ODA Project R4611

Annual Report 1992

The protection role of Jamaican catchment forests and their resistance to and recovery from the impact of Hurricane Gilbert

School of Agricultural and Forest Sciences
University of Wales
Bangor

Project Details

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The protection role of Jamaican catchment forests and their resistance to and recovery from the impact of Hurricane Gilbert

Start and Finish Dates:

1 January 1991 - 31 December 1993

Staff involved:

Principal investigators: Dr John R Healey, University of Wales, Bangor; Dr Edmund V J Tanner, University of Cambridge

Research collaborators: Mr Paul A Stevens, Institute of Terrestrial Ecology, Bangor; Dr John B Adams, University of Washington, Seattle

Local collaborator: Dr P V Devi Prasad, Head of Department of Botany, University of West Indies

Research officers: Dr Morag A McDonald, University of Wales, Bangor (full-time); Dr Valerie Kapos and Mr Mark Aldrich, University of Wales, Bangor (short-term contracts)

Research Associates: Mr Peter J Bellingham, University of Cambridge; Ms Shannon Morin, University of Calgary; Ms Victoria Scott, University of Newcastle; Mr Guillaume Akogo Muogo, Mr Gae Y Gowae, Mr Kemonna K Keapoletswe, Mr Mahendra R S Suwal, Mr Neil Tanner & Mr Robert P Wood, University of Wales, Bangor

Staff employed on a casual basis: Dr Helen Tomlinson

Summary

Chapter 1

The background to the project is the severe disturbance caused to the remaining 13 000 ha of rain forest on the steep hill-slopes of the Blue Mountains of Jamaica by natural (hurricane) and anthropogenic (shifting-cultivation) forces. Further details of the background and achievements during the first year of the project can be found in the 1991 annual report.

Chapter 2

Using a new "mixing model" analysis of LANDSAT TM-based satellite imagery, the areas of forest in the Blue Mountains that have suffered different degrees of damage from Hurricane Gilbert have been mapped. These areas are being compared with available ground data and this indicates that damage is relatively unrelated to aspect and that shelter is a much more important factor. A manuscript of a paper to be published on this work has been written.

Chapter 3

A major field-experiment on the effects of forest clearance, agriculture and agroforestry on soil conservation and sustainability has been set up in the buffer zone of the natural forest. The experiment has four replicate blocks (each being managed by a different partner farmer) and four treatments: secondary forest, forest cleared and maintained free of vegetation, forest cleared and planted with agricultural crops, forest cleared and planted with an agroforestry system (contour hedgerows of *Calliandra calothyrsus* with agricultural crops between). Collection of data of surface run-off, soil erosion, rainfall interception, soil physical and chemical properties and organic matter input and turnover is already under way.

One paper on this part of the project has been delivered at an international conference and another has been published in a professional newsletter. Two BSc dissertations have been completed on the condition of the soil under different land-uses in this area; they provide evidence of the negative impact that the removal of vegetation cover has had on soil physical and chemical properties. Two further BSc dissertations are currently being written.

Chapter 4

Ecological research has been carried out into the impact of severe hurricane and human disturbance on the natural forests of the Jamaican Blue Mountains and their subsequent recovery. In a paper presented at an international conference, the evidence provided by data from a study of Jamaican montane rain forest for the predictability of natural regeneration following disturbance was reviewed. No simple rules could predict accurately which species and which cohorts would dominate. However, seedling density and recruitment rate soon after the disturbance event were found to have the best correlation with subsequent species dominance. The potential value of transition probability matrix models of population biology data in assessing the course of regeneration was investigated with mixed results. Recommendations were made for the structure of research programmes and future research priorities.

Two separate studies have been carried out on the role of vegetative resprouting and coppicing in the recovery of the forest from severe natural and human disturbance respectively. One of these studies has resulted in a paper to be submitted for publication and the other in an MSc dissertation. A high proportion of the tree species were found to have an ability to resprout (93%) and coppice (84%), but the mode of resprouting and the occurrence of sprouting before the hurricane disturbance varied greatly between species. 61% of tree stems resprouted after the impact of hurricane Gilbert: the rate was higher for those that were broken or completely defoliated. It is proposed that resprouting is a means by which species diversity and relative abundance is maintained in these forests. Following cutting of trees at ground level in plots in two different forest types, 75% of stumps coppiced in one and 47% in the other. Coppice shoots dominated the biomass of the regrowth of the former, but not the latter.

Two further degree dissertations, one MSc and one BSc, have been completed on work carried out in collaboration with this project. In the former, a detailed analysis of the structure of an area of natural forest in the Blue Mountains was carried out. The high density and shape of the tree crowns, the lack of canopy stratification, the lack of many emergent crowns and the spatial distribution of the trees and saplings were all compatible with the hypothesis that growth of individual trees and stature of the forest as a whole is limited by strong winds. In the latter, the biogeographical background to the conservation of biodiversity in these forests was examined. A high level of endemism of the tree flora was detected and the levels of endemism were highest amongst those species whose regeneration is most dependent on undisturbed conditions. This indicates the importance of the control of disturbance in these forests for the conservation of global biodiversity.

Two other MSc dissertations are nearing completion. One is concerned with the rate of regrowth and biomass recovery of natural forest in the Blue Mountains following clear-cutting. In the other, the factors controlling seedling growth and survivorship during regeneration following more natural disturbance are being investigated.

Chapter 5

A wide range of extension and dissemination activities have been carried out during the year. In addition to those listed above, project staff have: distributed copies of a comprehensive report on the project; chaired a workshop session; assisted in training sessions for National Park rangers; taught an undergraduate course at the University of the West Indies; supervised a Jamaican research student; run courses for secondary school children, teachers and Jamaican and Caribbean practitioners in conservation education; and held numerous other meetings with staff from Jamaican government departments, NGOs, other development projects and local farmers.

Chapter 6

The objectives of the project for the next year include a continuation of the monitoring of the existing plots in the study of the recovery of the natural forests from hurricane damage and the experimental study of the effects of land-use on soil conservation and sustainability. The extension side of the project will be developed by the establishment of a tree nursery and the production of diverse extension material based on the project's findings and in collaboration with local farmers and the Jamaican authorities. At least three papers will be published on the impact of Hurricane Gilbert and recovery of the forests.

Contents

Chapter 1

Previous achievements in 1991

1. In the remote sensing component of the project, a new technique was developed to allow the quantification of hurricane damage to the forests from LANDSAT images.

2. Two papers were published as a result of the project's work on ground-based assessment of the impact of Hurricane Gilbert on the forests of the Blue Mountains:

Tanner, E V J, Kapos, V, Healey, J R (1991). Hurricane effects on forest ecosystems in the Caribbean. *Biotropica*, 23, 513-21.

Bellingham, P J (1991). Landforms influence patterns of hurricane damage: evidence from Jamaican montane forests. *Biotropica*, 23, 427-433.

3. A field reconnaissance mission for the main experimental component of the project on the effects of forest clearance on the protection of catchments was completed. Discussions were held with government departments, NGOs and local people in Jamaica and experts elsewhere. This resulted in the production of two comprehensive reports reflecting the agreed proposals of the Jamaican and British collaborators which have formed the basis of the experimental study established in 1992:

Soulsby, C & Stevens, P A (1991). The catchment protection role of Jamaican forests: assessment of contemporary catchment management problems in the Blue Mountains and proposals for catchment- and plot-based studies of hydrological and soil erosion processes, pp 22.

McDonald, M A, Healey, J R (1991). The catchment protection role of Jamaican forests: proposal for a study of soil physical properties, erosion and mineral nutrient cycling in forest and non-forest land, pp 18.

4. Two MSc dissertations were completed in collaboration with this project:

Vernon, P (1991). Predictability of seedling dynamics in a Jamaican montane tropical rain forest. University of Wales, Bangor, pp 181.

Snell, R (1991). An assessment of forest structure and plant species diversity, distribution and abundance in the Blue Mountains of Jamaica. University of Wales, Bangor, pp 82.

5. A pilot project was completed on tree growth-ring analysis and a report written:

Meir, P (1991). The impact of past hurricanes on the forests of the Blue Mountains: a pilot study of tree ring formation, pp 30.

6. The field-work was completed on a pilot project on soil erosion and fertility.

7. An article was published on the work of the project in a professional newsletter:

Healey, J R (1991) Tropical forestry research at Bangor. *Agroforestry in the U.K.*, 2 (1), 23-4.

Chapter 2

Progress in LANDSAT TM-based detection and interpretation of damage by Hurricane Gilbert (1988) to the Blue Mountains forests of Jamaica

V Kapos

Summary

During this year we obtained pre-hurricane satellite data to complement the post-hurricane data and subjected both data sets to detailed mixing model analysis at the University of Washington. This analysis enabled us to overcome most of the difficulties associated with differences in lighting geometry between the two images and those presented by the steep topography of the study area. After delimiting the forested area of the Blue Mountains prior to Hurricane Gilbert, we quantitatively defined hurricane damage in this area in terms of an increase in the normalized fraction of woody material between the two TM images outside the range of variation in woody fraction seen in the forest before the hurricane. This definition accords with ground observation of extensive canopy defoliation and less frequent felling of trees by the hurricane. Based on the quantitative definition of damage, we were able to estimate and map the areas suffering different degrees of damage, and are still in the process of checking their correspondence with available ground data. We have also combined the results of the mixing model with a digital terrain model of the area supplied by The Nature Conservancy to assess landscape-scale patterns of forest damage in relation to aspect and altitude.

Interestingly, in contradiction to our first impressions (and observations made in locally restricted ground surveys) this analysis suggests that damage is relatively unrelated to aspect as such, and that shelter is a much more important factor. Subsequently, it will be possible to analyze these relationships in more detail, perhaps using GIS, to examine patterns of the extent of contiguous areas of damage and the combinations of physical factors that define shelter. Such analyses could be used to formulate predictive models of long term influence of hurricanes on forest structure and hurricane risk to commercial forestry, which could then be tested by visiting selected sites in the field. A manuscript on the LANDSAT-based analysis of damage by Hurricane Gilbert is now in preparation.

Details of Methods and Results

After the initial difficulties in selecting and acquiring appropriate pre- and post-hurricane LANDSAT data, we obtained all the necessary data tapes by mid-1992. The greatest problem proved to be finding a sufficiently cloud-free image to serve as a pre-hurricane reference. The post-hurricane image from 22 November 1988 proved to be unusually clear over the Blue Mountains when compared with about 10 years of images of the area. The best pre-hurricane TM image available was from August 1987, and it contained significant amounts of cloud within the Blue Mountains area.

Using false colour composites of TM bands 3, 4 and 5 from the pre-hurricane image, we defined the perimeter of the forested area of the Blue Mountains prior to the 1988 hurricane. We took this subset as the 'study area' and further excluded any parts of it that were covered by cloud in either the 1987 or the 1988 images. The forested area of the Blue Mountains was about 42 km^2, and of that 74% (31 km^2) was cloud free in both TM images.

The data from this area of the two TM images was subjected to spectral mixture analysis at the University of Washington, using both three- and four-endmember models. The endmembers used were shade, green vegetation (GV), woody material (non-photosynthetic vegetation, NPV) and soil. For the Blue Mountains forested area, there was little effect of including the soil endmember, so the three-endmember model was the basis for all our subsequent analyses.

The use of the shade endmember allowed us to compensate for the substantial differences in lighting geometry due to seasonal differences in solar elevation between the two images and for some of the effects of the steep topography of the study area. By subtracting the shade fraction and re-expressing the fractions of GV and NPV so that they had a total of one, we removed the effects of the different amounts and distributions of shade within and between the two images. The analyses of hurricane damage were based on comparing such normalized data between the two images.

We defined forest damage by the hurricane in terms of increasing normalized NPV fraction in a given pixel between the pre- and post-hurricane images. That is, because Hurricane Gilbert defoliated tree canopies, and to a lesser extent felled trees, greater amounts of branches, trunks and litter (all forms of NPV) would have been exposed to the satellite's "view" in hurricane-damaged forest. Of the pixels having spectral characteristics "typical" of the pre-hurricane Blue Mountains forests (i.e. not in the tails of the distribution), 82% had increased NPV fractions following the hurricane. Thus, about one fifth of the area was undamaged or little-affected by the storm.

We are now in the process of trying to verify that this pixel-based spectral definition of hurricane damage highlights areas that coincide with areas of damage observed on the ground. Further, we will link classes of damage defined as different increments in exposed NPV with classes of damage observed on the ground (e.g. simple defoliation versus significant numbers of wind-thrown trees) in so far as this is possible. The major difficulty in this process is adequately locating the areas for which we have ground data on the image. especially because many of the field plots were covered by cloud in one image or the other.

The LANDSAT pixel-based data on hurricane damage have been combined with a digital terrain model of the Blue Mountains provided by The Nature Conservancy. Although there are some problems with the terrain model, we believe that it is adequate to provide a further dimension to our analysis of landscape-scale patterns of hurricane damage. This analysis has shown that damage is not strongly related to either aspect or altitude in themselves: damaged pixels occur at all aspects and all elevations within the study area. It is likely, however, that more complex measures of landscape-scale damage and of physical features will reveal that contiguous areas of severe forest damage were less "sheltered" by topography (not equivalent to aspect) than other areas of the forest. Such (GIS-based) analysis may ultimately be used in combination with historical records of hurricane tracks to formulate predictive models of the long-term influence of hurricanes on forest structure, which can then be tested by visiting particular sites in the field. This analysis will also have the potential to increase the accuracy of "hurricane risk assessment" (and mapping) for land-use planning (especially for commercial forestry) in the mountainous hurricane-prone areas of the world.

A paper has been written about this work for submission to the *Journal of Ecology*:
Tanner. E V J. Smith. M O. Kapos. V. Adams. J B. Bellingham. P J & Healey. J R. Hurricane damage to Jamaican montane forests assessed by analysis of Landsat TM images. pp 16.

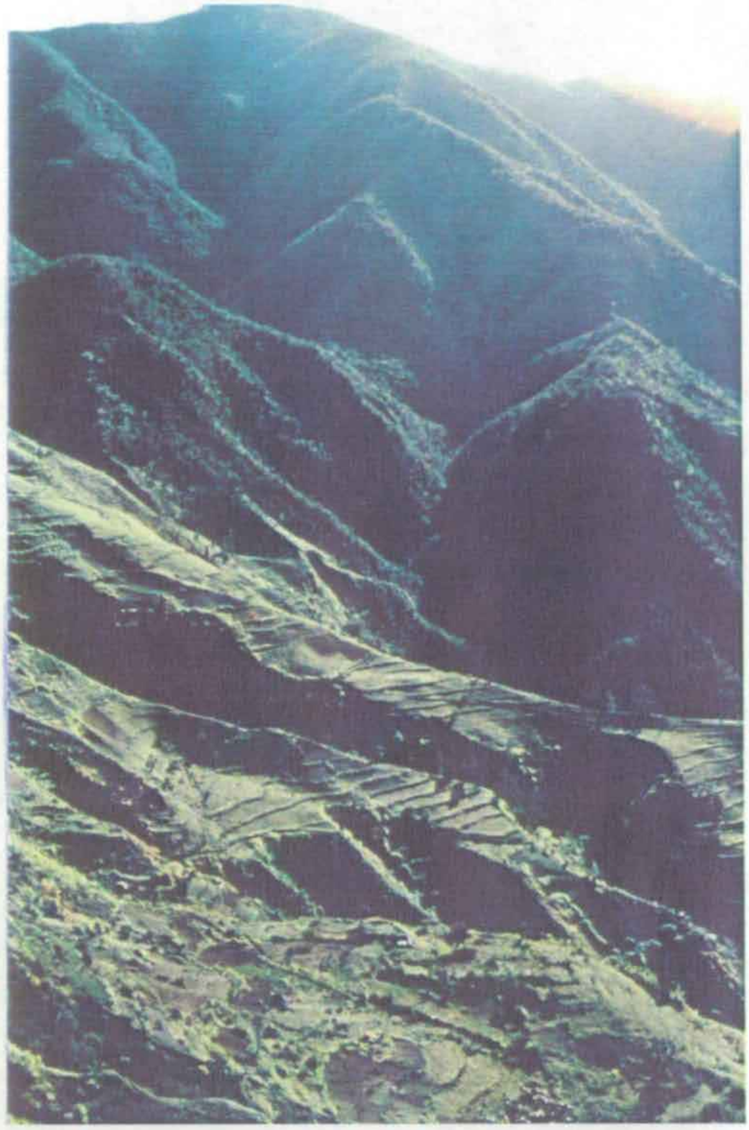

Fig.1. The Green River Valley catchment in which the experiment is located. Note the contrast between the forested upper slopes and the cleared lower slopes, with a buffer zone of shifting-cultivated secondary forest in between.

Fig.2. Looking east from Cinchona over the Green River Valley - the area has a history of forest clearance and fire and is now seriously degraded.

Chapter 3

The effects of forest clearance and subsequent land-use on soil conservation and sustainability

3.1. The effects of forest clearance on soil conservation and the potential of an agroforestry system for increasing the sustainability of agriculture in the Blue Mountains of Jamaica

M A McDonald, J R Healey & P V Devi Prasad

Introduction

There are around 13,000 hectares of natural rain-forest remaining in the Blue Mountains of Jamaica. Their importance as a biological resource, from the point of view of their influence on water and soil conservation as well as being a unique ecosystem, has been acknowledged, and this area has recently been designated as a National Park. Thus, contemporary land-use issues in the Blue Mountains are those of preventing further deforestation, buffer-zone management and ensuring sustainable land-use alternatives in areas originally cleared of natural forest.

The Blue Mountains are a geologically recent tropical mountain range, characterised topographically by steep slopes and highly dissected terrain, with sharp ridges and deep gullies. Natural soil development is poor, owing to a combination of steepness of slope, intensive rainfall and therefore significant erosion.

The natural forests of the Blue Mountains have a long history of clearance, most recently for two major land uses: cash crop cultivation by small farmers and the establishment of coffee plantations (Eyre, 1987) (figure 1). Historically, clearance for agriculture was rarely accompanied by appropriate soil conservation techniques, and often resulted in excessive erosion and land degradation (Finch, 1952) (figure 2). The Yallahs Valley Land Authority (YVLA) was initiated in 1951 to provide planning and development for agriculture in the Blue Mountains (Floyd, 1970) and was responsible for allocating land to tenant farmers, introducing new agricultural production techniques, implementing soil conservation measures and providing technical support to farmers. Unfortunately, although this represented an early progressive initiative in improved watershed management, the focus was lost with the dissolution of the YVLA in the 1970s. Cultivation of cash crops such as escallion, thyme, carrots and peppers is now largely by a system of rotation, with clearance by fire being widespread prior to crop establishment (Barker and McGregor, 1988).

The hydrological and erosion impacts of these land-use changes are complex. Replacement of a tropical rain forest canopy with an agricultural crop has been shown to increase water yields by between 110-825 mm in the first year after clearance. However, the reduced infiltration following forest removal may result in more overland flow and consequently greater flood peaks and reduced dry season flows (Bruijnzeel, 1990). Indeed, there is increasing concern over the impact that contemporary deforestation has had on water resources in the Yallahs Valley, the catchment into which most of the montane head-waters of the southern slopes of the Blue Mountains drain. The two bodies responsible for water resource management in Jamaica, the National Water Commission and the Underground Water Authority, have both implied that deforestation has resulted in: reduced water yields during the dry season, increased magnitude and frequency of downstream flooding and increased turbidity of river water as a result of erosion (Soulsby and Stevens, 1991).

Clearance of land by burning exposes the top soil to wind and water erosion, and the combustion of organic matter reduces soil cohesivity and fertility. Thus, the potential benefit of trees on cleared land is not solely in the control of erosion. In practical development planning, their role should be integrated with maintenance of soil fertility and other aspects of agricultural improvement. Agroforestry systems will be very important in realising these objectives. Agroforestry is best described in this instance as a land-use system in which trees or shrubs are grown in association with agricultural crops with the objective of stabilising and increasing overall productivity. Various forms of agroforestry have been practised in Jamaica for many centuries, but not in any disciplined manner, and not to any great extent on mountainous, steeply-sloping agricultural land. There is a need to investigate suitable tree species and systems for these environments and methods for the propagation of the trees.

The Cinchona Botanic Garden is ideally placed to be a centre for the study of the ecology and propagation of tree species. Indeed, in 1903, the Jamaican Government leased Cinchona to the New York Botanical Garden for a period of ten years as a laboratory and propagation station for tropical plants. This development could have led to the evolution of local botanical facilities of wide importance in tropical botany. However, the advent of the first World War, and the untimely death of the then Director of Public Gardens, prevented this from occurring. This would seem to be an opportune time to resurrect this facility, given the pressing environmental problems and the current availability of expertise in the area.

Objectives

The effects of forest clearance on site fertility are being assessed by studying a number of parameters. The rates of soil erosion after forest clearance and conversion to agriculture (including a potential agroforestry system) are being measured. The effects of the different vegetation-types on water balance are being considered by comparing net precipitation and run-off. Inputs of plant litter (quality and quantity), rates of litter decomposition and quantities of below-ground biomass are being estimated and related to the nutrient capital of the sites.

Fig.3. The initial clearance of the forest is of smaller diameter trees by cutlass. Larger trees are afterwards felled with an axe.

Fig.4. Burning the experimental plots. This is a traditional part of land clearance in this area. The burn is carried out from the top of the plot downwards to prevent fire spreading.

Fig.5. "Ploughing" by hand, after burning, using pick axes to remove small tree stumps and roots.

Fig.6. Erosion trough and gutter with freshly laid front lip (the metal strip is removed when the cement is set).

Treatments

1. Secondary forest
2. Forest area cleared, burned and subsequently maintained weed-free
3. Forest area cleared, burned and planted with agricultural crops
4. Forest area cleared, burned, planted with agricultural crops and intercropped with *Calliandra calothyrsus* hedges.

Methods

Establishment of experimental plots

Four blocks, each containing one plot of each treatment, have been established in the Green River Valley of the Upper Yallahs watershed in the Blue Mountains in areas of secondary forest, originally cleared for coffee, cinchona or agriculture and subsequently abandoned. These secondary forests lie in the buffer zone of the natural forest of the Blue Mountains National Park. Each plot is 10 m x 20 m, with an innermost assessment plot of 8 m x 15 m. The plots were cleared in July, 1992 in accordance with local practice - smaller trees were removed with cutlasses, and the larger ones with axes (figure 3). The plots were subsequently left to dry until August and then broadcast burned (figure 4). The plots were then left for up to three weeks to "sterilise" the soil (a local practice), ploughed (figure 5) and planting began in September, 1992.

Currently, escallion, thyme, carrots, Irish potatoes, beetroot, cabbage, sweet pepper and cucumber are amongst the major crops cultivated in the area for subsistence and sale in the local markets. Therefore, a mixture of these crops has been established in the agricultural plots in this experiment (figure 10).

Calliandra calothyrsus is a very suitable species for an intercropping system (Thompson, 1986; Macqueen, 1992), is recognised as having global potential for the rehabilitation of degraded forest and abandoned agricultural land (NRC, 1983) and has been identified as having potential for fuel-wood production in the Blue Mountains National Park buffer zone (Kerr *et al*, 1991). It is very popular with the local farmers, nitrogen-fixing, produces large quantities of N-rich litter, dense fuel-wood, coppices well after one year and branches close to the ground (therefore it is good for soil protection). The system of hedging in this experiment is designed after Young (1989) and involves three hedgerows per plot. The hedgerows are 5 m apart and comprise triple rows of trees at 1 m intra-row spacing and 0.5 m inter-row spacing. The rows are arranged in a staggered manner down-slope to maximise the area of coverage (figure 9).

The trees were grown from seed collected from trees already established in the locality in and around Cinchona Botanic Garden during February/March 1992. The collection was supplemented by a small amount of germplasm donated by the United States Department of Agriculture. The seeds were sown in March, 1992 in seed trays, transplanted to pots after germination (figure 8), and kept in a shade house at Cinchona until out-planting at an average height of approximately 1 m (figure 11).

Fig.7. Trough and gutter complete with collecting bucket. The buckets are covered, and some are fitted with overflows.

Fig.8. *Calliandra calothyrsus* seedlings in the project's shade-house at Cinchona Botanic Garden, prior to planting out.

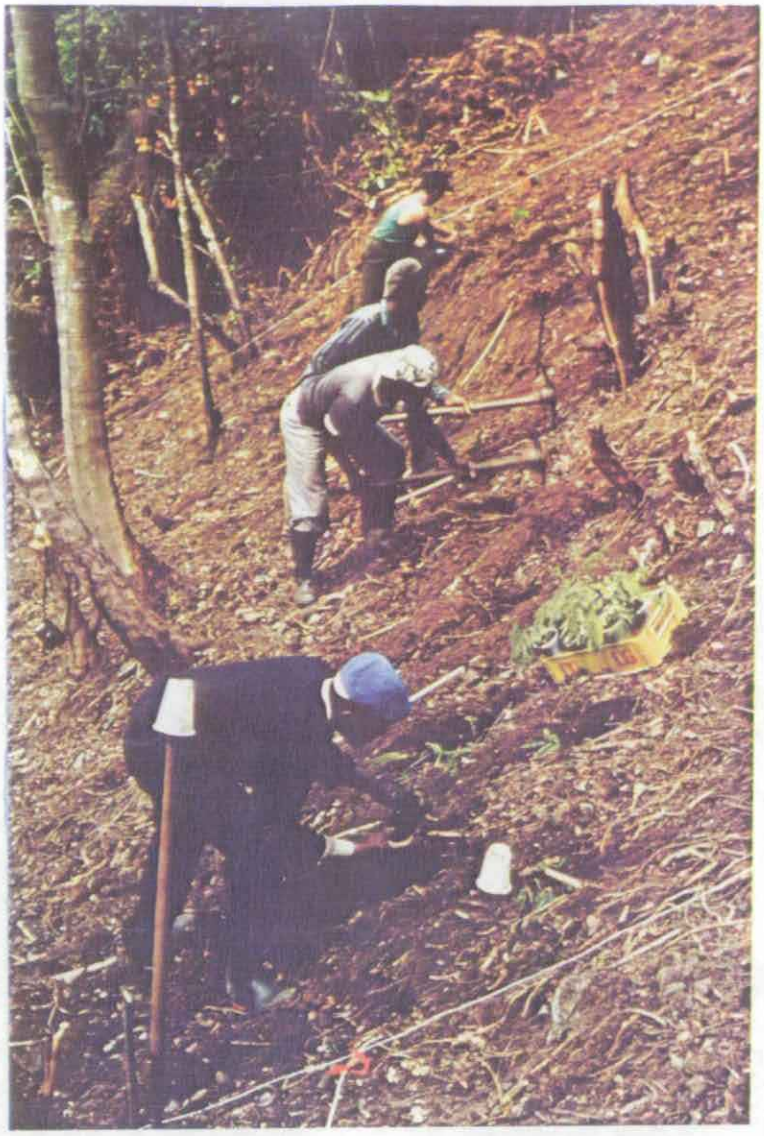

Fig.9. Planting the first hedgerow of *Calliandra calothyrsus* in an agroforestry treatment plot.

Fig.10. Agroforestry treatment plot 6 months after clearance.

Environmental measurement

Forest conversion to other land-uses involves gross disruption of nutrient cycles and water balances. The magnitude of this disruption is being assessed by monitoring temporal changes in:

1. Run-off

Three Gerlach troughs have been installed in each plot (Morgan. 1979) (figure 6). Sediment and runoff is channelled from the gutters into collecting buckets (figure 7). All the apparatus are covered with lids to prevent the direct entry of rainfall (figure 10). Samples are collected from the buckets on a fortnightly basis. Total volumes of run-off are recorded and a sub-sample filtered and retained for nutrient analyses. Bulked samples from each plot are analysed once per month. The total mass of soil eroded is also recorded, and the entire sample separated into litter, stone and sediment fractions. A bulked sample of the sediments from each plot will also be analysed for nutrient content on a monthly basis. The analyses conducted are outlined in Appendix 1.

2. Interception

A data-logging rain-gauge has been established at each block to record the amount and intensity of rainfall. Nutrient contents of bulk precipitation will be assessed on a three-monthly basis.
Throughfall collectors to measure effective precipitation reaching the soil surface have been placed in the forested plots. Five collectors of 1 m^2 in each plot are emptied and relocated on a fortnightly basis. Quantities are recorded and bulked samples collected on a plot basis for subsequent nutrient analyses.

3. Organic matter inputs (quality and quantity)

Five litter traps of approximately 1 m^2 have been placed in each of the forest plots. These are emptied on a monthly basis. the contents dried and weighed. and. where relevant, separated into leaves. small woody litter and reproductive structures. The samples will be bulked on a three-monthly basis and analysed for nitrogen and carbon content as an index of litter quality.

4. Decomposition rates

Fresh leaf litter of *Pittosporum undulatum* (a species abundant in the area) was collected to use as a standard decomposition substrate. Five replicates of known quantities of the material have been placed into each plot. Sub-samples will be collected on a three-monthly basis and weight-loss recorded.

5. Soil structure and mineral nutrient availability

Three soil cores were collected from each plot, prior to clearance in June, 1991, and subjected to the analyses outlined in Appendix 1.

Fig.11. *Calliandra calothyrsus* seedling, 6 months old, one month after out-planting.

Fig.12. *C. calothyrsus* trees form a hedgerow in the agroforestry treatment plot.

Species trial

Although only one tree species is being examined in the main trial, a subsidiary experiment has been established to compare the relative growth rates and coppicing abilities of *Acacia mearnsii*, *Pittosporum undulatum* and *Calliandra portoricensis* (all are naturalised in Jamaica and found growing locally, the former two are Australian) and *Clethra occidentalis* (a native tree species). Transplanted seedlings of each species, each about 1 m tall, were planted in six blocks containing five individuals of each species in October, 1992. This trial was located adjacent to one of the main experimental blocks. Growth rates will be recorded over the next six months, and the trees then cut back to 1 m stumps. Resprout production (number and biomass) will be recorded over the subsequent six months.

Background studies of soil under different land-uses

Three student projects have been carried out in collaboration with the project on the soils of this area. They have provided valuable background information on the condition of the soil under different land-uses. Although it is not possible to definitely attribute variation in soil properties to particular causes on the basis of such comparisons, taken together these studies to provide evidence of the negative impact that the removal of vegetation cover has had on soil physical and chemical properties in this area. Two of these studies (by Aldrich and Scott) have been completed and further details are included in this report. The field-work for the third project, a study on soil classification of primary and secondary forests, has been completed by Shannon Morin, a student of the University of Calgary. This study is currently being written-up as a BSc dissertation.

Collaboration and liaison with other projects

Project staff have held meetings with a number of other organizations in 1992 in order to ensure the optimum collaboration between this and other related projects. In particular, meetings have been held with the following:

(a) Professor A. Young, Principal Research Scientist at the International Council for Research in Agroforestry.

(b) Patrick Evans, FAO Officer on a Dutch Government Agroforestry Development Project (a part of the Jamaican National Forestry Action Plan). To date, this Dutch project has been located in central Jamaica, however it is now to be extended into the Blue Mountain region in collaboration with our ODA project.

(c) Robert Kerr, Director, Blue Mountains and John Crow Mountains National Park. There is close collaboration between project staff and the staff of the National Park. The project is making a particular input into the development of buffer zone management for the National Park.

(d) Dr Duncan McGregor, Lecturer, Royal Holloway College, London.

Extension activities

Project staff have engaged in a number of extension activities in Jamaica throughout the year. Further details are given at the end of the report. This work will be further assisted by a BSc dissertation project that is currently being carried out by N Tanner of the University of Wales, Bangor. He is carrying out a study of the history of land-use in the Blue Mountains of Jamaica. Particular attention is being paid to the considerable agriculture and forestry research and extension activities that have been carried out over the past 120 years and which are well documented in the bulletins of the Jamaican Departments of Agriculture and Forestry. This study should provide a valuable historical context for current and planned future extension initiatives. There has already been a long history of trial and error in extension in this region and it is important to learn from past experience rather than repeating mistakes that have already been made.

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Appendix 1

Water Samples:

- Dissolved (K, Ca, PO_4-P, NO_3-N, NH_4-N, Organic-C)
- Total (P (Organic-N + NH_4-N)N)

1. Runoff: 16 plots x 3 gerlach troughs (bulked) x 12 occasions (max.)
   = 192 samples (Aug. 1992 - Sept. 1993)

2. Throughfall: 16 plots x 5 collectors (bulked) x 12 occasions (max.)
   = 192 samples (Aug. 1992 - Sept. 1993)

3. Rainfall: 4 samples x 3 occasions (max.)
   = 12 samples (Aug. 1992 - Sept. 1993)

Soil Samples:

- Stone content
- Particle size analysis
- Organic matter content
- Bulk density
- pH
- Total N. P. K. Ca. Mg.
- Available (Bray's) P
- Exchangeable K. Ca. Mg and Al

1. Pre-treatment analysis: 16 plots x 3 samples
   = 48 samples (September 1992)

2. Post-treatment analysis: 16 plots x 3 samples (6 from *Calliandra* plots)
   = 60 samples (September 1993)

3. Runoff sediments: 16 plots x 3 troughs (bulked) x 12 occasions (max.)
   - Stone content
   - Organic matter content
   - Total N. P. K. Ca. Mg.
   = 192 samples (Aug. 1992 - Sept. 1993)

Litter Samples:

- Total N. C

1. Decomposition study: 16 plots x 5 reps. (bulked) x 3 occasions
   = 48 samples (February. June and Sept. 1993)

3.2. The effects of forest clearance on soil conservation and the investigation of a potential agroforestry system for more sustainable agriculture in the Blue Mountains of Jamaica

Paper presented at the Institute of British Geographers Inaugural British-Caribbean Seminar. University of the West Indies, Mona, Kingston, Jamaica, 17-21 August, 1992.

M A McDonald, J R Healey & P V Devi Prasad

Summary

This ODA-funded project is designed to study the effects of forest clearance on site fertility. The rates of soil erosion after forest clearance and conversion to agriculture (including a potential agroforestry system) are being measured. The effects of the different vegetation types on water balance are being assessed by comparing net precipitation and run-off. Inputs of plant litter (quality and quantity), rates of litter decomposition rates, and quantities of below-ground biomass are being estimated and related to the nutrient capital of the sites.

The treatments are:

1. Secondary forest
2. Forest area cleared, burned and subsequently maintained weed-free
3. Forest area cleared, burned and planted with agricultural crops
4. Forest area cleared, burned, planted with agricultural crops and intercropped with *Calliandra calothyrsus* hedges.

Although only one tree species is being examined in the main trial, additional plots have been established to compare the relative growth rates and coppicing ability of *Acacia mearnsii*, *Pittosporum undulatum* and *Clethra occidentalis*.

The treatments have been imposed, and monitoring will take place until October, 1993, with further measures of productivity made in April, 1994.

3.3. A study of soil erosion and fertility under different land use types in the Blue Mountains of Jamaica

BSc dissertation, University of Wales, Bangor, pp 115

M Aldrich

A field-study of soil erosion and fertility under different land-use types was carried out in the Green River Valley, a part of the upper Yallahs Valley catchment in the Blue Mountains of Jamaica. An initial visual survey of land use in the area, combined with discussion with local farmers, helped to highlight the role of the loss of permanent vegetation cover in the process of land degradation.

Sites were selected on hill-slopes which were subject to a number of land uses:
- Undisturbed forest
- Disturbed secondary forest
- Grassland
- Recently burnt grassland (an experimental treatment)
- Crop agriculture (escallion, *Allium fistulosum*).

Experimental work carried out as follows:
- Assessment of soil surface exposure,
- Measurement of surface soil erosion using erosion pins.
- Physical and chemical analyses of surface soil samples.

The results of the studies of soil surface exposure and soil analyses showed some significant differences between the different land-uses. The crop agriculture had very high levels of soil surface exposure (95%). The soil surface exposure of the grassland was increased from 20% to 85% by burning. The forest soils had a higher total percentage nitrogen content than all the soils from the non-forest areas. In addition, the humic component of the forest soils had significantly higher percentage moisture, and sodium and magnesium concentrations than the crop agriculture soil. The percentage clay content of the grassland soils was higher than that of the forest soils.

The results from erosion pins proved inconclusive. However, evidence was found that the presence of soil organic matter and vegetation cover are of major importance in soil conservation.

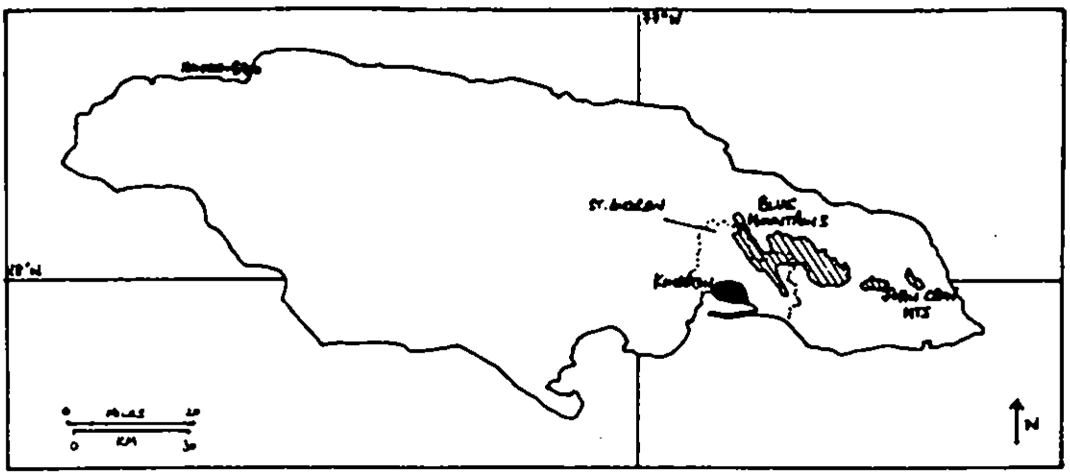
From the results of this study, recommendations for further experimental work are made, along with suggestions of how current land management practices might be improved. Particular recommendations are made for the increased use of: intercropping, mulching, vegetation barriers, tree planting and the control of burning.

A more detailed description of this work was written as an article, entitled "Land Use in the Blue Mountains of Jamaica", in a professional newsletter (below).

Association of Professional Foresters,
Newsletter, September 1992, 54 - 62

LAND USE IN THE BLUE MOUNTAINS OF JAMAICA

by Mark Aldrich



Source: Clarke 1974

FIGURE 1. OUTLINE MAP OF JAMAICA SHOWING THE LOCATION OF THE BLUE MOUNTAINS - the contour is at 925m (3000ft).

In July of last year (1991) I travelled to Jamaica to carry out research work for my BSc Agroforestry (Honours) dissertation, '*A study of soil erosion and fertility under different land use types in the Blue Mountains of Jamaica*'. The work was also designed as a pilot study for an Overseas Development Administration funded research project (R4611), which is investigating the catchment protection role of Jamaican forests and the sustainability of forest and non-forest land uses.

INTRODUCTION

The Blue Mountains provide a spectacular backdrop to the city of Kingston, capital of Jamaica. However, as in many other mountainous regions of the world, pressure on the land as a resource for use by man has resulted in all but the highest slopes being cleared of natural forest cover.

There has been a large population living in the area for the past 300 years - 30% of the country's total population (2.5 million) is located in the parish of St. Andrew (Figure 1). Many were slaves working on high altitude coffee plantations, but following emancipation in the mid 19th Century a large number turned to small scale farming. As a result a large proportion of the steep slopes on the southern side of the main ridge are already under settlement and cultivation. This is despite the fact that a large proportion of land in the Blue Mountains is comprised of slopes in excess of 25°. Traditional land classification systems recommended that all steep land should remain under forest cover. However it is economically, socially and politically unacceptable to require that these should be abandoned.

The removal of permanent vegetation cover has led to very high rates of soil erosion. There have been a number of reports in recent years describing the problems of land degradation in the Blue Mountains. Particular concern has been expressed over the effects of deforestation and subsequent use of inappropriate land management techniques by small scale farmers, which have prevented the development of a sustainable local agricultural economy. In addition, soil erosion and siltation have led to major problems in the maintenance of a regular, high quality supply of water for domestic and industrial use in Kingston and farmers in the lower flood plains, and severely damaged coral reefs and valuable marine fisheries.

Consequently there is an urgent need to control deforestation and develop land use techniques, particularly those involved with cultivation of cash crops, which are more environmentally acceptable.

THE STUDY AREA

The Blue Mountains are found at the eastern end of the island of Jamaica, with the highest, Blue Mountain Peak at 2256 m. The study area was located to the south-west of the main ridge in the watersheds of the Green River and Clyde River, both headwater tributaries of the Yallahs River

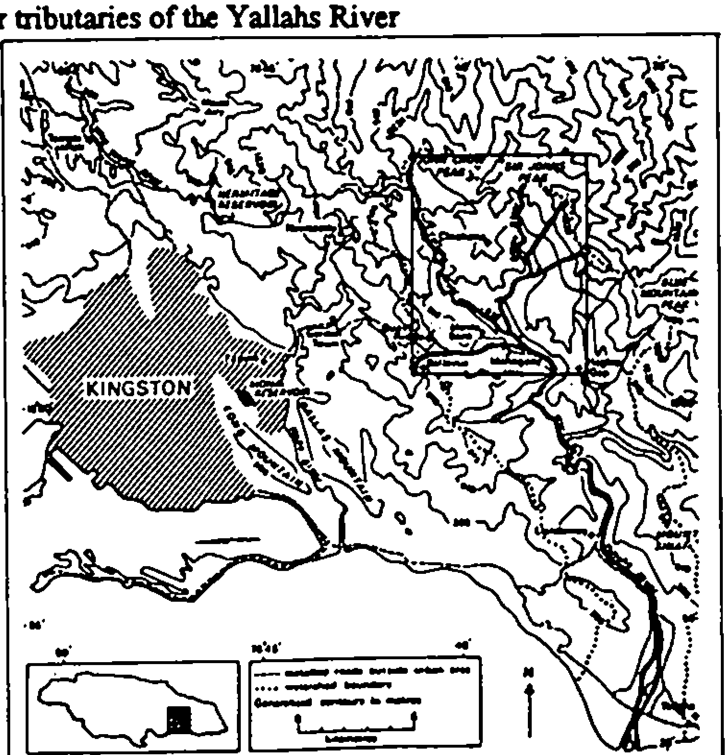
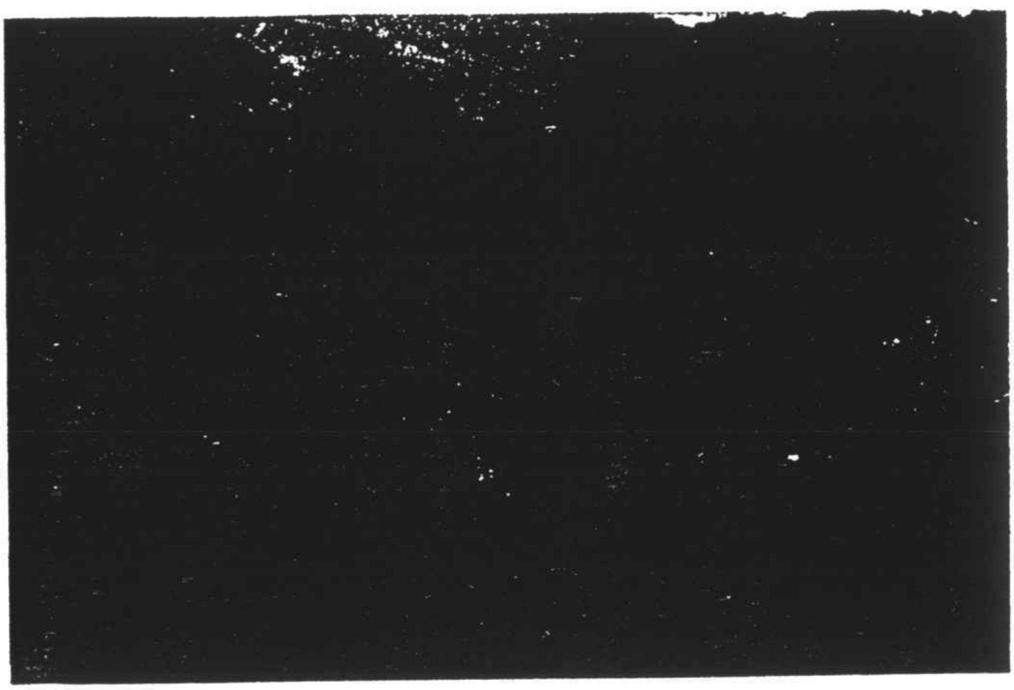


FIGURE 2: THE YALLAHS BASIN AND KINGSTON (Source: Barker and McGregor 1988)

The Yallahs Basin has a high natural propensity for erosive activity since it is part of a geologically recent tropical mountain range, which is characterised topographically by steep slopes and highly dissected terrain with sharp ridges and gullies (Fig. 3). Soils are predominately lithosols, with ultisols under the forest in some areas. They are in a state of continual breakdown and removal due to rapid weathering and slopes in excess of 30° (75% of the area comprises land sloping at more than 30°), and are acidic sandy/clay loams of low chemical fertility usually less than 1m deep, with a stony subsoil.

Figure 3: THE GREEN RIVER VALLEY LOOKING SOUTHWARD FROM THE MAIN RIDGE OF THE BLUE MOUNTAIN



Jamaica has a maritime tropical climate, distinguished by warm and equable average temperatures throughout the year, relatively high rainfall, and prevailing winds from the north-east. The island experiences two wet seasons with the highest rainfall usually between mid-September and January, with a small peak in May. However, both locally and island wide, irregularities in total annual rainfall and its distribution throughout the year are becoming increasingly common. This is believed to be leading to increased incidence of drought - a suggestion confirmed by several local farmers. Convectional storms result in very heavy downpours and these, combined with the risk of hurricanes (most recently Hurricane Gilbert in September 1988), only serve to aggravate the problem of erosion on inherently unstable terrain.

LAND USE HISTORY

The watershed of the Yallahs River remained under natural forest cover until British occupation in the mid 18th Century. The process of land degradation began as a result of extensive coffee production, which involved clearance of forest from large areas for the establishment of coffee plantations and subsistence cultivation of food by plantation slaves. Techniques of cultivation were poor, with little use of shade trees and clean weeding between bushes leaving large areas of topsoil exposed and thus susceptible to erosion as a result of heavy rainfall. In the late 19th/early 20th Century the coffee plantation system was gradually abandoned. A decline in Jamaica's reputation as a high quality producer, combined with a generally depressed post-Second World War coffee market, led to an acceleration in the switch to banana production. Much of the land has reverted to ruinate or scrub land, which today forms the secondary forest cover which is limited only to the higher slopes with reconverted land at lower altitudes.

In the 1840s the rise of peasant agriculture in the post emancipation period continued the process of soil erosion and land degradation. Production primarily involved the cultivation of subsistence crops, eg. sweet potato *(Ipomoea batatas)* and banana *(Musa cvs)*, with any surplus sold at markets in Kingston. Since the end of the 19th Century there has been a steady increase in cash crop production in response to increased demand for fresh vegetables and fruit from the growing population in and around Kingston. However the cultivation and marketing of produce was poorly organised and lacked structure until the introduction of the Yallahs Valley Land Authority (YVLA) in 1951.

One major improvement was the introduction of physical soil conservation structures on which the short season market crops could be grown more sustainably. This was the first time such measures had been used in the area, and during the life of the YVLA many kilometres of contour barriers and terraces were constructed with the aim of reducing erosion. They were however expensive to construct and required regular maintenance, and with the demise of the YVLA in the late 1960s the employment of soil conservation measures ceased almost immediately.

PRESENT SITUATION - PERSONAL OBSERVATIONS

Today, little seems to have changed since the late 1960s. In the Green River Valley, a large number of smallholders farm one or more small fields (in 1982, 53% farmed less than 0.4ha, dotted around the valley. To many this represents virtually their only income, and so they continue to grow market crops year round, for example escallion *(Allium fistulosum)*, thyme *(Thymus vulgaris)* and tomato *(Lycopersicon esculentum)* for sale at weekly markets in either downtown Kingston, or Papine, a small commercial centre on the eastern edge of the city with a significant expatriate clientele. There is little evidence of soil conservation measures, apart from a few basic attempts using bamboo or wooden poles (Fig. 4), and the remains of terraces built around the former YVLA HQ at Strawberry Hill are still clearly visible (Fig . 5).

FIGURE 4: Basic soil conservation measures using bamboo or wooden poles

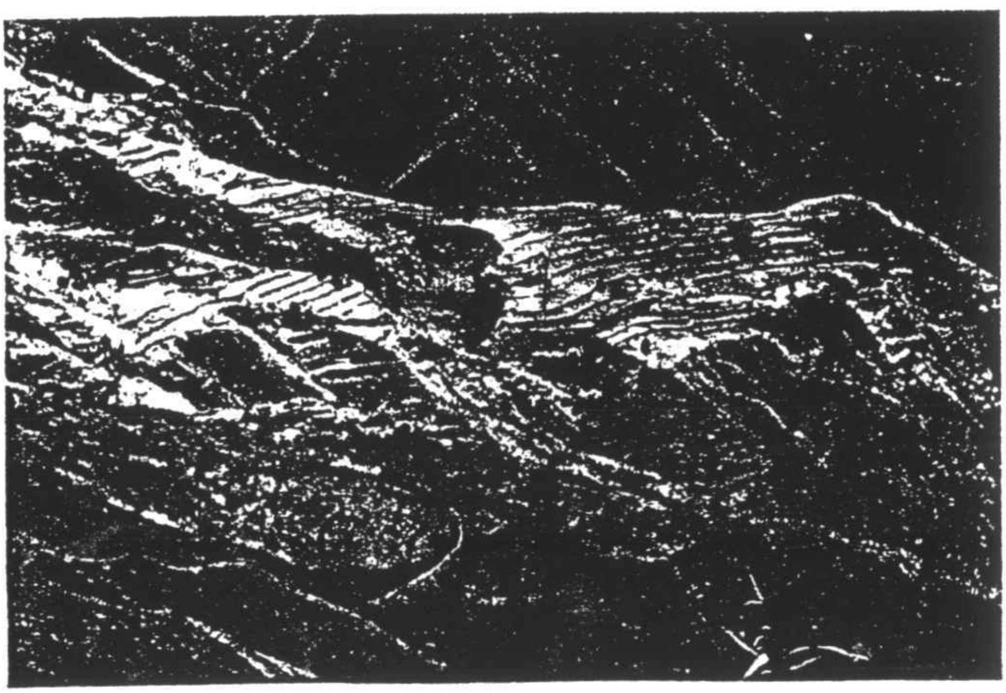
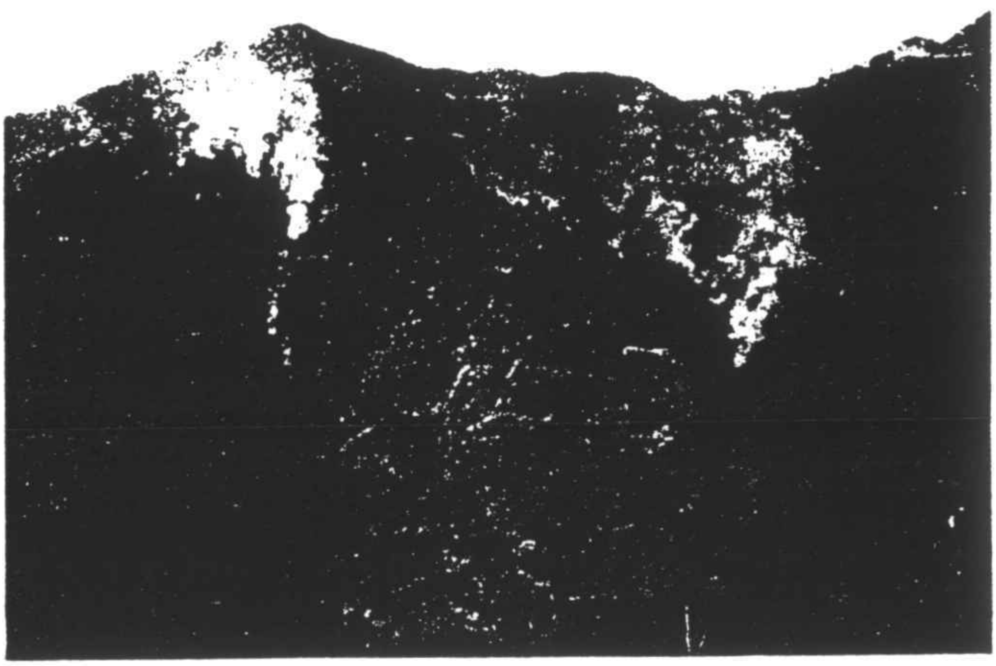


FIGURE 5: The remnants of terraces constructed during the time of the Yallahs Valley Land Authority

The soil erosion potential seemed considerable on the steep slopes, often in excess of 35°, particularly under the agricultural crops which were kept weed free. The situation was made worse by the widespread use of uncontrolled burning to clear undergrowth. Fires were a major factor - during the field work period of this report, July to September 1991, fires were visible almost every day, some spreading wildly out of control up hillsides, fuelled by tinder dry undergrowth resulting from drought conditions for several months, and dry north-eastern breezes channelled up the valleys (FIGURE. 6 below shows fire spreading out of control through tinder dry undergrowth.)



Coffee cultivation was still very much in evidence, in both government and privately owned plantations, and in small patches on smallholdings. Many of the plantations had been decimated by Hurricane Gilbert, with considerable losses of mature bushes. However, even in areas where a high density of mature bushes remained (spacing c. 8m²), the ground cover was poor with little use of shade trees or retention of other ground cover. Since Hurricane Gilbert when there was widespread destruction of planted coniferous forest plantations - mainly Caribbean pine *(Pinus caribbea)* - there has been very little official Forest Department activity in the area, with virtually no replanting being carried out. Large areas of windblown plantation forest were being burned and cleared for coffee cultivation, whilst a small number of private individuals had obtained legal concessions to remove dead and fallen timber. Many of the few remaining live pine trees of reasonable quality were being illegally felled and planked, and sold on the black market. The edges of natural forest cover are visibly moving up the hillsides as small pockets are cleared for cultivation, or trees cut for charcoal production and fuelwood.

A recent development of great potential influence on the situation has been the designation of the Blue Mountains/John Crow Mountains as a National Park. The park boundary runs through the Green River Valley and as a result the area will be of particular importance with respect to buffer zone management.

CONCLUSIONS

From this initial survey work, I was able to highlight the loss of permanent vegetation cover as a major cause of soil erosion. I found the construction of a causal diagram very helpful in identifying the contributory factors (Fig. 7 below.)

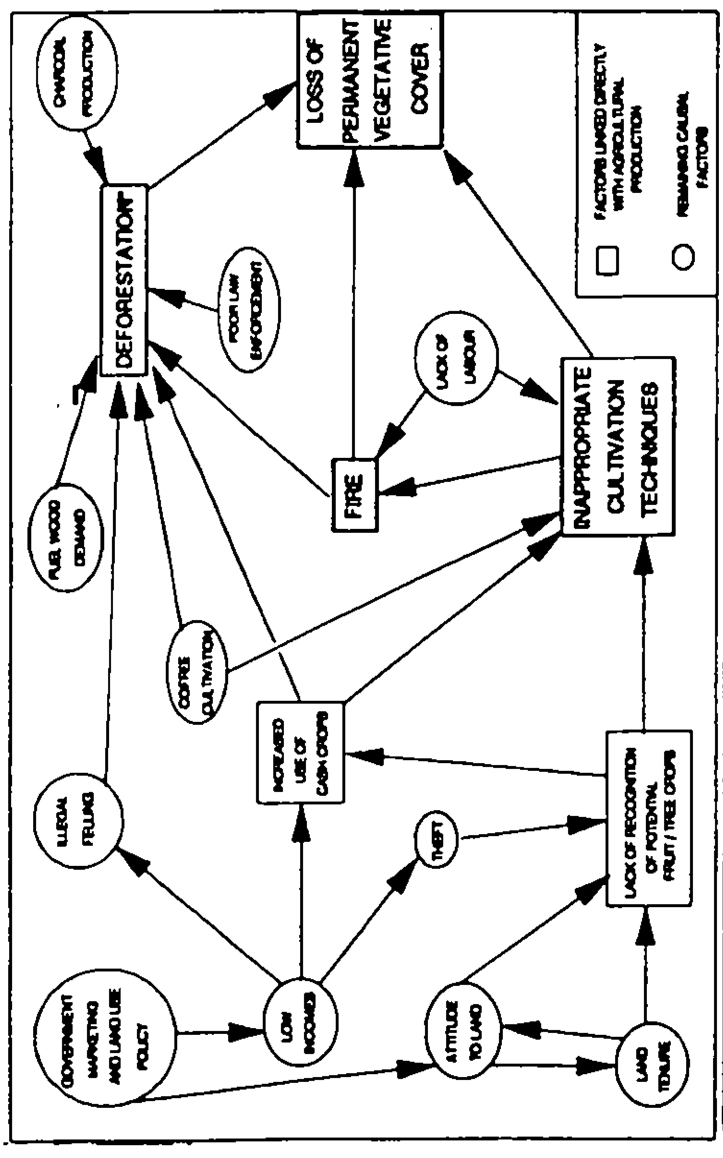


FIGURE 7: CHANGES IN VEGETATION COVER - A CAUSAL DIAGRAM

The diagram shows that a number of factors are directly linked to methods of agricultural production and as a result have greater potential for improvement by changes in management techniques. The remaining factors, whilst no less important, have more deep rooted origins and rely on a more complex series of measures, including changes in government policy and improvements in social structure before changes can be initiated. It may prove difficult to affect such changes at all in some cases, whilst others may only take place over a considerable timescale.

RECOMMENDATIONS

Traditionally, selection of soil conservation methods was based on the application of a land capability classification, where appropriate use of terraces, contour cultivation or drains and other physical structures was recommended according to soil depth and slope to reduce the steepness and length of slopes. Such a classification has been carried out in Jamaica. Under this scheme land steeper than 25° was considered suitable only for food and fruit trees where the soil was deep enough, otherwise a complete forest cover should be maintained. However as a result of increasing pressure on land, these steep slopes are already under cultivation.

The construction of terraces and extensive drainage systems is often not practical on small patches of very steep individually owned land, which in many cases are inaccessible to machinery. In addition small farmers are unlikely to employ these methods as they require high input costs and labour requirements for construction and maintenance. Consequently there is a need for simple, low cost techniques requiring little maintenance which are suitable for poor farmers.

As a result of further surveys and more detailed experimental work (not described in this report), I was able to suggest the following improvements to current land management practices.

a) Intercropping

One of the simplest and most effective methods of reducing erosion is by providing increased ground cover. This can be achieved by intercropping a mixture of agricultural crops both in a spatial and temporal sense, and would represent a significant improvement over clean weeded escallion, for example. The use of a leguminous crop may also provide benefits in terms of nitrogen fixation. Potential leguminous crops for use in this area would include 'gungo pea' = pigeon pea *(Cajanus cajan)* or groundnut *(Arachis hypogaea)*. Red beans = kidney beans (*Phaseolus vulgaris*) are already cultivated, but like escallion, as a monoculture.

b) Use of mulch

A complementary method of erosion control is the use of mulch. The retention of weeds and crop residues or use of tree prunings which are spread over the cropped area will protect the soil surface. It will also improve water infiltration, supply an additional source of organic matter with its associated benefits, and as it decomposes it releases a supply of nutrients to the soil, thus helping to maintain fertility

c) Vegetative barriers

Surface soil erosion from runoff is significantly reduced by planting of vegetative barriers along the contour which serve to reduce the length of slope. Barriers of trees, shrubs or hedgerows for erosion control must be closely spaced (4-5m apart), and to be acceptable to farmers they must be narrow, productive or both. These barriers are permeable, meaning that excess runoff in storm events will pass through, causing relatively little damage. If damaged they are relatively easily replaced. Crops are grown between the barriers, which are kept pruned to avoid shading. These prunings may be used as mulch (or livestock fodder) spread over the crop area. From observations made during this study, barriers may have another function in this area. Progressive development of terraces is possible, if initial bamboo or wooden barriers are supplemented by planting of hedgerows, leading to accumulation of eroded soil upslope of barriers and hedges, and stabilisation of the risers by stem and roots.The use of tree species confers many benefits - they may be productive in terms of prunings or fruit, their roots may improve soil structure and draw nutrients and water up from deeper in the soil. Choice of nitrogen fixing leguminous species may also improve fertility.

d) Control of burning

The use of the recommendations given above is pointless if the widespread use of uncontrolled burning continues. Its use must be discouraged, although it has proved impossible to enforce a prohibitive policy. Experience from the work of the YVLA found that an educational approach relying on persuasion rather than compulsion was more suitable. Demonstrations of the benefits of cutting of vegetation and its subsequent use for mulch, or the use of controlled burning techniques are more likely to have an effect. Indeed many of the farmers are already well aware of the dangers of fire, but are powerless to prevent its use by others.

This summer (1992) I shall return to Jamaica to work as a research assistant on ODA project R4611. The work will involve laying out experimental plots planted with escallion, both with and without hedgerow barriers of *Calliandra calothyrsus*, a leguminous tree species with multi-purpose potential which grows in the area. These plots will be used to compare rates of surface runoff and soil erosion. It is also hoped that they will serve as demonstration plots for the local farmers, many of whom have already expressed considerable interest.

ACKNOWLEDGEMENT

I would like to take this opportunity to thank the APF for their grant from the Education Fund, which helped to cover the costs of my undergraduate project work.

3.5. A study of soils from the Cinchona area of the Blue Mountains, Jamaica

BSc dissertation, University of Newcastle, pp 93

V Scott

Field work was carried out on steeply sloping valley sides in the Cinchona area of the Blue Mountains, Jamaica.

Soil pits were dug at eight sites under three different vegetation types and the soil profiles were examined: forest (three sites), coffee plantation (three sites) and grassland (two sites).

Laboratory analyses were carried out to determine any differences between the soils and to examine the effects on the profiles of removal of forest vegetation. The soils were classified using the US soil taxonomy system.

The soils formed under forest vegetation were classified as ultisols. The forest profiles were more strongly developed and deeper than those formed on the coffee sites. Since not all the coffee profiles showed evidence of clay movement and accumulation within the profile, they were classified as weakly developed ultisols or strongly developed inceptisols.

The grassland soils were all very homogeneous with large stones present throughout the profiles. These were classified as lithosolic weakly-developed soils due to their depth. However, it is thought that these profiles were dug on sites onto which material had been deposited by a landslide.

Because of the similarities in their climate and topography, it was assumed that all the sites had ultisols developed on them before forest clearance.

The coffee and grassland soils were both shallower, had lower organic matter contents and lower cation exchange capacity values than the forest soils.

It was concluded that the removal of forest vegetation was causing degradation of the soils' mineral nutrient content and structure and exposing them to severe erosion. The implications of this in terms of land use and the socio-economic factors related to the issue of deforestation are briefly discussed.

Chapter 4

Assessment of the impact of severe disturbance on the natural forests of the Jamaican Blue Mountains and their subsequent recovery

4.1. Predictability of natural regeneration in a montane tropical forest

Paper presented at a UNESCO conference on "The ecology of tropical forest tree seedlings", University of Aberdeen, 31 August - 5 September 1992.

J R Healey

Summary

The evidence provided by data from a Jamaican montane rain forest for the predictability of natural regeneration following disturbance in tropical forests is reviewed.

No simple rules could predict accurately which species and which cohorts would dominate. Nonetheless, seedling density immediately following the first phase of post-disturbance seed germination and recruitment rate during this period were found to have the best correlation with subsequent species dominance.

The potential value of transition probability matrix models of population biology data in assessing the course of regeneration was investigated. The relative performance of the species predicted by the models was poorly correlated with observed results. Nonetheless, sensitivity analyses of the models indicated the importance of the rate of survival of the advance regeneration during and after gap creation in controlling the subsequent number of individuals of the dominant species in the tallest sapling size class.

Current analyses are concentrating on the factors controlling the growth and survival rates of seedlings and the extent to which they do form a fixed hierarchy. Future research should concentrate on the relative importance and interactions of size, age and environment in controlling the success of individuals and the factors controlling the size reached by individuals of different species in the understorey seedling bank.

Introduction

The existing approaches to an ecological understanding of tree seedling ecology and forest dynamics are reviewed in order to determine what, ultimately, they have to offer the forester. One of the greatest contributions that ecologists can make to the successful management of tropical forests may be an improvement in the capacity to predict future stand composition under different environmental and management conditions. There is a general need to investigate mechanisms rather than just end results or isolated phenomena.

There is also a clear need to decide what modelling framework will be used within which to interpret data in order to determine the relative contribution of different processes on the course of regeneration. The capacity of any model for sensitivity analysis to assess the effects of changes in each of the variables is crucial. The successful extrapolation of results from one situation to another is very dependent on adequate quantitative characterisation of the "host" and "recipient" environments (including the range of vegetation dynamics and species auotoecologies that occur in each) as well as a suitable modelling framework.

The structure of research activities

A sequence of activities for tropical forest ecological research is recommended in which the first phase is quantitative observation, followed by the generation of broad hypotheses. These are then investigated by perturbation field experiments which generate narrow hypotheses (theoretical and applied). These can then be tested by more highly controlled experimentation and ecophysiological measurements.

Research into natural regeneration in Jamaican montane forests

Research in the montane tropical rainforests of the Blue Mountains of Jamaica has passed through these stages. The principal perturbation experiments have been the creation of experimental gaps imitating the disturbance caused by hurricanes. It was found that gap creation did not lead to an increase in the relative dominance of the most dominant species. Rather, dominance has become spread more widely between a larger number of species. Nonetheless, by four years after gap creation the top of the species dominance hierarchy has stabilized. Therefore, further analysis was carried out to determine which species had become established as the dominants and why (in terms of their regeneration ecology and population biology).

It was found that the dominant species were a wide mixture of those with "light demanding" and "shade tolerant" regeneration ecologies. In terms of age, dominance of the regenerating vegetation in the gaps was shared between individuals from three different cohorts (advance regeneration present before gap creation, seedlings recruited in the first nine months after gap creation, and seedlings recruited between 9 and 18 months). However, the rate of recruitment of seedlings dropped off sharply after 18 months. Therefore, there was an 18 month "window of opportunity" after gap creation for the recruitment of pioneer and other light-demanding species. By 52 months, conditions for germination in the gaps had reverted to those of the forest understorey. The rate of survival of the advance regeneration was much greater than, and was diverging from, that of the new recruits. However, the mean absolute growth rate of the surviving 0-9 month recruits was greater than that of the advance regeneration.

Therefore, by 52 months after gap creation, it has not been possible to produce any simple rules that would have predicted accurately which species and which cohorts would dominate in gaps of the sort created in this experiment. A simple index of the "shade tolerance" of each species or its occurrence in particular cohorts had not accurately predicted its regeneration success.

More detailed analysis tested which "state variables" before and soon after gap creation were best correlated with the subsequent dominance of each species at 52 months, and the increase in the accuracy of the correlations with time. At 0 and 9 months after gap creation, density had the strongest correlations with subsequent dominance (the r^2 values were 32% and 65% respectively). By 18 months, the r^2 value for density had fallen slightly to 62% and dominance itself (as estimated from the sum of seedling heights) had the best correlation (r^2=68%). Therefore, initially, the density of seedlings of each species was the index which was best correlated with their subsequent success. However, the closeness of the correlation was greatly increased nine months after gap creation, after the first flush of seedling recruitment in open conditions.

Further analyses were used to investigate which "rate" variables of the performance of each species were most closely correlated with their subsequent dominance at 52 months. Of the nine rate variables tested only two (recruitment between 0 and 18 months after gap creation, and growth rate of the advance regeneration between 0 and 18 months) were significantly correlated with subsequent dominance. The rate of recruitment had the strongest correlation, but this only explained 49% of the variation in species dominance in a linear regression and the r^2 values for all the other comparisons were less than 10%.

Clearly, such separate testing of individual pairs of variables is a naive approach. The next analytical approach should be step-wise multiple regression and the use of generalized linear models. However, transition probability matrix models were considered to be the most potentially useful general modelling approach that would allow the non-independent population biology data of the rates of recruitment, survival and growth of each species to be synthesized and their combined effects determined.

Transition probability matrix models

Data of four species in the experimental gaps in the Jamaican montane forests were used to investigate the potential value of transition probability matrix models to predict future regeneration success. A poor correlation was found between observed and expected (model predicted) results. This can be accounted for by the system failing to match two of the assumptions required for accuracy: (a) the transition probabilities between size classes did not remain constant with time, because their populations did not have a stable age distribution; (b) the transition probabilities do not describe a first order Markov process, i.e. the previous performance of an individual does influence its subsequent performance.

Nonetheless, transition probability matrix models may still give the best summary of current trends in regeneration. They are valuable for contrasting the processes occurring in different time periods and in different environments. Their capacity for sensitivity analysis is valuable for directing future research. This should provide a clear indication of which stage (size or age) was most limiting and so should be the primary focus of observations in further experiments, e.g. a more applied study to determine the influence of silvicultural treatments on future tree species composition.

The potential value of sensitivity analyses were investigated with the Jamaican data. The relative importance of seed input, survivorship, transition probabilities and initial size structure in determining the rate of recruitment into the largest size classes were tested. This showed that the subsequent number of individuals of the dominant species in the tallest sapling size class were influenced primarily by the rate of survival of the advance regeneration during and after gap creation; shortage of propagules was not a limiting factor. This result needs to be contrasted with that of the correlation found between the dominance of species and their earlier rates of recruitment from propagules. Nonetheless, this sensitivity analysis result implies that, were production forestry to be practised in a forest of this type, silvicultural treatments should concentrate on minimising damage to the largest individuals in the advance regeneration and ensuring their subsequent release.

Current analysis of the factors controlling regeneration success

Current analyses are concentrating on an assessment of the factors that could be controlling the relative regeneration success of different species and the extent to which the species do form a fixed hierarchy. The relative importance in controlling the subsequent performance of individual seedlings of their: species, previous height, previous growth rate, local seedling density (conspecific and other species) and microsite environment is being assessed. The extent to which species differ in their response to changes in inter- and intra-specific density is of great importance because of its potential role in the maintenance of species diversity in the community (Janzen-Connell model). It is particularly important to determine the effects of spatial scale on these processes. Over what area does a "competitive" hierarchy of individuals remain constant? What is the relationship between the size of a sample area and the correlation between individual performance and seedling density within the sample area?

Future research

There is a need to determine the difference in environmental requirements of the species at different stages of their regeneration cycle. It would be valuable to know whether the different stages are best defined by the size of the individual or its age, and the extent to which the individual's environmental requirements are determined by the conditions in which it became established. Of particular importance for the recovery of many tropical forests from disturbance is the relative performance of seedlings and resprouts from damaged trees.

The value of studying the factors that control the size reached by individuals of different species in the understorey seedling bank of advance regeneration is indicated by the evidence that the tallest individuals from the advance regeneration that survive gap creation have the greatest probability of dominating the subsequent regeneration.

Modern portable infra-red gas analysers enable field measurements to be made of the photosynthetic performance of different species. However, it is very important that such studies are accompanied by measurements of the morphology and architecture of the species (both mean values and variation between and within age classes). The comparative performance of seedlings and resprouts should be assessed both in terms of ecophysiology and growth analysis. Other areas of importance are the leaf demography and level of mycorrhizal infection of the species. It is important not only to assess the overall difference between species in these parameters, but also the extent to which the success of individuals is associated with particular character traits which may have potential value to the forester in regeneration sampling.

Two MSc projects are currently under way which involve research relevant to the theme of this paper. In one the correlations of seedling growth and survivorship in the Jamaican gap plots with previous seedling height and growth rate, and local seedling density are being assessed (G. Akogo Muogo, MSc University of Wales, Bangor). In the other, an assessment is being made of the rate of regrowth and biomass recovery of the natural forest following clear cutting in another plot (K. Keapoletswe, MSc, University of Wales, Bangor).

4.2. The role of vegetative resprouting in the maintenance of diversity of tree species in a Jamaican montane forest

Paper to be submitted to the *Journal of Ecology*, pp 52

P J Bellingham, E V J Tanner & J R Healey

The numbers and vertical distribution of epicormic resprouts were measured on the trunks and major branches of trees ≥3 cm dbh in montane forests in the Blue Mountains after a major hurricane. Stems assessed included those broken, uprooted or completely defoliated during the hurricane. Growth rates of some resprouts were measured before and after the hurricane. Survivorship among resprouting stems was recorded in two separate inventories, and changes in the numbers of resprouts and their vertical distribution were measured.

Most stems (61.2% of 4949 stems) and most species (39 of 42 common species) had resprouts. However, there was a great range in the proportion of resprouting stems among different species (0-100%). Broken stems resprouted proportionately more than intact stems, and completely defoliated stems resprouted proportionately more than those not completely defoliated, but there was no clear trend among uprooted stems.

Some species had resprouts prior to the hurricane, and these resprouts grew more rapidly in height after the hurricane.

Some species produced resprouts predominantly from the basal parts of trunks, while others produced resprouts predominantly from upper parts of trunks. Some species had relatively few resprouts, while others produced great numbers. The different modes of resprouting of different species can be related to their regeneration requirements.

Short-term survivorship of resprouting stems was high, and it is likely that long-term recovery of these forests from the hurricane will proceed at least in part by resprouting stems. There was high survivorship of resprouting stems of species which seldom regenerate by seed. We propose that resprouting is a means by which species diversity is maintained in these forests.

4.3. Coppicing and resprouting in montane tropical rainforests in Jamaica

Msc dissertation, University of Wales, Bangor, pp 118

M R S Suwal

Two aspects of the vegetative regrowth of trees (coppicing from cut stumps and resprouting from the trunks of naturally damaged trees) were investigated in Jamaican montane tropical rain forests. Coppicing was studied in two plots, one on a Mor Ridge site and the other on a well-developed Mull Ridge (wdMR) site, in which all the trees had been cut at ground level by Tanner for biomass measurement 12 and 10 years respectively before this study. In the study, the stump of every cut tree was relocated and all sprouts were measured in terms of height, diameter and crown volume.

Resprouting was observed in more detail over a shorter time period in three wdMR forest plots in which all the trees taller than 5 m had been pulled down to ground level in order to imitate the natural impact of a severe hurricane. A few sprouts existed on the trees before the disturbance, and a sample of these were labelled. The damage to the trees led to considerable production of new sprouts and a sample of up to three sprouts per tree were measured and labelled 9 months after disturbance. These sprouts were re-recorded (survivorship and height) 18, 27 (in 1 plot) and 52 months after disturbance. Additional sprouts were labelled to replace those that had died.

In the Mor Ridge plot 38 out of 51 stumps (75%) and 10 out of 12 species coppiced. There was an average of 4.3 shoots per stump. In this plot before felling 25% of trees and 50% of species had multiple trunks indicating past vegetative regrowth. The rate of coppicing was lower in the wdMR forest plot: 30 of the 64 stumps (47%) had coppice shoots but for 11 of these all the shoots were dead: there was an average of 3.6 live + dead shoots per stool. Nonetheless, 16 of the 19 species had coppiced. Before felling only 6.8% of trees and 21% of species in this plot had multiple trunks, indicting a lower rate of past vegetative regrowth than in the Mor Ridge forest.

In the Mor Ridge plot no significant relationship was found between the basal area of the stump and incidence of sprouting. However, there was significant correlation between trunk size and sprout number, tallest sprout height and sprout crown volume. In the wdMR plot the incidence of sprouting was significantly greater for larger trees. There were clear differences between the species in the Mor Ridge plot, *Cyrilla racemiflora* and *Ilex macfadyenii* produced a large number of medium sized "bushy" sprouts, whereas *Persea alpigena* and *Alchornea latifolia* produced a smaller number of taller sprouts.

In the naturally damaged wdMR plots, 107 of the 206 saplings and trees (individuals that had been taller than 3 m) (52%) produced trunk sprouts. However, only 5 of the 32 species represented by at least 2 individuals failed to produce any sprouts. For those species with at least four individuals, the percentage which sprouted covered the full range from 0%-88%. There was no simple relationship between tree size and incidence of sprouting: the trees which had suffered breakage (but not complete severance) of their trunks or breakage in their crowns had the highest percentage of individuals sprouting (78%). The lowest percentages of individuals sprouting were amongst those that had been uprooted (32%) or had suffered no major physical damage (21%).

Mean and maximum sprout height growth rates were calculated over 9-18 and 18-52 month time periods for the trees of the six most abundant species: they differed significantly at the P=0.001 level; *Hedyosmum arborescens* had the highest rates of sprout growth and *Podocarpus urbanii* the lowest. Five of these species had a lower growth rate of sprouts between 18-52 months than between 9-18 months.

The species that had coppiced and resprouted most vigorously occupied a much greater proportion of the basal area of the Mor Ridge Forest (89%) than of the wdMR forests (31%). These species did tend to have a higher proportion of trees with multiple trunks, e.g. *V. meridionale*, *C. racemiflora*, *A. latifolia* and *H. arborescens*. In the Mor Ridge plot the biomass was dominated by the coppice shoots (e.g. they comprised 73% of stems taller than 4 m (though coppicing stumps comprised only 53% of separate individuals)). In the wdMR plots, seedlings were dominant over coppice/sprouting shoots. No clear negative correlation was found between species resprouting ability and their seedling regeneration ability. Some species with poor seedling regeneration showed some evidence of good resprouting, e.g. *V. meridionale*, *C. racemiflora* and *Meriania purpurea*, but others did not, e.g. *P. urbanii*, *Haenianthus incrassatus* and *Chaetocarpus globosus*. Several species showed a good ability to regenerate via both mechanisms, e.g. *Myrsine coriacea*, *Palicourea alpina* and *Alchornea latifolia*; however these species were not dominant in this forest.

4.4. The population structure and spatial distribution of tree species in a Jamaican montane tropical rainforest

MSc dissertation, University of Wales, Bangor, pp 74

G Y Gowae

In six non-contiguous 240 m^2 square plots in an area of Jamaican montane tropical rainforest all stems at least 3.2 cm in diameter at breast height (dbh) (trees) or 3 m in height (saplings) were recorded. The stems were identified to species and mapped accurately, their dbh and height were measured, and in one plot the size of their canopies was recorded. After plotting the species-area curve, projection to the asymptote indicated that the number of tree species in this particular 1 ha area of forest would be approximately 56 which is considerably less than the 143 species that have been recorded in the surrounding area of c. 10 ha.

The diameter and height-class distribution of the stems were clearly positive (having a reverse J-shaped decline in numbers with increase in size) in each of the six plots. The curves of heights of individual stems plotted sequentially were smooth for each of the six plots, providing clear evidence that there was no stratification of the canopy into any discrete layers. The relationship of height to diameter showed the expected curved shape with a gradual reduction in gradient. Nonetheless, over the size range of the majority of the trees (from 3 cm to 30 cm dbh) the relationship was approximately linear: the linear regression of height on diameter for all tree stems (which had a y axis intercept of 4.9 m height) had an r^2 value of 61% (the P value was less than 0.001). The mean height to diameter ratio was 80:1, however this ranged from 150:1 for stems of 3 cm dbh to 50:1 for trees of 30 cm dbh. The flattening of the curve for trees above 30 cm dbh indicated that, for canopy trees above approximately this diameter, further diameter increase was not matched by a proportionate increase in height. Emergent tree crowns above the main canopy height (16-18 m) were rare, a high proportion of the trees had narrow crowns and the density of trees whose crowns reached the canopy was high. All of these structural attributes of the forest are compatible with the hypothesis that the growth of individual trees and the stature of the forest as a whole is limited by strong winds. It is suggested that further research is carried out on the relationship between the wind-induced compactness of the canopy and the low overall rates of productivity of these forests.

Ten of the most abundant tree species were selected for more detailed study; in total they accounted for 58% of the trees and 61% of the total basal area in the plots and they were each represented by more than 20 stems. They ranged in maximum height from 7 m to 23 m, in maximum dbh from 10 cm to 64 cm, and in mean height:diameter ratio from 139:1 (*Eugenia virgultosa*, the thinnest) to 51:1 (*Cyathea pubescens*, the thickest).

The six plots were each divided into four quarter plots (24 in total) in order to examine the spatial distribution of trees and saplings (<3.2 cm dbh but >3 m height). The distributions of trees and of saplings of all species combined were found to be regular (over-dispersed); they differed significantly from random (Poisson). The same result was found for the trees of two sub-canopy species (*E. virgultosa* and *Dendropanax pendulus*) when they were tested individually. However, the saplings of these two species had a clumped distribution, as did both the trees and saplings of two other understorey species (*Hedyosmum arborescens* and *Psychotria corymbosa*), the trees of one canopy species (*Ilex harrisii*) and the saplings of another (*Bumelia montana*). The remaining five tree and one sapling distributions were all found not to differ significantly from random (Poisson).

Forty-five individual tests were made of the association between pairs of species in their distributions. Only two of these tests showed a significant result at the $P<0.05$ level (one was a positive association and the other was negative) which is remarkably close to the result that would have been predicted entirely by chance. This would indicate the absence of any true positive or negative associations between species which would be an interesting result. However, before any firm conclusions can be drawn, the power of the test which was used must be investigated. Furthermore, this result is entirely a facet of the scale of sub-plot size that was arbitrarily chosen, i.e. it reflects a very preliminary stage in the analysis and there would be value in investigating the effect of plot size on the results.

It is recommended that the next step in the analysis of the structure of the tree populations in these forests is, for each species, to plot the height and dbh of each individual and so define the range of sizes and shapes it occupies. The next step in the investigation of the spatial distribution of the trees should be nearest-neighbour analysis. Given the high density of stems, this would be feasible even for these small plots; it was found that only 15% of the trees were nearer to the plot edge than to another tree. The size of the individual stems should be considered in such analyses so that the interactions between mature (established) and immature individuals can be investigated. This will enable assessment of replacement probabilities between species and provide information of particular relevance to the development of selection silvicultural systems.

4.5. Biological distribution, endemism and regeneration biology in a Jamaican montane rainforest

BSc dissertation, University of Wales, Bangor, pp 64

R P Wood

Jamaica is an island of 10 830 km^2 which is quite isolated being 650 km from the nearest mainland (Honduras) and 150 km from the nearest other large island (Cuba). The published flora of Jamaica (Adams, 1972) was used as the principal source of information on the distribution of the tree species.

Adams (1972) recognized 2888 flowering plant species as occurring in Jamaica, of which 27% were thought to be endemic to the island. The size of the flora was increased to 3003 by Proctor (1982). A biogeographical analysis was carried out of the tree flora recorded above 4500 ft (1372 m) altitude. i.e. in the montane forests of the Blue Mountains. Adams recorded 99 species of trees as occurring above 4500 ft in altitude. As is often the case for island floras the species are widely distributed throughout different genera (69) and families (39). In addition, a further two species of gymnosperm trees from two families and 9 species of tree ferns (Proctor, 1985) have been recorded above an altitude of 4500 ft giving a total of 110 species that reach tree size.

The apparent level of endemicity is high: of the 110 species 52 (47%) are recorded as being endemic to Jamaica (a much higher figure than for the flora of the island as a whole) and ten of these (9% of the total) are endemic to the Blue Mountains region (the Parishes of Portland, St Thomas and St Andrew). Of the 58 species that have been recorded outside Jamaica, 22 are confined to the islands of the Greater Antilles and a further six are confined to the islands of the West Indies as a whole. Cuba is the island with the greatest number of tree species in common with the Blue Mountains above 4500 ft (41 species, 37%); 12 of the Blue Mountain species have also been recorded in the Sierra Maestra Mountains in Cuba (Borhidi, 1991). A further six of the species have been recorded in other montane forests in the Greater Antilles. Of the 30 continental species, 11 occur on the Central American mainland, 7 on the South American mainland and the remaining 12 species are found throughout the neotropics (two of these are regional montane specialists, and for another two Jamaica is their only location in the West Indies).

Tanner (1982) studied the reproductive biology of 53 of the Blue Mountain tree species. He found that 84% appeared to be insect pollinated and 84% appeared to be dispersed by birds. All the species had seed weights of less than 1 g. A comparison of the reproductive biology and biogeographical distribution of these species is currently under way. Healey (1990) studied the regeneration of 27 Blue Mountain tree species in detail and classified them into five regeneration ecology groups. The species that were most strongly gap (light/disturbance) demanding for their regeneration had a wider biogeographical distribution than average (six have been recorded in other montane forests throughout the region, and only one is endemic to Jamaica). The species whose regeneration was favoured in undisturbed conditions (shade-tolerant) had a much higher incidence of endemism to Jamaica (6 of the 7 species) than average. Further work is being carried out on these comparisons and on comparisons between the known abundance of tree species in the Blue Mountains and their biogeographical distribution.

The data analysis that has been carried out so far indicates that there have been many different sources of plant colonization of the Blue Mountain region, both from Central America directly (possibly by previous land connections) and from island to island through the West Indies (by long-distance dispersal). The high levels of endemicity of the Blue Mountain tree flora may be accounted for by a combination of speciation in Jamaica, and the extinction of taxa elsewhere.

These results indicate the high levels of tree species diversity in the Blue Mountain region, including the presence of a number of endemic tree species not known to occur anywhere else in the world. Kelly (1988, 1991) has provided additional information about the occurrence of endemic and rare non-tree species in the Blue Mountains. This rich and unique biodiversity indicates the importance of conservation of the natural montane forests in the Blue Mountains. It is particularly noticeable that the levels of endemism were highest amongst those species whose regeneration is most dependent on undisturbed conditions. This provides clear evidence of the threat to global biodiversity that excessive levels of disturbance to these forests will cause. Careful monitoring is required of the recovery of the forests from the high levels of natural (hurricane) and human disturbance that are currently occurring. There may be a need for active conservation management to prevent excessive human disturbance and to control exotic weed species which may threaten biodiversity in the forests.

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Chapter 5

Extension and dissemination activities in 1992

January

Copies of a comprehensive 139 page annual report on the project were distributed widely to relevant government departments and NGOs in Jamaica and the U.K.

February

Dr McDonald chaired a workshop session on botanic gardens and research. This was a component of a workshop organised by the National Arboretum Foundation of Jamaica to define a national strategy for Jamaica's botanic gardens.

March

Dr McDonald assisted in training sessions for National Park rangers in ecology and conservation. This included participation in workshops organised by the Forest Department of Jamaica.

Three BSc dissertations were completed on work carried out in collaboration with this project. Two of these studies, by M Aldrich of the University of Wales, Bangor and V Scott of the University of Newcastle investigated the condition of the soil under different land-uses and provided evidence of the negative impact that the removal of vegetation cover has had on soil physical and chemical properties in this area. The third study, by R Wood of the University of Wales, Bangor, was concerned with the biogeographical and ecological basis for the conservation of the biodiversity of the natural forests of the Blue Mountains. Abstracts of these three dissertations are included in this report (sections 2.2., 2.4. and 3.5. respectively).

April/May

Dr McDonald, Dr Tanner and Dr Kapos taught an undergraduate course on applied ecology and agroforestry at the Botany Department of the University of the West Indies. This included a workshop on the project.

July

Dr McDonald started the supervision of a post-graduate student of the Department of Botany, University of West Indies who is carrying out a research project associated with this ODA project.

August

Dr McDonald ran a two day summer school for secondary school children from all over the island on plant ecology organised by the Wildlife Education Committee at Hope Zoo. Kingston.

Dr McDonald presented a paper on the project at the inaugural British Institute of Geographers British-Caribbean seminar at the University of the West Indies. Jamaica. 17-21 August. 1992. An abstract is included in this report (section 2.2.). In addition. Dr McDonald organized a field-trip for the seminar participants.

Mr Aldrich held several meetings with members of the local farming community in the area of the project in order to discuss the most pressing extension needs perceived by the farmers (particularly about agroforestry) and which extension methods would be most appropriate. As a result of these meetings, Mr Aldrich has developed proposals for further on-farm agroforestry research in the area.

September

Dr Healey presented a paper on a part of the work of the project to a UNESCO conference on "The ecology of tropical forest tree seedlings". at the University of Aberdeen. 31 August - 5 September. 1992. An abstract is included in this report (section 3.1.).

An article on a part of the work of the project written by Mr Aldrich was published in a professional journal. the Newsletter of the Association of Professional Foresters. An abstract is included in this report (section 2.4.).

October

Dr McDonald lectured and conducted a practical session on "Basic Botany Skills" to Jamaican secondary school teachers as a part of a workshop designed to raise confidence and provide teaching materials for such teachers organised by the Wildlife Education Committee at Hope Zoo.

An MSc dissertation was completed by M Suwal. University of Wales. Bangor. on work carried out in collaboration with this project. A high proportion of the tree species in the natural forests of the Blue Mountains were found to have an ability to coppice after cutting and resprout after more natural disturbance. An abstract of this dissertation is included in section 3.3. of this report.

November

Dr McDonald lectured on agroforestry and assisted in field sessions for a workshop on "Forest Ecology and Conservation Education" for Jamaican and Caribbean practitioners in environmental fields organised by the International Council for Bird Preservation.

December

Two manuscripts of papers to be submitted to the Journal of Ecology have been completed. One is on the remote sensing component of the project (chapter 2) and the other concerns the work of the project on the recovery of the natural forests from hurricane damage by resprouting (section 3.2.).

An MSc dissertation was completed by G Gowae, University of Wales, Bangor, on work carried out in collaboration with this project. A detailed analysis of the forest structure and distribution of trees and saplings in an area of natural forest in the Blue Mountains provided evidence of the influence of strong winds. An abstract of this dissertation is included in section 3.3. of this report.

Four student dissertations on research associated with the project are currently under way. Two MSc projects are close to completion. K Keapoletswe, University of Wales, Bangor, has investigated the rate of regrowth and biomass recovery of the natural forest following clear-cutting. G Akogo Muogo, University of Wales, Bangor, has examined the regeneration of the forest following more natural disturbance; the main focus of his work is the correlation of seedling growth and survivorship with previous seedling height and growth rate, and local seedling density.

Two BSc projects will be completed by March, 1993. N. Tanner, University of Wales, Bangor, is researching the history of land-use in the Blue Mountains of Jamaica in a study that should provide a valuable context for current and planned future extension initiatives. Shannon Morin, University of Calgary has carried out a field study on soil classification of primary and secondary forests.

Chapter 6

Objectives for the next year of the project (1993)

1. To continue monitoring the existing plots in the study of the recovery of the natural forests from hurricane and human damage.

2. To continue making the full set of environmental measurements in the plots of the experimental study of the effects of land-use on soil conservation and sustainability. This will include chemical analyses of water, soil and litter samples as described in appendix 1 of section 3.1.

3. To develop the extension side of the project by establishing a small multi-purpose tree nursery to be run and administered by the local farming community.

4. By working with local farmers and the Jamaican authorities and using the data on the impact of forest conversion to other land-uses, to develop guidelines and systems for soil conservation, and to produce extension material to this effect. Diverse extension material will be produced based on the nursery and any success of the contour agroforestry hedgerows in the experimental on-farm trials.

5. To complete analysis of the remote-sensing and ground survey data on the impact of Hurricane Gilbert and recovery of the forests and to have at least three papers on this work accepted for publication.