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Sustainable use of biomass resources: a note on definitions, criteria, and practical applications[1]

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1. Introduction

Does rural fuelwood use, and more generally rural biomass use, cause forest degradation? This question has been debated in scientific and policy circles for at least two decades now[2]. Three generic problems have plagued this debate: confusion about what constitutes degradation or sustainable use, inadequate discussion of the criteria for assessing its presence, and insufficient empirical data for use with these criteria. In this paper, I present a framework for defining degradation and sustainable use of forests that might help clarify some of the confusion. An overview of common sustainability criteria then follows. I discuss at some length the criterion most often used in assessing the impact of fuelwood extraction on forests, i.e., the comparison of production and harvest. I then present results from the application of this criterion in a case study of forest use in southwestern India, and highlight some methodological and practical issues.

2. Defining forest degradation and sustainable biomass use

Sustainable resource use is generally understood as maintenance of an undiminished flow of benefits from the resource to its users over time. But forests provide different benefits to different users, and these benefits are generally *not simultaneously maximized.* A typical list of the benefits provided by forests and their differential distribution across local, regional, and global communities is given in Table 1. Note how changes in the type of vegetation on forest lands create tradeoffs between products and between beneficiaries.

Consequently what one user or beneficiary community calls a ''good'' or ''sustainably used'' forest may be seen by another as a ''degraded'' or ''unsustainably used'' forest simply because the two beneficiaries differ in their choices of *what (benefit or mix of benefits) is to be sustained.* In other words, ''degradation'' and ''sustainability'' are social constructs, involving many subjective choices[3] that necessarily value some products over others and therefore privilege certain beneficiaries over others.

A refusal to recognise this fact is responsible for much confusion in the debate on forest degradation. For instance, in the heavily forested but long-settled district of Uttara Kannada in Karnataka state of southwestern India,

Table 1. Magnitude of benefits provided by different vegetation types [(a)]

Vegetation type [(d)]	Product, service or other benefit								
	''Regional''	''Local'' [(c)]				''Regional''		''Global''	
	Timber	Fuelwood	Leaf mulch & manure	Fodder (mostly grass)	''Minor'' produce	Hydrological benefits	Soil conservation	Biodiversity	Sequestered carbon
Dense ''natural'' forest	0	++	++	0	+++	++?	+++	+++	+++
Dense lopped forest	++	+++	+++	+	++	++?	+++	++?	++
Open lopped forest	+	++	++	+++	+?	++	++	++	+
''Pure'' grassland	0	0	0	+++	0	+++	+++?	+	+
Monoculture plantation	+++	+	+	+	0	++	+	0	++
Paddy cultivation	0	0	0	++	0	++?	++?	?	0
Barren land	0	0	0	0	0	–	–	0	0

Magnitude of benefits:[(d)] +++ = high; ++ = medium; + = low; 0 = none; – = negative; ? = uncertain

Notes:

(a) This table highlights the differential distribution of forest benefits across society, and the tradeoffs resulting from changes in the type of vegetation on the forest land. Thus, e.g., timber production would be maximized under a plantation that may hardly yield any biodiversity benefits, whereas fuelwood and grass production is likely to be maximized in tree savannahs that provide limited carbon storage or timber. The list of benefits is only typical, not exhaustive. It best corresponds to the situation in the case study region of Uttara Kannada district in southwestern India.

(b) Non-vegetative uses of the land, such as for dam projects, buildings, or roads, are similarly divergent in their distribution of benefits.

(c) The categories ''local'', ''regional'', and ''global'' refer broadly to the location of the beneficiaries of a particular product or service provided by the forest. These differences result from a combination of the nature of the ecological process (e.g., water flow that links upstream forests with downstream farmers) and the social institutions distributing rights across communities (e.g., current forest rights in India that enable most of the timber benefits to flow to urban timber consumers rather than rural ones). The fluidity of these categories is indicated by distinguishing them using different patterns rather than full separation lines.

(d) The magnitudes are only indicative; significant uncertainties exist, as indicated by the ''?''.

villagers harvest large quantities of fuelwood, timber, fodder, manure, mulch, and minor products to support their domestic, agricultural and livestock systems. In the process, they have ''disturbed'' and indeed manipulated the vegetation significantly, resulting in vegetation different from that in ''natural'' forests. Over the past century, foresters, trained to think of only natural climax forests or dense timber stands as good forests, have criticized these ''open forests'' as degraded and have predicted ''ruin and desolation'' from such use [MacGregor, 1894; Reddy et al., 1986]. The disturbed forests, however, continue to produce useful biomass even today, albeit with some changes.

A recognition of the multiplicity of definitions, and of the values and beneficiaries that these definitions correspond to, will force researchers and policy-makers to define the ''problem'' with greater care, preferably incorporating the perspectives of the resource users themselves. In this context, it would be useful to adopt a terminological convention that differentiates between situations according to the likelihood that different user groups would agree in their evaluation, as shown in Figure 1. The broad rubric of resource degradation should be decomposed into at least two categories. Unsustainable use should refer to use that results in declines in a particular benefit over time, which *ceteris paribus* would be seen as undesirable by all users. Changes in the mix of benefits provided by the forest resource should generally be non-judgementally termed as landuse changes; the exception being when the change affects only a single user or homogeneous user group who can unambiguously evaluate the *net* result. Ideally, research should encompass the plurality of interests, and provide the information required to understand the implications of a particular change from these different perspectives.

Value judgements are also involved in specifying whether ''benefits'' are to be measured in physical terms, as natural/physical scientists tend to do, or in economic ones, as resource economists urge. The answer again should depend primarily upon the perceptions of the users of the resource. In many situations, the biomass flows are not perceived by the users to be continuously substitutable with other materials or with cash that can purchase these substitutes in the market; in such cases, physical units would be more appropriate.

In general, the definition chosen, underlying value judgements, and user groups it corresponds to should be made explicit at the beginning of any discussion. Thus, in the empirical research cited below, I chose to define sustainability as maintaining the benefits from biomass flows to the villagers using the forest, and measured these benefits in physical units for the reasons outlined above. This definition coincides with that implicit in much of the literature on rural biomass use.

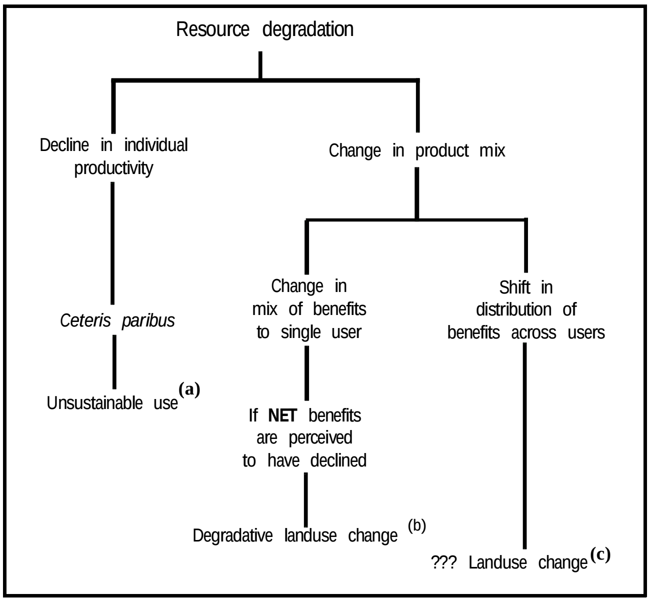

Fig 1. Proposed convention for ''degradation'' and ''unsustainable use''

Notes

(a) We assume here that the ''individual'' product or benefit flows to a single user, or changes in its productivity affect all users similarly.

(b) Such unambiguous aggregation of benefits and costs across multiple products is generally possible only for a single individual. However, it is also possible for a multiplicity of users if they all have similar rankings for the benefits, i.e., have essentially congruent utility functions.

(c) This change is hardest to ''evaluate'' as degradative or beneficial, since any such evaluation requires making additional value judgements about how to weigh benefits and disadvantages flowing to different users / user groups.

3. Sustainability criteria and the particular case of the production-harvest balance

Corresponding to any particular definition of sustainable use, there are different methods for determining its presence or absence in a given situation. In the case of definitions based on average physical productivion of biomass used by villagers, the six methods listed in Table 2 seem typical. The first two seek to predict future resource productivity by measuring its temporary or spatial trends, the third seeks to predict this trend on the basis of current production and harvest, and the remaining three base their prediction on specific biophysical factors controlling future production, viz., plant regeneration, soil physical and chemical conditions, and specifically the soil nutrient balance. The advantages and disadvantages of each approach are mentioned briefly in the table[4].

The method most commonly adopted, particularly in the context of fuelwood use, is the production-harvest balance, i.e., the comparison of the rate of biomass production with that of harvest for a given resource boundary. Here, the implicit model is one of a homogeneous resource stock (B), to which biomass is added at a stock-dependent rate (P), and from which a homogeneous harvest (H) is removed. Thus, if H exceeds P, then the future stock, and hence future productivity, will decline.

The assumptions of homogeneity and stock-dependence of growth, however, bear closer examination. For instance, in the case of grass biomass, harvest reduces above-ground biomass stock, but within-season growth is only partly controlled by this stock, and growth in future seasons is controlled largely by seed stocks or below-ground root stocks. Similarly, in the case of leaf removal from trees, future leaf production does not bear any simple relationship to the stock of leaves remaining after har-

Table 2. Common criteria for sustainable biomass use[a]

Criterion	Method / data	Remarks
1. Productivity not declining over time (the basic definition)	Gather longitudinal productivity[b] data and examine trend	Sufficient time-series data are difficult to obtain, esp. for slow-growing biomass (i.e., trees). Must control for temporal variations in rainfall, etc.
2.Productivity not less than what it ''should be''	Gather cross-sectional productivity[b] data; compare with some theoretical or empirical ''benchmark''	Obviates need for longitudinal data. But choosing benchmark requires controlling for spatial variations in soils, rainfall, temperature, etc. And lower production may represent either a declining trend or a stable less productive state.
3. Production-harvest balance	Compare annual production[b] and harvest within certain boundary	In theory, obviates the necessity of both time-series and cross-sectional data, and has predictive power. In practice, many pitfalls and limitations: see text.
4. Vegetation age-structure ensures future growth	Estimate regeneration; predict future growth from model, or compare with benchmark[c]	Estimates medium-term sustainability. Currently, few theoretical benchmarks available for disturbed, multi-species, uneven-aged vegegation.
5. Soil condition ensures future growth	Gather cross-sectional data on soil condition: compare with benchmark	Estimates long-term sustainability; needs extensive sampling & careful controls for inherent variability due to geology, topography, rainfall, etc.
6. Soil nutrient balance	Compare nutrient inflow (precipitation, weathering, etc.) with outflow (runoff, extraction, etc.)	Estimates long-term sustainability; practical estimation is very difficult, esp. of rates of nutrient inflow through weathering.

Notes

(a) All criteria listed here correspond to the definition of sustainable use as that which maintains undiminished physical productivity of the useful biomass in the forest. Other definitions will lead to other criteria. E.g., if biodiversity is to be sustained, criteria may be based on gene flow, habitat quality, or landscape features.

(b) In measuring biomass productivity, which includes change in standing biomass and litterfall and mortality, some practical considerations are: how to capture litterfall before its decay, how to estimate tree standing biomass when destructive sampling is unacceptable and non-destructive measurements are onerous, and how to protect the plants from harvest so as to measure full production and yet incorporate physiological effects of harvest on growth.

(c) For uneven-aged single-species timber stands, an ''inverse-J shaped'' age curve has been posited to result in a steady flow of harvestable biomass (Meyer, 1952; Davis and Johnson, 1987, pp.56-63); its validity for pruned, multispecies stands is not known. Similarly, there are thumb-rules specifying the fraction (typically half) of the peak grass biomass to be left behind at the end of a growing season to ensure next-season productivity, but their applicability is not known.

vest. Finally, if only dead leaves or dead wood are being collected, the harvest does not reduce the growing stock, and hence has no direct effect on future production[5]. The domain of applicability of the P-H balance therefore seems to be restricted to the case of live wood extraction from trees. Even within this restricted domain, proper application of the criterion is not easy. Estimating total production involves accounting for tree mortality, biomass increment in survivor trees, recruitment, and litterfall. Further, the effects of varying soil-climatic conditions, of competition, and of harvesting regimes on these elements of production have to be factored in. (See also Note (b) in Table 2.)

Many attempts to characterize the impact of fuelwood or biomass extraction on forests pay insufficient attention to these limitations and requirements of the criterion. The P-H balance is often applied to *aggregate* biomass, including tree, shrub, and grass, or to only leafy biomass [Bhat and Huffaker; 1991]. P is equated to the rate of net increment [Reddy et al., 1986; Ravindranath et al., 1992], leaving out woody litterfall and whole-tree fall, but fuelwood collections normally include deadwood. Relationships between tree biomass and tree dimensions derived at one location are used indiscriminately across vastly varying conditions [Ravindranath et al., 1992]. These tendencies vitiate the reliability of the conclusions drawn about the prevalence of unsustainable biomass use.

4. P-H balance for woody biomass extraction from *soppinabetta* forests of Uttara Kannada district

With the above discussion in mind, I applied the P-H balance criterion only to evaluate the sustainability of tree woody biomass use in the rural hilly part of Uttara Kannada district in Karnataka state (southwestern India). I shall describe briefly the methods used and results obtained from the point of view of their broader implications[6].

To be able to estimate the amount of annual harvest from a particular forest patch and to conduct controlled growth measurements, we had to exclude open-access areas. The study therefore focused on *soppinabettas*, forest lands on which individual households exercise exclusive usufruct rights[7]. Multi-year data from various forest plots in this region monitored by the Centre for Ecological Sciences were used to generate relationships of increment, recruitment, and litterfall with tree girth, species, site, and harvesting regime. These relationships were applied to the vegetation in individual *betta* plots, and in the village *betta* area as a whole. Estimates of harvest were also con-

Table 3. Application of the P-H balance criterion to the extraction of above-ground tree woody biomass in *soppinabetta* lands[(a)] in the hilly region of Uttara Kannada district

Table 3(a). Plot-level comparisons

Sample betta plot	Tree density	Tree basal area	Standing woody AGB	Survivor increment [t/ha/yr]		Recruitment [t/ha/yr]		Twig regrowth [t/ha/yr]		Net live wood production [t/ha/yr]		Estimated harvest [t/ha/yr]
[code]	[#/ha]	[sq.m/ha]	[t/ha]	Mean	SE	Mean	SE	Mean	SE	Low	High	
SM-BETTA	359	12.6	37	0.9	0.0	0.1	0.0	0.2	0.1	1.0	1.4	NA
BK-DVH	555	23.8	92	2.2	0.3	0.2	0.0	0.4	0.1	2.1	2.9	NA
BK-LOP	371	13.3	48	1.3	0.1	0.1	0.0	0.2	0.1	1.3	1.7	NA
AP-AVH	385	19.5	99	1.9	0.2	0.1	0.0	0.3	0.1	1.7	2.5	0.8 *
AP-GMH	444	29.1	156	2.2	0.3	0.1	0.0	0.4	0.1	1.9	2.8	2.4
GK-GBHAT	495	34.4	201	3.6	0.3	0.2	0.1	0.4	0.1	3.2	4.3	1.7
TK-GGH	257	11.7	47	1.1	0.1	0.1	0.0	0.2	0.0	1.0	1.4	1.1
TK-RTH	510	14.6	51	1.5	0.1	0.1	0.0	0.3	0.1	1.6	2.0	0.6 *

Table 3(b). Village-level comparison of P & H

Village name	Betta users		Total wood harvest [t/yr]		Total wood production [t/yr]		Possible ratios of harvest:production		
	# of hhs	Population	Low	High	Low	High	High:low	Low:low	High:high
Arasapura	15	102	82	117	316	423	0.4	0.3	0.3
Golikoppa	12	96	77	110	254	336	0.4	0.3	0.3
Sirsimakki	25	194	155	223	119	189	1.9	1.3	1.2
Mundagesara	42	327	262	376	228	348	1.7	1.1	1.1
K. Sarakuli	11	74	59	85	77	121	1.1	0.8	0.7
Tattikai	20	183	146	210	202	318	1.0	0.7	0.7
Malenalli	37	280	224	322	726	973	0.4	0.3	0.3

Notes

(a) Except in Malenalli village, where there are no *soppinabetta* lands, but where households were known to extract from the open-access Minor forest and state-controlled Reserve forest within the village boundary.

(b) *Total* woody production = increment in bole and branchwood of survivor trees + recruitment of new individuals into measurable class + regrowth of twigs after pruning + litterfall (excl. whole tree mortality). *Net live* wood production = first three terms of previous equation *minus* whole tree mortality (because this biomass needs to be made up before any biomass can be considered harvestable if total tree biomass is to be maintained constant).

(c) Village-leval production was estimated by dividing the village *betta* lands into areas with high, medium, and low tree densities, and then using production estimates from plots that were closest to these location-density combinations.

(d) Plot-level estimates of harvest are based on monitoring of live wood harvested by households during annual pruning, which contributes the major portion of household wood use, and estimation of other live wood extraction (including timber) by questioning and sample weighings. Households marked with * were in the process of shifting to bio-gas, and hence had somewhat lower harvests. NA = the households for which monitoring of harvest could not be completed.

(e) Village-level estimates of wood harvest are derived from estimated household *consumption*, with the assumptions that all the wood consumed by the *betta*-holder households comes only from the *betta* lands in the village, and that only these households extract wood from the *betta*-lands, except in the case of Malenalli village (see Note (a) above). The errors coused by these two assumptions are considered to be small and in opposite directions. The low and high village-level values correspond to total woody biomass consumption levels (fuelwood + other) of 0.80 t/capita/yr (0.65 + 0.15) and 1.15 t/capita/yr (0.90 + 0.25) respectively; they assume that all households cook with fuelwood only, and use traditional stoves. The shading highlights cases where which H > P.

structed on these two scales, i.e., for sample *betta*-holder households through direct monitoring of live wood cut, and for each viIlage's *betta*-holder population as a whole using estimates of average household consumption, which included live and dead wood (primarily as fuel). Accordingly, the former was compared with *net live* wood production, while the latter was compared with *total* wood production (i.e., including woody litterfall and deadfall). These two-level comparisons are presented in Table 3.

The results provide some interesting general insights. Firstly, the mean estimates for net live wood production in these ‘‘highly disturbed open forests’’ ranged from 1.2 t/ha/yr to 3.7 t/ha/yr. This range is much higher than the values typically assumed in the literature, such as the 0.6 t/ha/yr used by Reddy et al. [1986]. Moreover, total wood production (not shown, but used in Table 3b) ranged from 1.6 to 5.4 t/ha/yr. This highlights the importance of including deadwood when estimating total sustainable fuelwood supply.

Secondly, the two-level comparisons indicate that over-extraction is definitely not pervasive in these forest lands[8]. This result contradicts conventional wisdom about these forests [MacGregor 1894; Shyam Sunder and Reddy, 1986]. And it raises the possibility that similar wisdom elsewhere may also be based upon some combination of implicit notions of what a ''good'' forest is, improper application of the P-H criterion, and a failure to estimate the uncertainties associated with values derived from typically scanty primary data.

Thirdly, the usefulness of the P-H balance criterion needs to be reconsidered. The supposed advantage of this criterion is that it does not require temporal data or any ''benchmarks'' (see Table 2). However, this case study shows that generating reasonably certain estimates of production and harvest for diverse, heavily utilized, and under-studied tropical forests is difficult: witness the large uncertainties in the estimates in Table 3. Thus, obtaining meaningful results will in most cases require vast multi-year data collection efforts, constraining the criterion's usability. Research may therefore have to focus on the development of simple thumb rules, such as the number of stems or branches or saplings to be left intact, or pruning frequencies to be maintained, that may have broader applicability. ■

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Notes

1. This paper has been adapted from a presentation titled "Sustainable use of biomass resources: definitions, criteria, and application" made at the BioResources '94 conference in Bangalore in October 1994. The empirical research cited herein was conducted in affiliation with the Energy & Resources Group (University of California, Berkeley) and the Centre for Ecological Sciences (Indian Institute of Science, Bangalore); financial support for it was provided by the Ford Foundation, American Institute for Indian Studies, U.S. Man & Biosphere Program, WWF-US, and to CES by the Ministry of Environment & Forests, Government of India. The writing of this paper was supported in part by a grant from the Hewlett Foundation and a fellowship from the Bullard Fund at Harvard University.
2. In fact, the debate in India began as early as the late nineteenth century, when the British colonialists took over the country's forests.
3. These choices pertain not only to the question what is to be sustained, but also for how long, with what certainty, and at what costs distributed in what manner.
4. See Lélé [1993, Chap. 2] for a detailed discussion.
5. Indirect effects through the removal of nutrients are ambiguous and take many decades to become manifest.
6. See Lélé [1993, Chap.3] for details.
7. *Soppinabetta* forests constituted between 75% and 100% of the forests in six of the seven villages studied. The tree vegetation in all these lands is mixed evergreen or moist deciduous, with varying densities. Villagers extract wood, primarily for fuel but also for fencing and house work, by pruning the trees, cutting saplings, collecting deadwood, and on rare occasions by felling whole trees.
8. The plot-level comparison shows little possibility of harvest exceeding production in 4 out of 5 plots, and a harvest value around the mid-value for production in the 5th plot. At the village level, under generous assumptions of wood consumption levels (~1 t/capita/yr), and assuming that this value was the same for all villages, 2 villages out of 7 showed a distinct possibility of over-harvest. However, questionnaire data indicated that the actual average consumption in these two villages is in fact lower than that in the other villages.

Results of an Indo-Swiss programme for qualification and testing of a 300-kW IISc-Dasag gasifier

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1. Introduction

The results of the tests conducted on an open core gasifier system rated for 100 kW_e are presented here. These results are the outcome of collaborative testing between the Indian Institute of Science, Bangalore, India, Dasag, Switzerland, and ETH, Switzerland. The gasifier system developed at the Indian Institute of Science was tested to determine the gas quality and consistency in its operation for a possible deployment of this technology on gasifiers in European countries.

The gasifier system consists of an open core reactor, a cooling and a filtering system along with a blower and a burner. The details of the configuration of the system are described in Mukunda et al. [1994]. The tests conducted were in the thermal mode, i.e., after cooling and cleaning the gas, the gases were flared. The main objectives of the tests were to determine the gas composition, and tar and particulate levels at the hot and cold ends at various loads.