ANNEXES

Annex 1
Definitions and conversion factors

DEFINITIONS OF "CITY" AND OTHER RELATED TERMS

Defining a city seems, as a first step, a rather simple issue – a single political jurisdiction that contains the historical city centre. But immediately questions arise. Not all historical centres are core to the built-up areas we know as cities. The political jurisdiction of these areas extends far beyond a rather small historical centre. From a statistical approach, a number of countries (105) base their urban data on administrative criteria while another group (100) refers to size or population density. Thus, beyond the city definition and concept, in terms of livelihood and energy supply/demand, we should refer to *cities*, *urban agglomerations* and *megacities* as representing aspects of the same phenomenon. Cities are the reference unit in policy and institutional terms, while the urban agglomeration results from clusters of new and old settlements leading to a noticeable urban area not necessarily coinciding with the city boundaries.

The United Nations defines an urban agglomeration as a built-up or densely populated area containing the city itself, the suburbs and continuously settled commuter areas; in this sense it does not coincide with a *metropolitan* area, i.e. the term referring to a set of formal local government areas that normally comprise the urban area as a whole plus its primary commuter areas. Megacities represent continuous dense settlements with more than 10 million residents (sometimes called metacities or hypercities, referring to a number of residents exceeding 20 million).

Urbanscape, or urban landscape, refers to the complex of biotic organisms, abiotic factors and human-induced processes that interact over time in a landscape characterized by the prevailing presence of a city.

Urbanization refers to a process in which an increasing proportion of an entire population lives in cities and suburbs. It is defined as the increase in population density or extent of cities and towns over time, or a combination of these factors. With reference to a specific place, urbanization means increased spatial scale and/or density of settlement and/or business and other activities in the area over time. The process may occur either as a natural expansion of the existing population (usually not a major factor since urban reproduction tends to be lower than rural), the transformation of the peripheral population from rural to urban, incoming migration, or a combination of these factors. In all cases, urbanization has a considerable effect on the ecology of a region and on its economy; the process of urbanization and urban development implies substantial and dramatic changes affecting the landscape, a new hierarchy in land use and an abrupt shift in the arrangement of spatial and time patterns in living conditions and use of resources.

DEFINITIONS OF URBAN AND PERI-URBAN FORESTS AND FORESTRY

Urban forest "the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan regions" (Miller, 1997)

Urban forestry "an integrated, city-wide approach to the planting, care and management of trees in the city to secure multiple environmental and social benefits for urban dwellers" (Miller, 1997)

Urban forest or **woodland** "a forest ecosystem (or rather: an area of land dominated by tree vegetation) in or near a specific urban area, of which the use and related decision-making processes are dominated by urban actors and their interests, values and norms" (Konijnendijk, 1999)

City forest "an area – thought of and managed as a forest – in or near a city, of which the use by the inhabitants of the city concerned is significantly greater than the use by others. A city forest is accessible and within reach for all inhabitants of the city concerned" (Konijnendijk and Vlasman, 1993)

DEFINITIONS OF SELECTED WOOD ENERGY TERMS

These definitions are taken from *Unified Bioenergy Terminology* (UBET) (FAO, 2004a).

Bioenergy	Energy from biofuels
Biofuel	Fuel produced directly or indirectly from biomass
Biomass	Material of biological origin, excluding material embedded in geological formations and transformed to fossil
Charcoal	Solid residue derived from carbonization, distillation, pyrolysis and torrefaction of fuelwood
Demolition wood	Used wood from demolition of buildings or civil engineering installations
Energy forest trees	Woody biomass grown specifically for its fuel value in medium- to long-rotation forestry
Energy plantation trees	Woody biomass grown specifically for its fuel value as short-rotation trees
Firewood	Cut and split oven-ready fuelwood used in household wood-burning appliances such as stoves, fireplaces and central heating systems. Firewood usually has a uniform length, typically in the range of 150–500 mm
Forest fuel	Woodfuel produced where the raw material has not previously had another use. It is produced directly from forest wood by a mechanical process
Fuelwood	Woodfuel where the original composition of the wood is preserved. This category includes wood in the raw and residues from wood-processing industries
Renewable energy	Energy produced and/or derived from sources infinitely renovated (hydro, solar, wind) or generated by combustible renewables (sustainably produced biomass); usually expressed in energy units and, in the case of fuels, based on net calorific values
Wood energy systems	All the (steps and/or) unit processes and operations involved in the production, preparation, transportation, marketing, trade and conversion of woodfuels into energy
Wood energy	Energy derived from woodfuels corresponding to the net calorific value of the fuel
Woodfuel	All types of biofuels originating directly or indirectly from woody biomass. This category includes fuelwood, charcoal and black liquor (the latter is not significant in the context of this study since its cycle is entirely within the paper industry)

BASIC PARAMETERS AND CONVERSION FACTORS

Wood – Net calorific value (30 percent moisture content, dry basis)	13.8	MJ/kg
Charcoal – Net calorific value (5 percent moisture content, dry basis)	30.8	MJ/kg
Charcoal/fuelwood	165	kg charcoal/m^3
Wood density (air dry)	725	kg/m^3
Wood density (oven dry)	593	kg/m^3

Annex 2
GFPOS model projections 1970–2030

The FAO Global Forest Products Outlook Study (GFPOS) produced fuelwood and charcoal consumption projections for the period 1970–2030 for all countries of the world, based on existing survey data and modelling techniques (FAO, 2001a).

The broad aim of the modelling exercise was to supply best possible estimates of fuelwood and charcoal consumption to fill information gaps on forest products in the online Corporate Database for Substantive Statistical Data (FAOSTAT). It responded to concern over previous FAO estimation procedures, basically projecting woodfuel consumption on population growth, which were considered too simplistic.

GFPOS models were based on a range of independent explanatory variables, which included:

- per capita gross domestic product (GDP) purchasing power parity (ppp) in US$ (1997)
- forest area per capita
- urban proportion of the population
- oil production in barrels per capita (1997)
- national land area in thousands of hectares
- temperature
- dummy variables determined for each country.

Country estimates were based on national, regional or global models, depending on the data available. Seventeen models were developed – nine for fuelwood consumption (Table A2.1) and eight for charcoal consumption, belonging to two sets:

- one based only on FAOSTAT, limited to countries that supplied at least ten valid questionnaires, used to estimate and project total fuelwood and charcoal consumption;
- another based on all available information, including a relatively rich data set of national and subnational field surveys assembled for the purpose from "grey" literature and FAOSTAT, used to estimate household and non-household fuelwood consumption and total charcoal consumption.

TABLE A2.1
GFPOS model types of fuelwood consumption and countries of application

Fuelwood consumption models		
Model type		**Countries**
FAOSTAT 1	FAOSTAT model relating the log of total national fuelwood consumption to the log of GDP ppp in US$ (1997)	14
FAOSTAT 2	FAOSTAT model relating the log of total national fuelwood consumption to the log of population	12
FAOSTAT 3	FAOSTAT model relating the log of per capita fuelwood consumption to the log of per capita GDP ppp in US$ (1997)	20
FAOSTAT linear	F linear-FAOSTAT model relating total national fuelwood consumption to GDP ppp in US$ (1997)	2
FAOSTAT constant	F constant-constant total national fuelwood assumption	1
National household model + national non-household model		2
National household model + continental non-household model		11
Regional household model + continental non-household model		142
Regional household model + national non-household model		1

The FAOSTAT fuelwood consumption models were based on the fuelwood fraction of the broader FAOSTAT category "woodfuel including wood for charcoal".

Beyond providing "gap filling" estimates, a promising additional application of GFPOS modelling is to serve as an adjustment function for short- and long-term consumption projections based on new reference data.

The data set collected and harmonized for model development includes data from over 160 countries on woodfuel consumption at national and subnational level, by sector and by area over the period 1960–1999. The data set is extremely heterogeneous in terms of representativity and reliability but nonetheless represents a valuable effort that deserves to be pursued.

TABLE A2.2
GFPOS model types of charcoal consumption and countries of application

Charcoal consumption models		
Model type		**Countries**
F1 FAOSTAT	FAOSTAT model relating the log of total national charcoal consumption to the log of GDP ppp in US$ (1997)	3
F2 FAOSTAT	FAOSTAT model relating the log of total national charcoal consumption to the log of population	1
F3 FAOSTAT	FAOSTAT model relating the log of per capita charcoal consumption to the log of per capita GDP ppp in US$ (1997)	1
F4 FAOSTAT	FAOSTAT model relating the log of per capita charcoal consumption to the urban proportion of the population	2
FAOSTAT linear	FAOSTAT model relating total national fuelwood consumption to the urban proportion of the population	6
FAOSTAT constant	Constant total national fuelwood assumption	1
Global total consumption model		180
National total consumption model		11

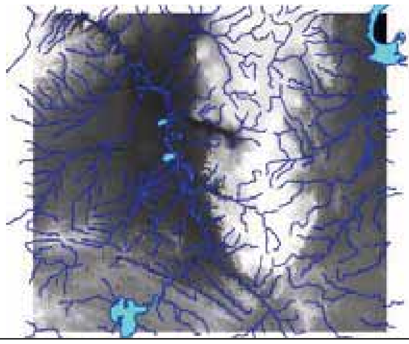
Annex 3
Cost maps as the basis for the assessment of physical accessibility

In order to simulate, as best possible, the efforts necessary to bring woodfuels from production sites to selected urban areas, and not simply the linear distance from their origin, the analysis procedure included the use of cost maps based on slope, derived from the digital terrain model, and on the distance from roads and settlements (Lorenzini, pers. com., 1999a). The production procedure for these cost maps is illustrated in Figure A3.1

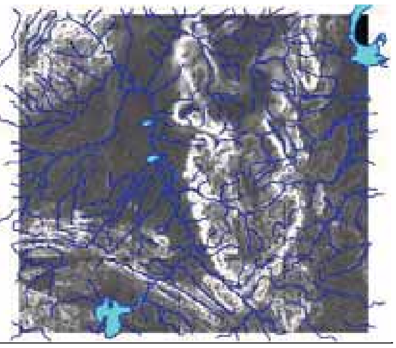
FIGURE A3.1
Cost map development procedure

Step 1. A slope map was generated from the global 30 arc-sec GTOPO30 digital elevation model of the Eros Data Center (ed: 1997), expressed as a percentage rise. The slope, varying from 0 (0°) to infinite (90°), was assumed to be the cost in crossing each specific cell of the slope raster map.

Digital elevation model (DEM)



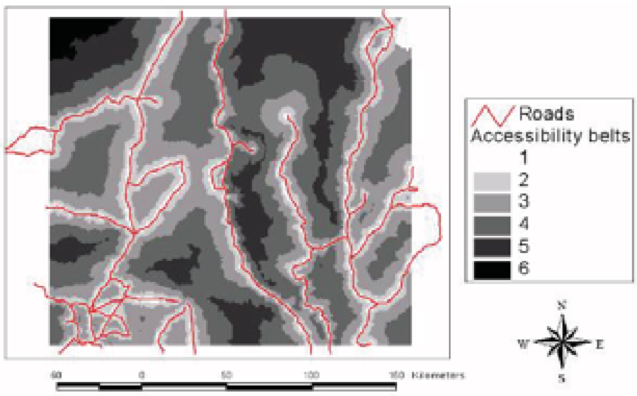
Slope map



Step 2. A raster map was generated as the least accumulative cost surface resulting from the function
sum(cost * distance_from_roads)
estimated from all the roads mapped in the Digital Chart of the World (DCW), as shown on the right.

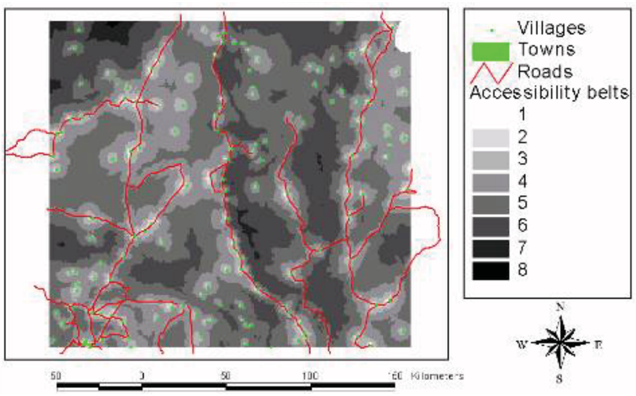
Step 3. A raster map was generated as the least accumulative cost surface resulting from the function
sum(cost * distance_from_villages/towns)
estimated from all the villages/towns mapped in the DCW.

Cost map based on distance from roads and slope



Step 4. The final cost map, shown on the right, was produced by combining the two maps obtained during steps 2 and 3 with the following formula:
finalcost = int(ln(cost_urban*cost_road))+1

Cost map based on distance from roads, settlements and slope



Source: Lorenzini, 1999b.

Annex 4

Main steps of urban woodshed analysis based on East African and Southeast Asian WISDOM data

A brief description is given of the analytical steps undertaken for the delineation of woodfuel supply zones (urban woodsheds) in selected urban centres in East Africa and Southeast Asia.

The cities selected from the East African data set are Dar-es-Salaam and Arusha-Moshi in the United Republic of Tanzania; Kampala in Uganda; and Khartoum in the Sudan. Those from the Southeast Asian data set are Phnom Penh and Battambang in Cambodia; and Vientiane and Luang Prabang in the Lao People's Democratic Republic.

TABLE A4.1
Available layers

East Africa	Southeast Asia
Woodfuel consumption data: estimated consumption of woody biomass in 5 arc-min cells (9 km at the equator) by urban, rural settlements and rural dwellers	Woodfuel consumption data: estimated consumption of woody biomass in 30 arc-sec pixels (0.9 km at the equator) by urban, rural settlements and rural dwellers
Potential sustainable productivity of woody biomass (high resolution Africover vector data and 5 arc-min cells) Total woody biomass stocking based on LCCS class definitions (FAO, 2005c) Estimated annual increment of woody biomass from high resolution LCCS vector data and field references	Potential sustainable productivity of woody biomass (30 arc-sec pixels) Total woody biomass stocking based on the Global Land Cover (GLC) map (2000). Tree cover percentage and field references (30 arc-sec) Estimated annual increment of woody biomass from high resolution LCCS vector data

ADDITIONAL GIS PROCESSING FOR WOODSHED ANALYSIS

Definition of accessibility restrictions based on legal factors (protected areas) for the East African data set

The main steps were the following.

- Downloading of latest IUCN WCMC protected area maps. Merging of IUCN area categories and other relevant non-IUCN designated areas into a single protected area map.

  National parks and other areas dedicated to the conservation of nature present various levels of restriction on the exploitation of wood resources. In order to account for these legal constraints, a tentative "legal accessibility factor" was allocated to the protected areas on the basis of IUCN definitions of protected area management categories. On this basis, as for the Southeast Asian WISDOM study, it was assumed that categories I to III give no access to wood exploitation, while categories IV and V allow controlled exploitation by local communities, tentatively estimated at 50 percent; category VI allows even greater access, indicatively estimated at 75 percent.

- Intersecting protected area map and land cover and woody biomass data at the resolution of the original LCCS data set (FAO, 2005c) in order to assign the legal accessibility factor to land cover and biomass data.
- Recalculating stock and increment according to the new polygon areas.
- Calculating legally accessible increment according to protection level.

The analysis of legal accessibility was limited to East African countries since it was already available for Southeast Asia.

Definition of the share of woody biomass available for local consumption and for urban wood energy markets

Deduction of industrial roundwood production and estimation of woody biomass available for local consumption

Deduction of industrial roundwood was re-estimated for selected East African countries on the basis of the most recent FAOSTAT references, with the following results.

- The total Tanzanian production of industrial roundwood (all wood extracted except woodfuels) for the year 2000 was estimated at 2.3 million m^3, approximately 1.7 million tonnes (FAOSTAT, 2006). This amount was deducted entirely from the legally accessible dense forest formations (suitability class 1 in Table A4.2), whose energy-available increment was reduced by 6.3 percent.
- In Uganda, industrial roundwood for 2000 was estimated at 3.2 million m^3, approximately 2.3 million tonnes (FAOSTAT, 2006). This amount was deducted entirely from the legally accessible dense forest formations (suitability class 1 in Table A4.2), whose energy-available increment was reduced by 33.9 percent (factor 0.6613).
- In the Sudan, industrial roundwood for 2000 was estimated at 2.1 million m^3, approximately 1.6 million tonnes (FAOSTAT database ed. 2006). This amount was deducted entirely from the legally accessible dense forest formations (suitability class 1 in Table A4.2), whose energy-available increment was reduced by 28.7 percent (factor 0.713).

The woody biomass available for local consumption was estimated from all land cover classes from legally accessible areas, by application of assumed constraints to the exploitation of woody resources based on IUCN categories and deduction of industrial roundwood (amount deducted entirely from dense productive formations). An additional reduction of 10 percent was made on account of other non-energy uses (posts, poles, etc.) and of resources not accessible for other reasons.

This analysis was carried out for African countries only since the values originally used for Southeast Asia were up to date.

Estimation of woody biomass available and suitable for commercial charcoal and fuelwood production for urban markets

The basic assumptions are that:

- local consumption (within a few kilometres from the resource location) makes use of woody biomass growing in all land cover classes, including farmlands, degraded shrub formations, etc. while commercial fuelwood and charcoal production for distant urban centres takes place prevalently in dense tree formations;
- the resource available and suitable for commercial fuelwood and charcoal production was assessed according to the estimated productive capacities (restricted approach) as well as after deduction of the woody biomass needed to satisfy local needs (expanded approach). In this second approach, the resource available for urban centres was limited to surplus amounts resulting from local supply/demand balance.

The woody biomass available and suitable for commercial fuelwood and charcoal production for urban markets was limited to that in natural tree and woody formations of higher density, assuming that they would be more suitable from a commercial perspective in guaranteeing an acceptable return for the investment. A minimum stocking value for profitable charcoal production, if available, could be used to define the commercial/non-commercial threshold (*Question*: What is the minimum stocking/ha for economically viable charcoal production?)

This subset was determined on the basis of class description (denser tree and woody formations).

- For the East African data set, based on LCCS, the commercial sources were limited tentatively to the suitability classes ranked 1 to 3 in Table A4.2.
- For the Southeast Asian data set, based on GLC (2000), the commercial sources were limited tentatively to land cover classes 1 to 9, as shown in Table A4.3.

In the delineation of the expanded supply zones, the woody biomass available for urban markets was estimated considering the supply/demand balance and not only the accessible (total or commercial) productivity. For the expanded-total supply zone the estimate considered the entire surplus from local supply/demand balance.

For the expanded-commercial supply zone, the estimate considered that only the commercially suitable surplus would be available for urban consumption. In this case, a commercial balance (Comm_bal_t) was estimated. This implied the accounting of deficit conditions as such but, for surplus conditions, the available resource was limited to its potentially commercial share, as follows:

if Local balance (Loc_bal_t)	<= 0	(deficit or balanced condition),
		then Comm_bal_t = Loc_bal_t
if Local balance (Loc_bal_t)	>0	(surplus condition) and Comm_wbio_t < Loc_bal_t,
		then Comm_bal_t = Comm_wbio_t
if Local balance (Loc_bal_t)	>0	(surplus condition) and Comm_wbio_t > Loc_bal_t,
		then Comm_bal_t = Loc_bal_t

TABLE A4.2
Woody biomass resources by categories of suitability for woodfuel production for urban markets based on LCCS (FAO, 2005c)*

Rank	Suitability for fuelwood and charcoal production for urban markets	Description	Legally accessible woody biomass increment	Woody biomass annually available for energy use after deduction of industrial roundwood and unproductive margin	
			(t^6)	(t^6)	(%)
1	High suitability	Closed tree and/or woody formations, medium-high homogeneity	26.8	22.6	39
2	Medium suitability	Prevalently closed tree and/or woody formations, medium homogeneity	9.1	8.2	14
3	Low suitability	Open tree and/or woody formations, medium-high homogeneity	11.3	10.2	17
4	Marginal suitability	Open tree and/or woody formations, low homogeneity	8.2	7.3	13
5	Marginal suitability	Lower fraction of open tree and/or woody formations, low homogeneity	1.5	1.4	2
6	No unsuitability	Very open or unsuitable formations	9.9	8.9	15
	All	All	66.8	58.6	100

*Quantitative values refer to East African WISDOM data for the United Republic of Tanzania.

DETERMINATION OF THE AREA OF INFLUENCE AROUND SELECTED URBAN CENTRES

Accessibility buffers

In order to assess the efforts necessary to bring woodfuels from production sites to selected urban areas the procedure of analysis included the use of cost maps based on slope and on distance from roads and settlements (Lorenzini, pers. com., 1999a), as shown in Annex 3.

Country-level cost maps were used to determine accessibility buffers around the selected urban areas by means of the Environmental Systems Research Institute (ESRI) cost-distance function. The continuous cost-distance maps resulting from the process were then reclassified into discrete values in order to create cost buffers more suited to the subsequent geostatistical analysis.

Definition and delineation of urban supply zones

Different supply zones around the selected cities were determined according to the four definitions, i.e. restricted-total, restricted-commercial, expanded-total and expanded-commercial. The supply zone relative to each definition was determined by the number of accessibility buffers around the selected city whereby potential woodfuel production and consumption relative to each definition achieved equilibrium.

TABLE A4.3

Tentative distinction of woody biomass sources by suitability for commercial woodfuel production for urban markets based on GLC 2000 class description*

	Tentative estimate of mean productivity of above-ground woody biomass suitable for woodfuel production (t/ha/yr)	**Tropical rain forest**	**Tropical rain forest Equatorial**	**Tropical mountain system Equatorial**	**Tropical mountain system**	**Tropical moist deciduous forest**	**Tropical dry forest**	**Tropical shrubland**	**Subtropical humid forest**	**Subtropical mountain system**
	GLC 2000 class name	11-TAr	10-TAr_Eq	15-EqM	16-TM	12-TAwa	13-TAwb	14-TBSh	21-SCf	25-SM
Classes more suitable for commercial woodfuel production										
1	Tree cover, broad-leaved, evergreen	3.8	5.1	5.1	2.7	3.0	2.8	2.8	3.1	3.1
2	Tree cover, broad-leaved, deciduous closed	3.0			2.7	2.7	1.8	1.8	3.1	3.1
4	Tree cover, needle-leaved, evergreen	1.4			1.2	1.1			1.3	1.2
7	Tree cover, regularly flooded, freshwater	0.9	4.4	4.4			0.6	0.6		
8	Tree cover, regularly flooded, saline water	0.9	4.4	4.4		0.9	0.9	0.9		
9	Mosaic: tree cover/other natural vegetation	2.6	5.6	5.6	1.3	1.4	1.2	1.2	1.8	1.8
Classes less suitable for commercial woodfuel production										
11	Shrub cover, closed-open, evergreen	1.7	3.2	3.2	0.9	1.0	0.8	0.8	1.2	1.2
12	Shrub cover, closed-open, deciduous	1.7	3.2	3.2	0.9	1.0	0.8	0.8	1.2	1.2
13	Herbaceous cover, closed-open	1.1	2.0	2.0	0.6	0.6	0.5	0.5	0.8	0.7
14	Sparse herbaceous or sparse shrub cover	1.1	2.0	2.0	0.6	0.6	0.5	0.5	0.8	0.7
15	Regularly flooded shrub and/or herbaceous cover	1.1	2.0	2.0	0.6	0.6	0.5	0.5	0.8	0.7
16	Cultivated and managed areas	1.1	2.0	2.0	0.6	0.6	0.5	0.5	0.8	0.7
17	Mosaic: cropland/tree cover/other natural vegetation	2.1	4.0	4.0	1.1	1.2	1.0	1.0	1.5	1.5
18	Mosaic: cropland/shrub and/or grass cover	2.1	4.0	4.0	1.1	1.2	1.0	1.0	1.5	1.5
19	Bare areas	0.4	0.7	0.7	0.2	0.2	0.2	0.2	0.3	0.2
20	Waterbodies									
21	Snow and ice									
22	Artificial surfaces and associated areas	0.4	0.7	0.7	0.2	0.2	0.2	0.2	0.3	0.2
23	No data	1.7	3.2	3.2	0.9	1.0	0.8	0.8	1.2	1.2

*Quantitative values refer to average class productivity by ecological zone (Southeast Asian WISDOM, FAO, in press).

Annex 5

Monitoring land cover changes: key methodological aspects[11]

The study of land cover changes is no trivial task, for the driving factors behind change are complex and often highly location specific. The changes are elusive events that are difficult to predict and that defy generalization. They present a high statistical variance; are often small, compared with many other conventional mapping items; and suffer from less consistent estimation procedures than those commonly accepted for other more conventional purposes such as simple land cover mapping. These factors necessitate the use of rigorous methodologies in design and implementation monitoring initiatives. Thus, it may be useful to highlight a few important methodological aspects in the assessment of land cover changes based on high-resolution remote sensing data.

1. The **reliability** of the measurement of change depends primarily on the level of **coherence** in class delineation among all elements of the time series. Under an operative point of view the interdependent visual interpretation of multitemporal images (FAO 1996), nowadays carried out within GIS vector editing environments, is still the most used method because it can make full use of an analyst's experience and knowledge and, fundamentally, the recognition capacity of human brain. The **visual interdependent interpretation procedure** developed in the framework of the remote sensing component of the 1990 FAO forest resources assessment (Drigo, 1995; FAO, 1996) was designed to induce the highest level of thematic and spatial consistency among the classifications of the series of images covering the study areas.[12] A fundamental aspect of this interpretation procedure is that the class delineation of each image of the time series implies the consultation of all images in the series. This is an iterative process that eliminates the propagation of the types of error that are typical of independent image interpretation. The visual interpretation approach was considered appropriate and was preferred to automated change detection since it favours a critical and consistent interpretation of time-series data in spite of the common diversity among the images of a series due to seasonal characters, atmospheric disturbances, etc.. The distinction between a real land cover change and the effect of temporary seasonal or meteorological factors is often subtle and in this the human brain is by far more efficient and flexible than any numerical algorithm. Moreover, the visual approach proved more accessible to the interpreters whose main required competence was knowledge of specific field conditions, rather than remote sensing, GIS, or digital processing capacities.. In addition to thematic maps, key outputs of this procedure are consistent and highly informative change matrices.

   More recently, object-based methods have been proposed for forest change detection to combine the contextual analysis of visual interpretation with the quantitative aspect of pixel-based approaches (Desclée et al., 2006). The interest for object-based methods has increased with the improvements in image segmentation techniques and in the availability of commercial advanced software (the main one is eCognition, or Definiens Imaging as it is now commercially defined) (Baatz & Schäpe, 2000) specifically developed for such a task.

2. Other essential aspects that allow a more consistent evaluation of change are the following.
   - Simple **land cover classification schemes** based on distinct physiognomic classifiers that can be detected with acceptable confidence on remote sensing images. Given that a change is more reliable when there is a sharp contrast between the original land cover class and the final one (FAO, 1996), the presence of many classes with similar biomass densities separated by only small tonal differences may generate a cloud of low-reliability transitions, thereby enhancing the “noise” in the resulting transition matrices.
   - Time series composed of **compatible remote sensing data** (high resolution satellite or airborne imagery), with similar resolution or interpretability at the scale of interpretation.
   - **Common season** of image acquisition to limit to a minimum the chromatic variations linked to plant phenology.
   - **Clear interpretation responsibility**. The study in any given location must be carried out from A to Z by a single person with a good knowledge of local field conditions, land uses, common practices, etc.

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[11] Adapted from Drigo, 2005.
[12] A similar interpretation procedure was adopted in the study by Achard *et al*., 2002, where it was adapted to the visual on-screen interpretation of digital data, which guaranteed consistent results and simplified the digital mapping process considerably.

3. **Spatial and temporal scale aspects**. The study of land cover changes appears to be conducted most conveniently for intermediate-scale strategic planning purposes, e.g. over entire provinces, catchment areas (river basins) or, in this context, over urban woodsheds of a few million hectares, and over suitably long time intervals, to become cost effective. The methodology thus appears optimal at intermediate scales (ranging between 1:100 000 and 1:500 000) and over time intervals of more than five years. At more detailed levels, i.e. 1:50 000 and higher resolution, the analysis would become far more complex and expensive, since suitable historical satellite data would not be available, leaving as the sole alternative the use of historical aerial photographs, if accessible. Similarly, over very short time intervals the size of change would be too small to be detected with acceptable reliability.
4. **Cost**. The cost of this approach is relatively low, if based on high to medium resolution satellite data (i.e. Landsat TM series, MODIS 250m). Current pricing policies of remote sensing data, particularly those of the Landsat Programme and of the cost-free MODIS, and the availability of rich data archives, make the analysis of land cover changes relatively inexpensive. However, higher resolution analyses (below 20m pixel size) and elaborate image processing procedures may considerably increase the cost of the analysis.

URBAN WOODSHED APPLICATIONS

The monitoring methodology based on satellite time series is suitable for national and subnational applications where it may provide essential information for the development of local models and scenarios to support territorial resource planning initiatives. The spatial resolution of the remote sensing data used and thematic detail of this approach, i.e. land unit classification and change matrix analysis, are also suitable for local applications, for instance to study and describe the processes of change at a district, province or catchment level or, most relevant for the present context, for urban woodshed studies.

As regards the survey design for urban woodshed monitoring studies, complete coverage is the obvious and most convenient approach. In addition, in a local monitoring study it would be easier to relate the observed land cover changes to other territorial features such as drainage pattern, slope and soil characteristics, settlements and infrastructural developments such as roads or dams, as well as take socio-economic variations (both in space and time) into account. Knowledge of the processes of change occurring in a certain area, as well as their impacts and trends, adds significantly to simple statistics on available resources as derived from remote sensing and so facilitates the development of more realistic models and scenarios of land use change and inference on cause-effect mechanisms.

TRANSITION MATRICES AND BIOMASS FLUX DIAGRAMS

As an example of land cover change analysis, Table A5.1 and Figure A5.1 show the results of the analysis carried out over an area of approximately 1 million ha in the East Godavari district of Andhra Pradesh, India, from January 1973 to January 1995 (FAO, 1995). The table shows the transition matrix reporting land cover class areas in 1973 and 1995 and the individual class-to-class transitions.

Much information may be derived from the matrix. First, area totals for the two dates may be compared and the net change for each land cover class assessed. The *closed forest* class, for instance, changed from 238 900 ha in 1973 to 207 000 ha in 1995. But more can be learned from examining the inner part of the matrix. This provides, *inter alia*, along the diagonal all areas that remained stable during the period under consideration and, away from the diagonal, all individual class-to-class transitions. The light grey cells within the matrix identify negative transitions, implying a loss in biomass while the others identify positive ones, implying an increase.

The information on land cover dynamics contained in the change matrix can be represented efficiently, and in a more accessible manner, in the form of a so-called woody biomass flux diagram. This was conceived in order to express better the magnitude of the land cover changes through the allocation of biomass densities to the individual land cover classes (FAO, 1995). By including the biomass perspective, it is possible to visualize and understand more clearly the change processes, and even assess their environmental impact through the release (or sequestration) of woody biomass related carbon. A nominal biomass value for each class thus permits the estimation of the biomass changes related to each class transition. The flux diagram may be considered a kind of “signature”, representing the dynamic character of a certain area over a certain period of time.

TABLE A5.1
Area transition matrix in the East Godavari district, Andhra Pradesh, India, 1973–1995

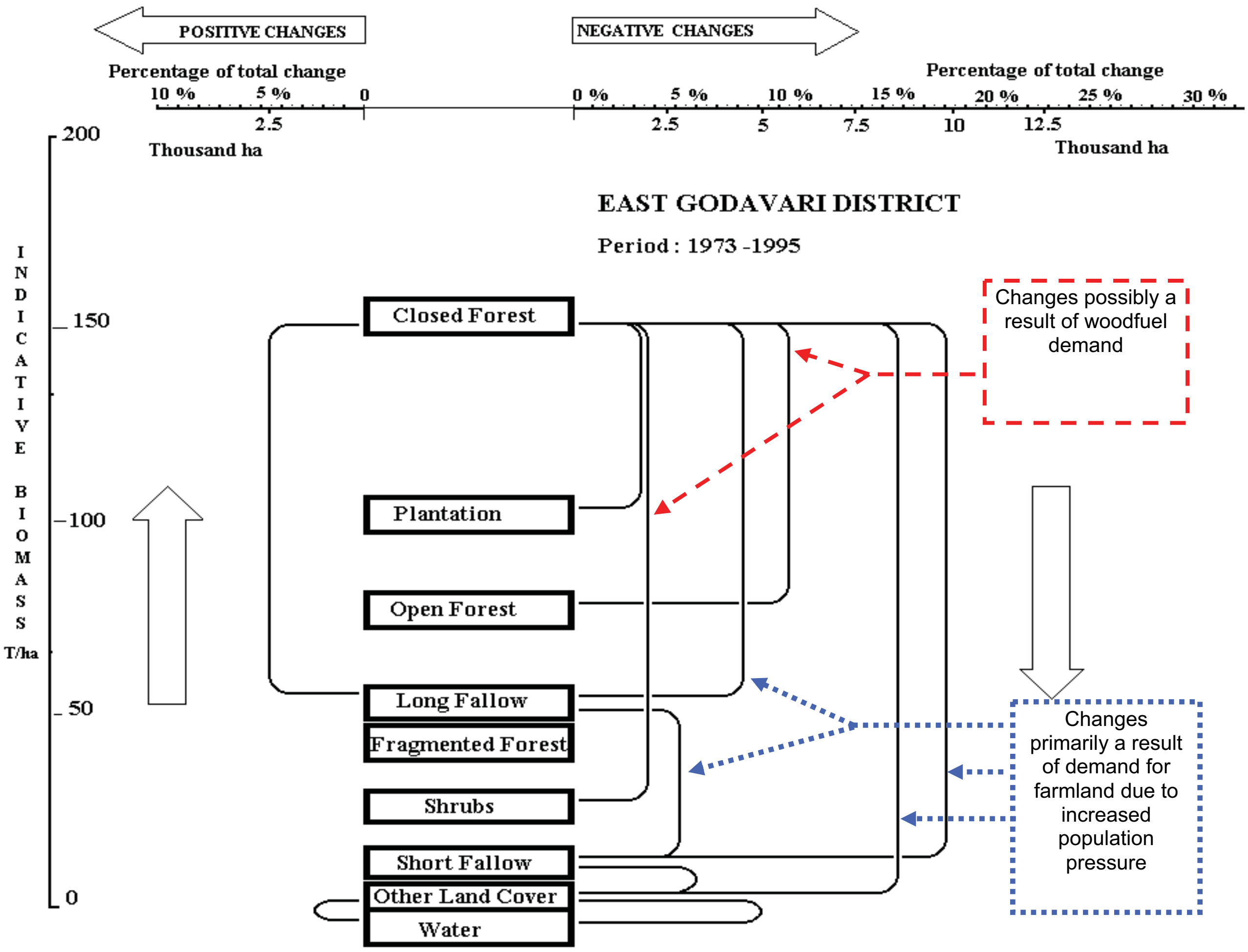
('000 ha)			**Land cover classes in 1995**								
Land cover classes in 1973	**State in 1973**	**% of land area**	**Closed forest**	**Open forest**	**Long fallow**	**Frag-mented forest**	**Shrubs**	**Short fallow**	**Other land cover**	**Water**	**Planta-tions**
Closed forest	238.9	23.7	204.1	5.8	4.6	0.8	2.1	9.9	8.7	0.8	2.1
Open forest	9.9	1.0		8.3			0.4	0.4	0.8		
Long fallow	14.5	1.4	2.5		8.3			2.9	0.4		0.4
Fragmented forest	5.4	0.5				4.6			0.8		
Shrubs	38.9	3.9					35.6		3.3		
Short fallow	9.1	0.9	0.4					7.9	0.8		
Other land cover	571.0	56.7							565.6	5.0	0.4
Water	116.4	11.5							1.2	115.1	
Plantations	3.3	0.3									3.3
State in 1995	**1007.4**		**207.0**	**14.1**	**12.8**	**5.4**	**38.1**	**21.1**	**581.8**	**120.9**	**6.2**
% of land area		**100.0**	**20.6**	**1.4**	**1.3**	**0.5**	**3.8**	**2.1**	**57.7**	**12.0**	**0.6**

The woody biomass flux diagram in Figure A5.1, which combines the rates of change listed in Table A5.1 with estimated biomass values, is structured as follows.

- The Y-axis, with its indicative biomass values, shows the order of the classes by their estimated biomass per hectare.
- The X-axis shows the areas of class-to-class transition, divided into positive and negative changes. The left of the diagram represents the lower-left part of the matrix, showing the positive class transitions (the arrow pointing upwards indicates an increment in biomass), while the right-hand side represents the upper-right part of the matrix, showing the negative class transitions (the arrow pointing downwards indicates a loss of biomass).

The process here is fairly complex, involving the expansion of short fallow subsistence farming and permanent agriculture on closed forest areas; various phases of forest degradation (closed to open forest and closed forest to shrubs); and expansion of long fallow shifting cultivations in closed forest areas and regrowth of forest in previous long fallow areas, in a cycle that was common in the past but nowadays is very rare. The study was not carried out specifically to assess the impact of woodfuel production and it is not possible, without adequate auxiliary field data, to pinpoint the causes of change. A reasonable guess is that fuelwood collection may be responsible for forest degradation processes (*closed* to *open forest* and to *shrubs*) and may be a concomitant cause of the deforestation processes (*closed forest* to *short fallow* cultivation and to *other land cover*).

FIGURE A5.1
Woody biomass flux diagram in the East Godavari district, Andhra Pradesh, India, 1973–1995



Annex 6

Pan-tropical fuelwood species[13]

A brief description of the characteristics of fuelwood species for different land use systems and for main environmental services is given below. Tables A6.1, 2 and 3 list the main pan-tropical species suitable for fuelwood and charcoal production by broad ecological zones with an indication of their suitability in different land use systems and environmental services.

Silvopastoral systems

Silvopasture combines trees with pasture forage and livestock production. Trees with palatable foliage, pods and twigs may contribute to pastoral production, especially at the end of the dry season, when shortages of fodder occur. The trees can also provide shade for livestock but have to be tolerant to the impact of the animals and withstand damage to their root systems and bark. The leaves and fruits should not be poisonous for livestock and the crowns should be above their reach. A thin canopy is ideal because it allows transmission of light for pasture forage. Profuse production of pods and foliage is necessary.

Agroforestry

Agroforestry is a mix of agricultural crops with trees and shrubs. The latter provide farmers with fuelwood, fodder, mulch, fruit, green manure, nitrogen fixation and controlled shade for agricultural crops. Trees should not compete with crops for nutrients or for light. Deep-rooting systems are ideal. The tree canopy should allow acceptable light penetration for crops. Trees should not be damaged by the cultivation or harvesting of surrounding crops. In addition, they may produce marketable products.

Woodlots

Woodlots are small areas of land that people devote to trees. They provide not only fuelwood but also timber and poles. The trees in woodlots are generally fast growing and able to coppice or regenerate easily. Woodlots can bring steep slopes, river banks and other inaccessible land into production. If planted on a marginal site, trees should be tolerant to harsh conditions.

Large plantations near cities

To supply fuelwood for residents, extensive plantations are established for cultivation around settlements and cities. These plantations provide large amounts of fuelwood and charcoal for the convenience of city dwellers as well as for industrial purposes. They are set up with the species that are most in demand on the market, which should also be appropriate for charcoal production. Dense wood is preferable because wood is usually transported by lorry. Since the plantations are large, trees should be highly resistant to disease and fire.

Land rehabilitation

Some species can be used for rehabilitation on land that has been overgrazed, eroded or depleted of nutrients. Land rehabilitation aims at gradually increasing the production potential of the site. Tree species suited for rehabilitation can stand harsh conditions. Tolerant of drought, poor soils and neglect, the trees should be fast growing to establish a new environment and they should be deeply rooted in order to obtain water in dry conditions. They should be able to raise soil quality by nitrogen fixing and improve soil fertility by providing green manure and mulch. The latter implies the production of litter with a high nitrogen content that adds organic matter to the soil.

Erosion control

Trees protect against erosion if they impede soil migration. Erosion control species develop an extensive lateral root system to bind the soil. Development of root suckers makes a tree useful for erosion control (CABI, 2005). To protect against erosion, windbreaks also slow the wind entering the site.

Windbreaks

Windbreaks are valuable in agriculture because they raise productivity by sheltering crops from the velocity and drying effects of wind. The trees have to be low-branched and suitable for dense planting in at least double rows. Small shrub species mixed with larger species in between give rise to a more effective shelter

[13] Adapted from Van de Vreken, 2005.

against the wind. If the windbreak consists of just one species, branching has to extend to the ground. Trees in windbreaks need to have wind-firm root systems. The crown should be bushy and allow some wind penetration. The branches have to stand firm against the wind; they should be pliable and not easily breakable. The trees should not harbour pests from adjacent crops and the root system should not compete excessively for water with crops (Wilkinson *et al*., 2000). If the windbreak is set up in coastal areas, the trees should be salt tolerant.

Living fences

Living fences serve to screen houses for privacy. They also enclose fields and meadows. Thorny branches are ideal to fence in livestock. Dense foliage is needed to impede visibility. The trees can stand being closely planted to form a fence. They should be able to tolerate frequent clipping.

Ornamentation

Ornamental trees are distinguished by their beauty, in that they have attractive flowers, lush foliage or a special crown. When used in cities or along avenues, resistance to air pollution is desirable. In addition, they should preferably provide shade.

Shade

A shade tree has dense foliage that persists throughout the hot season. The shade provided is useful for cities, gardens, pastures or fields, humans, animals and crops.

TABLE A6.1
Main fuelwood species of arid and semi-arid tropical regions and their suitability for different land uses and environmental services

Arid and semi-arid regions (rainfall <800 mm or <6 humid months)

	Silvopastoral systems	Agroforestry	Woodlots	Large plantations near cities	Land rehabilitation	Erosion control	Windbreaks	Living fences	Ornamentation	Shade
Acacia cyclops	x					x				
Acacia nilotica	x	x		x	x	x	x	x	x	
Acacia raddiana	x					x		x		x
Acacia senegal	x	x		x	x	x	x			
Acacia seyal	x	x								
Albizia lebbeck	x	x	x		x	x	x		x	x
Anogeissus latifolia	x				x	x				
Azadirachta indica		x	x	x	x	x		x		x
Balanites aegyptiaca	x		x				x	x		x
Cajanus cajan	x	x	x			x	x	x		x
Cassia siamea	x	x	x		x	x	x		x	x
Dalbergia sissoo	x	x	x	x	x	x	x	x		
Eucalyptus camaldulensis			x	x	x	x	x		x	x
Eucalyptus citriodora					x					x
Eucalyptus microtheca				x		x	x	x	x	x
Eucalyptus occidentalis			x		x	x	x		x	x
Parkinsonia aculeata	x				x	x	x	x	x	x
Pithecellobium dulce			x				x	x	x	x
Populus euphratica	x				x		x			
Prosopis alba	x				x	x	x		x	
Prosopis juliflora	x				x	x	x	x	x	
Sesbania sesban	x	x			x	x	x	x		x

TABLE A6.2
Main fuelwood species of humid tropical regions and their suitability for different land uses and environmental services

Humid tropics (rainfall >800 mm or >6 humid months)

	Silvopastoral systems	Agroforestry	Woodlots	Large plantations near cities	Land rehabilitation	Erosion control	Windbreaks	Living fences	Ornamentation	Shade
Acacia auriculiformis		x		x	x	x			x	x
Calliandra calothyrsus	x	x	x		x	x		x	x	x
Casuarina equisetifolia		x	x	x	x	x	x	x	x	
Eucalyptus brassiana				x						x
Eucalyptus deglupta						x			x	x
Eucalyptus pellita				x						
Eucalyptus urophylla				x	x					
Gliricidia sepium	x	x	x		x	x	x	x	x	x
Gmelina arborea		x		x					x	x
Guazuma ulmifolia	x				x			x	x	x
Hibiscus tiliaceus					x	x		x	x	
Leucaena leucocephala	x	x		x	x	x	x	x		
Mimosa scabrella	x	x		x	x				x	x
Muntingia calabura		x			x	x			x	x
Pinus caribaea		x		x	x	x			x	x
Sesbania grandiflora	x	x			x		x	x	x	x
Syzygium cumini	x		x		x		x	x	x	x
Tamarindus indica	x	x	x				x		x	
Terminalia catappa		x		x	x	x			x	x
Trema orientalis		x		x	x	x	x	x	x	x

TABLE A6.3
Main fuelwood species of tropical highlands and their suitability for different land uses and environmental services

Tropical highlands (above 1 500 m)

	Silvopastoral systems	Agroforestry	Woodlots	Large plantations near cities	Land rehabilitation	Erosion control	Windbreaks	Living fences	Ornamentation	Shade
Acacia decurrens		x	x		x	x	x			x
Acacia mearnsii		x				x				x
Alnus acuminata	x				x					
Eucalyptus globulus			x	x	x	x	x		x	x
Eucalyptus grandis		x		x	x	x			x	x
Eucalyptus robusta				x	x	x	x	x		x
Eucalyptus tereticomis				x	x	x				x
Gleditsia triacanthos	x	x	x		x	x	x	x	x	x
Grevillea robusta	x	x	x	x	x				x	x
Melaleuca quinquenervia					x	x			x	
Melia azedarach	x	x	x		x	x	x		x	x
Sapium sebiferum		x							x	

Annex 7

Sectors, subsectors, branches and sub-branches of woodfuel end uses

Productive sector	Subsector	Branch	Sub-branch	Woodfuel end use
Primary	Agriculture	Crop production	Grains and oilseeds	Drying of grains and oilseeds
			Tobacco	Tobacco curing
		Animal production	Pigs	Cooking feed
			Poultry	Poultry houses
			Other	Heating
				Other
Secondary	Manufacturing industry	Food and beverages	Sugar, granulated	Producing steam
			Sugar, brown	Evaporating cane juice
			Coffee	Drying, roasting
			Tea	Withering, drying
			Tobacco	Curing
			Herbs	Drying
			Oils	Producing steam
			Milk products	Steam
			Bread	Baking
			Confectionery	Cooking, sterilizing
			Maize tortillas	Nixtamalization
			Tapioca meal	Drying
		Metal minerals	Iron	Reduction, smelting
			Steel	Carbon restoration, blacksmithing
		Non-metal minerals	Lime	Calcination
			Chalk	Dehydration
			Cement	Clinkering
			Tiles and bricks	Firing, ceramization, glazing
			Pottery	Firing, glazing
			Salt	Evaporation-crystallization
			Kaolin	Drying
		Pulp and paper	Pulp and paper	Steam and power for processing

		Wood-based products	Wood	Wood drying
Tertiary	Commerce and services	Food and beverages	Restaurants	Food preparation
	Tourism and leisure		Hotels Camping sites	Heating, hot water, food preparation, laundering
	Public	Health	Hospitals Schools	Laundering Food preparation

Source: FAO, 2002a.