Understanding forest degradation in Nepal

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A rich experience in ground-based inventory provides a solid basis for a multi-method approach to measuring forest degradation.

Forests play an integral role in the farming system of Nepal

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Forests provide a wide range of regulating, cultural and supporting services for human well-being collectively known as ecosystem services. The sustainability of forest ecosystems requires careful management, efficient utilization and effective protection measures against deforestation and forest degradation. In a mountainous country such as Nepal, forests are important for the protection of water catchments, the conservation of soil and the maintenance of biodiversity, as well as for their contributions to sustainable rural livelihoods and the maintenance of the environment. It is imperative to develop common understanding of the effects of forest degradation among the users of forests, forest managers, policy-makers and politicians so that appropriate public policy to address it can be developed.

This article reviews past forest resources assessments, methodologies and findings on forest degradation in order to identify a way forward in understanding and addressing forest degradation. It proposes that using satellite images in conjunction with field surveys could be a suitable approach for assessing forest degradation in Nepal. It includes discussion on major drivers of degradation and methods of their detection, and proposes using a participatory valuation approach applying the ecosystem services index to quantify forest degradation.

ROLE OF FORESTS IN NEPAL

The widespread forest degradation in developing countries remains poorly understood and quantified (Niles *et al*., 2001). It has been argued that a single major cause of degradation is that forest resources are grossly underpriced and are, therefore, undervalued by society (Richards, 1994). In countries in which the primary sector – the use of raw materials from the earth – is the mainstay of the national economy, and, in particular, in countries in which the resources are land-based natural resources, such as forests, these resources are both an important source of national revenue and a staple of rural livelihoods.

In Nepal, the role of forests is particularly evident in rural communities that rely on forests for securing assets such as energy, employment, supplementary foods, safe drinking water and good health to sustain and improve their livelihoods. In these communities, forests are also an integral part of the farming system. For example, it has been estimated that, in the high-altitude area of Nepal, to maintain one hectare (ha) of paddy land requires up to 50 ha of forest and grazing land (FAO, 1980), whereas, in the Middle Hills, an area of 3.5 ha of forest is required (Wyatt-Smith, 1982).

National Forest Inventory data have estimated forest and shrub, in combination, to cover 39.6 percent of the country area, and the average annual rate of deforestation to be 1.7 percent (DFRS, 1999; 2008); degradation of forests represents a serious threat to livelihoods. A common understanding of forest degradation must be developed among all stakeholders so that appropriate public policy can be formed and implemented.

FOREST RESOURCES ASSESSMENTS UNDERTAKEN

Historical assessments

Forest degradation has been understood, among the assessments over the past fifty years, as a reduction in capacity to produce timber, or timber volume, tree canopy cover, tree density and regeneration. Assessments have been focused on investigating the association of canopy cover with commercial timber volume. This approach recognizes neither ongoing degradation within dense canopy forests nor degradation of the understory. Further, the trade-off of different kinds of ecosystem services has not been considered.

In order to provide a common way to view results of the studies conducted over the past fifty years, this section provides a brief description of each major assessment of Nepal's forest resources that has been undertaken. Further sections and accompanying tables analyse the data gathered on the basis of thematic elements of sustainable forest management, methodology used for data collection, land cover, and forest degradation as a function of increase in shrub land. The section concludes with a table comparing the different methods used for assessment.

Forest Resources Survey, 1963/64

The Forest Resources Survey Office conducted the first forest inventory during the period 1963–1967. Using aerial photography from 1953–1958 and 1963–1964, the inventory involved visual interpretation of aerial photographs and mapping, combined with field inventory. The land categories included forest, crop, grass, urban, water, badly eroded and barren. The forest land was subdivided into commercial and non-commercial forest (HMG, 1968; 1969; 1973). The inventory focused on assessing extent of forest area and growing stock per ha that was up to 10 cm in top diameter.

Land Resource Mapping Project, 1978/79

The Land Resource Mapping Project (LRMP) was implemented with financial support from the Government of Canada. The objective was to develop appropriate forest land-use maps based on forest types, composition, structure and status of land degradation. The project was implemented during the period 1977 to 1984 (LRMP, 1986a; 1986b). The forest resources assessment was prepared through the combined use of aerial photographs (1977–79) and extensive ground-truth checks, land surveys and topographic maps.

Master Plan for the Forestry Sector, 1986

The Master Plan for the Forestry Sector (MPFS) Project was implemented by the Ministry of Forests and Soil Conservation. The data were based on LRMP information and forest inventory data from the Department of Forest Research and Survey (MPFSP, 1989a; 1989b). The aim was to update resource information with changes that had occurred during the intervening period since LRMP.

National Forest Inventory, 1994

The National Forest Inventory (NFI) was started in the early 1990s and completed in 1998, with a base year of 1994 (DFRS, 1999). The programme was implemented with support from the Government of Finland. The NFI involved satellite image analysis – using Landsat (an Earth-observing satellite programme currently managed jointly by the National Aeronautics and Space Administration of the United States of America and the United States Geological Survey), aerial photographs and field measurements.

Forest cover change analysis of the Terai districts, 1990/91–2000/01

The Terai districts are near or bordering the Siwalik Hills, the lowest outer foothills of the Himalaya. This study,

Forest infested by* Mikania micrantha *("American rope", "Chinese creeper", "mile-a-minute weed"), central Nepal. Forest health and vitality, and biodiversity, have not often been a focus of forest resources assessments

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TABLE 1. National-level forest assessments in Nepal and linkages to sustainable forest management

Study	Thematic element of sustainable forest management
Forest Resources Survey	1, 5
Land Resource Mapping Project	1, 5
Master Plan for the Forestry Sector	1, 5, 7
National Forest Inventory	1, 5
Forest cover change analysis of the Terai districts	1
Economic valuation of ecological goods and services	2, 4, 5, 6, 7
Contribution of forestry sector to gross domestic product in Nepal	2, 4, 5, 6, 7

Note: The thematic elements of sustainable forest management are. 1. Extent of forest resources; 2. Contribution to the carbon cycle, forests and climate change; 3. Forest health and vitality; 4. Biological diversity; 5. Productive functions of forests; 6. Protective functions of forests; and 7. Socio-economic functions of forests (FAO, 2011).

commissioned by the Department of Forests, estimated the extent of forest cover and the annual rate of change of 20 Terai districts. The forest cover change was estimated by analysing satellite images, supported by ground verification (Department of Forests, 2005).

Economic valuation of ecological goods and services, 2005

This study, commissioned by the Ministry of Forests and Soil Conservation, aimed to estimate the value of goods and services of forest ecosystems representing different ecological zones and management regimes (MoFSC, 2005).

Contribution of forestry sector to gross domestic product in Nepal, 2008

This study aimed to estimate the actual contribution of the forestry sector to national gross domestic product (GDP). Both "use" and "non-use" values were taken into consideration in estimating the contribution. The use values included consumptive goods such as timber, fuelwood, grass/fodder/bedding materials, non-timber forest products, sand and boulders. Non-use values included recreation, ecotourism, soil conservation and carbon sequestration (DFRS, 2008).

Linkages with thematic elements of sustainable forest management

FAO (2011) has defined the thematic elements of sustainable forest management to be: extent of forest resources; contribution to the carbon cycle, forests and climate change; forest health and vitality; biological diversity; productive functions of forests; protective functions of forests; and socio-economic functions of forests.

Thematic elements of sustainable forest management covered in each assessment undertaken are described in Table 1. By the standards of the FAO framework, not all elements are covered in the assessments. Resource assessments are focused on the extent of forest area and standing timber volume. None incorporates the elements of carbon stocks, biodiversity, forest health and vitality and protective functions of the forests in the assessment report.

Methodology

There is consensus that measuring forest degradation is more complex and difficult than measuring deforestation (Panta, Kyehyun and Joshi, 2008; Lambin, 1999; Souza *et al*., 2003). Table 2 summarizes the criteria and methods used by each study in defining and assessing forest degradation.

TABLE 2. Review of methodology of forest assessment studies

Study	Degradation criteria	Methods
Forest Resources Survey	• Stocking class (crown cover < 10 percent is a non-forest area) and density class • Scrub and shrub • Encroached forest	• Means estimator • Visual interpretation of aerial photographs • 1:12 000 to 1:60 000 aerial photographs • Dot counting • Area rectification and adjustment • Field inventory, in commercial forests
Land Resource Mapping Project	• Stand stocking • Soil surface erosion	• Visual interpretation of aerial photographs (black and white, scale 1:20 000 to 1:50 000) • Ground-truth checks by helicopter • Land surveys • Topographic maps
Master Plan for the Forestry Sector	• Crown closure • Regeneration	• Desk review • Visual interpretation of aerial photographs and field verification
National Forest Inventory	• Crown cover–stand density	• Satellite images, Geographic Information System (GIS), topographic maps, vector data boundary • Ground-based inventory • Visual interpretation of aerial photographs, scale 1:50 000
Forest cover change analysis of the Terai districts	• Crown cover	• GIS, satellite image analysis and ground verification
Economic valuation of ecological goods and services	• Crown cover • Use value of ecosystem services	• Forest inventory • Questionnaires • Market price/substitutes • Benefits transfer • Total net stock
Contribution of forestry sector to gross domestic product in Nepal	• Crown cover	• Ground-based forest inventory • Questionnaire • Market price • Market price of substitutes • Benefits transfer • Total net stock

The tree canopy stocking level is the main criterion used in assessments. Therefore, it seems accepted among them that forest degradation is the reduction in timber volume, or perhaps changes in species, sizes, structure, or in the capacity of a forest to produce timber.

The stocking level (stems/ha) is linked to forest productivity or growth and yield potential. Proxies used include canopy closure, number of mature trees, number of preferred trees, density, cut stumps, growing stock, regeneration capacity, stand maturity, lopping, species composition, grazing and soil surface erosion. The level of canopy cover at which land is described as "forest area" is 10 percent. Among the studies, there is a lack of clarity among the definitions of forest and shrub land, shrub and scrub land, and forest and degraded forest.

Results: shrub, scrub and degradation

The extent of land falling into the forest and shrub categories, respectively, is shown in Table 3. The Forest Resources Survey recognizes the quality differentiation primarily based on stand size, density classes, crown closure and merchantable volume.

There is neither clear national definition nor clear national assessment of forest degradation. Rather, degradation is characterized by fewer trees, lopped trees, unwanted species, heavy grazing pressure, unpalatable species and bushy species. The study does identify encroached forest as a kind of degraded forest.

Total forest area has not changed very much, through the various studies (Table 3), although forest cover is recorded as having been degrading (Table 4). Taking into account the Department of Forest Research and Survey definition of shrub land (DFRS, 1999), and the data from the studies (Tables 3 and 4), one can assume that shrub lands are those forest areas from which tree stems have been removed but that maintain woody vegetative cover.

TABLE 3. Extent of forest and shrub land cover in Nepal

Study	Forest *'000 ha*	Forest *%*	Shrub *'000 ha*	Shrub *%*	Forest and shrub total *'000 ha*	Forest and shrub total *%*
Forest Resources Survey	6 402	45.5	–	–	6 402	45.5
Land Resource Mapping Project	5 616	38.1	689	4.7	6 285	42.8
Master Plan for the Forestry Sector	5 424	37.4	706	4.8	6 210	42.2
National Forest Inventory	4 268	29	1 560	10.6	5 828	39.6

TABLE 4. Estimation of forest degradation rate in terms of increase in shrub land

Study	Shrub land *'000 ha*	Shrub land *%*	Forest degradation (1978/79 to 1994) *% per year*
Land Resource Mapping Project	689	4.7	5.57
National Forest Inventory	1 560	10.6	

Therefore, shrub land can be viewed as an outcome of forest degradation or as a kind of degraded forest.

A comparison of the NFI study with the LRMP shows that the area classified as shrub land increased by 126 percent between 1978/79 and 1994, at an annual rate of 5.57 percent (Table 4). There is no substantial change in total forest and shrub land area. However, the estimate of degradation does not include degradation that remains within the category of "forest", i.e. above 10 percent crown cover.

The Department of Forests (2005) definition of a degraded forest includes shrub land. However, other elements among the different inventories cannot readily be compared across the inventories because the definitions used and coverage are too varied.

Degradation assessment methods

The different assessment methodologies used in the various surveys can be grouped into aerial photography, field survey, satellite image and ecosystem service valuation. Table 5 compares strengths and weaknesses among these methodologies. This analysis would lead to the conclusion that accuracy of the assessment of forest degradation increases if methods are combined, and, in particular, if remote sensing methodologies are supported by the ground-based information.

DISCUSSION

Definition

For the period of 1978/79 to 1994, the average rate of forest conversion to shrub land (5.57 percent per year) was significantly higher than the rate of deforestation (1.7 percent per year). This statistic would indicate that forest degradation may be a more important issue to consider in efforts to reduce carbon emissions or boost the resilience capacity of forest ecosystems.

But there is no global definition for forest degradation. Classical forestry literature assumes that degrading forests are characterized by such attributes as loss of canopy cover, declining population of tree species, loss of reproductive potential, poor regeneration and loss of capacity to produce various consumptive forest products. More recent literature adds the loss of potential to sequester carbon, conserve biodiversity, harvest water, realize recreational value, and others. These environmental attributes have also been considered as important indicators of forest degradation.

The lack of a uniform definition also applies to the differentiation between shrub land and forest. The NFI defines shrub land as forest area without well-defined stems, whereas the assessment by the Department of Forests defines sparsely distributed trees or forest land with less than 10 percent crown cover – including shrub lands – as degraded forests. Neither assessment offers a clear, simple and consistent definition of degraded forests and shrub lands.

Context of the studies adds yet more variables to the definition of degradation. Forest degradation in one context may not necessarily hold the same meaning in another context. The scale and scope of its measurement may vary along with change in management objectives and expected outcome for the forests.

Drivers

Though no consensus has been reached on what constitutes degradation, policy does need to attempt to address it, and particularly at the source of the degradation. Regulatory and market instruments generally work if appropriate policy, institutions and legal frameworks are in place. But there are limitations to the influence that policy can have. For example, the cause of forest degradation can be loosely divided into the categories of anthropogenic and natural, although there is no clear demarcation between them. But natural causes would be considered exogenous and uncontrollable, and policy instruments would not help to control them.

The sources of degradation are commonly referred to as “drivers” of degradation. Drivers of degradation usually correlated to the anthropogenic category can be viewed as direct or indirect. Direct drivers could include, but are not limited to, over-extraction, intentional fire, free grazing, targeting of high-quality commercial tree species, illegal logging, encroachment, shifting cultivation and forest fragmentation. Indirect drivers might include market failure, unplanned development, policy failure, weak tenure rights and capacity gaps.

The vulnerability of a particular forest to such drivers depends on intensity and magnitude of individual drivers,

TABLE 5. Relevance of different forest degradation assessment methodologies in Nepal[a]

Methodology	Advantages	Disadvantages	Accuracy level	Costs	Implications for Nepal
Aerial photography	• Easily understood by local community • Easy to demonstrate forest degradation such as crown cover change, shifting cultivation, forest fragmentation • Long experience • Infrastructure exits • Requires low input on technology	• Difficulty in mountain area • High costs • Long time requirement • Nearly abandoned and replaced by new technologies • No latest aerial photographs available • Degradation elements such as grazing, fire damage, non-timber forest products (NTFPs) and understory damage, encroachment are not completely detectable	High	High	No recent aerial photographs available – less useful
Field surveys	• Data available for comparison • More accurate • Widely understood • Cheap labour • Considerable experience • Simple technology • Capture all kinds of ecosystem services • Local to national scale possible • Case study and research data available	• More resources • Time-consuming • Difficult in mountain terrain • No recent data available	High (standard error for the top 4 volume ranged from 2.61–6.66 percent)	Medium	Considerable experience exists; labour is cheap; community involvement is available – a good option
Satellite image analysis and GIS	• Global uniformity • Rapidly advancing technology • Easy interpretation in high-resolution images • High-resolution images usable as a map for demonstration • Requires low forest inventory	• Technical capacity and infrastructure demanding • Cloud, shadow and slope in hilly areas • Few control plots for ground verification • Seasonal images availability • Limited data to replace ground inventory • Difficult to assess understory, including NTFPs	Medium to high (67– 98 percent to distinguish in different stocking class)	Low or medium (i.e. free to moderately expensive – Landsat to IKONOS)	Difficult terrains support it; needs capacity development – if combined with field survey, is one of the best options
Ecosystem service valuation	• Recognizes broader value of forest ecosystem	• Technically demanding • Outside forestry discipline	Medium to high	Low to moderate	Community participation, true valuation of forest services

[a] Based on photographs 1:12 000 to 1:60 000 and Landsat TM images.

as well as the scale of their interaction with other factors. Methods to detect degradation may not be inclusive of all factors. Understanding the direct and indirect drivers of degradation assists in estimating the extent of degradation. The key is detecting the degradation through appropriate means of measure (Table 6). Although the drivers of forest degradation are complex, direct drivers are often detectable through observation or image analysis. Indirect drivers are more difficult to understand, and, therefore, to measure discretely.

Forest encroachment and invasion of alien species have emerged as important drivers of forest degradation, and in Nepal, particularly in the Terai plains. Illegal settlement drives forest degradation, and may lead to the permanent conversion of forests to non-forest land uses. Invasion and colonization by alien species can slowly reduce growth and potential for restoration of forests, and infestations can ultimately affect entire forests. Another important driver is forest fire. Additionally, high-altitude forests suffer degradation as a direct result of the stocking of livestock units in quantities up to nine times greater than their carrying capacities (MoEST, 2008; MoFSC, 2002).

Indicators

Past assessments based on spatial and temporal mapping of forest conditions suggest that forest degradation is causing changes in the forest structure, function and other attributes. Sharma and Suoheimo (1995) found that about 45 percent of trees in the Makawanpur and Rautahat districts are affected by rot diseases. Acharya (2000) found that there is degradation of existing forest stock resulting from repeated logging practices, which has resulted in a change of forest type. An illustration is made of conversion of Sal forest (> 60 percent of basal area) to Sal Terai hardwood, and finally to Terai hardwood (Sal basal area < 20 percent).

Crown cover is often taken as a proxy indicator to detect forest degradation. It may, however, not be a sufficient indicator to determine forest degradation. Canopy reduction will reduce carbon sink potential, but it may enhance watershed conservation and biodiversity. The understory may remain intact. Conversely, loss of ground vegetation or understory, which may not be detected, could also be key degradation element, as it affects ecosystem resilience (Table 6). Therefore, crown-cover-based assessment alone is not sufficient to detect the drivers of degradation. Field-survey-based assessment in combination with remote sensing techniques produces more technically robust information that better captures the key degradation elements and their consequences.

Value

Forest degradation can be understood on the basis of the reduction in the capacity of forests to produce all ecosystem services. Therefore, a comprehensive methodology should include understanding and valuing forest degradation on the basis of provision of ecosystem services. An effective approach to measuring degradation would use satellite images combined with field survey. To value services, and therefore degradation, a participatory ecosystem services valuation approach (PESVA) would be recommended. Such an approach captures a “degradation factor” by valuing ecosystem services comprehensively (Table 7).

The PESVA is based on the concept of the forest ecosystem services index (ESI). ESI is a summary index of ecosystem services of a forest. It measures the average performances of use values of the forest. The ESI is estimated against ecosystem services as defined by

TABLE 6. Anthropogenic drivers of degradation and their detection potentiality

Drivers of degradation	Level of significance	Key degradation element	Detectability (1 = low; 3 = high)		
			Field survey	Aerial photographs	Images
Overexploitation of wood products	High	Crown cover, biomass, understory	3	2	1
Overexploitation of non-wood products	High	Green biomass, crown density, species diversity, understory	3	1	1
Forest encroachment (illegal settlement or occupancy)	High	Crown cover, habitat, biomass, understory	3	2	2
Overgrazing	High	Surface soil, natural regeneration, habitat	3	1	1
Unplanned development: road, hydropower, etc.	High	Crown cover, habitat, commercial species, biomass, fragmentation	3	3	3
Wildfire	Medium	Understory, biomass, soil, biodiversity	2	1	2
Invasion and colonization of alien species	Medium	Biomass, understory, habitat, biodiversity	3	1	1
Pests and diseases	Low	Biomass	3	1	1

TABLE 7. Survey and measurement methods for selected variables

Key parameters observed	Indicators of degradation	Data source	Detection or measurement techniques
Biological attributes			
Canopy cover	Decreasing	NFI/DFSP/ CFOP	Image analysis/field inventory for data validation
Growing stock level	Declining	NFI/DFSP/ CFOP	Image analysis/field inventory for data validation
Forest structure	Poor regeneration and missing young stands	NFI/DFSP/ CFOP/FGD	Image analysis/field inventory for data validation
Species composition	Abundance of inferior tree species	NFI/DFSP/ CFOP/FGD	Forest inventory Field observation
Invasion and alien species	Invasion by exotic species	CFOP/FGD	Field observation
Environmental attributes			
Watershed conservation	Increasing surface erosion	NFI/DFSP/ CFOP	Participatory observation
Carbon sequestration	Increased forest fire and reduced carbon stocks	FRA/DFSP/ CFOP	Forest carbon inventory
Biodiversity	Loss of species abundance	FRA/DFSP/ CFOP	Field inventory
Water harvesting	Polluted water	FGD	Participatory observation Field survey
Resilience capacity	Poor forest restoration	FGD	Participatory observation
Wildlife conservation	Disturbed habitat	FGD/ observation	Participatory observation Field survey

Note: NFI is National Forest Inventory; DFSP is District Forestry Sector Plan, an integrated approach to forest resource management planning at the district level; CFOP is Community Forest Operational Plan, a management plan for community forests for a given period of time; FGD is focus group discussion; and FRA is Global Forest Resources Assessment.

the Millennium Ecosystem Assessment (2005). Periodic monitoring and comparison of indices with a base-line index will provide information about the extent of forest degradation or enhancement.

The PESVA requires expert inputs to develop ranking matrices and procedures for acquisition of information, to set default values and to interpret results. However, if implemented properly, it should be simple and manageable for community institutions so that local people can actively participate in the process of detection and measurement of forest degradation.

CONCLUSIONS

In Nepal, forest degradation has had adverse, and overlapping, ecological, environmental and social implications. Ecological outcomes have included a reduction in canopy cover, a decline in forest quality, structure and composition, a decrease in the productive capacity of forests, an increase in invasive species and a loss of biodiversity. The environment has undergone soil erosion, fragmentation of habitats and shifts in wildlife movement resulting from new obstacles. The combination of these factors has had broad and damaging implications on society and livelihoods, as the number of natural disasters has increased, and the production of forest products and services has declined.

Nepal has substantial experience in ground-based forest inventory, and the inventories conducted over the past half century have established considerable data sources on forest stock. The methods used have been aerial photographs, field inventories and satellite image analysis. The further development of methodologies to assess forest degradation will largely depend on establishing a consensus definition of degradation that includes full ranges of biophysical and socio-economic conditions and, in particular, forest ecosystem services. In Nepal, for example, a clear distinction between shrub land and degraded forest, and methods to assess shrub lands, are required. In addition, a robust methodology that can capture a range of drivers causing forest degradation is necessary.

The methodologies currently in use can be improved in two ways. First, measurement should use satellite images supported by ground-based inventory, to combine the strengths of both methods. Second, the PESVA should be adopted to provide information about the extent of forest degradation or enhancement.

There is a need for capacity and data-management development at national and local levels. Pilot studies should be conducted to test methodology and gather information on forest degradation. A better understanding of forest degradation needs commitments at a political level, and national strategy that understands both the drivers of degradation and methods to detect them, and the resources required. Then, the need to establish an effective degradation monitoring system can be met. ◆

References

Acharya, K.P. 2000. Unfavourable structure of forest in the Terai of Nepal needs immediate management. *Banko Janakari*, 10(2): 25–28.

DFRS. 1999. *Forest resources of Nepal (1987–1998)*. Publication No. 74. Kathmandu, Department of Forest Research and Survey, Ministry of Forests and Soil Conservation & Forest Resource Information System Project, Government of Finland.

DFRS. 2008. *Contribution of forestry sector to gross domestic product in Nepal*. Kathmandu, Department of Forest Research and Survey, Ministry of Forests and Soil Conservation, His Majesty's Government of Nepal.

Department of Forests. 2005. *Forest cover change analysis of the Terai districts (1990/91–2000/01)*. Kathmandu, Ministry of Forests and Soil Conservation, Department of Forests, His Majesty's Government of Nepal.

FAO. 1980. *Agronomy research in the Hill Areas of Nepal*. Hill Agricultural Development Project. Terminal Report, by P.T.S. Whiteman. Kathmandu.

FAO. 2011. *What is sustainable forest management?* Available at: www.fao.org/forestry/sfm/24447/en/.

His Majesty's Government of Nepal (HMG). 1968. *Forest statistics for the Tarai and adjoining regions, 1967*. Forest Resources Survey. Kathmandu, Forest Resources Survey Office.

HMG. 1969. *Timber resources and development opportunities in the Lower Bheri and Karnali watersheds*. Forest Resources Survey No. 6. Kathmandu, Forest Resources Survey Office.

HMG. 1973. *Forest statistics for the Hill Region, 1973*. Forest Resources Survey. Kathmandu, Forest Resources Survey Office.

Lambin, E.F. 1999. Monitoring forest degradation in tropical regions by remote sensing: some methodological issues. *Global Ecology and Biogeography*, 8(3–4): 191–198. DOI: 10.1046/j.1365-2699.1999.00123.x.

LRMP (Land Resource Mapping Project). 1986a. *Land Utilisation Report*. Kathmandu, HMG, Survey Department & Kenting Earth Sciences Limited.

LRMP. 1986b. *Summary Report*. Kathmandu, HMG, Survey Department & Kenting Earth Sciences Limited.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis*. Washington, DC, Island Press.

MoEST. 2008. *State of the Environment* (Agriculture, Forest and Biodiversity). Kathmandu, Ministry of Environment, Science and Technology.

MoFSC. 2002. *Nepal Biodiversity Strategy*. Kathmandu, Ministry of Forests and Soil Conservation.

MoFSC. 2005. *Economic valuation of ecological goods and services*. Kathmandu, Ministry of Forests and Soil Conservation.

MPFSP (Master Plan for the Forestry Sector Project). 1989a. *Master Plan for Forestry Sector: Main Report*. Kathmandu, Ministry of Forests and Soil Conservation.

MPFSP. 1989b. *Master Plan for Forestry Sector: Forestry Resource Information and Planning Report*. Kathmandu, Ministry of Forests and Soil Conservation.

Niles, J.O., Brown, S., Pretty, J., Ball, A. & Fay, J. 2001. *Potential carbon mitigation and income in developing countries from changes in use and management of agricultural and forest lands*. Centre for Environment and Society Occasional Paper 2001-04. Essex, UK, University of Essex.

Panta, M., Kyehyun, K. & Joshi, C. 2008. Temporal mapping of deforestation and forest degradation in Nepal: applications to forest conservation. *Forest Ecology and Management*, 256: 1587–1595. DOI: 10.1016/j.foreco.2008.07.023.

Richards, M. 1994. Towards valuation of forest conservation benefits in developing countries. *Environmental Conservation*, 21(4): 308–319. DOI: 10.1017/S0376892900033610.

Sharma, S. & Suoheimo, J. 1995. *Observation on rot in Sal forests in the Terai*. Forest Management and Utilization Development Project Working Paper No. 20. Kathmandu, Ministry of Forests and Soil Conservation & Finnish International Development Agency.

Souza, C. Jr., Firestone, L., Silva, L.M. & Roberts, D. 2003. Mapping forest degradation in the Eastern Amazon from SPOT4 through spectral mixture models. *Remote Sensing of Environment*, 87(4): 494–506. DOI: 10.1016/j.rse.2002.08.002.

Wyatt-Smith, J. 1982. *The agricultural system in the hills of Nepal: the ratio of agricultural to forest land and the problem of animal fodder*. Agricultural Project Services Centre Occasional Paper 1. Kathmandu, Agricultural Project Services Centre. ◆