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# NATURAL REVEGETATION ON LANDSLIDES IN HUMID TROPICAL ARUNACHAL PRADESH: COMMUNITY DYNAMICS AND SOIL PROPERTIES

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ARUNACHALAM, A., ARUNACHALAM, K., BHATTACHARJEE, A. & NAG, A. 2000. **Natural revegetation on landslides in humid tropical Arunachal Pradesh: community dynamics and soil properties.** Vegetation patterns and soil properties of areas disturbed by landslides within the state of Arunachal Pradesh, northeast India, were investigated. Four sites with varying degrees of ecosystem recovery and one control site were examined for their vegetal status and various physical, chemical and biological properties of the landslide soils. Disturbed sites were first invaded by annual forbs. Perennial species that entered the ecosystem gradually gained dominance by prohibiting the immigrants through niche pre-exemption. The dominance of plant species showed an increasing trend along the recovery gradient. Young sites showed greater percentage of sand content in the soil. Higher acidity and temperature were found in disturbed areas. Soil organic matter increased gradually for the four years of the revegetation study. Concentration of soil organic carbon, total Kjeldahl nitrogen and available phosphorus increased with recovery period. Soil respiration and microbial population also increased with time following landslide occurrence.

Key words: Landslide - microbial population - soil - vegetation

ARUNACHALAM, A., ARUNACHALAM, K., BHATTACHARJEE, A. & NAG, A. 2000. **Pertumbuhan semula secara semula jadi di atas tanah runtuh di kawasan tropika lembab di Arunachal Pradesh: dinamik komuniti dan ciri-ciri tanah.** Corak pertumbuhan dan ciri-ciri tanah di kawasan yang terganggu oleh tanah runtuh di negeri Arunachal Pradesh, timur laut India dikaji. Empat tapak dengan pemulihan ekosistem yang berbeza-beza darjahnya dan satu tapak yang dikawal diperiksa bagi status pertumbuhan dan pelbagai ciri fizikal, ciri kimia dan ciri biologi tanah di kawasan tanah runtuh. Tapak yang terganggu diceroboh terlebih dahulu oleh herba daun lebar. Spesies saka yang memasuki ekosistem mencapai kedominanan secara beransur-ansur dengan mencegah pokok imigran melalui prapengecualian nic. Kedominanan spesies pokok menunjukkan trend pertambahan di sepanjang cerun yang mengalami pemulihan. Tapak-tapak baru menunjukkan peratus kandungan pasir yang lebih besar di dalam tanah. Kemasinan dan suhu yang lebih tinggi didapati di kawasan yang rosak. Bahan organik tanah bertambah secara beransur-ansur bagi empat tahun kajian pertumbuhan semula. Kepekatan karbon organik tanah, jumlah nitrogen Kjeldahl, dan ketersediaan fosforus bertambah dengan tempoh pemulihan. Respirasi tanah dan populasi mikrob juga bertambah dengan masa berikutan dengan kejadian tanah runtuh.

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## Introduction

Landslide disturbance, common on steep slopes, has important effects on plant regeneration. Landslide disturbance may cause scarcity or complete absence of advance regeneration due to impoverished soil seed bank, low soil nutrient status, unstable substrate, lack of mycorrhizal inoculum and greater radiation (Myster 1993, Fernandez & Myster 1995, Myster & Fernandez 1995). Though these landslide associated problems have been noticed and reported in the tropical environment of this area, there is little information about their spatial and temporal dynamics, and post-landslide plant community recovery. Nevertheless, such studies may help in evolving some management package to mitigate this natural disaster.

Arunachal Pradesh, bestowed with rich and diversified forest resources, faces serious land degradation due to acute and chronic landslide activity and shifts to use steep lands for agriculture. Problems associated with landslide activity include perturbations in communication, soil erosion and loss of invaluable forest wealth. Very few studies have examined the after-effects of landslides, especially the impact of landslides on vegetation and soil in an integrated manner (e.g. Pandey & Singh 1984/1985, Gauriguata 1990). The present experimental study has three objectives: (1) to determine variation in micro-environmental factors during revegetation in landslides, (2) to investigate the revegetation dynamics along an age sequence of recovering landslides, and (3) to quantify the soil physio-chemical and biological properties in naturally revegetated landslides.

## Materials and methods

### *Study area*

#### Location

Four sites recovering from landslide degradation were selected. Site selection covering a range of time since landslide occurrence included 6-month-, 1-y-, 3-y- and 4-y-old slopes. With regard to flow path of landslides, all our study sites are located in the region where deposition dominates, which is about 20–60 m away from the region of initiation of landslides. In addition, one control site in a hilly terrain where landslide had not occurred for at least ten years was selected having similar physiographic conditions (Table 1). They are located in a dense tropical moist forest zone in the Itanagar capital complex of Arunachal Pradesh (26° 28'–29° 30' N, 91° 31'– 97° 30' E; altitude 210–320 m asl) along the National Highway 52-A covering a stretch of 29 km. The 'time lapse' between the occurrence of landslide and the study period was determined by consulting local people. Major tree species surrounding our study sites are *Terminalia myriocarpa, Mesua ferrea, Duabanga grandiflora, Tectona grandis, Shorea robusta, Chukrasia tabularis,* etc. and the ground vegetation consists mainly of herbaceous elements such as *Begonia roxburghii, Colocasia* spp., *Musa* spp., *Arundinella bengalensis, Bambusa nana, Cyathea gigantea, Equisetum diffusum, Lycopodium clavatum* and *Selaginella wallichii.*

**Table 1.** Physiographic features and microclimate of the study sites

| Site No. | Age (y) | Altitude (m asl) | Slope (%) | Slope aspect | Width (m) | Height (m) | Area approx. (m²) | Light intensity | RH (%) | Temperature (°C) Air | Soil |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1/2 | 210 | 45 | N | 29 | 25 | 725 | 11333 | 58 | 30.1 | 22.2 |
| 2 | 1 | 210 | 40 | NNE | 9 | 8 | 72 | 8580 | 50 | 31.7 | 21.8 |
| 3 | 3 | 310 | 52 | NE | 23 | 13.5 | 310.5 | 8517 | 61 | 30.9 | 20.5 |
| 4 | 4 | 320 | 70 | NE | 13 | 10 | 130 | 6247 | 78 | 28.5 | 19.7 |
| Control | - | 320 | 76 | NNE | 24 | 11 | 264 | 3710 | 61 | 25.5 | 17.8 |

## Climate, geology and land use

Arunachal Pradesh has predominantly hilly topography with rugged terrains. The land mass is clothed with dense vegetation of great diversity ranging from tropical to alpine forests. This thick vegetation offers protection to soil and stabilises the land. Despite this, biotic interference in the form of shifting agriculture and commercial logging, and developmental activities like road constructions, and concurrent heavy rainfall during the monsoon make the land unstable causing landslips and erosion. The most important disturbance in the vicinity of the study is shifting cultivation ('jhumming'), the major cultivation practice of the state. Due to increasing population and expansion of the capital complex, severe pressure is posed on the limited land for jhumming. According to the State of Forest Report (1997), Arunachal Pradesh suffered a loss of 75 km² of forest due to shifting cultivation, while gain of forest cover due to natural regeneration was 56 km². The net loss of forest cover was thus 19 km².

Climate is dominated by three distinct seasons, namely summer (March–May), monsoon (May–September) and winter (October–March). Average annual rainfall is 2500 mm. Occasional rainfall occurred during the study period lasting from January to March of 1998. The average minimum and maximum air temperatures were 31.8 °C and 21.6 °C respectively. The relative humidity varied from 55 to 77%. The soil of this sub-Himalayan system formed from Precambrian quartzite rocks of Sela group is sandy to sandy loam in texture in the lower altitudes (Arunachalam 1998).

## *Methods*

### Determination of microclimatic variables

The air temperature and relative humidity were determined using a thermo-hygrometer (TFA, Germany), while soil temperature was measured using a soil thermometer (ELITE). Light intensity was determined using a lux meter (Lutron LX-101).

### Vegetation analysis

Across each site, three 10 × 1 m study plots were demarcated during February 1998. Species–area curve was prepared and accordingly, in each plot, three to five (1 × 1 m) quadrats were laid for vegetation analysis. Density, frequency, basal area, dominance, abundance, importance value index (IVI), species richness index, species diversity index, species evenness index and similarity index were determined following standard methods and formulae given in Misra (1968), and Muller-Dombois and Ellenberg (1974).

### Soil analysis

From each site, nine soil samples within the upper 10 cm of the soil profile were collected using soil auger, brought to the laboratory, and stored at 4 °C in a deep freezer until use. Soil samples collected from each site were pooled irrespective of plots and used for all analytical purposes (Allen *et al.* 1974). Each soil sample was then divided into two equal parts. One part was sieved through 2-mm mesh screen, air-dried under laboratory conditions for seven days and then subjected to texture analysis (Boyouncous Hydrometric method) and analysis of water holding capacity (Keen's box method). Remaining soil samples were again sieved through 0.5-mm mesh screen and used for analysis of soil organic carbon (rapid titration method), total Kjeldahl nitrogen (semi-micro Kjeldahl's procedure) and available phosphorus (molybdenum blue method). The other part of soil was immediately (within 24 h) sieved and analysed for pH (pH meter), moisture content (gravimetric method), ammonium-N (indo-phenol blue method) and nitrate-N (phenol-disulphonic acid method).

Bacterial and fungal populations (dilution plate technique) and soil respiration (laboratory incubation method) were determined. For these tests, soil samples (0–10 cm depth) were collected randomly from five places in each site and pooled for a composite sample. Soil was dug out from the plots for isolation of bacteria and fungi. Soil corers (1.5 cm inner diameter) were wiped with ethanol before every insertion to prevent microbial contamination. These samples were immediately incubated in the laboratory for soil respiration experiment and extracted for isolation of bacterial and fungal populations under aseptic conditions. Bacteria was cultured in bacterial agar medium and fungi in rose-bengal agar medium according to procedures given in Maithani *et al.* (1996) and Arunachalam *et al.* (1997a). The colonies developed during BOD incubation (at 25 ± 1 °C) were counted for subsequent five days using a colony counter. Soil respiration was determined by incubating 1 kg of field moist soil in sealed rectangular jars with 1N NaOH and 50 ml distilled water under laboratory conditions (MacFadyen 1970).

### Statistical analysis

The data were subjected to Tukey's test with a probability level of $p<0.05$ to compare the mean values across the sites. Linear regressions were also worked out wherever necessary according to Zar (1974). Analysis of variance was used to find out the difference between sites in terms of vegetation and soil properties.

## Results

### *Microclimate*

Light intensity on the floor of the site was found to be more in the six-month-old site and declined with progression of revegetation and was lowest in the control site. The air and soil temperatures showed a declining trend with decreasing light intensity. The relative humidity, on the other hand, showed an increasing trend (Table 1).

### *Floristic composition*

Among the 34 plant species identified, there were 13 grass species (bamboo + other grasses), 8 dicot herbs, 4 shrubs, 2 climbers, 3 trees (including tree fern) and 4 herbaceous ferns. *Phyllostachys assamica,* a bamboo species, was the only species present in all the landslide points. A few pteridophytes, viz. *Equisetum diffusum, Selaginella wallichii, Cyathea gigantea, Lycopodium clavatum* and *Gleichenia longissima,* were also present, of which, the latter two species were found both in the self-regenerating landslides and in the control slope (Table 2). Bamboo was represented by *P. assamica, Bambusa nana* and *Cephalostachyum fuchsianum.*

### *Community structure*

*Arundinella bengalensis* and *P. assamica* together dominated (10.99 plants ha$^{-1}$) the 6-month-old site. The 1-y-old site was co-dominated by *Sonerila maculata* (Table 2), while the dominant species was *Saccharum spontaneum. Macaranga indica* had greater density in the control site followed by *Phyllostachys assamica* and ferns. *Phyllostachys assamica* was the dominant one both in the 3- and 4-y-old sites; *Lycopodium clavatum* and *Selaginella wallichii* shared codominance in the 3-y-old site, while *Cephalostachyum fuchsianum* and *Ageratum conyzoides* in the 4-y-old site.

The abundance of monocots was generally greater on landslides, while the dicots dominated the control. However, amongst the landslide points, the abundance of monocots showed an increasing trend with the progression of vegetation recovery. There was poor similarity between the sites. The Sorensen's similarity index varied between 0 and 38. The 3-y-old and 4-y-old sites had greater similarity in plant species composition (38.04%). On the other hand, there was no similarity between the six-month-old and control sites. Across the recovery process, it is observed that the similarity gradually increased at least up to four years of vegetation, i.e. from 6-month-old to 1-y-old stage the index was 19, from 1- to 3-y-old stage it was 24, and from 3- to 4-y-old stage it was 38.

**Table 2.** Density (plants $m^{-2}$) of plant species on the self-regenerating landslides

| Species name | Age of site (y) | | | | Control |
|---|---|---|---|---|---|
| | 1/2 | 1 | 3 | 4 | |
| *Ageratum conyzoides* | - | 1.00<br>(22.64) | - | 4.00<br>(15.94) | 0.33<br>(11.32) |
| *Alocasia fornicata* | - | 0.33<br>(14.15) | - | 0.66<br>(7.96) | 1.33<br>(31.13) |
| *Arundinella mutica* | - | 1.00<br>(22.64) | - | - | - |
| *Arundinella nepalensis* | - | 0.33<br>(14.15) | - | - | - |
| *Arundinella bengalensis* | 6.33<br>(50.5) | - | - | - | - |
| *Bambusa nana* | - | - | - | 1.66<br>(10.62) | - |
| *Boehmeria glomerulifera* | - | - | - | - | 1.66<br>(36.79) |
| *Carex phacota* | 1.33<br>(26.7) | - | - | - | - |
| *Cyperus cuspidatus* | - | 0.33<br>(11.32) | - | - | - |
| *Cyathea gigantea* | - | - | - | - | 0.33<br>(11.32) |
| *Cephalostachyum fuchsianum* | - | - | - | 4.33<br>(74.34) | - |
| *Desmodium motorium* | 0.33<br>(20.79) | - | - | - | - |
| *Equisetum diffusum* | 0.33<br>(23.76) | - | - | - | - |
| *Erigeron bonariensis* | 1.00<br>(26.7) | - | 2.33<br>(28.57) | 1.00<br>(10.62) | - |
| *Forrestia hookeri* | - | - | - | 0.66<br>(7.96) | - |
| *Gleichenia longissima* | - | - | 1.33<br>(40.0) | 2.00<br>(13.27) | 3.33<br>(36.79) |

Contd.

Table 2 (continued)

| | | | | | |
|---|---|---|---|---|---|
| *Ischaemum rugosum* | 0.33<br>(29.7) | - | - | - | - |
| *Imperata cylindrica* | - | - | - | 2.00<br>(10.62) | - |
| *Lycopodium clavatum* | - | 3.00<br>(22.64) | 34.33<br>(68.57) | 0.33<br>(7.96) | - |
| *Macaranga indica* | - | 2.33<br>(56.6) | - | - | 5.00<br>(39.62) |
| *Maesa montana* | - | - | - | - | 0.66<br>(19.81) |
| *Mastersia assamica* | - | - | - | 0.33<br>(7.96) | - |
| *Molineria gracilis* | - | - | - | 0.66<br>(7.96) | - |
| *Musa sapientum* | - | - | - | - | 0.66<br>(28.3) |
| *Osbeckia nutans* | 1.66<br>(35.64) | 0.33<br>(11.32) | - | - | - |
| *Phyllanthus glaucus* | 1.00<br>(23.76) | - | - | 0.33<br>(7.96) | - |
| *Phyllostachys assamica* | 4.66<br>(62.4) | 3.00<br>(36.74) | 43.33<br>(94.29) | 41.66<br>(82.30) | 4.00<br>(84.9) |
| *Pouzolzia sanguinea* | - | 0.33<br>(16.98) | - | - | - |
| *Selaginella wallichii* | - | - | 12.00<br>(68.67) | - | - |
| *Saccharum spontaneum* | - | 6.00<br>(36.74) | - | - | - |
| *Sonerila maculata* | - | 5.00<br>(33.96) | - | - | - |
| *Thysanolaena maxima* | - | - | - | 1.00<br>(10.62) | - |
| *Thysanolaena agrostis* | - | - | - | 1.00<br>(10.62) | - |
| *Zehneria umbellata* | - | - | - | 3.00<br>(13.27) | - |

(-)→absent; values in parentheses are importance value indices.

In the 6-month-old site, the IVI distribution shows that the site was dominated by two species (IVI >50) and all other species (7 in number) had similar importance value. In the case of the 1-y-old site, only one species had IVI >50 (Table 2), whereas, out of 5 species, 3 had IVI >50 in the 3-y-old site. In the 4-y-old site, only 2 species had IVI >50 whilst the rest shared equal dominance. Nevertheless, the control site showed monodominance of *Phyllostachys assamica* (IVI=85) while other species shared the dominance in a gradual decreasing order.

### *Species diversity*

The total numbers of plant species were 9, 12, 5, 16 and 9 for the 6-month-, 1-y-, 3-y-, 4-y-old recovering landslides and the control site respectively. When pooling the 6-month- and 1-y-old sites and the 3-y- and 4-y-old sites, it was observed that the average number of species was 10 which was not significantly different from the control (9). The species richness index is somewhat similar in all sites, barring the 3-y-old site. The species diversity index did not show any marked trend either. The species evenness index was less in the 4-y-old site and the control (Table 3).

**Table 3.** Abundance (plants m$^{-2}$), dominance (m$^{-2}$) and species indices of different plant groups on the self-regenerating landslides

| Parameter | Age of site (y) | | | | Control |
|---|---|---|---|---|---|
| | 1/2 | 1 | 3 | 4 | |
| **Abundance** | | | | | |
| Monocots | 15.33 | 20.00 | 55.33 | 61.16 | 6.00 |
| Dicots | 14.50 | 20.50 | 7.00 | 24.00 | 14.50 |
| Pteridophytes | - | 9.00 | 38.33 | 7.00 | 4.33 |
| **Dominance** | | | | | |
| Monocots | 40.98 | 40.91 | 32.81 | 137.06 | 3.89 |
| Dicots | 47.78 | 70.04 | 14.86 | 3349.46 | 37804.77 |
| Pteridophytes | - | 2.26 | 9.82 | 9.82 | 364.78 |
| **Species indices** | | | | | |
| Species richness index | 2.035 | 2.598 | 0.710 | 2.847 | 2.025 |
| Species diversity index | -2.123 | -2.323 | -1.502 | -2.195 | -1.974 |
| Species evenness index | -0.965 | -0.935 | -0.933 | -0.792 | -0.898 |

### *Soil physical properties*

The percentage of sand decreased with increasing recovery period, with the lowest value recorded at the control site (Table 4). However, the percentage of silt plus clay together increased with increasing age. The water holding capacity (WHC) also increased with progressive recovery period. The soil moisture content (SMC) was very low (12–18%) in the study sites.

### *Soil chemical properties*

All soils were slightly acidic (5.29–6.59); the minimum value was recorded in the 6-month-old site. The soil organic carbon (SOC) gradually increased with the progression of vegetation recovery, whilst the control site possessed significantly ($p<0.05$) higher SOC (Table 4). The total Kjeldahl nitrogen (TKN) content did not vary between the 4-y-old and control sites. C/N ratio did not show any trend, the highest ratio was observed in the 1-y-old site (18.72) and is comparable to the control site (18.14). Ammonium-N in the soil was lowest in the 6-month-old site and highest in the control site, while nitrate-N concentration was maximum in the 1-y-old site and minimum in the 3-y-old site. Available phosphorus level was highest in the 4-y-old site and lowest in the control (Table 4).

**Table 4.** Physico-chemical properties of soil in the self-regenerating landslides and control site

| Character | Age of site (y) | | | | Control |
|---|---|---|---|---|---|
| | 1/2 | 1 | 3 | 4 | |
| **Physical properties** | | | | | |
| Texture | | | | | |
| Sand(%) | 94.22 | 94.75 | 83.10 | 88.45 | 77.82 |
| Silt + clay(%) | 5.78 | 5.25 | 16.90 | 11.55 | 22.18 |
| Water holding capacity (%) | 28.10 | 33.60 | 34.70 | 40.60 | 34.70 |
| Soil moisture content (%) | 12.00 | 17.20 | 17.40 | 16.10 | 17.60 |
| **Chemical properties** | | | | | |
| pH (1:2.5 w/v $H_2O$) | 6.59 | 5.96 | 5.29 | 6.27 | 6.16 |
| Soil organic carbon(%) | 0.03 | 0.40 | 0.40 | 0.50 | 1.02 |
| Soil organic matter(%) | 0.06 | 0.68 | 0.68 | 0.85 | 1.75 |
| Total Kjeldahl-N (%) | 0.03 | 0.02 | 0.04 | 0.06 | 0.06 |
| C/N ratio | 1.17 | 18.72 | 9.36 | 8.78 | 18.14 |
| Ammonium (mg 100 $g^{-1}$) | 0.0008 | 0.0044 | 0.0016 | 0.0037 | 0.0151 |
| Nitrate (mg 100 $g^{-1}$) | 0.253 | 0.753 | 0.227 | 0.385 | 0.587 |
| Available phosphorus (mg 100 $g^{-1}$) | 0.665 | 0.781 | 0.638 | 1.413 | 5.625 |

### *Soil respiration and microbial population*

Soil respiration rate was significantly ($p<0.05$) greater in the control soil compared to that of the landslides. The unsieved soil recorded greater respiration rate than the sieved soil. There was an increasing trend in soil respiration rate with the progress of natural revegetation on the landslides (Table 5).

The number of colonies of both bacteria and fungi increased regularly with incubation period up to five days. The bacterial population increased gradually up to three years of recovery, followed by a significant ($p< 0.05$) decline in the fourth year; the control site possessed greater bacterial population (Table 5). On the other hand, fungal population increased with the progression of vegetation recovery.

**Table 5.** Soil respiration (mg $CO_2$ 100 $g^{-1}$ fresh soil $day^{-1}$) and microbial population (colonies x$10^{-4}$ $g^{-1}$ of dry soil) in the study sites

| | Age of site (y) | | | | |
|---|---|---|---|---|---|
| Parameter | 1/2 | 1 | 3 | 4 | Control |
| **Soil respiration** | | | | | |
| Unsieved soil | 36 ± 1 | 42 ± 4 | 154 ± 3 | 110 ± 7 | 222 ± 8 |
| Sieved soil | 22 ± 3 | 22 ± 1 | 44 ± 9 | 44 ± 3 | 72 ± 5 |
| ***Microbial population*** | | | | | |
| **Bacteria** | | | | | |
| 1st day | 22.0 ± 6.0 | 46.0 ± 16.0 | 59.5 ± 10.5 | 47.5 ± 5.5 | 164.0 ± 8.0 |
| 2nd day | 30.5 ± 3.5 | 55.0 ± 18.0 | 79.5 ± 18.5 | 62.0 ± 7.0 | 191.5 ± 1.5 |
| 3rd day | 38.5 ± 1.5 | 62.5 ± 20.5 | 98.5 ± 21.5 | 67.5 ± 3.5 | 225.5 ± 5.5 |
| 4th day | 48.0 ± 1.0 | 69.5 ± 20.5 | 106.5 ± 23.5 | 71.0 ± 3.0 | 238.0 ± 7.0 |
| 5th day | 57.0 ± 1.0 | 77.0 ± 18.0 | 112.0 ± 23.0 | 75.0 ± 2.0 | 250.5 ± 7.5 |
| **Fungi** | | | | | |
| 1st day | 15.5 ± 2.5 | 11.0 ± 2.5 | 14.5 ± 1.0 | 16.5 ± 5.5 | 7.0 ± 3.0 |
| 2nd day | 18.0 ± 5.0 | 13.5 ± 2.5 | 20.5 ± 0.5 | 23.0 ± 7.0 | 11.5 ± 4.5 |
| 3rd day | 20.0 ± 3.0 | 16.5 ± 1.5 | 24.5 ± 0.5 | 26.0 ± 7.0 | 13.5 ± 5.5 |
| 4th day | 26.0 ± 6.5 | 26.0 ± 3.5 | 34.5 ± 2.0 | 39.5 ± 11.0 | 31.5 ± 1.5 |
| 5th day | 27.5 ± 8.0 | 29.5 ± 4.5 | 37.5 ± 1.5 | 45.0 ± 11.5 | 41.5 ± 0.5 |

± SEM(n=3)

## Discussion

### *Community dynamics*

Community characteristics including species composition, density, dominance and species diversity showed marked differences among the four self-regenerating landslides. The first plants to invade the disturbed sites were annual forbs (e.g. *Erigeron bonariensis, Carex phacota, Phyllanthus glaucus,* etc.; Table 2). These ruderal pioneers are either immigrants to the disturbed sites or residuals emerging from buried seeds exposed due to soil movement and mixing during the process of landslides. These species have reproductive and growth strategies which lead to successful invasion of disturbed sites. Salisbury (1942), in this context, pointed out that species with light, mobile seeds often invade a highly disturbed situation, while species with heavier seeds, often animal-disseminated, usually enter the ecosystem at a later stage of development. According to Bormann and Likens (1979), disturbance triggers the germination of buried seeds, and mechanisms which synchronise the germination of such seeds with disturbance are paramount control features in ecosystem dynamics, initiating a homeostatic response held in reserve for just such an occasion.

The abundance of monocots lasted for four years of recovery; however, in all sites the distribution pattern was not uniform owing to recurrent soil erosion and deposition, permitting the occurrence of both monocots and dicots. Abundant monocots entered the ecosystem in the initial stages of recovery, shared the dominance and after three years of revegetation (Table 3), the dominance shifted largely to the dicots. The relative abundance of dicots on the landslides and the tremendous dominance in the adjacent undisturbed ecosystem indicate their shade requirement. The dicotyledonous annuals in the early developmental phase are characterised by high rates of growth and reproduction (r selection). During the later phase of ecosystem development, high numbers of perennials (e.g. woody species) occur that are characterised by low growth potential but better capabilities for competitive survival (K selection). Shrubs appeared on the disturbed sites after six years of landslide recovery in a moist temperate forest zone of India (Pandey & Singh 1984/1985). In the present study also, perennial herbaceous and shrub species were abundant even in the 6-month-old site in this humid tropical zone, but their population could not stabilise even after four years of recovery. Overall, performance of *Phyllostachys assamica* was found to be better on the landslides and might possess greater potential in giving stability to the slopes due to their dense creeping root network.

The abundance of plant species progressively increased up to four years of recovery. The control site had less plant abundance which may be attributed to the site characteristics. Although our site was not a climax community, it was a mature community existing on the slope where disturbance had not taken place for the past ten years. Nevertheless, the dominance of plant species showed an increasing trend along the recovery gradient and was higher in the control site, owing to presence of tree saplings that contributed significantly to the total basal area growth.

In the present study, species content on an average (6-month- and 1-y-old sites and 3-y- and 4-y-old sites) was *c.* 11 per site on the landslides. Species diversity showed a positive relationship with species number ($Y=4.27+3.74X$, $r=0.858$, $p<0.05$); it increased from the 6-month-old to 1-y-old site and dropped in the 3-y-old site and again increased sharply in the 4-y-old site. Such variations in species diversity index fully corroborate the hypothesis of Bormann and Likens (1979) who reported that in a secondary successional forest community species diversity increases, followed by a decline and again increases as the community approaches stabilisation.

Connell and Slatyer (1977) have proposed three models for the mechanism that would bring about successional change after perturbations. One model they recognised is the 'facilitation model', which suggests that entry and growth of later species is dependent upon the earlier species 'preparing the ground'. Only after this can the later species colonise. The second, the 'tolerance model', holds that species may tolerate each other's presence and succession leads to a community composed of those species most efficient in exploiting the resources available. The third, 'inhibition model', states that no species necessarily has competitive superiority over another and whichever colonises the site first holds it against potential immigrants. The chronosequence of dominant species in this study (annuals → annuals + perennials → perennials) superficially represents a situation similar to the 'relay floristics', or the 'facilitation' model. Moreover, the species similarity between different sites was poor (up to 38%), but then there was increasing tendency in the index during the progress of revegetation (6-month-old→1-y-old→3-y-old→4-y-old site). This indicates that the perennial species that entered the ecosystem gradually gained dominance by prohibiting the immigrants through niche pre-exemption. This gradual increase in the similarity indices during revegetation process indicates the long drawn-out dominance of perennials, even though certain pioneers persisted to the last stage, and reinforces the importance of initial floristic composition. However, Horn (1974) argued that early successional species should persist in the climax as long as a few openings occur from time to time.

Bornkamm (1981) used the community coefficient to calculate the rates of secondary succession. Low similarity was considered to be indicative of high rate of change, and vice-versa. A very slow rate, i.e. high percentage similarity, indicates temporal stability. In the present study, the floristic components on the landslides differed markedly from that of an undisturbed site (as evidenced by low similarity) reflecting the individualism in exchanging transient species and populations through time. This also underlies the importance of local reservoirs of disseminules (MacMahon 1980). Based on natural revegetation data on landslides, the rate of change is high from the 6-month- to the 1-y-old site, which then slowed down as the recovery progresses. It should also be noted that large changes in species richness at certain stages of succession does not necessarily mean large compositional turnover, since species compositional turnover means the change in species abundance which may be uncorrelated with species presence or absence.

### *Soil properties*

As a result of landslides, there occurs erosion of the top soil due to extreme rainfall events. Loss of finer soil particles leads to an increase in the proportion of sand during the early developmental stages after disturbance. This could be true in the present study as well, since the soil in the control site had greater proportion of silt+clay compared to the landslides. Soil moisture content was very low (e.g. 12 to 18%) which might have been due to soil sampling during cold and dry winter season (February first week).

The soils of the study area are slightly acidic (pH 5.29–6.59). Low pH is detrimental to plant growth in extreme conditions; however, tolerance to acidity varies from species to species. But pH as such may not be the main factor associated with the revegetation of acidic soils. Berg and Vogel (1973) suggest that the availability of certain elements such as iron, aluminium and manganese to plants increases as soil pH decreases which may result in conditions toxic to plants under very acidic conditions. Williams and Chadwick (1977) reported greater accumulation of reaction products in soils owing to lower rate of leaching at higher soil temperatures that might reduce the pH. But in the present study, the trend was not so, because the soil temperature was greater in landslides where the pH was slightly higher compared to the control. This indicates that the activity of soil reaction is low on landslides, as also substantiated by lower soil respiration rate (Table 5).

In the studies carried out by Odum (1960), organic matter concentration in soils of regenerating ecosystem decreased during the first three years of fallow, thereafter it increased. In the present study with landslides, the soil organic matter (SOM) increased gradually at least up to four years of revegetation, while the control site possessed almost double the SOM level in the landslides (Table 4). Such a low SOM could be due to less plant biomass (Arunachalam *et al.* 1996).

Bormann and Likens (1979) suggested for the Hubbard Brook system that the nutrients shared within the ecosystem provide the capability to ameliorate change in the functional characteristics of the ecosystem. In the present study, the concentration of soil organic-C (SOC) and total Kjeldhal nitrogen (TKN) as well as the fine-soil content (silt+clay) increased with time (Table 4). Pandey and Singh (1984/1985) reported that the rate of change in soil nutrients declined as succession progressed. On the other hand, the rate of fluctuation in the available nutrients (Table 4) was high on landslides without any definite pattern along the revegetation gradient. Nevertheless, nitrate-N was significantly ($p<0.05$) greater than ammonium-N. This indicates greater nitrification in the disturbed sites which might lead to a potential loss of available-N from the system, owing to leaching and/or less dense vegetation (Arunachalam *et al.* 1996). Available phosphorus concentration was significantly greater in the control site. This suggests that most of the phosphorus in the landslide exposed mineral soil and weathered rock is biologically unavailable. Because phosphorus is replenished into the soil solution almost entirely from the weathering and breakdown of primary minerals in parent rock material, landslides may be important in rejuvenating the supply of biologically available phosphorus to the forest soils. Long-term studies of soil phosphorus transformation on recent landslides and along chronosequences are needed to test such hypotheses in this tropical rain forest zone of Arunachal Pradesh.

The nutrient enrichment of the soil becomes stable at the same time as the plant biomass. Therefore, it is expected that the recovery of nutrients and biomass accumulation exhibit, in the initial stages, a positive feedback moving the system quickly towards a stable nutrient status and recycling. It is suggested that the added carbon from the developing vegetation stimulates the immobilisation of nutrients, which are constantly being generated by the geological weathering aided by rainfall, in the soil biomass. This would counteract the process of leaching and release the nutrients at a slower, but more stabilised rate of recycling by the vegetation.

Otrosina *et al.* (1984) reported dramatically larger fungal and bacterial population on sites with herbaceous cover due to increased substrate afforded by residues from grass and herbaceous plants. In the present study, soil respiration rate increased gradually with the progression of vegetation recovery on landslides; the trend was similar both in sieved and unsieved soil samples. Nevertheless, the unsieved soil samples had significantly ($p<0.05$) greater soil respiration rate (Table 5) both on landslide points as well as in the control site. This could be attributed to the abundance of plant detrital matter like fine roots, etc. that has been reported to contribute significantly to the soil respiration (Arunachalam *et al.* 1997b). Soil respiration is also an indicator of microbial activity. Evidently, soil respiration rate had positive relationship with the bacterial (r=0.861, p<0.05) and fungal (r=0.733, p<0.05) populations. The initial increase in the fungal population during recovery of landslides could be attributed to the availability of organic matter resources which were washed along the slide. This population, however, declined after six months of recovery because of reduction in the plant detritus expectedly. We had earlier attributed the increased microbial population (Table 5) to the availability of plant detritus as effected by the dense growth of plants *vis-á-vis* production of fresh litter.

## Conclusion

Based on the experimental data on the revegetation patterns and soil properties of areas disturbed by landslides, the following points could be made:

- The dominance of monocots on landslides lasted for a few years and is gradually replaced by dicots as evidenced by the dominance of dicots in the 4-y-old self-regenerating landslide and the control site.
- The low similarity indices among landslides as well as between landslides and the control site indicate the temporal instability in the revegetation process.
- The presence of a relatively high amount of sand and the heavy rainfall in the area signal the occurrence of splash erosion leading to loss of finer soil particles.
- The rate of fluctuation in the available forms of nutrients (ammonium-N, nitrate-N and available P) is due to mixing of soil strata with both the top and bottom soils coming together during landslide. Due to exposing of the parent rock at some parts and top soil at other parts, leaching becomes sporadic and different at different points.
- With a recovery period, the soil organic matter level gradually increases.
- In general, bacterial and fungal populations showed an increasing trend with the recovery process.
- In order to stabilise steep slopes, growth of monocots, especially *Arundinella bengalensis* and *Phyllostachys assamica*, can be promoted, as the former species was found useful in holding the soil in the 6-month-old site and the latter in the later stages of revegetation on landslides. Nevertheless, in the vicinity, spreading of jute net along the slopes with intermittent grass and bamboo growth has been found useful in preventing landslips on steep lands with a slope < 50%.

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