Chapter 4

Forest, agroforestry and slope stability

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4.1 Introduction

If, as appears to be the case, climate change is bringing less predictable seasonal rainfall patterns to much of the Himalayas, the survival of a high number of hill farmers must depend upon their resilience. Examples of increasing resilience include improving water storage for droughts or reducing the erosion of fertile soil from terraces during inundation. This chapter deals with the importance of forest to Himalayan agriculture and will explore the relationship between agroforestry and slope stability at local catchment[1] level. The next chapter will consider slope stability and soil conservation for *bari* (upland rainfed) terraces. 'Adaptation to climate change' is now a mantra in international development, but unless we understand what is actually changing, adaptation strategies have the potential to make things worse. This chapter therefore begins by looking briefly at the Himalayan landscape degradation hypothesis of the 1970s, and its subsequent debate, for parallels to the present situation.

[1] Confusion can arise over the use of the word watershed, which has a different meaning in UK English from American English. In UK English a watershed is a topographical high point which determines the directions of stream flow, even at a local level. American English uses the word watershed with the meaning ascribed to the word catchment in UK English. We will use UK English throughout this text, but the reader should be aware of the difference when referencing journals.

4.1.1 Forestation and deforestation: some definitions

Before looking at the landscape degradation debate, it is useful to define 'forest' and 'deforestation'. John Metz demonstrates the difficulty of defining forest:

> A UN Food and Agriculture Organisation (FAO) project which mapped the "Ecological Units" of Nepal, used a "greater than 50% crown cover" definition to designate 29.1% of Nepal as forested land. The Canadian sponsored Land Resources Mapping Project (LRMP) distinguished areas with forest covers of 10 – 39%, 40 – 69%, and greater than 70%. Using a "greater than 40% crown cover" definition, 28.1% of Nepalese territory is forest. In contrast, the government of Nepal defines "forested land" as those areas with land greater than 10% cover, which makes 38.1% of Nepal "forested land." The LRMP definition of "greater than 40% crown cover" seems reasonable…[2]

The Government of Nepal's National Adaptation Programme of Action to Climate Change (NAPA) publication of 2010[3] gives forest 39.6% of the total land area based on their Department of Forest report of 1999, presumably based on their 10% cover criterion.

Deforestation is even more difficult to define: In Metz's view rate of change (or degradation) is one defining factor, although he suggests no values by which this might be measured.

> In the Himalayas, a primary distinction is between uses which gradually change forest structure and species composition and uses which convert forests to a different type of vegetation.[4]

Table 4.1: Changes in forest land plus shrubland 1965 – 79 (areas in km^2)

Region	1964 – 5 photos	1978 – 9 photos	Change ha	Change %
High & Middle Mountain	394380	401620	+7240	+1.8
Siwaliks	173930	147600	-27630	-15.1

Source: Metz 1991 after Nield for the Kathmandu Water & Energy Commission Secretariat (1985)

The above table shows the rate of change in cover over a 15 year period but it also expresses the difficulty of gathering and interpreting data in this environment. For while there is a 15% loss over cover in the Siwaliks, any net gain in the High and Middle Mountains might easily be the result of abandoned terraces reverting to shrub, as we shall see.

4.1.2 The Himalayan landscape degradation debate of the 1970s and '80s[5]

In the mid 1970s, international press headlines announced that deforestation in the Himalayas was now so bad that it was causing slope failures with wholesale loss of agricultural land. One source of these reports was a wide-ranging article by Erik Eckholm in *Science*[6], which, if slightly

[2] Metz, J. 1991, p. 806; his citations omitted.
[3] Ministry of the Environment, 2010.
[4] Metz, J. 1991 p.806.
[5] This debate is not fully explored here and discussion is necessarily limited to a couple of papers. A wider view can be gained from following the references given by Sharma, K.P. *et al.* 2000, 142 – 3.
[6] Eckholm, E. 1975.

emotive in tone, nevertheless drew on prestigious sources.[7] Only about one page referred to Nepal, but it contained the now much quoted sentence, 'Topsoil washing down into India and Bangladesh is now Nepal's most precious export, but one for which it receives no compensation.'[8] Anthropogenic *acceleration* of natural erosion processes was presented as the chief threat. Population pressures were necessitating the terracing of ever steeper forest slopes, effectively reducing slope stability and intensifying the demands on the remaining forest for both fodder and fuel-wood. In consequence soil fertility was, in some places, much reduced by a proportional decrease of (cattle) herd sizes in relation to the crop land for which they provided fertiliser. Eckholm cited a statistic that, in the most densely populated eastern hills, 38% of the land area consisted of abandoned fields as an example of the extent of the problem. The reasons for terrace abandonment are discussed in the next chapter, but the fact that he did not cite any supporting evidence for this statistic detracted considerably from the strength of his argument, which was heavily criticised by Jack Ives, who pointed out *inter alia* that compared to past centuries, deforestation was at an all-time low.

We will return to Ives later, but it is important to understand the context of Eckholm's article, which was written at a critical time for Nepal's remaining forests. One researcher suggested that two million hectares of forest were destroyed in the eleven years up to 1975, although this would have included the Terai, which is outside the scope of this article.[9] However the destruction of the Nepalese forest[10] had probably begun under state ownership in the pre-Gorkha period because of the crippling 50% tax demands on Nepal's peasantry. One of the few escapes from this was obtaining permission to bring a parcel of forest into cultivation, which gave a three year tax holiday upon that parcel. In the Gorkha period (1769 – 1845), demand continued for 'dry land' crops (maize and potato), which had been introduced in the middle of the eighteenth century. The Gorkha regime also introduced a *rakan* system of land tenure by which each family had to supply 75 days' labour a year, particularly in the Kathmandu area. This duty often included the provision of 864kgs, the better part of a ton, of fuel wood for Gorkha military needs but it is difficult to quantify the effect this may have had on forest scope and density; there is apparently some evidence that it may have engendered some collective responsibility at local level. Yet despite the importance of forests to the Gorkha regime as a source of revenue and energy, it appears to have been indifferent to forest management. The high level of tax had a depopulating effect upon Nepal's mountains, while a living could be made with lower tax stress in neighbouring states. In consequence under Rana rule (1845 – 1950) a 10% bonus was added in perpetuity to the 3-year deforestation tax break.

During the period 1950 – 60 Nepal effectively underwent an interregnum. The nation's forests were nationalised in 1957, yet the difficulties of government may have precluded effective administration. King Mahendra's (1960 – 1972) land reforms included the 1961 *Forest Act*, which encouraged some local forest rejuvenation by granting small parcels of land; it also transferred forest use and management to the panchayat communities, while ownership remained firmly

[7] These included: UNDP report by Nepal's chief conservator of forests (1967), Nepal's National Planning Commission Secretariat (1974), a report from The Government of India's Department of Agriculture (1967) and the United States Agency for International Development (1967).
[8] Eckholm, E. 1975, pp. 764 – 5.
[9] Rasul, G. & Karki, M. 2007 citing Wallace, M. 1981. The citation has not been verified here.
[10] Mahat *et al*. 1986 from which the following information is drawn. See also Metz 1991, pp. 807 –809.

with the state. The 1967 *Forest Preservation (Special Arrangement) Act* appears to have had little effect on richer sections of the community (who had the means to circumvent the legislation) while punishing infringements by the poor. Eckholm's 1975 article seems therefore to have been written in the context of a period of well-intentioned legislation[11] whose impact may have done little to enhance conservation and which had the potential to make matters worse. Certainly at local level there must have been an incentive towards deforestation while the means of enforcement remained underdeveloped. Interestingly the *First Amendment of the Forest Act*, which introduced *inter alia* the concept of protected forest, was passed two years after his article (1977).[12]

Twelve years later, Ives[13] laid out an eight-point discourse of the Himalayan degradation hypothesis, with a view to dismantling the whole concept point by point. Briefly stated, he suggested that the Himalayas are too multifaceted to make any such generalisations useful. Where generalisations can be made, he suggests that they do not support the landscape degradation theory; furthermore landsliding and deforestation are not necessarily linked in a simple cause and effect relationship. No relationship between change in land use and sediment load on the Ganges and Brahmaputra plains had been established.[14] Based on his own findings and the extensive findings of a number of scientists' work published in a special issue of *Mountain Research and Development*,[15] Ives goes on to state that

> …it is concluded that one of the major linkages of the theory of Himalayan Environmental degradation – post-1950 deforestation resulting in rapid population growth and it accompanying demands for fuelwood – is indeed a latter day myth.[16]

In his detailed rebuttal of the Himalayan landscape degradation theory, Ives asserts that the Himalayan 'subsistence farmer must be appreciated as an important part of the solution rather than deprecated as a substantial cause of the problem.'[17] He suggested that 'it is postulated that the Himalayan region is facing a rapidly evolving crisis. The theory on which development planning and implementation has been based confuses cause and effect and ignores the great complexity of the region and its peoples'.[18]

Whether or not one accepts the totality of Ives's arguments is not the question here. Ives was concerned that development interventions based on poor scientific evidence and inaccurate

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[11] Mahat, T. *et al*. 1986 cite The Birta Abolition Act (1959), The Land Reforms Act (1964) and The Pastureland Nationalisation Act (1974), p.230.

[12] According to Mahat, T. *et al*.1986, over 50% of government revenue came form forestry in 1952 – 3. Thirty years later this had fallen to under 4%.

[13] Ives, J. 1987 Whether or not Ives represents Eckholm and others involved in this debate with total fairness (given the context in which they were writing) must be left to the judgement of the reader. For example he makes no mention of Nield, 1986, who found that forests were being degraded three times faster than planted. Subsequently a study by Brown, S & Shrestha, B. 2000 demonstrated a reduction in forest cover from ~45% to < 20% between 1947 and 1981 in the Jhikhu Khola catchment.

[14] While Ives was correct to note that Eckholm had not produced scientific evidence to establish a relationship between changes in land use and sediment load, much recent research has sought to establish such a correlation. A useful overview is given by Lu *et al.* 2011.

[15] 1987, Vol. 7, No 3.

[16] Ives, J. 1987 p.196.

[17] Ives, J. 2004, p.12.

[18] Ives, J. 1987, p. 189.

perceptions might do more harm than good. He also saw the landscape degradation issue as being exploited by an interest group seeking a means to enhance incoming foreign aid. His work stands as a statutory warning to those involved in development in the Himalayas today. For today, most workers would consider 'that the Himalayan region *is* facing a rapidly evolving crisis'. Indeed not to see this crisis in terms of climate change would risk being thought wilfully ignorant by many scientists. In this parallel situation we need to be equally cautious of the vested interests of the climate change 'industry' especially when the poor quality of much of the available data gives plenty of scope to confuse cause and effect.

4.2 What is the quality of forest and what factors affect it?

A schematic view of Nepal's forests can be gained from the following figure 4.1. One of the most recent and extensive surveys of Himalayan forest is that undertaken by Chris Carpenter in north-eastern Nepal, published in 2005.[19] He suggests that preconceptions about altitude/latitude substitution in the Himalayas will bring difficulties. Although it lies 400km north of the Tropic of Cancer much of Nepal is protected from cold northerly airflows by the Himalayan massif, making them ecologically tropical up to 1000m. Likewise, at those elevations, the 'norm' that land area will decrease with altitude is also incorrect. He describes the tree distribution as follows:

> The relative abundance of gymnosperm and angiosperm[20] trees changes on the elevation gradient.[21] At low elevation, forests are angiosperm dominated. Above 2000m, conifer abundance increases at a linear rate. The dominant angiosperm leafing phenology also changes with elevation: angiosperms below 1000m and above 3000m are mostly deciduous, those at middle elevations are mostly evergreen.[22]

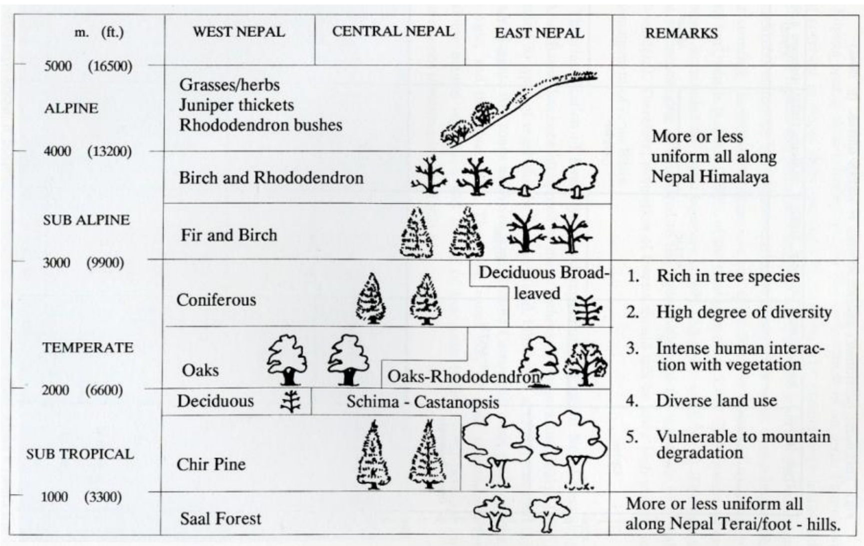

Figure 4.1: Vegetation distribution in the Nepalese Himalayas[23].

[19] Carpenter, C. 2005. Carpenter asked that Robert Zomer's input and collaboration be acknowledged. (Personal communication April 2011)
[20] Angiosperm, flowering plant with seeds developing in an ovary. Gymnosperm, 'naked seed' *eg* pine cone.
[21] The degree to which species decline numerically with altitude,
[22] Carpenter C. 2005 p.1007.
[23] Shrestha,T.B. 1989, p. 31. See also Amatya, S. & Newman, S. 1993 and Carpenter, C. 2005 for greater local detail.

Carpenter describes the relationship of land cover and land use to elevation in figure 4.2. He noted that the greatest species density, both of trees and of understory occurred at 1400 – 1500m, but declined above that elevation <2500m, most particularly in the 1750 – 2250m range, which he tentatively attributed to anthropogenic activity and, to a lesser extent, to dominant tree species exclusion. He also noted that the elevation gradient above the tree line was not as sharp as might be expected but that many tree and understory species continued above the tree line to 4400m often in *krummholz*[24] forms.

The statistics in Table 4.1 belie the fact that in 1978 nearly 50% of the High Mountain and 70% of the Middle Mountain forest and pastureland were in poor condition. Yet during the 1980s NAFP planted two districts with 90km^2 of forest and continued at a rate of 20km^{2-a}, while in a number of other districts other agencies planted a further 80km^2 in the early 1980s.[25]

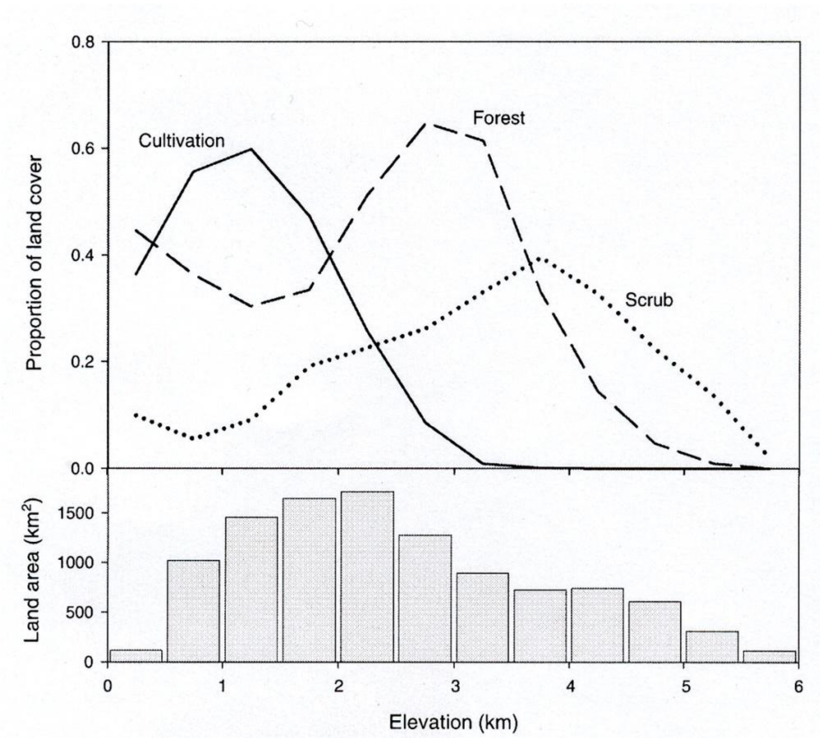

Figure 4.2: Land cover and land area by elevation: Land area has a humped distribution on the elevation gradient with the most land at the 2000 – 2500 elevation. Forest and cultivation have a reciprocal relationship below *c.*2500m elevation. In this figure 'forest' above 4100m is better labelled 'moist alpine scrub', dominated by Rhododendron and Juniper in *krummholz* growth form. Based on Landsat imagery provided by WWF-US. [26]

While deforestation undoubtedly continues in some areas, one of Nepal's most important success stories is the involvement of communities in forest management in recent years. Since the *Forest Act* of 1993 and *Forest Regulations* of 1995, considerable autonomy has devolved to local

[24] Stunted woody growth.
[25] Metz, J. 1991.
[26] Carpenter, C. 2005 p.1006. In a personal communication, April 2011, the author suggested not placing too much emphasis on the 0 – 500m short bar for quantitative reasons in the area surveyed.

level. Forest remains in state ownership, but is managed in a three-tier system: national, district and local. Forest User groups (FUGs) at local level are not permitted to clear forest for agricultural land, but are recognised as self-sustained independent entities with (effectively perpetual) rights to manage forest in a manner appropriate to their needs as approved at district level. Management criteria and enforcement will vary at district level, but have been demonstrated to be effective, at some if not all levels.[27]

Through their national Federation of Community Forest Users, Nepal (FeCoFUN), FUGs can ensure members rights and lobby effectively at national and district levels. Furthermore FUGs have an important role in other aspects of local development.[28] While organisations such as Winrock International acclaim Nepal as a world leader in community forestry, the process has not always been an easy one; and some profound problems remain at local level.[29] Furthermore there is always the possibility of an historic bureaucratic-cultural divide between the Forest and Agricultural Ministries reasserting itself. In the past the very term 'agroforestry' has been omitted from official correspondence.[30] There is a great deal more work to be done as can be ascertained from the following NAPA report:

> Almost one-third of the forest area in Nepal is under community-based forest management systems including community forest, collaborative forest, leasehold forest, buffer zone community forests and conservation areas. These systems have evolved through local knowledge based initiatives. The Livelihoods and Forestry programme has initiated work with forest user groups for implementing local climate change adaptation action plans. This work is being implemented with 2500 forest user groups in some 3000 VDCs [village development committees] in 15 districts. Community adaptation funds are being established. The main stakeholders are forest user groups, VDCs and local NGOs. The identification of adaptation programmes has been initiated in some communities. They have identified watershed management, farm and conservation, forest management, awareness raising, and capacity building through income generation activities.[31]

Writing in 2007, Ramakrishnan stresses the importance of traditional ecological knowledge (TEK) to connect ecological and social systems. This is seen as enhancing 'value systems that local communities understand and appreciate and therefore participate in the process of development, with the possibilities of local initiatives taken to a regional scale…'[32] The importance of this concept stretches beyond the local forestry communities since global markets tend to encourage the reduction of economic diversity to gain a comparative advantage. In the Himalayas, reducing economic diversity would inevitably reduce ecological diversity at a point when farmers increasingly need to diversify as an adaptation strategy to climate change. The importance of fostering ecological and agricultural diversity as a response to climate change cannot be overstated. For not only can it offer some possible alternatives to the crops that fail as a result of unpredictable seasonal weather patterns, it also provides a potential hedge against

[27] Schweik, C. 2000.
[28] Rasul, G. & Karki, M. 2007.
[29] Some of these problems are set out by Karki, G. 2006. See also Carson, B. 1992 pp. 19 – 20.
[30] Carson, B. 1992.
[31] Ministry of the Environment 2010, p.27.
[32] Ramakrishnan, P.S. 2007 p. 309.

future changes in climate that cannot yet be quantified. The importance of diversity is further considered in the next chapter.

4.2.1 Invasive species: ***Banmara***

One of the key factors in conserving forests is the understory. Invasive plant species now need to be discussed both in terms of their effect on forest regeneration and slope stability. *Banmara* (forest killer) is a term given to some invasive plant species in Nepal. At present the name is commonly applied to four species: *Lantana camera*, a toxic plant of the *Verbenaceae* family, *Mikania micrantha* a climbing plant of the *Asteraceae* family[33] and two further species, also *Asteraceae*,[34] which are discussed here. Both these have allelopathic leaves which inhibit forest floor regeneration.[35]

Figure 4.3: *Banmara. Eupatorium adenophorum*
(Photo: Chudamani Joshi)

Eupatorium adenophorum (Crofton Weed) is known as *kalo* (black) *banmara* because of its dark stem. A native of tropical America the plant was probably introduced into Nepal via India before 1950.[36] This species grows to a height of about 0.5m and has a wide altitudinal range of 250 – 3000m and has successfully colonised the entire country at these altitudes.[37] It is prone to invade open spaces particularly where *swidden*, shifting agriculture, is practiced. This is known locally as *khorea phadani* (slash and burn). The plant can reproduce vegetatively but appears to be only mildly frost inhibited. It will lose its reproductive capacity after a 6 year period if left on fallow

[33] More information about these can be found on the ICUN website (see bibliography).
[34] Cruttwell McFadyen nd; Ambika & Jayachandra nd.
[35] Zaho, X. *et al.* 2009; Ambika, S. & Jayachandra nd.
[36] Banerji, N. 1958. (*E. glandulosum* is a synonym).
[37] Personal communication Chudamani Joshi 10 Feb 2011.

ground.[38] It also has highly effective capacity to invade forest understory. It can be fatal if eaten by cattle or sheep but is apparently edible by goats.[39]

Figure 4.4: *Banmara. Eupatorium adenophorum.* Left: a close up of the flower (withstanding the deposit of the eggs of a fly, *Procecidochares sp.* causing a swelling within the stem); Right: Unchecked domination at Jhirubas, Palpa. (Photos: Chudamani Joshi)

Chromolaena odorata, seto (white) *banmara* was introduced as a garden plant around Calcutta before 1840,[40] growing to a maximum altitude of 1000 – 1100m,[41] and limited to sub- and neo-tropical environments with rainfall in excess of 200mm and temperatures between 20^{o} and 37^{o}C.[42] In its feral state it has been observed growing to heights of 3m in open situations and up to 8m in forest interiors. Muniappan & Marrutani[43] suggest that flowering takes place in November to

[38] Kamakrishnan, P.S. & Mishra, B. 2006 (See note re authorship in bibliography).
[39] Rymer, C. 2008.
[40] Joshi, C 2006. Muniappan, R. & Marutani, M. nd cite other sources and dates for its introduction.
[41] Ambika, S. & Jayachandra nd and Joshi 2006.
[42] Ambika, S. & Jayachandra nd.
[43] Muniappan, R. & Marutani, M. nd (post 1987).

Figure 4.5: *Banmara.* Above: *Chromolaena odorata* growing near Tumlingtar, Sankhuwasabha (Photo: Chudamani Joshi); Right growing in the Solu Khumbu Middle Mountains in November 2009. (Photo: The Glacier Trust)

December and seed dispersal in February. However Joshi[44] has observed a wider temporal range in the Himalayas, namely flowering October – February and seed dispersal February – April

It carries with it a list of problems. Its leaves are allelopathic, inhibiting or preventing the growth of tree seedlings or other understory. The high nitrate levels in its leaves are toxic to browsing cattle which can die of tissue anoxia. Even though its juice is used to cure open wounds,[45] hand weeding may cause skin allergy.[46] Senescent stems are a forest fire hazard, from which the understory may not recover but which seldom affect the plant's basal clump, which can regenerate in the rainy season, to the exclusion of other species.[47] However maize yields may be improved on sites where *banmara* has been growing; pH may also be increased in acidic soils.[48]

It is not frost resistant however, which limits its upslope (and also northern) advance in Nepal. With fewer frosts in the mid hills there is also potential for upslope migration. The plant also requires a growing season of about 7 months and appears to be substantially constrained in western Nepal (west of Pokhara ~83ºE) possibly as a result of shorter rainfall periods.[49]

Banmara needs light for its seeds to produce seeds. Dense forest canopy can usually withhold it but degraded canopy can not. There is also evidence that banmara is excluded by a well vegetated understory even when light is sufficient. But cattle browsing may reduce this predominance, allowing the weed to take hold.[50]

While *banmara* may prevent surface erosion in the short term, in the longer term slope stability will be reduced because of the control it exerts on tree regeneration.

4.2.2 Timber demands on the forests

When effective forest controls lie out of reach, particularly in remote areas, any sense of common ownership can become degraded and necessity-driven over-exploitation can occur. Consequentially, forest degradation can increase fuel collection time at the expense of time spent on agriculture.[51]

Because of the poor quality of communication and lack of roads throughout much of the Himalayas, there is often very little demand for forest-cut timber (lumber) outside the immediate vicinity, particularly in the more mountainous regions. This can mean that where pine was planted in upland areas, as an initiative to reforest degraded land in the 1970s and 80s, there is often no value to the trees which are now maturing, neither does the acidic understory admit any

[44] Personal communication 8 Feb 2011.
[45] Prasad, U. *et al.* 1996.
[46] Ambika, S. & Jayachandra nd.
[47] Ambika, S. & Jayachandra nd.
[48] Prasad, U. *et al.* 1996
[49] Joshi C. 2006. An illustrated life cycle is given on p. 107 of this thesis.
[50] Joshi, C. *et al.* 2006.
[51] Bluffstone, R. 1995.

useful form of groundcover for livestock to browse.[52] Of course this may change with the aggressive road building that is taking place.

One estimate has suggested that the average household spends about 50 person-days a year gathering firewood.[53] However establishing average *per capita* use of fuelwood is problematic. There have been some wildly differing estimates[54], which may simply be the result of unstructured surveying procedures or differences in altitude. Metz found that private forests often provide a high percentage of fuel wood (sometimes on landslide sites), although downslope there may be an increasing dependence of public forest for this resource. *Per capita*, requirement for timber was thought marginally to exceed 1m^3 or 600 Kg, 90% of which is used for fuelwood.[55] Other workers give the mid hills consumption of fuel wood per household in excess of 365kg,[56] although this has been shown to be an order of magnitude greater where the tourist trade is involved.[57]

4.2.3 The relationship of forest quality to alternative wage sources

It stands to reason that degraded forest reduces environmental security, which, in turn, would contribute to migration, particularly male migration.[58] However Bluffstone[59] suggests that where alternative income is available from outside the subsistence system (*i.e.* from migrational labour markets) there is a potential change in relationship to the forest. While fuelwood requirement is relatively constant, an increase in wage may engender an increased demand for wood. However the ability to buy grain reduces the household requirement for cattle and will therefore reduce their fodder requirement. This may reduce pressure on the forest and allow the forest to regenerate. While Bluffstone's argument is well presented, much will depend on local conditions, in particular the locality of the source of the grain that is being purchased with the external income, otherwise a local problem is merely being exported to another locality.

4.3 Forest cover and its importance to Himalayan agroforestry

> …(F)orests have never stood apart as a separate sector in Nepal but have always been inextricably interwoven with other land uses and with political, social, demographic and economic change.[60]

Nepali hill farming is usually (but not invariably) handled with great precision, sustainability and understanding of the local environment and with a view to optimising the ratio of tree cover to crop land for maximum agricultural activity. The ratio of forest to farmland needs to be of the order of 4:1[61] to provide sufficient fodder for cattle but can be much higher. Where this ratio is

[52] Brown, S. & Shrestha, B. 2000.
[53] Shrestha, S.S. & Bhandari, P. 2007, citing a paper by Baland *et al.* from 2004, (source not verified).
[54] Derided by Thompson, M. *et al.* 2007 and cited by Ives, J. 1987 p. 195.
[55] Bluffstone, R. 1995. See also Mahat, T. 1987, who cites Donovan, D. 1981 *Fuelwood: How much do we need?* Institute of Current World Affairs, Hanover (sic). (Source not verified here.)
[56] Amacher, G. *et al.* 1999.
[57] Christiensen, M. *et al.* 2009.
[58] Shrestha, S.S. & Bhandari, P. 2007. There will of course be other reasons for migration.
[59] Bluffstone, R. 1995.
[60] Mahat, T. *et al*. p. 224.
[61] This 'rule of thumb' is suggested by Ives, J. & Messerli, B. 1989. Amatya, S. & Newman, S. 1993 suggest anything between 2.8:1 and 18:1.

reduced, unsustainable pressure may be placed on the forest.[62] An indicator of the importance of livestock lies in its being an important component of the value of sales in a *haat* (weekly market). A survey of the Middle Mountains from 1992[63] showed that *khet* (paddy) terraces accounted for 7% of land area, *bari* 15%, while forest, grazing and shrubland accounted for 76%, somewhat short of the 4:1 ratio.

Agroforestry is central to Himalayan land management and hill farming. Whether at an individual or community level, agroforestry usually contains a symbiosis of three elements: *forestry* to provide fodder, fuel, animal bedding, timber, medicine and fruits; *agriculture* providing grains such as maize or wheat and cash crops such as cardamom or tea; *livestock* for animal fertiliser, ploughing, meat, milk, wool, leather *etc*.[64] Animal fertilizer is thought to have the potential to increase maize output by 95.3 kg and paddy by 309.5 kg per hectare. [65] The additional compost and fertiliser that agroforestry brings to the terraced field system enhances both moisture and nutrients that would otherwise leach to lower soil horizons. [66]

Excessive livestock numbers will have negative impact on this eco-system. Carson suggests that six animals (livestock units) are required per hectare whether cattle, goats or buffalo. But because lower quality cattle cannot be culled, there is a destructive surplus demand for grazing on both forest and common grazing lands, acting as an impediment to other forms of agricultural management. Bluffstone suggests:

> That there are too many cattle and buffalo in the hills of Nepal is also well accepted, however, and the stocking rates typically exceed recommended rates by a factor of three. Despite this overstocking, in the hills average yields of major foodgrains declined by 35% during the period 1960 – 1980, and have continued to decline. The erosion linked to deforestation is often cited as a major reason, but agricultural expansion onto marginal lands has probably also played a role.[67]

Aspects of agroforestry have the potential to be more profitable than either forestry or agriculture on their own. For example some forms of *taungya* (intercropping) can take a period of 20 years to develop, but which can then produce dramatically increased returns when set against some other forms of agriculture. Similarly, growing cardamom (*Amomum subulatum*) under alder (*Alnus nepalensis*), a fast growing tree with good nitrogen fixing properties provides both stable economic returns and excellent conservation values.[68] For example the understory provides good protection against erosion, and the prunings provide cattle bedding and ultimately a good source of manure. Other kinds of intercropping (for example beans and maize) can be affected on a seasonal basis. If *khoriya phadani* (shifting agriculture) is classified as agroforestry, it is really only viable if the population remains static, otherwise population pressure can reduce the number of years when the land is allowed to remain fallow, increasing erosion and reducing yields. This is still practised in Nepal, particularly on steeper slopes, which are unsuitable for terracing.

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62 Sharma, K.P. *et al*. 2000.
63 Carson, B. 1992.
64 Amatya, S. & Newman, S. 1993; Sharma, S.P. 2007.
65 Bluffstone, R 1995.
66 Carson, B. 1992.
67 Carson 1992 pp. 43–44.
68 See Zomer & Menke 1993.

Figure 4.6: *Khorea phadani* 'slash and burn' or swidden agriculture in the Siwaliks, April 2011. The forest in the left hand image had only recently been burnt, causing widespread destruction of the understory in the surrounding area. (Photos: The Glacier Trust)

The nature of agroforestry may also change with altitude. Metz suggests that above 2400m, forest (his definition of which was given under 4.1.1) can be stratified as follows: (*a*) Lower and middle reaches where more sparse forest gives rise to clustered and often irrigated fields, with quite intensive farming aided by livestock manure. The livestock is maintained from forest fodder or private fodder trees. (*b*) Further upslope the forests are used more intensively and transhumant agriculture predominates by which livestock are moved from field to field for direct manuring. After field planting the animals browse the forest understory. These applications would seem to pertain mostly to western Nepal and in the trans-Himalayan inner valleys where the reach of the monsoon is reduced.

Carpenter's observations from eastern Nepal are slightly different, noting a high rate of abandonment of terraces at 1750 – 2250m, and where cleared forest has been left to pasture. Forest understory is browsed by livestock, which can inhibit regeneration and fodder gathering can reduce crown cover. This altitude also marks a drop in population density. Agricultural activity tends to decline at approximately the crossing point 'from warm (subtropical) evergreen broad-leaved forest to cool (temperate) evergreen and winter deciduous broad leaved forest.[69] Above about 2200m, the outfacing slopes receive high monsoon rainfall and are too cold to farm in winter. Above 2250m to the tree-line forest cover can increase to over 50% of the land area, running out into juniper scrub and rhododendron above the tree line.

[69] Carpenter, C. p.1006.

4.4 Forestry, agroforestry and slope stability

> Rather than being ignorant of how their land uses affect erosion and mass wasting, many farmers have detailed knowledge of the susceptibility of their various soils and slopes to landslides, watch these lands closely for signs of incipient problems, and adjust their land use accordingly[70].

When dealing with the question of the controls exerted by forest over erosion it is important, as Bruijnzeel & Bremmer point out, to be clear about which type of erosion is under discussion. It may be argued that on a macro-scale, the erosional forces are sufficiently strong to make human intervention irrelevant. Yet the Middle Mountains carry a remarkably high population and its potential for impact or intervention should not be understated. Mass erosion (heavy landsliding) is discussed in a subsequent chapter. Here we are concerned with local issues 'on-site' (field or local catchment) splash, sheet and rill erosion and landsliding. Human impact and intervention will be among the most important controlling factors in the downslope movement of colluvium. Both Bruijnzeel & Breemer and Metz[71] find evidence that shallow landslides can be linked to forest removal. Even so, this might only provide 10% of total mass wasting sediment, given the geological forces at work, which include slope angle, tectonics, geomorphology and orogenic uplift. These forces have the power to increase down cutting and undercutting on steepening slopes. Colluvium will not necessarily reach the valley floor with each seasonal precipitation and may find various points of deposit, becoming vegetated or embanked before being incorporated in the next cycle.

Diurnal rainfall patterns during the summer monsoon are also significant. A number of studies[72] have demonstrated that in mountain districts peak rainfall occurs around midnight local time causing peak intensity to occur within valleys, while daytime precipitation peaks during mid to late afternoon when precipitation is usually heavier, sometimes multiples heavier, on ridge tops than on the valley floors. The significance of this pattern is that it substantially reduces the transpiration capacity of vegetation.

Barros and colleagues observed that at 4000m 'the cumulative monsoon rainfall is comparable to the highest amount recorded in the Indian subcontinent.' This fundamentally contradicts a widespread perception that upslope rainfall was likely to be lighter in intensity than that experienced at lower altitudes.[73] Because the extent to which the loss of topsoil is critical to field fertility, control or delay of overland flow from higher up slope, where forest predominates, should be considered for its potential to reduce the erosion of terraced slopes. But some types of forest may reduce a slope's factor of safety. First, as Bruijnzeel & Bremmer point out, that intervention of the forest canopy itself may actually increase surface erosion potential by increasing raindrop size. Second, vegetation surcharge (the downward force of the mass of timber) can increase the sheer stress on saturated soil. It is sometimes pointed out that larger trees may have a negative effect on slope stability upslope, but a positive effect at the toe of a slope.

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[70] Metz, J. p.810.
[71] Citing Ramsay 1986 (not verified).
[72] Barros A. *et al*. 2000; Barros A. & Lang, T. 2003 and Kansakar, S. *et al.* 2004 citing various sources.
[73] See, for example, Carson, 1985.

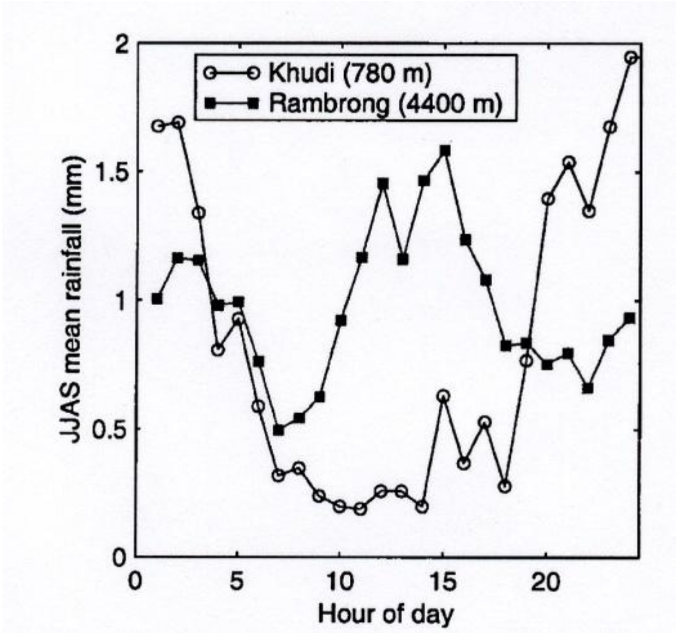

Fig. 4.7: An example of diurnal precipitation trends in relation to altitude.[74]

With protracted rainfall events, the sheer stress on a slope will increase as saturation reduces friction. Rain penetration of soil will also add weight. Together these factors suggest that forest vegetation may cause less frequent but larger magnitude slope failures.

However Metz cites experiments showing that short pulses of rainfall rates seldom exceed soil infiltration rates to create runoff, even on an overgrazed surface.[75] Summer monsoon precipitation can come in pulses that allow transpiration to reduce soil moisture content before the next pulse (although the net effect of transpiration during precipitation event itself will be minimal). Whether that holds true today under reported heavier precipitation events needs to be evaluated. If, as is widely reported (2.2), precipitation events are becoming more intense, transpiration may not be able to bring the soil's field capacity[76] back into balance.

Besides their function in transpiration, roots have two other functions in slope stability.[77] Fine roots are thought to play an important part in soil cohesion, enabling the soil to resist surface erosion. Second, they provide tensile strength but are generally only evolved to provide stability against wind and gravity. In this respect, the influence of their tensile strength recedes with distance from the plant. Since smaller scale precipitation-induced slope failures tend to occur at depths of 0.5 – 2.5m[78], tree roots will only enhance slope stability if they cross the sheer plain or become anchored in bedrock. Root depth is therefore critical.

Dahal provides the following table of comparison of different land uses and their relevance to slope stability:

[74] Barros *et al*. 2000 p. 3685.
[75] Metz, J. 1991, p 815 cites several papers in this respect.
[76] The moisture than can be held in the soil against gravity.
[77] Greenwood, J. *et al*., 2004.
[78] Dahal, R. *et al.* 2008.

Table 4.2: Land use, vegetation surcharge and root cohesion.

Land use types	Vegetation surcharge (kN/m²)	Root cohesion (kN/m²)
Dense Forest	0.3	5.5
Dry cultivated	0	1
Grassland	0	0.75
Shrubs	0.1	2.1
Sparse Forest	0.2	3
Sparse shrub	0.05	1.2

Source: Dahal *et al.* 2008 compiled from various sources

The type of canopy and understory will therefore have the potential to affect or delay overland flow. Table 4.2 may be regarded as indicative of the relative importance of understory and /or leaf litter in delaying or reducing the eroding power of overland flow: where it is removed erosion rates escalate in the order of 10 to 30 times. Here, the importance of forest lies in providing litter, which together with the forest understory absorb much of the frictional impact of precipitation. It will also increase field capacity and the infiltration capacity of the soil. Both litter and understory have the capacity to reduce desiccation cracking which is a powerful agent in the erosion process. But the extent to which litter and understory are able to absorb or retain water in sufficient quantities to delay overland flow is another question. Historically 80% of Nepal's rainfall is received between June and September. In some areas it is increasingly reported that summer rainfall is being concertinaed into July and August. More intense rainfall will therefore reduce the capacity of litter and understory to delay overland flow.

Table 4.3: Surface erosion in tropical forest and tree crop systems, based on about 80 ***non pro rata*** studies

		Tonnes per hectare per year		
No.	Type	Max	Min	Median
1	Natural Forests	6.2	0.03	0.3
2	Swidden, fallow	7.4	0.05	0.2
3	Plantations	6.2	0.02	0.6
4	Multi-storied Tree gardens	0.15	0.01	0.1
5	Tree crops with cover crop/ mulch	5.6	0.1	0.8
6	Swidden, crops	70	0.4	2.8
7	*Taungya* (intercropping)	17.4	0.6	5.2
8	Tree crops, clean-weeded	183	1.2	48
9	Plantations, litter burnt or removed	105	5.9	53

Source: Bruijnzeel & Bremmer after Wiersum (1984)

As D.P. Shrestha states, 'Removal of topsoil occurs generally through sheet erosion [*i.e.* erosion from runoff or overland flow]. Slope length and steepness, vegetation cover, surface soil condition, amount of rainfall are important factors.'[79] Table 4.4 shows clearly the limiting effect these factors have upon the transport capacity of detached material.

[79] Shrestha, D.P. 1997.

Table 4.4: The relationship of erosional capacity to transport capacity under different land uses and aspects using Morgan *et al.*'s model[80]

Land use	Mahadev Kola sub-watershed (south-facing)					Jogi & Bhandare Kola sub-watershed (north-facing)				
	Soil loss Tonnes per hectare per year			Detachment Tonnes per hectare per year	Transport capacity	Soil loss Tonnes per hectare per year			Detachment Tonnes per hectare per year	Transport capacity
	Min	Max	Average	Average	Average	Min	Max	Average	Average	Average
Grazing land	1.6	19.8	8.1	22.8	8.1	0.1	4.4	0.8	20.4	0.8
Dense forest	0.1	0.4	0.3	21.3	0.3	-	-	-	-	-
Degraded forest	0.1	8.6	2.5	23.3	2.5	0.1	0.5	0.2	20.1	0.5

Source: D.P.Shrestha 1997 based on studies in the Lihku Kola

There is a striking similarity of soil loss between 'natural' and 'dense' forest estimates in the two tables (the first observed, the second predicted). In the last decade maximum one day rainfall events have doubled those recorded in the previous three decades.[81] Where the understory is browsed by animals, its density will be reduced and its soil compacted perhaps by as much as 50%.[82] Rotational fodder collecting and browsing by animals might go some way to allow the understory to regenerate in order to have the maximum potential to intercept precipitation and recover its infiltration capacity in the critical periods.

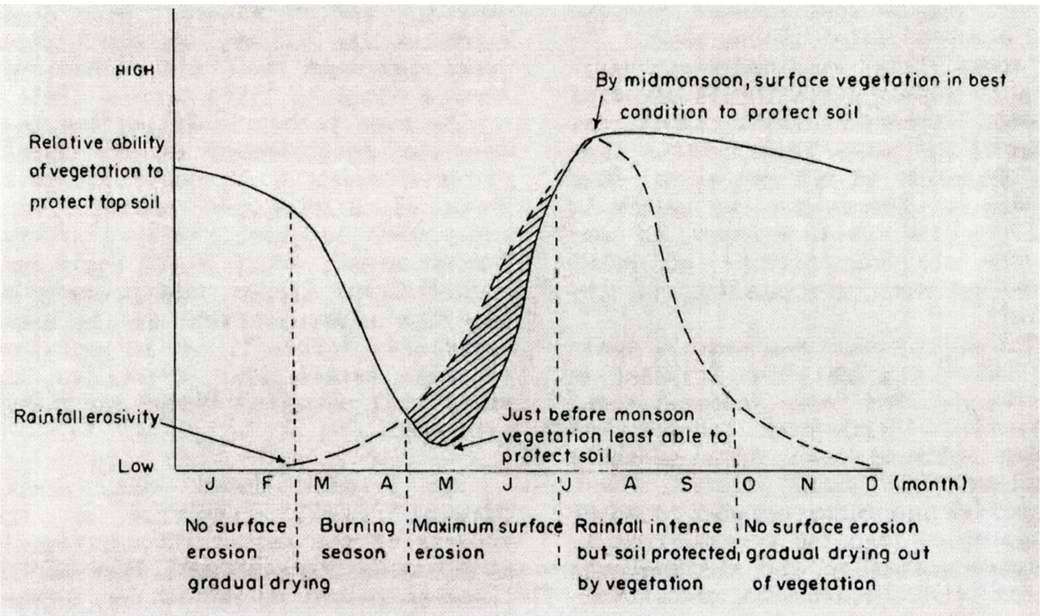

Figure 4.8: Relationship between erosivity of rain and condition of surface vegetation throughout the year in the middle mountains of Nepal.[83]

Landsliding is now commonly reported at two thirds of the way through the summer monsoon in the mid hills[84], some time later than that indicated in Figure 4.6. Whether this represents a

[80] Morgan, R. *et al*. 1984.
[81] Dahal, R. *et al*., 2008.
[82] Amatya, S. & Newman, S. 1993.
[83] Carson, B. 1985 p.19.

shift in climatic trends since Carson's 1985 diagram or whether the diagram fails to take adequate account of the point in the summer monsoon when soil saturation peaks will be difficult to determine without local information. When considering Carson's diagram above, it is also important to note that during the pre summer monsoon period, soil water deficit may be enhanced by increasing slope angle. These factors may reduce early runoff and therefore transport capacity. This aspect is discussed more fully in the next chapter.

4.4.1 Bamboo as a check against erosion.

Bamboos will grow up to an altitude of 3600m in eastern Nepal and tolerate a range of environments. The most impressive are restricted to lower elevations, including the rare *Dendrocalamus giganteus*, which reaches 30m in height and 20cm or more in diameter in the Terai besides *Bhalu bans* (*Dendrocalamus hookeri*) reaching 25m in height and 16cm in diameter. *Tama bans* (*Bambusa nepalensis*) and *Mal bans* (*Bambusa nutans*) reach 20m with 10cm diameter, all growing to an altitude of about 16 – 1800m and commonly cultivated in the mid hills. Several of the smaller *Thamnocalamus* varieties are frost hardy and grow to altitudes of 2600 – 3500m. These grow to a height of 3m tall. *Kalo nigalo* is the highest altitude clump-forming bamboo, *Borinda emeryi* reaching 2m tall and growing at altitudes of 2600 – 3200m. *Malingo Yushania maling, Y. microphylla* and *Sarocalamus racemosa* are spreading bamboos that will grow up to 3600m, although often grazed to a height of 50cm or so by livestock in pasture land.[85]

Montgomery[86] has demonstrated the beneficial effects of log jams on stream in forested catchments. Sediment transport capacity can be reduced and ecological diversity enhanced by their use. In the Himalayas planting of bamboo in gullies has the power to reduce down-cutting and therefore subsequent undercutting of stream banks.

> Bamboos are particularly suitable as the combination of deep and surface rooting with a bulky rhizome 'retaining wall' is extremely effective in the prevention of soil erosion in the gullies even when there is little ground vegetation because of grazing.[87]

Although some bamboo roots have good vertical penetration, these are generally insufficiently strong to prevent rotational slumping (which often occurs at a depth of 2 – 2.5m) and need the support of more lignified root systems, such as those provided by *utis* (*Alnus nepalensis*), an alder- see next section). Heavier bamboos such as *Dendrocalamus* and *Bambusa* species can provide stability at the toe of a slope, while light varieties (*e.g. Drepanostachyum*) are more suitable upslope and the dense surface root mat of bamboos may effectively reduce infiltration.[88] Bamboos thus guard against sheet erosion and make good retaining walls once established.[89] Larger bamboos may also be effective in mitigating small scale landslides and debris-flows on gentler slopes (Fig. 4.9) particularly where bedrock is within reach of the root system, for example in stream beds.

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84 Something confirmed by Kumar, K. *et al*., 2002
85 Personal communication from C. Stapleton 10 Feb 2011. See also Stapleton, C. 1994 [a]. Stapleton's comprehensive work is given in the bibliography under Stapleton C. 1994 [b].
86 Montgomery, D. *et al.* 1996.
87 Stapleton, C. 1989.
88 Stapleton C. personal communication, 5 January 2011.
89 Stapleton C. personal communication, 3 September 2009.

Figure 4.9: Bamboo may also have the potential to de-water small debris flows. Where water is allowed to run out of highly saturated moving regolith, friction is increased and the flow will come to a halt. (Photo: The Glacier Trust)

Bamboo is not always popular with farmers because of the large diameter of their root system which is competes for nutrients against other nearby crops; the extent of the shade produced by the crown can also inhibit growth. Their high transpiration rates can also reduce stream flow. These issues will also be discussed in the next chapter, but they can be tackled by cutting the spreading root and controlling the size of the canopy, using it for fencing, construction or fuel. Bamboo is an effective nitrogen 'pump' as its litter can break down to form soil nutrient.

All interventions related to the planting of bamboo need to be carefully monitored and controlled. One observation of the hillsides round Gyepla in the Kanchenjunga region, (~2700 – 3000m) where *Tsuga* forest had been destroyed by fire, was that invasive bamboo has effectively prevented forest regeneration.[90] Clearly bamboo has many advantages and disadvantages and needs to be controlled carefully. These aspects may benefit from further research.

4.4.2 Succession after landsliding

As Ives suggests, adapting to dynamic landscape has always been part of the Nepali mountain way of life. Where slope angle and soil depth permits, re-terracing is frequently attempted. Where landslide residues are dense and rocky, *utis* (*Alnus nepalensis*) appears as a pioneer plant on post-landslide sites in the mid hills, growing rapidly and at high density.[91] Although only moderate as a fodder, *utis* has excellent nitrogen fixing capacity and, together with some bamboos can prove a powerful agent of slope stability by virtue of the strength of its root system and transpiration. Although these pioneering woodlands can be low on species density in the early stage they do appear to have the capacity to reduce the down slope regolith movement as can be seen from the tree angles Figure 4.9. Exploitation of this rapidly growing timber as a fuel source is an adaptation strategy in this increasingly dynamic environment.

[90] Chris Carpenter, personal communication, April 2011.

[91] Carson 1992.

Figure 4.8: Re-cut terraces after a landslide. Cattle are allowed to browse to improved soil fertility (Photo Glacier Trust)
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Figure 4.9. Dense *Utis* 'pioneering' on a landslide site a few hundred meters form fig 4.4. Note the rocky ground which would prove difficult to terrace. Note also the downslope angle of the < five year old trees indicating that the slope is still active but its movement may be being delayed by root networks and transpiration. Perhaps in time this may regenerate the soil sufficiently to start cardamom planting. (Photo: The Glacier Trust)

4. 5 Summary

This chapter has identified a few of the many difficulties in attributing changes in the landscape to climate change. Even the term 'forest' has different definitions. The 1970s Himalayan degradation debate stands as a warning against an unstructured interpretation of events. No assessment seems yet to have been published using remote sensing data that would give a clearer picture of whether local landsliding is increasing and, if so, at what rate. Yet landsliding is reported as an increasing problem by hill farmers whose interpretation of events was seen broadly to match quantitative data in the previous chapter.

It is clear that vegetation plays an important roll in controlling or reducing erosion and has the power to reduce the transport capacity of overland flow. The extent to which it can mitigate landsliding in a situation of more intense rainfall has been demonstrated to be limited. Forest management will clearly be an increasingly important issue for hill farmers as they consider how to exploit planting programmes better to control erosion and enhance conservation. Rotational grazing, *i.e.* closing areas of forest to browsing livestock on a rotational basis may have positive effects but may also be an idealistic objective. Forest management is improving through FUGs and timber demands appear to be relatively stable in non-tourist areas, possibly as a result of the introduction of more efficient stoves. However, for forest users, this is a continuing struggle. Increased runoff from heavier rainfall events will exploit any erosional opportunity and invasive species, encouraged by the frost-free winters of the last decade, will exploit any available degradation of the forest understory.

Enabling farming communities is to increase resilience is therefore challenging. Greater exploitation of bamboo may bring benefits in terms of an under-exploited resource and slope stability. Allowing *utis* to populate landslide sites may also bring longer term benefits, cold comfort for those whose terraces have been destroyed. While use of both of these may be worth while, their impact is limited. 'Learning to live with' this dynamic environment has always been the lot of the hill farmer. The problem now is that solutions (in terms of forest development) may be overtaken by the speed of climatic change.

Chapter 4 Bibliography

Amacher, G., Hyde, W. & Kanel, R. 1999 Nepali Fuelwood production and consumption: Regional and household distinctions, substitution and successful intervention, *Journal of Development Studies*, 35, 138 – 163.

Amatya, S. & Newman, S. 1993 Agroforestry in Nepal: research and practice, *Agroforestry Systems*, 21, 215 – 222.

Ambika, S. & Jayachandra (sic), nd The problem of Chromolaena weed http://www.ehs.cdu.edu.au/chromolaena/pubs/problem.html , accessed 20 Decemeber 2010.

Banerji, N.L. 1958 Invasion of *Euphatoruim glandulosum* in east Nepal, *Bulletin of Botanical Society , University of Saugar*, 10, 14 – 18.

Barros, A., Joshi, M., Putkonen, J. & Burbank, D. 2000 A study of the 1999 monsoon rainfall in a mountainous region in central Nepal using TRIMM products and rain gauge observations, *Geophysical Research Letters*, 27, 3683 – 3686.

Barros, A. & Lang T. 2002 Monitoring the monsoon in the Himalayas: Observations in Central Nepal, 2001, *Monthly Weather Review*, 131, 1408 – 1427.

Bluffstone, R. 1995 The effect of labor market performance on deforestation in developing countries under open access: an example from rural Nepal, *Journal of Environmental Economics and Management* 29, 42 – 63.

Brown, S. & Shrestha, B. 2000 Market-driven land-use dynamics in the middle mountains of Nepal, *Journal of Environmental Management*, 59, 217 – 225.

Bruijnzeel, L. & Bremmer, C. 1989 Highland-Lowland interactions in the Ganges Brahmaputra River basin: A review of the literature, *ICIMOD Occasional paper*, No.11, ICIMOD, Kathmandu.

Carpenter. C 2005 The environmental control of plant species density on a Himalayan elevation gradient, *Journal of Biogeography* 32, 999 – 1018.

Carson, B. 1985 *Erosion and sedimentation processes in the Nepalese Himalaya*, ICIMOD Occasional Paper No. 1, ICIMOD Kathmandu.

Carson, B. 1992 *The land, the farmer and the future: A soil fertility management strategy for Nepal*, ICIMOD Occasional paper No.21, ICIMOD, Kathmandu.

Christiensen, M., Rayamajhi, S. & Meilby, H. 2009 Balancing fuelwood and biodiversity concerns in rural Nepal, *Ecological Modelling*, 220, 522 – 532.

Cruttwell McFadyen, R. nd History and distribution of Chromolaena odorata (L.) R.M.King and H. Robinson, http://www.ehs.cdu.edu.au/chromolaena/proceedings/first/History%20and%20distribution%20of%20Chromolaena%20odorata%20%28L_%29%20R_M_%20King%20and%20H_%20Robinson.htm , accessed 20 December 2010.

Dahal, R., Hasegawa, S., Nonomura, M. Yamanaka, M. & Dhakal, S. 2008 DEM-based deterministic landslide hazard analysis in the Lesser Himalaya of Nepal, *Georisk*, 2, 161 – 178.

Eckholm, E. 1975 The deterioration of mountain environments, *Science*, 189, 764 – 770.

Greenwood, J., Norris, J. & Wint, J. 2004 Assessing the contribution of vegetation to slope stability, *Geotechnical Engineering*, 157, 199 – 207.

IUCN nd http://www.issg.org/database/species/ecology.asp?si=56&fr=1&sts=&lang=EN accessed 14 February 2011.

Ives, J. 1987 The theory of Himalayan environmental degradation: its validity and application challenged by recent research, *Mountain Research and Development*, 3, 189 – 199.

Ives, J. 2004 *Himalayan Perceptions*, Routledge, Abingdon.

Ives, J. & Messerli, B. 1989 *The Himalayan Dilemma*, Routledge, London

Joshi, C. 2006 *Mapping cryptic invaders and invasibility of tropical forest ecosystems:* Chromolaena odorata *in Nepal*, Doctoral Thesis, ITC Enschede.

Joshi, C., de Leeuw, J., van Andel, J., Skidmore, A., Lekhak, H., van Duren, I. & Norbu, N. 2006 Indirect remote sensing of a cryptic forest understory invasive species, *Forest Ecology and Management*, 225, 245 – 256.

Kamakrishnan*, P. & Mishra, B. 1982 Population dynamics of *Eupatorium adenophorum* Spreng. during secondary succession after slash and burn agriculture (jhum) in north eastern India, Weed Research, 22, 77 –84. [* Re authorship: this appears to be a journal publisher's typographical error for *Ramakrishnan*]

Kansakar, S., Hannah, D., Gerrard, J. & Rees, G. 2004 Spatial pattern in the precipitation regime of Nepal, *International Journal of Climatology*, 24, 1645–1659.

Karki, G. 2006 Community Forestry in Nepal: An ethical journey to sustainable livelihoods is now at a cross road? http://www.forestrynepal.org/images/publications/Ethics_Gyanendra%20karki_2006.pdf , accessed 26 November 2010.

Kumar, K., Pant, D., Panda, Y. & Satyal, G. 2002 Runoff and soil loss from steep slopes treated with low cost bioengineering measures, *The Environmentalist*, 22, 133 – 141.

Lu, X., Zhang, S., Xu, J. & Merz, J. 2011 *The changing sediment loads of the Hindu Kush-Himalayan rivers: an overview*, Sediment Problems and Sediment Management in Asian River Basins, Proceedings of the Workshop held at Hyderabad, India, September 2009, IAHS, 349, 21 – 36.

Mahat, T. 1987 *Forestry-Farming linkages in the mountains*, ICIMOD Occasional Paper No.7, Kathmandu.

Mahat, T., Griffin, D. & Shepherd, K. 1986 Human impact of some forests of the Middle Hills of Nepal. 1. Forestry in the context of the traditional resources of the state, *Mountain Research and Development*, 6, 223 – 232.

Metz, J. 1991 A reassessment of the causes and severity of Nepal's environmental crisis, *World Development*, 19, 806 –820.

Ministry of the Environment 2010 *National Adaptation Programme of Action to Climate Change*, Government of Nepal, Kathmandu.

Montgomery, D., Abbe, T., Buffington, J., Peterson, N., Schmidt, K. & Stock, J. 1996 Distribution of bedrock and alluvial channels in forested mountain drainage basins, *Letters to Nature, Nature*, 381, 587 – 589.

Morgan, R., Morgan, D. & Finney, H. 1984 A predictive model for the assessment of soil erosion rink, *Journal of Agricultural Engineering Research*, 30, 245 – 253.

Muniappan, R. & Marutani, M. nd Ecology and distribution of Chromolaena odorata in Asia and the Pacific, http://www.ehs.cdu.edu.au/chromolaena/proceedings/first/1asia.htm, accessed 20 December 2010.

Neild, R. 1986 *Land use in Nepal: A summary of land resource mapping projects*, Water and Energy Commission Secretariat, Kathmandu.

Prasad, U., Muniappan, R., Ferrar, P., Aeschliman, J. & de Foresta, H. (Eds.) 1996 *Proceedings of the third International workshop on biological control and management of* Chromolaena Odorata, Univerisity of Guam, Guam.

Ramakrishnan, P.S. 2007 Sustainable mountain development: The Himalayan tragedy, *Current Science*, 92, 308 – 316.

Rasul, G. & Karki, M. 2007 *Participatory Forest Management in South Asia*, ICIMOD, Kathmandu.

Rymer, C. 2008 The effect of wilting and soaking *Eupatorium adenophorum* on its digestibility in vitro and voluntary intake by goats Animal Feed Science and Technology, 141, 49 – 60.

Schweik, C. 2000 Optimal foraging, institutions and forest change: a case from Nepal, *Environmetal Monitoring and Assessment*, 62, 231 – 260.

Sharma, K.P, Moore, B. & Vorosmarty, C. 2000 Anthropogenic, Climatic and Hydrologic Trends in the Kosi Basin, Himalaya, *Climate Change*, 47, 141 – 165.

Shrestha, D.P. 1977 Assessment of soil erosion in the Nepalese Himalaya, A case study in Likhu Valley, Middle Mountain Region, *Land Husbandry*, 2, 59 – 80.

Sharma, S.P. 2007 Agroforestry practices in Nepal, http://www.waldbau.uni-freiburg.de/Download/pdf/MCS_AgroFor_stud_pres_Agrofor_Nepal.pdf (accessed 1 September 2009).

Shrestha, S.S. & Bhandari, P. 2007 Environmental security and labor migration in Nepal, Population and Environment, 29, 25 – 38.

Shrestha, T.B. 1989 *Development Ecology of the Arun River Basin in Nepal*, ICIMOD, Kathmandu.

Stapleton, C. 1989 Chirang Hill irrigation project Damphu: Identification of bamboos and potential for incorporating the planting of bamboos into existing and possible activities, http://bamboo-identification.co.uk/CHIP_all.pdf, accessed September 2009.

Stapleton, C. 1994 [a] *Bamboos of Nepal*, Royal Botanic Gardens, Kew, available http://www.bamboo-identification.co.uk/ebsnepal2.pdf.

Stapleton C. 1994 [b] The bamboos of Nepal and Bhutan (Parts 1 – 3), *Edinburgh Journal of Botany*, 51, 1 – 32, 275 – 295, 301 – 330.

Thompson, M., Warburton, M. & Hatley, T. 2007 *Uncertainty on a Himalayan Scale*, Himal Books, Lalitpur.

Wallace, M.B. 1981 *Solving Common-Property Resource Problems: Deforestation in Nepal*, (?unpublished) PhD Thesis, Harvard University, p.19. (Source not verified.)

Zhao, X., Zeng, G-W., Nui, X-M., Li, W-Q., Wang, F-S. & Li, S-H. 2009 Terpenes from *Eupatorium adenophorum* and their Allelopathic Effects on Arabidopsis Seeds Germination, *Journal of Agricultural and Food Chemistry*, 57, 478 – 482.

Zomer, R. & Menke, J. 1993 Site index and biomass productivity estimates for Himalayan alder – large cardamom plantations: a model agroforestry system of the middle hills of eastern Nepal, *Mountain Research and Development*, 13, 235-255.