics in Northern Thailand. Assessing Change in Three Upland Watersheds. – Ambio. Vol. 24 (6), pp. 328-334.

FRENCH, David (1986): Confronting an Unsolvable Problem. Deforestation in Malawi. – World Development. Vol. 14 (4), pp. 531-540.

FUJISAKA, S., BELL, W., THOMAS, N., HURTADO, L. & E. CRAWFORD (1996): Slash-and-burn agriculture, conversion to pasture, and deforestation in two Brazilian Amazon colonies. – Agriculture, Ecosystems and Environment. Vol. 59 (1/2), pp. 115-130.

GILRUTH, Peter T., HUTCHINSON, Charles F. & Bademba BARRY (1990): Assessing Deforestation in the Guinea Highlands of West Africa Using Remote Sensing. – Photogrammetric Engineering and Remote Sensing. Vol. 56 (10), pp. 1375-1382.

GODOY, Ricardo, GROFF, S. & K. O'NEILL (1998): The Role of Education in Neotropical Deforestation. Household Evidence from Amerindians in Honduras. – Human Ecology. Vol. 26 (4), pp. 649-675.

HARRISON, Susan (1991): Population growth, land use and deforestation in Costa Rica, 1950-1984. – Interciencia. Vol. 16 (2). pp. 83-93.

HECHT, Susanna B. (1993): The Logic of Livestock and Deforestation in Amazonia. Considering land markets, value of ancillaries, the larger macroeconomic context, and individual economic strategies. – BioScience. Vol. 43 (10), pp. 687-695.[12]

HIRSCH, Philip (1990): Forests, forest reserve, and forest land in Thailand. – The Geographical Journal. Vol. 156 (2), pp. 166-174.[13]

HUDAK, A.T. & C.A. WESSMAN (2000): Deforestation in Mwanza District, Malawi, from 1981 to 1992, as determined from Landsat MSS imagery. – Applied Geography. Vol. 20 (2), pp. 155-175.

HUMPHRIES, Sally (1998): Milk Cows, Migrants, and Land Markets. Unraveling the Complexities of Forest-to-Pasture Conversion in Northern Honduras. – Economic Development and Cultural Change. Vol. 47 (1), pp. 95-124.

IMBERNON, Jacques (1999): Changes in agricultural practice and landscape over a 60-year period in North Lampung, Sumatra. – Agriculture, Ecosystems & Environment. Vol. 76 (1), pp. 61-66.

IMBERNON, Jacques (1999): A Comparison of the Driving Forces Behind Deforestation in the Peruvian and the Brazilian Amazon. – Ambio. Vol.28 (6), pp. 509-513.

IMBERNON, Jacques (1999): Pattern and development of land-use changes in the Kenyan highlands since the 1950s. – Agriculture, Ecosystems and Environment. Vol. 76 (1), pp. 67-73.

INDRABUDI, H., GIER, A. de & L.O. FRESCO (1998): Deforestation and its driving forces. A case study of Riam Kanan watershed, Indonesia. – Land Degradation & Development. Vol. 9 (4), pp. 311-322.

JAROSZ, Lucy (1993): Defining and Explaining Tropical Deforestation. Shifting Cultivation and Population Growth in Colonial Madagascar (1896-1940). – Economic Geography. Vol. 69 (4), pp. 366-379.

KAIMOWITZ, David (1997): Factors Determining Low Deforestation. The Bolivian Amazon. – Ambio. Vol. 26 (8), pp. 537-540.

KAIMOWITZ, David, THIELE, Graham & Pablo PACHECO (1999): The Effects of Structural Adjustment on Deforestation and Forest Degradation in Lowland Bolovia. – World Development. Vol. 27 (3), pp. 505-520.

KALIPENI, E. & D. FEDER (1999): A political ecology perspective on environmental change in Malawi with the Blantyre Fuelwood Project Area as a case study. – Politics and the Life Sciences. Vol. 18 (1), pp. 37-54.

KARTAWINATA, Kuswata, ADISOEMARTO, Soenartono, RISWAN, Soedarsono & Andrew P. VAYDA (1981): The Impact of Man on a Tropical Forest in Indonesia. – Ambio. Vol. 10 (2/3), pp. 115-119.

KING, Victor T. (1993): Politik pembangunan. The political economy of rainforest exploitation and development in Sarawak, East Malaysia. – Global Ecology and Biogeography Letters. Vol. 3, pp. 235-244.

KRAMER, Randall A., RICHTER, Daniel D., PATTANAYAK, Subhrendu & Narendra P. SHARMA (1997): Ecological and economic analysis of watershed protection in Eastern Madagascar. – Journal of Environmental Management. Vol. 49 (3). pp. 277-295.[14]

KUMMER, David M., CONCEPCION, Roger & Bernardo CANIZARES (1994): Environmental Degradation in the Uplands of Cebu. – The Geographical Review. Vol. 84 (3), pp. 266-276.[15]

KUMMER, David M. & Billie L. TURNER II (1994): The Human Causes of Deforestation in Southeast Asia. The recurrent pattern is that of large-scale logging for exports, followed by agricultural expansion. – BioSience. Vol. 44 (5), pp. 323-328.

LAWRENCE, Deborah, PEART, David R. & Mark LEIGHTON (1998): The impact of shifting cultivation on a rainforest landscape in West Kalimantan: spatial and temporal dynamics. – Landscape Ecology. Vol. 13 (3), pp. 135-148.

LEACH, M. & J. FAIRHEAD (2000): Challenging neo-Malthusian deforestation analyses in West Africa's dynamic forest landscapes. – Population and Development Review. Vol. 26 (1), pp. 17-43.

LOHMANN, Larry (1993): Land, power and forest colonization in Thailand. – Global Ecology and Biogeography Letters. Vol. 3, pp. 180-191.

MARQUETTE, Catherine M. (1998): Land Use Patterns Among Small Farmer Settlers in the Northeastern Ecuadorian Amazon. – Human Ecology. Vol. 26 (4). pp. 573-598.

MASSART, Michel, PÉTILLION, Marie & Eléonore WOLFF (1995): The Impact of an Agricultural Development Project on a Tropical Forest Environment. The Case of Shaba (Zaïre). – Photogrammetric Engineering & Remote Sensing, Vol. 61 (9). pp. 1153-1158.

McCRACKEN, Stephen D., BRONDIZIO, Eduardo S., NELSON, Donald, MORAN, Emilio F., SIQUEIRA, Andrea D. & RODRIGUEZ-PEDRAZA, Carlos (1999): Remote Sensing and GIS at Farm Property Level: Demopgraphy and Deforestation in the Brazilian Amazon. – Photogrammetric Engineering & Remote Sensing. Vol. 65 (11), pp. 1311-1320.

MENDOZA, E. & DIRZO, Rodolfo (1999): Deforestation in Lacandonia (southeast Mexico). Evidence for the declaration of the northernmost tropical hot-spot. – Biodiversity and Conservation. Vol. 8 (12), pp. 1621-1641.

MERTENS, Benoît & Eric F. LAMBIN (2000): Land cover-change trajectories in southern Cameroon. – Annals of the Association of American Geographers. Vol. 90 (3), pp. 467-494.[16]

MERTENS, Benoît, SUNDERLIN, W., NDOYE, O. & Eric F. LAMBIN (2000): Impact of macroeconomic change on deforestation in South Cameroon: Integration of household survey and remotely-sensed data. – World Development. Vol. 28 (6), pp. 983-999.

MORAN, Emilio F. (1993): Deforestation and land use in the Brazilian Amazon. – Human Ecology. Vol. 21 (1). pp. 1-21.

MORAN, Emilio F., BRONDIZIO, Eduardo & Paul MAUSEL (1994): Secondary Succession. – Research & Exploration. Vol. 10 (4), pp. 458-476.[17]

MORAN, Emilio F., BRONDIZIO, Eduardo, MAUSEL, Paul & You WU (1994): Integrating Amazonian Vegetation, Land-use, and Satellite data. – BioScience. Vol. 44 (5), pp. 329-338.

NEPSTAD, Daniel C., VERISSIMO, Adalberto, ALENCAR, Ane, NOBRE, Carlos, LIMA, Eirivelthon, LEFEBVRE, Paul, SCHLESINGER, Peter, POTTER, Christopher, COCHRANE, Mark & Vanessa BROOKS (1999): Large-scale impoverishment of Amazonian forests by logging and fire. – Nature. Vol. 398 (6727), pp. 505-508.

OCHOA-GAONA, S. & M. GONZALEZ-ESPINOSA (2000): Land use and deforestation in the highlands of Chiapas, Mexico. – Applied Geography. Vol. 20 (1), pp. 17-42.

OSEI, William Y. (1993): Woodfuel and Deforestation. Answers for a Sustainable Environment. – Journal of Environmental Management. Vol. 37, pp. 51-62.

PAULSON, D.D. (1994): Understanding Tropical Deforestation. The Case of Western Samoa. – Environmental Conservation. Vol. 21 (4), pp. 326-332.

PEDLOWSKI, Marcos A., DALE, Virginia H., MATRICARDI, Eraldo A.T. & Eliomar Pereira da SILVA FILHO (1997): Patterns and impacts of deforestation in Rondônia, Brazil. – Landscape and Urban Planning. Vol. 38, pp. 149-157.

PFAFF, Alexander S.P. (1999): What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data. – Journal of Environmental Economics and Management. Vol. 37 (1), pp. 26-43.[18]

PICHÓN, Franciso J. (1997): Settler Households and Land-Use Patterns in the Amazon Frontier: Farm-Level Evidence from Ecuador. – World Development. Vol. 25 (1), pp. 67-91.

REID, John W. & Ian A. BOWLES (1997): Reducing the Impacts of Roads on Tropical Forests. – Environment. Vol. 39 (8), pp. 11-13, 32-35.

REMIGIO, Amador A. (1993): Philippine forest resource policy in the Marcos and Aquino governments: A comparative assessment. – Global Ecology and Biogeography Letters. Vol. 3, pp. 192-212.

RICHARDS, John F. (1987): Environmental changes in Dehra Dun Valley, India, 1880-1980. – Mountain Research and Development. Vol. 7, pp. 299-304.

RIGG, Jonathan (1993): Forests and farmers, land and livelihoods, changing resource realities in Thailand. – Global Ecology and Biogeography Letters. Vol. 3, pp. 277-289.

RUDEL, Thomas K. (1995): When Do Property Rights Matter? Open Access, Informal Social Controls, and Deforestation in the Ecuadorian Amazon. – Human Organization. Vol. 54 (2), pp. 187-194.

SADER, S.A., SEVER, T., SMOOT, J.C., RICHARDS, M. & C.A. BEHRENS (1994): Forest change estimates for the Northern Petén region of Guatemala - 1986-1990. – Human Ecology. Special issue: Recent advances in the regional analysis of indigenous land use and tropical deforestation. Vol. 22 (3), pp. 317-332.

SADER, S.A. & A.T. JOYCE (1988): Deforestation rates and trends in Costa Rica, 1940 to 1983. – Biotropica. Vol. 20, pp. 11-19.

SAMBROOK, Richard A., PIGOZZI, Bruce W. & Robert N. THOMAS (1999): Population pressure, deforestation, and land degradation. A case study from the Dominican Republic. – Professional Geographer. Vol. 51 (1), pp. 25-40.

SCHREIER, Hans, BROWN, Sandra, SCHMIDT, Margaret, SHAH, Pravakar, SHRESTHA, Bubhan, NAKARMI, Gopal, SUBBA, Khagendra & Susanne WYMANN (1994): Gaining Forests But Losing Ground. A GIS Evaluation in a Himalayan Watershed. – Environmental Management. Vol. 18 (1), pp. 139-150.

SCHWEIK, Charles M., ADHIKARI, Keshav & Kala Nidhi PANDIT (1997): Land-cover change and forest institutions. A comparison of two sub-basins in the southern Siwalik Hills of Nepal. – Mountain Research and Development. Vol. 17 (2), pp. 99-116.

SIERRA, Rodrigo (1999): Traditional resource-use systems and tropical deforestation in a multiethnic region in North-west Ecuador. – Environmental Conservation. Vol. 26 (2), pp. 136-145.

SIERRA, Rodrigo (2000): Dynamics and patterns of deforestation in the western Amazon. The Napo deforestation front, 1986-1996. – Applied Geography. Vol. 20 (1), pp. 1-16.

SIERRA, R. & J. STALLINGS (1998): The dynamics and social organization of tropical deforestation in Northwest Ecuador, 1983-1995. – Human Ecology. Vol. 26 (1), pp. 135-161.

SKOLE, David L., CHOMENTOWSKI, W.H., SALAS, W.A. & A.D. NOBRE (1994): Physical and Human Dimensions of Deforestation in Amazonia. In the Brazilian Amazon, regional trends are influenced by large-scale external forces but mediated by local conditions. – BioScience. Vol. 44 (5), pp. 314-322.[19]

SMIL, Vaclav (1983): Deforestation in China. – Ambio. Vol. 12 (5), pp. 226-231.

SOHN, Youngsinn S., MORAN, Emilio & Francisco GURRI (1999): Deforestation in North-Central Yucatan (1985-1995): Mapping Secondary Succession of Forest and Agricultural Land Use in Sotuta Using the Cosine of the Angle Concept. – Photogrammetric Engineering and Remote Sensing. Vol. 65 (8), pp. 947-958.

SOUTHGATE, Douglas, SIERRA, Rodrigo & Lawrence BROWN (1991): The Causes of Tropical Deforestation in Ecuador. A Statistical Analysis. – World Development. Vol. 19 (9), pp. 1145-1151.

SOUTHGATE, Douglas & Morris WHITAKER (1992): Promoting Resource Degradation in Latin America. Tropical Deforestation, Soil Erosion, and Coastal Ecosystem Disturbance in Ecuador. – Economic Development and Cultural Change. Vol. 40 (4), pp. 787-807.

STONICH, Susan C. (1989): The Dynamics of Social Processes and Environmental Destruction. A Central American Case Study. – Population and Development Review. Vol. 15 (2), pp. 269-296.

STONE, Thomas A., BROWN, I. Foster & George M. WOODWELL (1991): Estimation, by remote sensing, of deforestation in central Rondonia, Brazil. – Forest Ecology and Management. Vol. 38, pp. 291-304.

STONE, Thomas A. & P. LEFEBVRE (1998): Using multi-temporal satellite data to evaluate selective logging in Para, Brazil. – International Journal of Remote Sensing. Vol. 19 (13), pp. 2517-2526.

SUSSMAN, Robert W., GREEN, Glen M. & Linda K. SUSSMAN (1994): Satellite Imagery, Human Ecology, Anthropology, and Deforestation in Madagascar. – Human Ecology. – Vol. 22 (3), pp. 333-354.[20]

TAYLOR, D.M., HORTIN, D., PARNWELL, M.J.G. & T.K. MARSDEN (1994): The Degradation of Rainforests in Sarawak, East Malaysia, and its Implications for Future Management Policies. – Geoforum. Vol. 25 (3), pp. 351-369.

THAPA, G.B. (1998): Issues in the conservation and management of forests in Laos. The case of Sangthong District. – Singapore Journal of Tropical Geography. Vol. 19 (1). pp. 71-91.

UHL, Christopher, VERÍSSIMO, Adalberto, MATTOS, Marli Maria, BRANDINO, Zeni & Ima Célia Guimãraes VIEIRA (1991): Social, economic, and ecological consequences of selective logging in an Amazon frontier. The case of Tailândia. – Forest Ecology and Management. Vol. 46, pp. 243-273.

VERÍSSIMO, Adalberto, BARRETO, Paulo, MATTOS, M., TARIFA, Ricardo & Christopher UHL (1992): Logging impacts and prospects for sustainable forest management in an old Amazonian frontier. The case of Paragominas. – Forest Ecology and Management. Vol. 55, pp. 169-199.

VERÍSSIMO, Adalberto, BARRETO, Paulo, TARIFA, Ricardo & Christopher UHL (1995): Extraction of a high-value natural resource in Amazonia. The case of Mahagony. – Forest Ecology and Management. Vol. 72, pp. 39-60.

VIÑA, Andrés & Jaime CAVELIER (1999): Deforestation Rates (1938-1988) of Tropical Lowland Forests on the Andean Foothills of Colombia. – Biotropica. Vol. 31 (1), pp. 31-36.

WALLACE, Ben J. (1995): How Many Trees Does it Take to Cook a Pot of Rice? Fuelwood and Tree Consumption in Four Philippine Communities. – Human Organization. Vol. 54 (2), S. 182-186.

WILKIE, David S. & John T. FINN (1988): A spatial model of land use and forest regeneration in the Ituri forest zone of Northeastern Zaire. – Ecological Modelling. Vol. 41, pp. 307-323.

XU, Jianchu, FOX, Jefferson, XING, Lu, PODGER, Nancy, LEISZ, Stephen & Ai XIHUI (1999): Effects of swidden cultivation, state policies, and customary institutions on land cover in a Hani village, Yunnan, China. – Mountain Research and Development. Vol. 19 (2), pp. 123-132.

YOUNG, Kenneth R. (1996): Threats to biological diversity caused by coca/cocaine deforestation in Peru. – Environmental Conservation. Vol. 23 (1), pp. 7-15.

YOUNG, Kenneth R., CHURCH, W.B., LEO, M. & P.F. MOORE (1994): Threats to Rio Abiseo National Park, northern Peru. – Ambio. Vol. 23, pp. 312-314.

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