FOREST AREA IN COSTA RICA: A COMPARATIVE STUDY OF TROPICAL FOREST COVER ESTIMATES OVER TIME

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Abstract. Forest area figures, at a given point in time and for a given region of interest, differ considerably, affecting the calculation of deforestation rates and thus confuse the political and scientific discussion on the state and change of the resource forest. This article discusses the variation of published forest cover figures, using Costa Rica as an example. A list of published figures on the forest cover of Costa Rica from 1940 onwards is analyzed. Reasons for the differences are hypothesized and discussed. These differences are mainly in the definition of forest and forest classes included, in the type of the studies conducted (mapping and/or sampling), in the precision of the estimates, and in the information sources used. It is concluded that part of the problem is inherent in the nature of the resource 'forest'. Quality and completeness of the presentation of the forest cover estimates are a clue to their correct understanding and interpretation. The latter point being especially relevant, as forest cover data have both a *technical-scientific* and a *political* meaning and are used as relevant arguments in many discussions. In the example of Costa Rica, a general downward trend is observed up to about 1985/1990, whereas after that forest area figures are on the average at a markedly higher level. Some hypotheses for this change in the trend are discussed.

Keywords: Costa Rica, forest definition, forest inventory, forest mapping, tropical deforestation

1. Introduction

Large area data on state and change of the environment and of the natural resources has become a key issue of national and international environmental and development politics, as is reflected in a number of international conventions, agreements and protocols, particularly recognized through the United Nations Conference on Environment and Development (UNCED) in 1992 in Rio de Janeiro. Forest data play a particularly important role in many agreements like Agenda 21, the Forestry Principles, and the conventions on climate change, desertification and biological diversity (Lund and Boley, 1995).

Forest cover is politically sensitive information. It is among the national-level indicators for the evaluation of sustainability, particularly when broken down into forest types, age classes and successional stages (Lammerts van Beuren and Blom, 1997), is easily understood and can supposedly easily be measured. However, published forest cover data often differ considerably making it a challenge to decide which one to consider the most appropriate. The same, of course, holds for information on deforestation which is usually derived from two subsequent forest cover estimates: how can one make a proper interpretation and use of deforestation data when there is still much uncertainty about the estimates at one point in time? It is surprising that relatively frequent mention is made with respect to the uncertainty of deforestation data, but less so with respect to forest cover data, which is the major input for deforestation estimations.

In this article we analyze forest cover figures for larger regions, where 'large' means geographical units such as provinces, countries, regions, continents, and make special reference to the tropics and to Costa Rica as an instructive example that has been repeatedly described in the literature. We want to identify causes for differences in forest cover figures, and to contribute to the discussion about the future development of large area forest inventories.

2. Large Area Forest Inventories: General Characteristics

In this section we give a brief overview of principal characteristics of large area forest assessments, where much of the forest data come from. There is broad literature in that field, covering theory, case studies, textbooks and educational materials, to which those readers who are interested in details are directed (for example FAO, 1971; Husch, 1971; Loetsch *et al.*, 1973; Malleux, 1982; De Vries, 1986; Schreuder *et al.*, 1993; Shiver and Borders, 1996; Prodan *et al.*, 1997). The classic *large area* forest inventories are to provide timely and reliable data about location, extent, condition, and functions of the forests in terms of current status and changes in order to give forest policy a sound decision base. More and more, these inventories adopt a multi-purpose and multi-resource character, and the data generated are also an important contribution to others outside the core forestry sector, for example in the context of conservation of biodiversity, carbon sequestration, erosion control, water protection, etc.

Large area forest inventories utilize various information sources such as maps, air photos, satellite images, documents and statistics from other sectors, expert guesses, estimations based upon models and projections of earlier results, and, of course, field data. Particularly in the tropics, one can observe a clear trend: while earlier inventories relied very much on field work and 'direct sensing', more and more studies nowadays are mapping projects based on remote sensing with a minor field phase. It is inherent that these two types of studies differ markedly in their information content. Mere field sampling will not produce a complete set of maps, and mere satellite image based mapping studies will not come up with, for example, the description of species composition of different forest types. A reasonable combination of the two approaches appears the most promising.

A typical example of large area forest inventories are national forest inventories (NFI) and global forest assessments. NFI support the definition and monitoring of national policies that are forest related (for example Loetsch *et al.*, 1973; Husch, 1978; Cunia, 1978). Global forest assessments attempt to provide similar data, among other reasons in order to help defining and monitoring international conventions (for example FAO, 1993; Mayaux *et al.*, 1998).

3. An Example: Forest Cover Assessments in Costa Rica

3.1. Costa Rica

Costa Rica covers about 51 000 km^2 of the land area of the Central American Isthmus and has highly diverse topography and vegetation. Twelve zones of the Holdridge life zone system (Holdridge *et al.*, 1970; UNDP/FAO, 1973) are found with their respective different forest types. Costa Rica was once almost 100% forested; Keogh (1984) estimates the natural non-forest area of Costa Rica to be 3.5%, consisting of swamps without forest, water, areas above the tree line and others; the area cleared by man before the arrival of the Spaniards is estimated to be 2% (Tosi, 1974). For the period of the most severe deforestation, between about 1950 and 1980, the principal causes were reported to be the demand for land rather than for wood (Hartshorn, 1982). The conversion of forest into other land uses was generally and legally considered land improvement and evidence of proper land management; it was a prerequisite to obtain a legal land title (Ley de Poseedores en Precario, 1942; cited after Hartshorn, 1982), as was common in other tropical regions.

In the 1970s and 1980s Costa Rica was mainly in the negative environmental headlines for having one of the highest deforestation rates worldwide; in the 1970s an average deforestation of 50 000 ha yr^{-1} is reported (MINAE, FONAFIFO n.y.), and for the period of 1950 to 1984 a deforestation rate of 3.9% per year (Leonard, 1986). The deforestation rates averaged consistently two to three times higher than the overall regional average for Latin America (Wendland and Bawa, 1996). Today, Costa Rica has a relatively efficient conservation system. About 25% of the national territory are protected areas (SINAC, 1999), most of it covered by forest. And, contrary to other regions, the protected areas receive largely real protection (Kaimowitz and Paupitz, 1998). While large forest areas outside the protected areas are rare, forest fragments and trees are found almost everywhere on non-forest land. Agroforestry was and is systematically promoted, determining a mosaic of forested, agricultural and agroforestry lands.

From a forest assessment point of view, Costa Rica is interesting. Much has been published on the forest area of Costa Rica. Early figures date back to the 1940s. Well known and frequently cited is also the series of forest cover maps that show the alarming decrease in forest cover from the 1940s onwards (MINAE, FONAFIFO n.y.), sometimes referred to as the ‘forest striptease’ of Costa Rica. These maps are shown in Figure 1, forest cover was mapped from air photos for

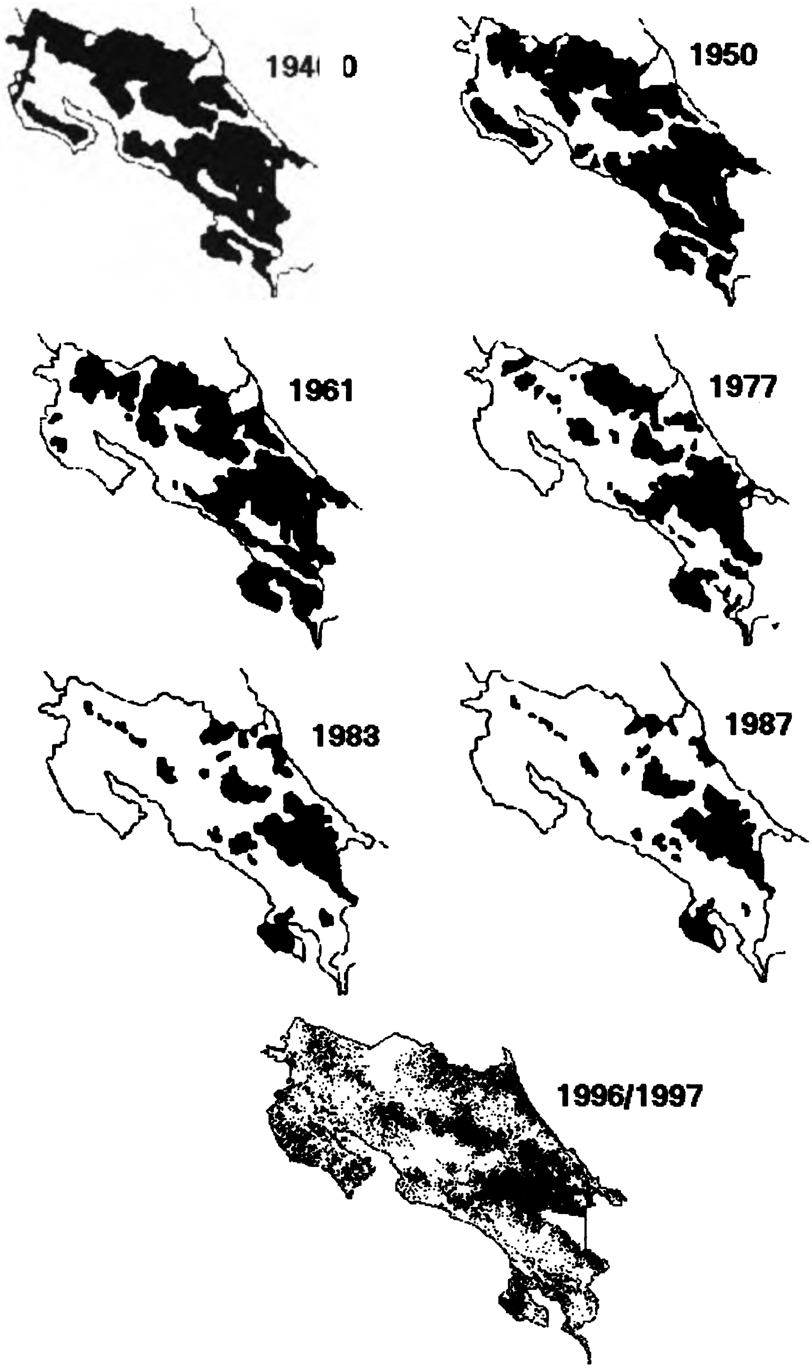

Figure 1. Series of forest cover maps of Costa Rica as repeatedly published (for example: Flores Rodas, 1985; MINAE, FONAFIFO n.y.).

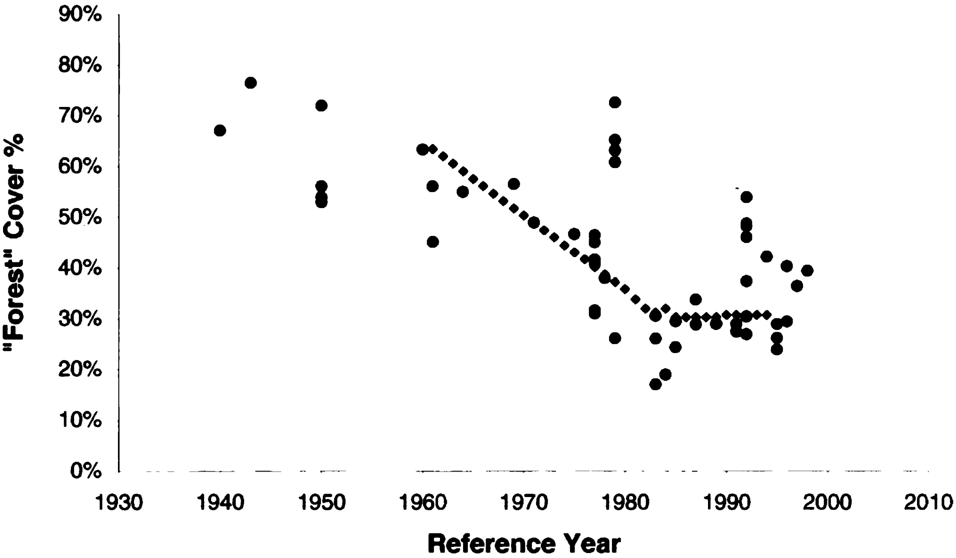

Figure 2. Forest cover figures in Costa Rica. Data from Table I. Each dot marks a published forest cover figure. The diamonds display the estimates up to 1994 as found in the FAOSTATS database (www.fao.org).

1940, 1950, and 1960, from Landsat MSS data for 1977 (OPSA, 1978) and 1983 (Flores Rodas, 1984), and from Landsat TM for 1996/1997. Other comparative studies carried out for Costa Rica are those of Keogh (1984), Sader and Joyce (1988) and Harrison (1991). Compared to other tropical countries, in Costa Rica there are many data on natural resources.

3.2. Forest cover figures for Costa Rica

In order to obtain an idea of the variability of published forest cover figures for Costa Rica the authors carried out a review of journals and reports. Table I gives a list for 1940 onwards, from a broad variety of publications. Different types of studies were analyzed: original sampling and mapping studies, studies on the basis of secondary sources, and some expert estimates. In some cases the original source could not be consulted, which is stated in those cases. The majority of the studies are forest and land use mapping projects. Sample based national forest inventories with a comprehensive ground phase were carried out by FAO in the 1960s and 1970s.

A graph of the cover figures over time is in Figure 2, showing some interesting features:

(1) Looking only at the period of 1940 to about 1990, a clear linear downward trend can be observed. The variability of these figures is approximately homo-

TABLE I

Forest cover figures for Costa Rica as found in publications. Target information is the *cover percent*. If this information was given directly, the corresponding figure in column 2 is underlined. If not, it was calculated by other data given (underlined figures in columns 3 and 4). It occurred that forest cover was given in terms of *absolute* area only; then, an area of 51 100km^2 was used as total area of Costa Rica to calculate the cover percent

	Year	Forest Cover		Area	Bibliographical	Classes	Observations
		%	km^2	CR	reference		
	1	2	3	4	5	6	7
1	1940	67.1%	34206	50990	Sader and Joyce 1988, Table I	'Primary forest': relatively undisturbed natural forest with an upper canopy covering more than 80% of the surface area. Authors state that other studies used 'more inclusive' forest classification criteria	Based on life zone map from Tosi 1969, forest map from OPSA 1978. 55ha minimum mapping unit.
2	1943	76.5%		51100	Keogh 1984	'Includes natural forest only; the extent of planted forest is insignificant'.	Data from a statistical model of forest cover change
3	1950	72%			Tosi 1974, p.8	'Natural forest'	
4	1950	53.0%	27084	51100	OPSA 1978, Table I	Includes 'dense forest', which is defined as having forest cover greater than 81.1%.	Also cited as Pérez and Protti (1978). Data from forest cover maps
5	1950	56.2%	28642	50990	Sader and Joyce 1988, Table I	See classes in line 1	See observations in line 1
6	1950	54%			Harrison 1991	'Primary forest cover'	
7	1960	63.4%		51100	Keogh 1984	See line 2	See line 2
8	1961	56.2%	28480	50700	Myers 1981, Table II	'Forests and woodlands'	Myer's original sources not consulted
9	1961	45.2%	23035	50990	Sader and Joyce 1988, Table I	See classes in line 1	See observations in line 1

TABLE I

Continued

	Year	Forest Cover %	Forest Cover km^2	Area CR	Bibliographical reference	Classes	Observations
	1	2	3	4	5	6	7
10	1961	45.2%	23122	51100	OPSA 1978, Table I	Includes 'Dense forest', which is defined as having cover greater than 81.1%.	Also cited as Pérez and Protti (1978).
11	1964	55%			UNDP/FAO 1973, p. 7		Estimation derived from 1964 cover map prepared by V.C. Plath and A.J. van der Sluis. FAO, Estudio Centroamericano, Part I, Costa Rica, August 1964. Original source not consulted.
12	1969	56.6%		50900	UNDP/FAO 1973, Table 7.1.	'Surface area covered by forest'	Areas of five forest cover classes were taken from the map for the whole country. The actual forest cover in each class was estimated by air photo samples. The total surface covered by forest was calculated then by weighting the class area with its average forest cover.
13	1971	49%			Tosi 1974, p.8	Natural forest	
14	1975	46.7%	23800		Cited from Sylvander 1981, p. 49.		Original source (not further specified in Sylvander (1981) and not consulted) Banco Central de Costa Rica 1975.
15	1977	41.7%	21308	51100	Keogh 1984	See line 2	See line 2
16	1977	40.9%	20882	51100	Sylvander 1981, Table I, p. 46	Includes mangroves (0.8%), natural palm forests (yolillo) (1.2%), and tree covered swamps (0.8%)	Does not include savanna, charral (young secondary forest) and páramo (sub-alpine region) Data from air photos, Landsat MSS and ground control

TABLE I
Continued

	Year	Forest Cover		Area	Bibliographical	Classes	Observations
		%	km²	CR	reference		
	1	2	3	4	5	6	7
17	1977	45.1%	23056	51100	Sylvander 1981, Table I, p. 46	Like line 13, but including 'other vegetation cover': young secondary forest, savannah land and high mountain forest (páramo)	
18	1977	31.7%	16154	50990	Sader and Joyce 1988, Table I	See classes in line 1	See observations in line 1
19	1977	31.1%	15901	51100	OPSA 1978, Table I	Includes 'Dense forest', which is defined as having forest cover greater than 81.1%.	Also cited as Pérez and Protti (1978).
20	1977	46.5%	23783	51100	OPSA 1978, Table II	Includes 'Dense forest' and 'Medium dense forest', which is defined as having cover greater than 81.1% and 45.1%, respectively.	Also cited as Pérez and Protti (1978).
21	1978	38.1%	19300	50700	Myers 1981, Table II	'Forests and woodlands'	Partly estimates. Myer's original sources not consulted
22	1979	72.7%	37136	51100	http://www.mideplan.go.cr	'Any type of forest'	
23	1979	63.2%	32225			Includes classes natural forest and secondary forest	From 'Proyecto Inventario Nacional de Fuentes y Sumideros de Gases con Efecto de Invernadero en Costa Rica 1995'.
24	1979	60.9%	31037		MINAE 1996 (Table 4 and 5 in 'Land cover'	Forest and plantations.	3 original sources given.

TABLE I

Continued

	Year	Forest Cover		Area	Bibliographical	Classes	Observations
		%	km²	CR	reference		
	1	2	3	4	5	6	7
25	1979	65.3%	33352	51100	Cited from CCAD/USAID 1998, Table 5, p. 19)	Sum of the classes: 'natural, intervened natural and secondary forest'	Original source: MAG 1996 (not further specified and not consulted). Not included: 5.7% of young secondary forest (charral), 0.4% of páramo and 1.4% of mangrove
26	1979	26.2%		51100	Flores Rodas 1985, Table 4, p. 21	'Dense forest', comprising those forests where the cover is more than 30%	Original source given: DGF/PNUD/FAO/COS/79/001 (not consulted)
27	1983	30.6%	15641		Gonzales 1995	'Closed forest and secondary forest'	Cited after CCAD/USAID 1998, Table I1. Data from Junkov (1984/1985)
28	1983	17.1%	8711	50990	Sader and Joyce 1988, Table I	See classes in line 1	Based on Flores-Rodas 1984 (not consulted)
29	1983	26.1%	13300		MINAE FONAFIFO n.y, Table 3.	'Forest cover' (cover more than 60%)	Original source given: Junkov (1984/1985), not consulted.
30	1984	19%			Harrison 1991	'Primary forest cover'	
31	1985	29.5%	15070		Data from DAF-DGF 1985. Cited from CCAD/USAI D 1998, Table I1, p.22		Original source: Gonzales 1993 (not consulted)
32	1985	24.4%	12460		Cited from MINAE FONAFIFO n.y., Table 3.		Original source given: DAF-DGF 1985 / Primer Congreso Forestal Nacional (not consulted).

TABLE I
Continued

	Year	Forest Cover		Area	Bibliographical	Classes	Observations
		%	km^2	CR	reference		
	1	2	3	4	5	6	7
33	1987	33.8%	17229		Data from Garrita 1987. Cited from CCAD/USAID 1998, Table I1, p.22	"Closed forest, secondary forests and 'charrales altos' (higher secondary forests)"	Data source: Landsat TM
34	1987	28.9%	14750		MINAE FONAFIFO n. y., Table 3.	'Natural Forest'	Original source given: Damaris Garita C. 1987. Includes also 40000ha of mangrove, 5120ha tree plantations and 247880ha 'charrales' and secondary forest.
35	1989	29.0%	14750		Utting (1991), p.3.	'Forest cover'	Original source given: MIRENEM 1990. Plan de acción forestal para Costa Rica: Documento base. San José. (not consulted)
36	1991	29.0%	13615		Sanchez 1997, p. 31	'Primary forest with canopy density >80%'	The study refers to 93% of the land cover of Costa Rica only (rest was under clouds). Minimum mapping unit 3 ha. Data source: Satellite images (TM)
37	1991	27.5%	14060		Pedroni 1992, p.31/32	'Natural primary forest'. Additionally are mentioned there (p.31/32): secondary forest 388, 000ha (7.6%) and plantations 50, 000ha (1%).	Original source given: Gonzáles, personal communication.
38	1992	54.0%	14713	51100	http://www.mideplan.go.cr	'Any type of forest'	

TABLE I

Continued

	Year	Forest Cover %	Forest Cover km^2	Area CR	Bibliographical reference	Classes	Observations
	1	2	3	4	5	6	7
39	1992	48.3%	24664	51100	Cited from CCAD/USAID 1998, Table 5, p. 19	'Natural, intervened natural and secondary forest'	Original source: MAG 1996 (not further specified and not consulted). Not included: 4.5% of young secondary forest (charral), 0.3% of páramo and 0.9% of mangrove
40	1992	37.5%	19063		Cited from CCAD/USAID 1998, Table I1, p.22	'Closed forest and secondary forest > 3m'	Data from Gonzales 1992 (not consulted).
41	92	48.8%	24942		MINAE 1996 (Table II in 'Land cover' section)	'Natural forest and secondary forest'	From 'Proyecto Inventario Nacional de Fuentes y Sumideros de Gases con Efecto de Invernadero en Costa Rica 1995'
42	1992	46.1%			MINAE 1996 (Table 4 and 5 in 'Land cover' section)	'Forest and plantations'	3 project reports given as references (not consulted).
43	1992	27.0%	13683		Cited from: MINAE FONAFIFO n.y., Table 3.	'Forest cover'. Does not include secondary forests nor reforested areas	Original source given: E. Cyrus DGF 1992 (not consulted). Data source: Landsat TM
44	1992	30.5%	15563		MINAE FONAFIFO n.y., Table 3.	'Forest cover'	Original source given: L.F. Gonzáles 1992 (not conulted). Includes also 40000ha of mangrove, 74196ha of reforestations and 350079ha secondary forest of more than 3m in height. Data sources: Field mapping, LANDSAT and review of studies

TABLE I
Continued

	Year	Forest Cover		Area	Bibliographical	Classes	Observations
		%	km^2	CR	reference		
	1	2	3	4	5	6	7
45	1994	42.3%	21567		Gonzales 1995	'Closed forest and secondary forest > 3m'.	Includes secondary forests of 3m and higher
46	1995	24%			Cited from Kaimowitz and Paupitz 1998, Table 26.1	'Forest area'	
47	1995	26.3%	13450	51060	Mayaux *et al.*, 1998, Table 5	'Evergreen and semi-deciduous forest'	TREES project (EU). Data source: coarse resolution satellite images.
48	1995	29%			CCAD 1998	'Estimated forest cover'	Data taken from Figure 3.2. in CCAD (1998), p. 93
49	1996	29.5%	15050	51060	Cited from P. Mayaux *et al.*, 1998.	'Closed Forest'	Original source: Harcourt and Sayer 1996 (not consulted). Reference year of cover estimate not clear.
50	1996	40.4%	20635		MINAE FONAFIFO n.y., Table 5.	Composition: forest (36.92%), Deciduous forest (2.48%), Mangroves (0.8%) High mountain forest (0.2%).	Given as Forest Cover in 1996/1997. Original sources given: FONAFIFO, CCT,CIEDES and CI.
51	1996	40.4%	20656	51075	CCT,CIEDES 1998, Table I, Annex	Composition: forest (33.09%), forest in the NW dry regions (6.4%), mangrove (0.8%), páramo (0.15%)	Given as Forest Cover in 1996/1997. 8.7% of the survey area was under clouds. The 44.4% represent the absolute forest area found in the 91.7% of area surveyed and are related to the total land area (100%). Data source: Landsat TM

TABLE I

Continued

	Year	Forest Cover		Area	Bibliographical	Classes	Observations
		%	km^2	CR	reference		
	1	2	3	4	5	6	7
52	1997	36.5%	18640	51130	Tuomasjukka 1997	Primary forest, secondary forest and plantations	Cited after CCAD 1998, Table 3.2.
53	1998	39.5%	20171		CCAD/USAID 1998, Table I, p.6		Modified estimation based on FONAFIFO 1998. Excludes 40.8 km^2 of mangrove forest

CCAD	Consejo Centroamericano de Ambiente y Desarrollo
CCT	Centro Científico Tropical
CI	Conservation International
CIEDES	Centro de Investigaciones en Desarrollo Sostenible
DGF	Dirección General Forestal
FAO	Food and Agriculture Organization of the United Nations
FONAFIFO	Fondo Nacional para el Financiamiento Forestal
FUNDECOR	Fondación para el desarrollo de la Cordillera Central
MINAE	Ministerio de Medio Ambiente y Energía
OPSA	Oficina de Planificación Sectoral Agropecuaria
UNDP (PNUD in Spamish)	United Nations Development Program
USAID	United States Agency for International Development

geneous over this time period, except for some points for 1979 that lie clearly outside. Also the forest cover data from the FAOSTAT database displays this general trend, though with a different slope.

(2) Looking only at the figures from about 1990 onwards, there are more cover estimates published per time period, the estimates display some more variation, and a clear trend is not observable. However, the points do not form a continuous trend with the former period, and are about 15% higher.

(3) No concluding explanations could be found for the outliers of 1979, stating extremely high forest covers in the range of about 60–70%. One hypothesis is that the figures reflect *potential* and not *actual* forest cover, though this is not specified as such in the publications.

Two principal questions arise, to be discussed in the following sections: (1) What are the reasons behind the considerable variation at a given point in time? And (2): What are the reasons behind the break in the trend that takes place around 1990? While question (1) is a general one, question (2) is specific for Costa Rica.

4. Causes of Differences in Forest Cover Figures

We now want to investigate the main causes for the considerable variability of the forest cover figures in Table I and in Figure 2, which actually can be observed for many countries. Costa Rica is used as an instructive example. Principal aspects are hypothesized to be

- the definition of forest, and the forest classes included,
- the reference area,
- the reference year,
- the type of the study (mapping/sampling),
- the precision of the estimates,
- the information sources used.

where, of course, there are interactions between those aspects.

We concentrate on technical and subject-matter aspects, not taking into account whether there might have been particular strategic interests behind a particular study. This is another relevant point, but has been deliberately left out here as it would enter too much into speculation.

4.1. THE DEFINITION OF FOREST AND THE FOREST CLASSES INCLUDED

In most of the studies the definition of forest and the definition of the forest types included are purely verbally, where terms like ‘natural forest’, ‘undisturbed forest’, ‘secondary forest’ are common. All too often the studies simply talk about ‘forest’.

While, for example, 'natural forest' gives the reader a basic idea of what forest types might be taken into account, it does not readily permit a comparison to other studies that also give the area in terms of 'natural forest'. Some of the studies do explicitly include forest types like secondary forest or young secondary forest (charral) and plantations, while others do not name explicitly the forest classes included so that a direct comparison is impossible. For example, Pedroni (1992) reports (on the basis of other sources) a 'natural primary forest cover' (bosque natural primario) of 27.5% for Costa Rica in 1991, which is then referred to in Segura *et al.* (1997) as 'forest cover' (cobertura boscosa); however, Pedroni (1992), gives additional numbers for secondary forest (7.6%) and for plantations (1%), so that also a forest cover of 36.1% could be correctly cited as forest cover from this source, then comprising the three categories natural primary forest, secondary forest, and plantation forest.

Quantitative and qualitative factors make a forest definition clear and eventually comparable to others. A number of recent studies look at the implications of differences in forest definitions (Kleinn, 1991, 1992; European Commission, 1997; Köhl *et al.*, 2000).

The *information sources* used determine largely what definitions are operational. Crown cover as a criterion, for instance, is difficult to estimate in the field, particularly for a larger reference plot; it is done more easily in air photos at appropriate scale, but again difficult in satellite images of lower resolution. In general, satellite based studies are more prone to confusion between forest and other tree covered lands (like coffee or cacao plantations, and pastures) than are studies with intensive field phases.

Another joint problem of *forest definitions* and *information sources* can occur in deciduous forest areas: in the leafless dry season they can hardly be identified as forest in satellite images though the dry season is normally preferable for image selection because of lesser cloud cover. The deciduous forests of the drier northwest province of Guanacaste do not appear in older forest maps (compare, for example, the forest cover in Figure 1 for the years 1987 and 1996/1997), because the imagery that was analyzed was taken during the leafless dry season (Calvo *et al.*, 1999). CCT/CIEDES (1998), for example, published a separate figure for forest (33.09%) and for the forests in the northwestern dry region of Guanacaste (6.4%), which gives an idea of the order of magnitude of the underestimation if this forest type is excluded or not identified.

Because of the lack of detail in most of the cited publications it is impossible to reliably assess the effect of the difference in forest definitions and classifications. However, the authors assume that the definition question is one of the most important factors.

Highly interesting are the studies that Sylvander (1981) presented, which reported on the forest inventories carried out by FAO in Costa Rica in the 1960s and 1970s. Parallel to a classic forest inventory, a landscape type of inventory was carried out over the entire country, where five classes were distinguished according to their *tree cover*. The interesting point is that this study refers to *tree cover*, not only to *forest cover*, thus taking into account, that the resource 'tree' is spread over almost all the country.

In general, it might be a promising approach to think more in terms of *trees* rather than in terms of *forest* in the planning of future forest and natural resources assessments. The inventory would, among other results, produce statistics and maps of tree density. Together with appropriate land use information, recorded in the inventory or overlaid by other information sources, this approach would allow then the derivation of estimates of forest cover under a set of different forest definitions. Of course, 'tree' still needs to be defined.

4.2. THE REFERENCE AREA

Reference area means the area to which a given forest cover percent refers. For national forest inventories, it is normally the area of the national territory. Sometimes lakes and off shore islands are not accounted for, and there are differences with respect to the reference area. This can be observed in Table I. However, in the case of Costa Rica these differences are of minor relevance. Also, there are cases where the national boundaries are still under dispute between neighboring countries, and no single true figure of area exists.

More frequently, we encounter the problem of *non-response* for a part of the study region, subdividing the population of interest in two strata: one with observations and the other without. In the humid tropics this occurs particularly in remote sensing based studies, where in some places clouds and shadows prevent a direct interpretation and classification, but also to field assessments, when some regions are not accessible for topographic or political reasons. As in any study with non-response, we cannot easily extrapolate from the observed stratum to the entire population without additional evidence or appropriate models. In *maps*, the non-response areas can easily be left blank, which gives the reader a clear impression of the relevance and spatial distribution of the non-response areas. In *tables* of results, the non-response area must be specified, for example in percentage of the total area – important information that is frequently not specified, or not further cited when citing results.

Another, also serious, confusion can arise when the sampling frame of a study is unknown or not clearly stated. The agricultural census of Costa Rica did publish forest area figures for the surveys of 1950 (43.6% forest), of 1963 (30.7% forest) and of 1973 (22.9% forest). These figures are deliberately not listed in Table I. They are referenced, for example, in Thrupp (1980, Table II) where the author describes the 'Evolution of the use of soil in Costa Rica'. A review of the original sources ('Censo Agropecuario de Costa Rica'), however, revealed, that, while there are 'forest area' numbers given, the censuses referred to *agricultural farms* only, explicitly excluding those farms that are mainly dedicated to forestry. The forest area numbers, therefore, refer to forest area on agricultural farms and not to forest area in the entire country. Any extrapolation to the national level would be speculative if not backed by other evidence.

4.3. THE REFERENCE YEAR

It is not always clear to which reference year the published forest cover estimate belongs. The publication of data is *after* the period of analysis, and this period in turn is *after* the acquisition of the primary data (be it field data or remote sensing imagery). Sylvander (1981), for example, states that in the study of Tosi (1974) the forest area estimates refer to the year 1971, while the area estimates of the other uses refer to 1973. Also, when satellite imagery or air photos are employed for forest mapping in the tropics, it is often not possible to acquire a complete coverage by reasonably cloudless images from the same point in time, so that the cover map (and the cover estimate) is a composite of several years. Also, field work in large area forest inventories often extends over several years. A clear reference date must be defined then, and possibly some data have to be adjusted for this reference data. Clearly, confusions regarding the reference year do matter particularly for periods and in regions with high deforestation rates.

4.4. THE PRECISION OF THE ESTIMATES

Maybe two seemingly different figures of forest cover are not statistically different: an estimate of 27% and another one of 33% may be both equally valid and provide unbiased estimates for the same population. To see and test this, we need to have information of the precision of the estimates. Clearly, we have more confidence in estimates with higher precision, because we may assume that these are on the average closer to the true population value.

The statistical precision achieved in a particular study depends on many factors and it reflects, grossly spoken: (1) the natural variability of the variable of interest (usually, in forest assessments the area of large compact forests is determined with a greater degree of precision and accuracy than fragmented ones), and (2) the sample size and design used (the more samples for a given design, the more precise the estimation). Frequently, low precision is willingly or unwillingly associated with an overall low quality of the whole study but in fact it has much to do with the nature of the variable analyzed, and with the resources invested into the study.

With the classic, sample-based forest inventory approach the quantification of precision is straightforward. In the case of Costa Rica, a statement of precision of the estimates of forest area is given in very few of the sources analysed. A statistical estimation of precision was found in the FAO studies in the 1960s and 1970s summarized by Sylvander (1981).

However, most of the forest surveys in tropical countries today are mapping studies, covering the entire region of interest. Maps are the most demanded, convincing and successful products of forest cover surveys. In that context, we are not so much talking about statistical precision but about *accuracy*, which is given in terms of thematic and geometric accuracy, more difficult to quantify and to make a proper interpretation of. The accuracy assessment is based upon field samples, where the completed image classification is compared to the classes found in a reference source of information considered true (Stehman, 1997; Congalton and Green, 1999; Stehman and Czaplewski, 1998). We then obtain an overall idea of the classification accuracy that can be broken down into a class by class analysis. In fact, classification accuracy can be very different between different forest classes. Often, however, it is not recognized that this type of accuracy assessment is a sampling exercise that must be statistically sound in order to be valid. No arbitrary samples must be taken, but only those in accordance with statistical principles. A roadside survey, for example, is unlikely to give an unbiased estimate of the classification accuracy.

Precision is frequently also given as the *sampling error* or *statistical error* of a study. Yet for a cartographer and for a statistician, 'error' has a different connotation. While for a statistician it is a normal component of an estimate, in cartography it means that something is not correct. Whether this is an important aspect or not, the fact is that in most forest mapping studies a comprehensive accuracy or precision statement is lacking, and makes a scientifically based comparison of forest area figures difficult. This, of course, is a general observation and does not refer only to the example Costa Rica.

4.5. THE INFORMATION SOURCES USED

Forest assessments differ in the information sources used, as mentioned earlier in different contexts. Field sampling, air photos, satellite images, and maps and reports are most frequently used. While traditional forest inventories had and have a comprehensive (and expensive!) field component, many of the more recent studies focus on mapping and make extensive or even exclusive use of remote sensing information sources, mainly satellite images. Some figures of forest cover listed in Table I are explicitly subjective estimates ('educated guesses').

The information sources utilized have to be seen in the context of the entire study undertaken: the forest classes that can be distinguished and also the set of attributes that can be observed are different between these data sources, as is precision and accuracy of the results. Budget constraints do play an important role: studies that include an extensive field phase are clearly more expensive than mere satellite image based assessments. Pedroni and Velasquez (1998) discuss the utility and limitations of the use of satellite imagery for the estimation of forest cover, using the example of Costa Rica.

Each assessment method has its justification, its advantages and limitations with respect to specific project objectives, and it is not possible to make a general quality ranking. However, it is easy to understand that the results for one and the same variable, found on the basis of different data sources can have considerably different quality and meaning.

4.6. Hypotheses for the Specific Trend Line for Forest Cover in Costa Rica

Observing the trends in forest cover figures over time in Figure 2 the most surprising feature is the break point at some time around 1990. To say it from the outset: the authors do not see only one reason for the break in the forest area trend line for Costa Rica, nor do they pretend to know the 'true' forest cover at any given point in time. Various factors that might contribute are discussed in what follows.

In general, the area under agricultural use decreased in the 1990s. Particularly, pastures were abandoned, due to an unfavorable development of the market conditions for Central American beef (Kaimowitz and Paupitz, 1998). An estimated 400 000 ha of pastures were given up between 1984 and 1994, and, as a consequence the estimated area of secondary forests was estimated 230 000 ha in 1984 and 425 000 ha in 1994 (Ortíz Valverde, 1996), thus potentially contributing to a stabilization or increase of the total forest area in Costa Rica.

Conservation issues gained more and more relevance. The first protected areas were created in the 1950s, in the 1980s the greater part of the protected areas was established and in 1986 a formal 'system of protected areas' was established with the creation of the Ministry of Environment and Energy. Today, this system comprises a total area of about 1.3 million hectares. One might hypothesize that the non-forested parts of these protected areas are gradually regaining forest cover now that the areas are under efficient protection.

Also the new forest law's incentives (compensation for owners of small and medium sized forests for the environmental services of forest) might help halting deforestation, and the increase in plantation forest area does contribute to an increase in total forest area.

Altogether, there are a number of factors that potentially have helped to halt deforestation and to come to an overall increase in forest area. However, it is unlikely that the causes addressed in the preceding paragraphs do explain the 15% increase that can be observed for the 1990s in Figure 2. Methodological reasons are likely to play an equally or more important role, as analyzed before. It might have to do with changes in the forest concept used: most of the more recent studies are based on satellite image interpretation where there is plenty of possible confusion with tree covered land uses other than forest. Secondary forests, for a long time not appreciated as 'production forest' (Pedroni, 1992), might have been left out more frequently in earlier surveys but included in the later ones. The same happened with the deciduous forests in the dry region of Guanacaste, which do not appear in some of the older forest cover maps, but are included in the newer ones. There can only be speculation about why this possible methodological change took place at about 1990. Possibly the intensified global discussion about environmental, conservation and forestry issues particularly after UNCED, 1992 led to a clearer picture of how to define forest and of which forest classes to include.

5. Discussion and Conclusions

Forest cover estimation is a complex issue – even within one single country. For a proper interpretation of forest cover figures one must take into respect a number of aspects that were discussed in this article, like reference area, reference year, data sources, analysis methods, rate of non-response, precision of estimates, accuracy of measurements, definitions, forest classes included, and minimum mapping unit in the case of mapping exercises. Only in scientific articles does a possibility exist to go into such detail (for example Calvo *et al.*, 1999).

In fact, *forest* is a classification concept that is highly useful for natural resources planning and management. But there is no such thing like a clear natural delimitation, so that there cannot be a *true* forest cover without giving the underlying idea or definition. The situation described in this article is not at all specific for Costa Rica, which was used here as a well documented example, but can be observed to some extent in any country if data are available. Because of the complexity of the issue, the authors do not believe that the problem can be resolved in a homogenization-of-definitions manner on a global level. Framework definitions like the one FAO is using, certainly help to reduce variability, but a great deal of uncertainty and incompatibility will remain.

Obviously, there is no one single truth about forest cover. Much depends on the concept, the definitions, the data sources employed, and perhaps on scientific or political intentions, as well. Principal technical arguments have been discussed in the previous sections. Besides these issues of scientific and technical design of the study, *clarity* and *credibility* are attributes discussed as important (Iles, 1994). These guiding principles have to do with the scientific and technical design, but also with the way in which the results are interpreted and presented. Then, we may break down the sources of difficulties of the interpretation of forest cover figures into three categories:

(1) Problems that refer to the resource 'forest' itself.
(2) Problems that refer to the assessment technique.
(3) Problems that refer to the presentation of the results.

We concentrated in this study on forest cover figures and their interpretation, being well aware that this is an important, but certainly not the *only* gross data on forests of large areas. The relevance of forest area information also comes from the intuitive idea that, for example, loss in species diversity and loss in biomass are largely associated with loss of forest area (deforestation). This is correct, but the converse is not true: maintaining forest area does *not* necessarily mean that there is no loss in diversity or biomass. Gradual forest degradation is not reflected in gross forest cover figures – and is even more difficult to estimate than forest cover. In this study we focused on *forest data quality*, but equally important is *forest quality data*.

Sutherland (1996) gives an interesting point of view in his excellent handbook 'Ecological Census Techniques' where he lists the twenty commonest censusing sins. Number 11 is '*Believing the results*' further explaining, 'Practically every census has biases and inaccuracies. The secret is to evaluate how much these matter'. This applies also to forest assessments, particularly to those of large areas. Maybe it applies more to large area forest inventories than to most ecological sampling studies: large area forest inventories do not only cover large areas with many completely different topographic, ecological, socioeconomic, etc. conditions, they also frequently extend over a long time period of several months or years, many – and at times changing – staff are involved in planning, implementation, analysis, and reporting. These facts alone are potential sources of problems with a perfect consistency and validity of the results.

Figures on forest cover have been used and are likely to continue to be used as one of the indicators for success or failure of conservation policies. Published figures are commonly taken as granted, and the considerable differences are rarely spelled out and analyzed. Some times, as happened in Costa Rica (Escofet, 1998), this leads to heated disputes about the scientific validity and also political appropriateness of a particular study. Forest cover will remain politically sensitive data, and forest cover figures, particularly in the tropics, will continue to be controversially discussed also among scientists. However, much could be gained by seeing estimates as estimates, by a complete presentation of techniques and results, by spelling out the specific problems encountered, and by making clear where the limits of interpretation are. Politicians should understand clearly the meaning behind the figures and technicians and scientists producing them should be aware of the information needs of the decision makers, and of the way their data are possibly used and interpreted.

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