

Final Report

Grant Number	RG/2006/EB/08
Title of the Project	Ecology of the Ussangoda serpentine flora
Principal Investigator	Dr. M.C.M. Iqbal Plant Biology Institute of Fundamental Studies, Hantana Road Kandy

Section 1

Information regarding Project/Project Personnel

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| i) | Grant Number | RG/2006/EB/08 |
| ii) | Title of the Project | Ecology of the Ussangoda serpentine flora |
| iii) | Principal Investigator | Dr. M.C.M. Iqbal |
| iv) | Co-Investigators | Dr. D.S.A. Wijesundera
Dr. G.W.A.R. Fernando |
| v) | Institutes where research was carried out | Institute of Fundamental Studies, Hantana
Royal Botanic Gardens, Peradeniya
Dept. of Physics, Open University of Sri Lanka,
Nawala |
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| vii) | Date of completion of Project | 30 April 2011 |
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| ix) | Total spent (Rs) | 1,206,648.81 |
| x) | Number of Research Students employed | One |
| xi) | Post graduate degree completed with dates | M.Phil submitted (April 2011), to the Post Graduate Institute of Science, University of Peradeniya.

M.Sc (2008), Post Graduate Institute of Science, University of Peradeniya. |
| xii) | Number of Technical Assistants and/or labourers employed | None |
| xiii) | Publications/Communications arising from the project during the reporting period. | |
| | Published in refereed journal | one |
| | Published in international conference | five |
| | Published in national conferences | two |

Section 2
Executive Summary of the Project

Executive Summary of the Project

Serpentine soils are derived from serpentine rocks composed of serpentine minerals and ultramafic rocks, with a high content of ferromagnesian minerals. Their weathering enriches the soil with Mg, Fe and other heavy metals which alter the physical and chemical properties of the soil creating an unfavourable environment for plant growth. Sri Lanka has six serpentinite sites. The Ussangoda site is on the southern coast in Hambantota. The objective of this project is to understand the serpentinite nature of the soil and plant adaptations.

Soil samples were collected to a depth of 10 cm to determine the soil physical and chemical properties. Plant samples were collected, for identification. Soil and plant samples were analysed for heavy metals and nutrients using an Atomic absorption spectrophotometer.

The soil was silt loam with small amounts of sand and clay. The levels of Ca, Mg, Ni and Fe were high. The mean Ca/ Mg ratio was 1.1 on the plains and ranged from 1.5 to 2.0 for the patches of shrubs. The moisture content, organic matter, NPK and CEC were low and the C/N ratio was high in the serpentine soil. All these contributed to unfavourable conditions for plant growth.

Thirty one plant families were identified of which seven families with 10 species occur on the serpentine plain. These were prostrate, dwarf or stunted, with small leaves, thick sclerenchymatous stems and extensive root systems. The other species are shrubs and trees occurring in isolated small patches. The prostrate species *Euphorbia*, *Evolvulus*, and *Vernonia cinerea* were hyper-accumulators of Ni. Few of the shrub species accumulated Ni but tolerated high Mg content in their tissues.

The soil shows typical characteristics of serpentinite soil elsewhere. Plant species have adapted and evolved on this soil to give a unique assemblage of plants with unusual morphological and physiological adaptations. This unique ecological habitat should be conserved to preserve its biodiversity and to study plant adaptation and the preserve the geological significance of this site.

Section 3

Report in detail

- I Introduction/background
- II Scientific scope of the project (overall and specific objectives)
- III Materials and methods (including statistical methods)
- IV Results/outputs
- V Discussion
- VI Conclusions
- VII References
- VIII Problems if any, encountered during the implementation of the project
- IX Major findings and follow up activities.

I INTRODUCTION

Serpentine soils occur in isolated patches all over the world particularly along continental margins. They are derived from serpentine rocks composed of serpentine minerals and ultramafic rocks, which have a high content of ferromagnesian minerals (Brooks, 1987). The weathering of these rock types enriches the soil with Mg, Fe and other heavy metals such as Ni, Co etc. These contribute to changing the physical and chemical properties of the soil towards an unfavourable and hostile environment for plant growth. Over time, plant species have adapted to these unusual soil conditions producing a unique association between the soil and plants. They can be regarded as a living laboratory for studying evolutionary biology and adaptations by the plant species to the extreme environment peculiar to serpentine soils.

Serpentinite rocks and soil

Rocks composed of serpentine minerals are referred to as serpentinites. Geologists refer to these as ultramafic rocks and when using the term serpentine add the suffix “-ite” and refer to it as ‘serpentinite’ (Alexander et al., 2007). Ultramafic rocks after weathering processes over time give rise to serpentinite soils. Serpentinite soils are observed throughout the world concentrated along continental margins and in regions of orogenesis (Rajakaruna and Boyd, 2008).

Serpentinite deposits found in Indonesia, Cuba and New Caledonia extend to larger areas greater than 5000 km². In western North America, the serpentinite deposits can be found in California and Oregon with extents of 2800 km² and 1100 km² respectively (Rajakaruna and Baker, 2004). In addition there are many more serpentinite deposits of varied size, concentrated in other parts of the world such as the Mediterranean, Africa, Australia, New Zealand and Asia (Rajakaruna and Boyd, 2008; Brooks, 1987). However, the sites in Asia are considered as the least explored sites compared to those in other parts of the world (Rajakaruna and Baker, 2004). Very little is known of the geology and flora of serpentine sites in Southeast Asia. In India, an ultramafic site was reported in the Orissa state of Calcutta (Brooks, 1987). The serpentine areas in the Malay Archipelago are well documented and many endemic species were identified (Brooks, 1987; Proctor 2003). The soil characteristics of the ultramafic sites in Malaysia, Indonesia and The Phillipines were also compared by Brearley (2005).

Serpentinite soils are unique because of the natural inheritance of heavy metals and variations in nutrients. The soil is deficient in essential nutrients such as N, P and K and rich in Mg and heavy metals such as Ni, Co and Cr. The characteristic feature of this soil is that it has a low Ca/Mg ratio. In addition, these soils are low in pH and have a low water holding capacity (Rajakaruna and Boyd, 2008; Brooks, 1987). These conditions present a harsh edaphic environment against which plants should adapt for survival.

Ultramafic soils are generally shallow with a high Mg to Ca ratio, deficient in essential plant nutrients and contain potentially toxic concentrations of heavy metals (Brooks 1987). The rocky nature of the soil, low clay and organic matter content provides a highly permeable soil with low water holding capacity. In the soil, the exchangeable Mg concentrations are high and exchangeable Ca concentrations are low and are deficient in the essential plant nutrients N, P and K (Seneviratne *et al.*, 2000). Plant life on serpentine soils have adapted morphologically and physiologically to this environment. Morphologically plants are dwarf with narrow, glaucous

thick leaves, strong sclerenchyma development and enlarged root system (Kruckeberg, 1984). Physiologically they are able to tolerate the heavy metal presence in the soil by absorption and sequestration or exclusion. Thus serpentine soils provide a unique ecological niche which is poor in diversity of plant species.

Plant adaptation

While most plant species are unable to survive on these sites, a few species have adapted morphologically and physiologically to colonize in these extreme conditions. Morphologically, plants are dwarf with narrow, glaucous thick leaves and an extensive root system. Physiologically they are able to tolerate extreme nutrient concentrations through absorption and sequestration or exclusion processes and/or mechanisms (Brady et al., 2005). In a global context, plants surviving on serpentinite soils exhibit a very high rate of endemism as observed in California, New Caledonia and Cuba (Rajakaruna and Boyd, 2008). However, plant endemism varies from site to site throughout the world.

Serpentinite sites of Sri Lanka

Geological studies in Sri Lanka have shown six serpentinite bodies at Ussangoda, Indikolapelessa, Ginigalpelessa, Katupota, Yodagannawa and Rupaha (Fig. 1). These lie close to a Precambrian suture zone between the lithotectonic units, the Vijayan and Highland series (Dissanayake & Van Riel, 1978; Munasinghe & Dissanayake, 1979; Munasinghe &



Fig 1. A simplified geological map of Sri Lanka with the serpentinite deposits (Kröner et al., 1991 and Cooray, 1994)

Dissanayake, 1980). Of these sites the geochemistry of the Uda-Walawe serpentine site has been described (Dissanayake & Van Riel, 1978; Dissanayake, 1982). The serpentinite deposit in Rupaha was identified as a metamorphosed ultramafic rock with different characteristics than the other sites (Fernando, 2001). A preliminary survey on the serpentinite vegetation at the Uda Walawe area was carried out by Wickramaratne (2000). Another preliminary study was carried out by Rajakaruna and Bohm (2002) to cover four serpentinite deposits including Ussangoda.

Ussangoda Serpentinite Deposit

The Ussangoda serpentinite deposit has been surrounded by various myths down the ages. It is thought that a meteorite had struck and burnt the vegetation, which gives its characteristic colour. Excavations carried out by the Archaeological Department revealed signs of early human settlements at Ussangoda (Deraniyagala, 1992). The Ussangoda hill area is identified as a high priority site in the list of archaeological, historical, religious and cultural sites in the latest National Coastal Zone Management plan (CCD, 2003).

The site is an important ecosystem to study geo-botanical aspects of plant development due to the peculiar and harsh soil characteristics for plant growth (Rajakaruna and Bohm, 2002). The potential of this site for industrial development has been overlooked – fortunately although a preliminary attempt was made by the ceramic industry of Sri Lanka to utilize serpentinite red soil as a source of colour pigment (Siritunge et al., 1987). Tennakone et al., (2007) have studied the extraction of metallic nickel from ores and plants present in Ussangoda.

The first scientific description of the Ussangoda serpentinite deposit dates back to Brooks (1987), when he described the site as “at Welipatanwila the heavily laterised ultramafics are almost completely devoid of vegetation except for a scattering of a small blue flowered herb, *Evolvulus alsinoides*. The boundary of the serpentine is marked by low thorn bushes interspersed with *Opuntia* species”. Seneviratne et al., (2000) conducted the first study on the flora and identified 14 plant species of which six were hyper-accumulators of Ni at the Ussangoda serpentinite deposit. Rajakaruna and Bohm (2002) identified 9 plant species and among them three are considered to be hyper-accumulators of Ni. In a recent study, 29 species of flowering plants were identified which included trees, shrubs, vines and prostrate plants growing on the serpentinite site at Ussangoda. *Cassia kleinii*, a prostrate plant was identified as a Ni hyper-accumulator (Iqbal et al., 2006). Thus in the last 20 years, few studies were devoted to study this unique habitat and much work remains to be done.

II Scientific scope of the project

The overall objective of this project is to determine the science behind this unusual plant ecosystem by studying the soil characteristics, plant adaptations, and the mineralogy of the Ussangoda serpentinite soil. There are two major vegetation patterns in this small serpentinite deposit: a large expanse of a few prostrate plant species with xeromorphic adaptations and isolated shrub dominated patches with stunted shrubs and trees, which occupy a small fraction of the total area.

For a comprehensive study of the Ussangoda serpentine site, it is necessary to determine the diversity of plant species, their physiological adaptations to the adverse soil environment and the soil characteristics contributing to their adaptations. This would subsequently assist in the study of the other serpentine sites in Sri Lanka and potentially contribute towards identifying heavy metal hyper-accumulating plant species.

Specific objectives of the study:

- Determine the physical, chemical and biological properties of the Ussangoda serpentinite soil,
- Identify plant-soil relationships at the Ussangoda serpentinite deposit,
- Determine heavy metal accumulation of selected plant species growing on serpentinite soil, and
- Identify the rock types and mineralogy responsible for the serpentinite soil.

III MATERIALS AND METHODS

Location of the Study Site and description

Ussangoda is a village in the Hambantota district close to the Nonagama junction on the A-2 highway between Matara – Hambantota. The serpentine study site in Ussangoda (Fig. 2) is a flat plain (approximately 1 km²) located close to the Nonagama junction (lat 06° 05' N, long 80° 59' E). The southern boundary of the plain is a cliff, approximately 30 m amsl, overlooking the Indian Ocean. The highest point on the plain is 34.5 m amsl. It is sharply demarcated by dense shrubby vegetation around the perimeter with a small water-body just outside the northern boundary. The people in the Ussangoda village are engaged in farming and animal husbandry, often using the Ussangoda serpentinite deposit plains to graze their cattle.

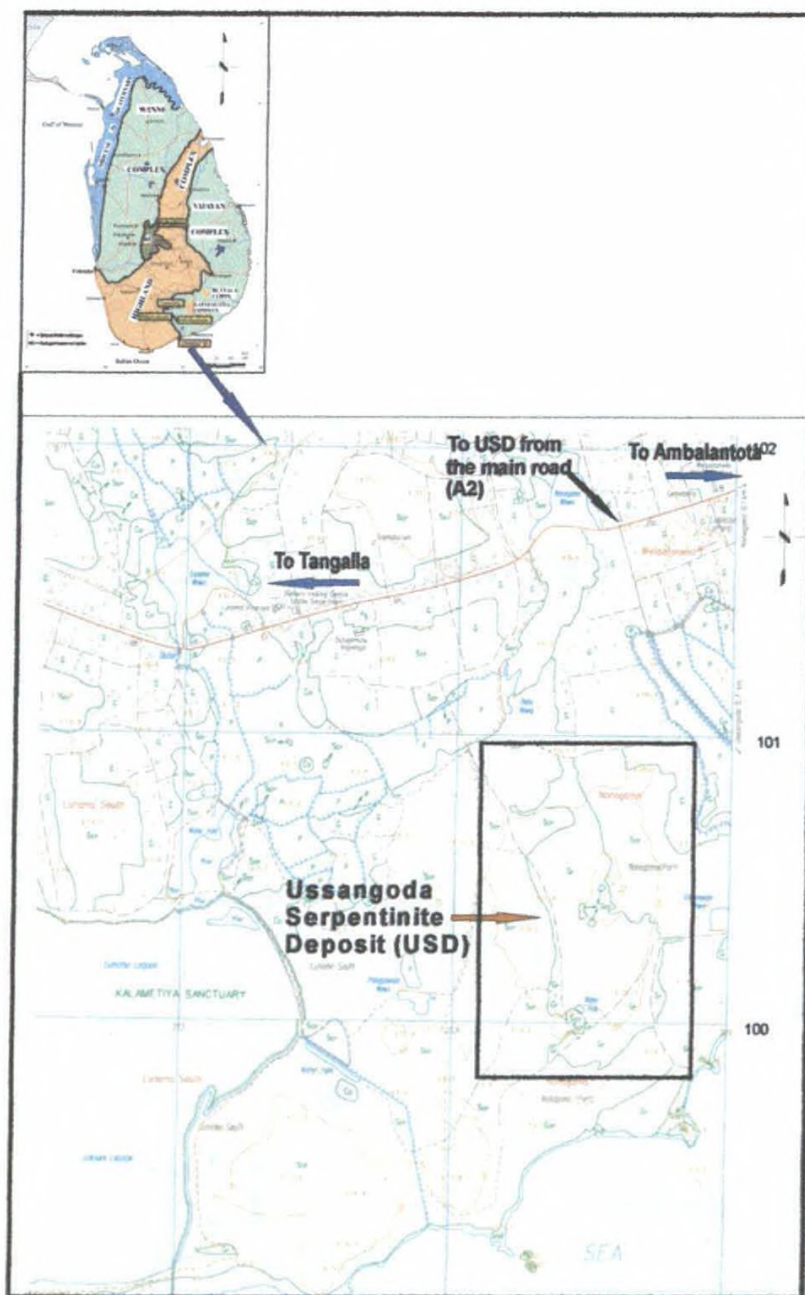


Fig 2. Location map of the Ussangoda area (compiled after the Sri Lanka Survey Department 1:10000 map).

Map of the Ussangoda Serpentine Deposit prepared using GIS

A map was prepared for the study site using GIS (Geographic Information System) indicating the demarcation of its boundary from the non-serpentine vegetation (Fig. 3A and 3B). Initially the GPS (Global Positioning System) points were recorded along the boundary of the site and then

the GIS map was prepared using ArcGIS software. The prepared GIS map was compared with the 1:10000 map of the survey department for its accuracy. Surface concentration maps for each physical and chemical property was prepared using the 'kriging' option of ArcGIS 8.1 software version.

Description of the Study Site

Landscape

The Ussangoda serpentinite deposit resembles a 'sea horse' and has a serpentine plain area with a few shrub dominated patches (Fig 4). The plain area has an elevation of 30 m from the sea level and has a gentle slope towards the perimeter. The Ussangoda serpentinite deposit is sharply demarcated from the non-serpentine area by dense thorny shrubs (Fig 4).

Vegetation

The serpentinite site contains two distinct forms of vegetation (Fig 4):

- i. Prostrate plants covering more than 95% of the serpentine plain area and
- ii. Shrubs and stunted trees confined to shrub dominated patches (randomly distributed across the plains which cover less than 1 % of the total area).

Soils

The soil is red in colour and is in the form of a fine powder with solid aggregated colloids. It is shallow and the depth varies within the site.

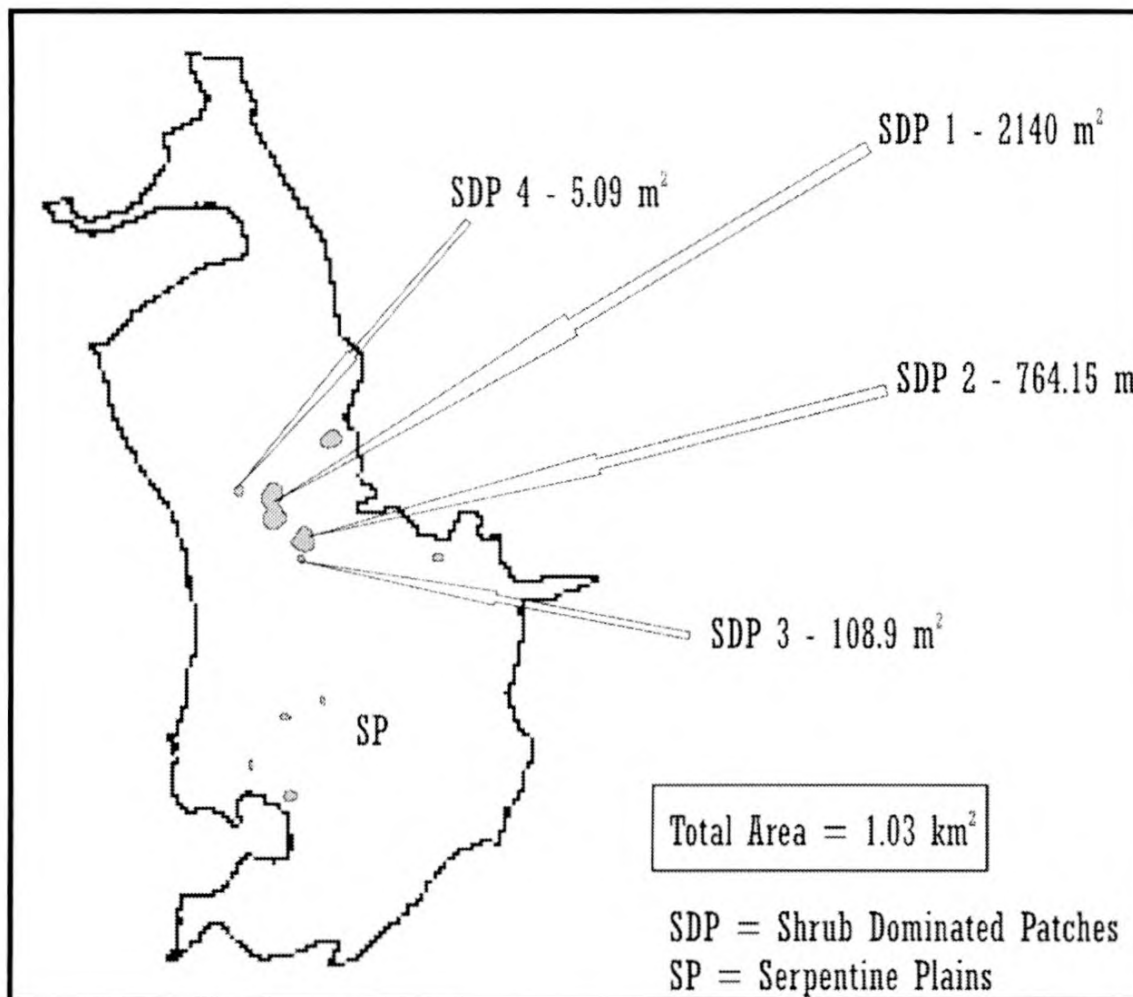


Fig 3A. GIS generated map of the Ussangoda serpentinite site showing boundary and shrub dominated patches and their extents

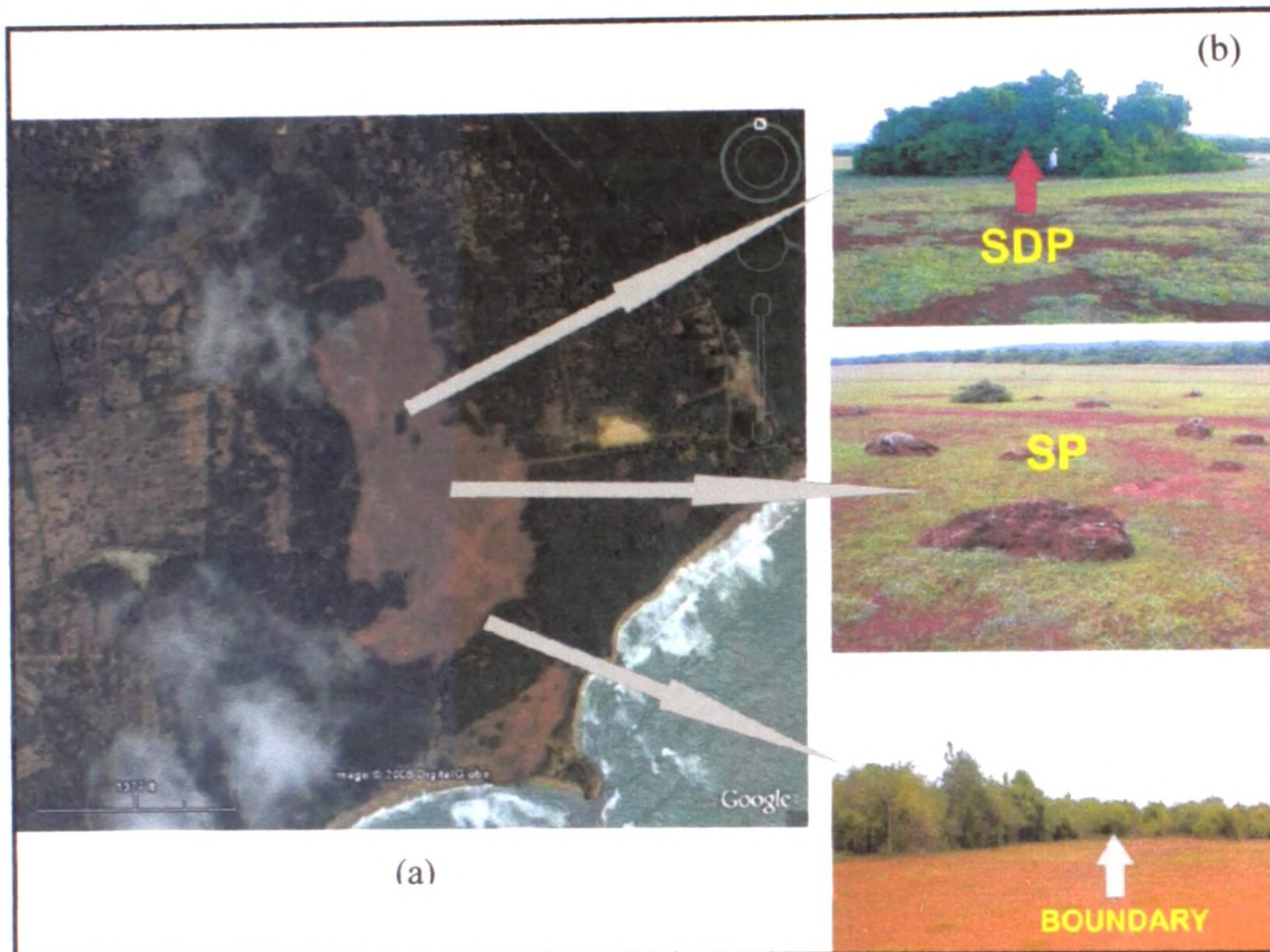


Fig 4. Satellite view of the Ussangoda serpentinite deposit (a) from GoogleMaps and stratified sub locations (b). Digital photographs of the Shrub dominated patches (SDP), serpentinite plains (SP) and the distinct boundary between serpentinite and non-serpentinite vegetation.

Climate

Ussangoda belongs to the dry zone and falls within the DL 5 region (Dry zone Low country) of the agro-ecological zone map of Sri Lanka produced by the Natural Resources Management Centre, Department of Agriculture. The mean annual temperature is 27.9 °C with a mean range of 31.1 °C to 24.6 °C. Daytime temperature during field visits reached 35.8 °C. The annual rainfall is less than 1250 mm (mainly from October – January) with more than 5 dry months with less than 50 mm rainfall (IUCN, 2004).

Experimental Design

The Ussangoda serpentinite deposit was stratified as the serpentinite plains (SP), Shrub dominated patches SDP (SDP1, SDP2, SDP3 and SDP4) and the boundary area (Fig 3A). In the initial survey, soil samples were collected at random from stratified locations SP, SDP 1, 2 and areas out of the serpentinite deposit. They were analyzed to determine the basic soil characteristics. Thereafter in the detailed study, soil samples were collected randomly from all the sub locations. Samples obtained from the non serpentinite area served as the control. The obtained results were statistically analyzed using Minitab 14.

Soil and plant sampling

Soil

Soil samples were collected to a depth of 10cm from the soil surface and were stored in labelled polythene bags until the samples were transported to the laboratory at the Institute of Fundamental Studies (IFS), Kandy. The soil samples were air dried at room temperature for a week and sieved using a 2 mm sieve set. Large particles were removed and the remaining soil was crushed gently with a wooden rolling pin and a ceramic mortar and pestle and then passed through the sieve. The process was repeated until all soil aggregates were crushed. The sieved soil samples were stored in labelled polythene bags.

Plants

Plant samples were collected, labelled and stored in paper bags in the field. Thereafter the good specimens were placed in between sheets of newspaper and dipped in methylated spirit to prepare herbarium sheets. All the samples were transported to the laboratory at the IFS, Kandy. The specimens were pressed, dried and mounted onto herbarium sheets. Plant shoots were sampled ensuring it was available for further propagation

Determination of soil physical parameters

Soil moisture

Five grams of fresh soil were dried to a constant weight in an oven at 105 °C for 24 h. The sample was weighed to an accuracy of 0.01 g after cooling in a desiccator for 30 minutes (Kalra and Maynard, 1991).

Soil Moisture = (weight of fresh soil – weight of dry soil)

Particle size analysis (fractionation of soil using sieves)

Soil was fractionated using 2 mm and 0.05 mm sieves. Soil retained in between 2 mm and 0.05 mm sieves (X) gave the total sand percentage. Soil that goes through the 0.05 mm sieve (Y) gave the total silt and clay percentage (Kalra and Maynard, 1991).

Total Sand (%) = (X/ sample weight) 100

Total Silt & Clay (%) = (Y/ sample weight) 100

Determination of soil chemical parameters

Soil pH (1:2 ratio)

The pH was determined by both de-ionized water and calcium chloride methods. Ten grams of 2 mm air dried soil was placed in a beaker. Thereafter 20 ml of de-ionized water or calcium chloride was added and stirred 4-5 times within 30 minutes. It was allowed to settle for another 30 minutes. The pH was measured by immersing the combination electrode of the pH meter (model: Russell-RL060P) into the supernatant solution (Kalra and Maynard, 1991).

Soil conductivity (1:2 ratio)

Forty grams of 2 mm air dried soil was transferred in to a flask and 80 ml of de-ionized water was added to it. The mixture was stirred well and the soil conductivity was measured using a conductivity meter (model: Consort EC meter K410) (Kalra and Maynard, 1991).

Soil cation exchange capacity (CEC)

A known amount of 2 mm air dried soil (2.5 g) was shaken with 33 ml of 1 M potassium chloride for 5 minutes in a 50 ml centrifuge tube and centrifuged until the supernatant was clear

(2500 rpm, 5 min). The supernatant was discarded and the above process was repeated 4 times. Thereafter 20 ml of 95 % ethanol was added to the suspension and shaken for 5 min. This was centrifuged until the supernatant was clear. The supernatant was discarded and the process was repeated twice. To this 33 ml of 1 M ammonium acetate was added and shaken for 5 min. It was centrifuged until the supernatant was clear. The supernatant was poured into a 100 ml volumetric flask and repeated twice. The flask was volume up to 100 ml with ammonium acetate and mixed well. The potassium concentration in the flask was measured by the Atomic Absorption Spectrophotometer - model: GBC 933AA (AAS) and thereby the cation exchange capacity was determined (Anderson and Ingram, 1993).

$$\text{CEC (cmol(+)/kg of dry soil)} = \frac{(\text{K conc.} * \text{dilution factor} * 10)}{(\text{K atomic weight} * \text{dry soil weight})}$$

Organic matter

The soil organic matter content was determined by the Loss-On-Ignition (LOI) method. Five grams of 2 mm size oven dried soil sample was gradually heated in a crucible to 550 °C in a muffle furnace for 4 hours. The organic matter was calculated (Nelson and Sommers, 1996; Ratnayake et al., 2007).

$$\text{Organic matter(\%)} = \frac{(\text{weight of oven dried sample} - \text{weight of sample after ignition})}{\text{weight of oven dried sample}} * 100$$

Soil exchangeable cations (Ca, Mg, Na & K)

Five grams of 2 mm air dried soil was mixed with 25 ml of neutral 1 N ammonium acetate and shaken for 30 minutes. Thereafter it was filtered and the filtrate was analyzed by the AAS for exchangeable cations (AESL, 1999; McIntosh, 1969).

$$\text{Cation concentration (\mu g/g)} = \frac{\text{AAS concentration} * \text{dilution factor} * 25}{\text{Weight of dry soil}}$$

Soil micronutrients

An air dried soil sample (2.5 g) was mixed well with 50 ml of diethylene-triamine-penta acetic acid (DTPA) extractant (0.005 M DTPA in 1 M NH₄HCO₃ – prepared fresh daily) in 250 ml conical flasks, without closing the flasks, and filtered through a Whatman 42 filter paper. The micronutrients were measured by the AAS using appropriate standards (Soltanpour and Schwab, 1977).

$$\text{Micronutrient concentration (\mu g/g)} = \frac{\text{AAS concentration} * \text{dilution factor} * 50}{\text{Weight of dry soil}}$$

Total nitrogen

A soil sample of 0.5 g was digested in a digestion mixture containing hydrogen peroxide (30 %), lithium sulphate, selenium powder and concentrated sulphuric acid at 400 °C for 3 hrs. The NH₄⁺ - N content in the digest was determined using the auto analyzer (Tecator, 1030 Kjeltex auto analyzer) (Anderson and Ingram, 1993).

$$\text{Nitrogen (\mu g/g)} = \frac{\text{Normality of HCl} * (\text{Sample volume} - \text{Blank volume}) * 14.01 * 4 * 1000}{\text{Weight of dry soil sample}}$$

Total phosphorous

A soil sample of 0.5 g was digested in a digestion mixture containing hydrogen peroxide (30%), lithium sulphate, selenium powder and concentrated sulphuric acid at 400 °C for 3 hrs. The digest was diluted up to 50 ml with de-ionized water and the solution was used to determine the

phosphorous concentration using the UV-Spectrophotometer (model: Shimadzu, UV-160A) (Anderson and Ingram, 1993).

$$\text{Phosphorous } (\mu\text{g/g}) = \frac{\text{P concentration} * \text{dilution factor}}{\text{Weight of dry soil sample}}$$

Plant Analysis

Determination of micro elements

Plant samples were washed by brushing briskly with a soft-stiff nylon bristle brush under running tap water. The cleaned samples were washed with ethylene-diamine-tetra-acetic acid (EDTA) for 1 min and thereafter 3 times with de-ionized water. The samples were covered with newspaper and dried at 80 °C for 24 h in a forced air oven. The dried samples were ground in a plant grinder and stored in air tight bags. The crushed sample (0.5 g) was weighed into a porcelain crucible and ashed in a muffle furnace at 550 °C for 8 hours. The ashed sample was dissolved with 5 ml of concentrated HCl and volume up to 50 ml with distilled water in a volumetric flask. It was shaken well and the micro nutrients were determined using the AAS (Kalra and Maynard, 1991).

$$\text{Plant Micro-nutrient concentration} = \frac{\text{AAS concentration} * \text{dilution factor} * 50}{1000 * \text{Weight of plant sample}}$$

IV Results

Map of the Ussangoda serpentinite site with the islands of vegetation

A map of the Ussangoda Serpentinite Deposit was prepared using GIS (Geographic Information System) to demarcate the boundary from the non-serpentinite vegetation.

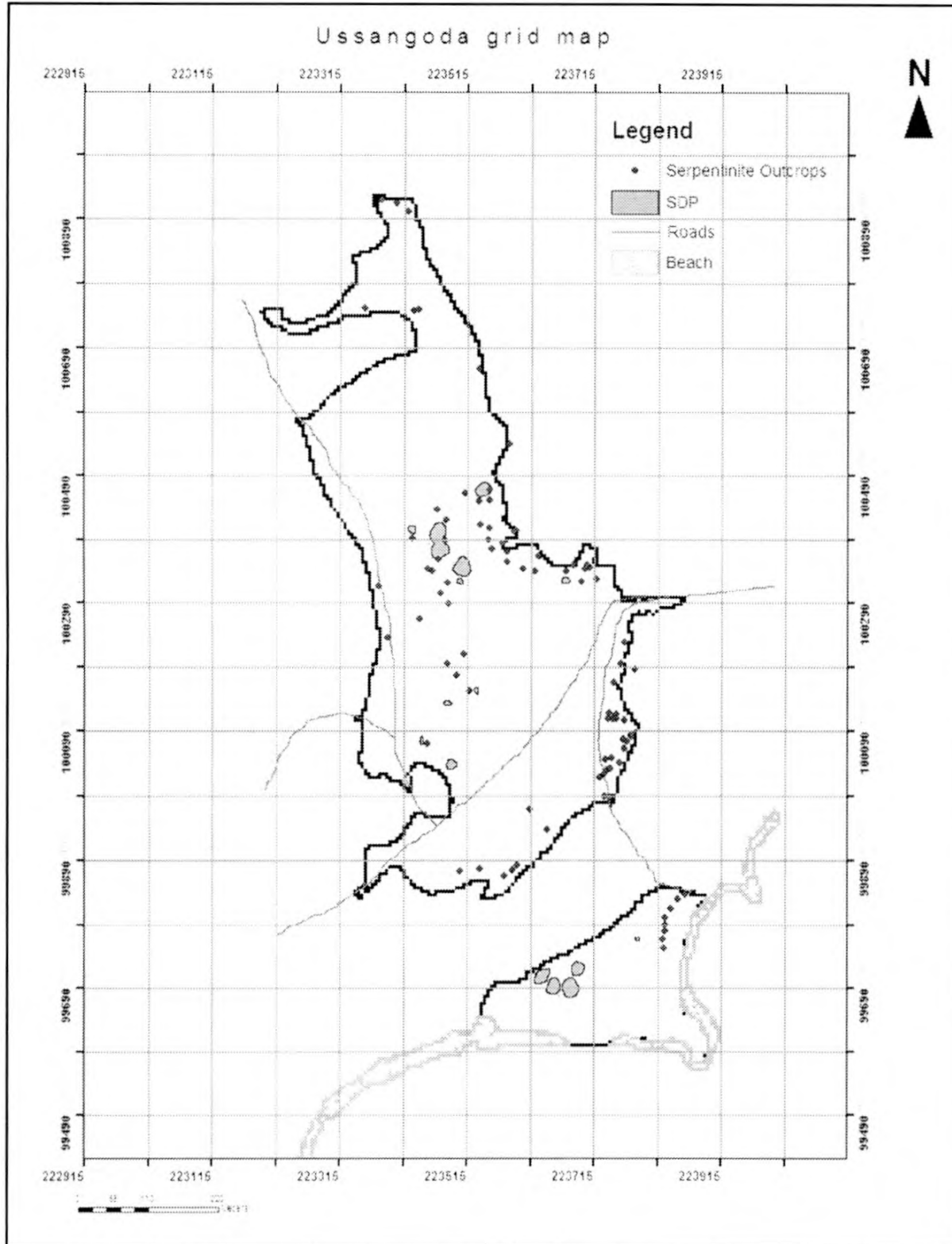


Fig 3B. Map of the Ussangoda Serpentinite Deposit prepared using GIS. The islands of vegetation are shown as Shrub Dominated Patches (SDP).

The map was validated by comparing with the map from the Survey Department of Sri Lanka and the satellite image from Google maps (Fig. 4). Our map represents the serpentinite deposit accurately. The isolated shrub dominated patches, which occur on the plains, were also mapped. This map would provide a useful baseline to determine future changes in the boundary with the non-serpentine vegetation and changes in the size and boundary of the shrub dominated patches

within the serpentinite plains. This map was also used to map the distribution of heavy metals within the serpentinite site.

Species composition on the plains and the shrub dominated patches

Flora on the Ussangoda serpentinite site

The diversity of plant families and species in Ussangoda is based on a field survey of the flora on the serpentine soil and a previous survey conducted by the IUCN on all the species in the Ussangoda region.

This study has identified to-date 31 plant families on the serpentine soil. Of these seven families with 10 species occur on the serpentine plain (Table 1). These species are prostrate, dwarf or stunted, with small leaves, thick sclerenchymatous stems and extensive root systems. The prostrate species *Evolvulus alsinoides*, had three colour morphs: white, pale purple and dark blue. They occurred either in close proximity or spread apart on the plains. The dominant family on the serpentine plains was Fabaceae with three species. The other families occur in the patches of shrubs and trees on the serpentine plain.

Table 1. Plant species on the Ussangoda serpentine plain.

Name of the Plant	Family
<i>Hybanthus enneaspermus</i>	Violaceae
<i>Evolvulus alsinoides</i>	Convolvulaceae
<i>Euphorbia thymifolia</i>	Euphorbiaceae
<i>Cassia kleinii</i>	Fabaceae
<i>Desmodium triflorum</i>	Fabaceae
<i>Crotolaria</i> sp.	Fabaceae
<i>Vernonia cinerea</i>	Asteraceae
<i>Eragrostis</i> sp.	Poaceae
<i>Frimbristylis ovata</i>	Cyperaceae
<i>Frimbristylis falcata</i>	Cyperaceae

The occurrence of species from the IUCN plant survey was compared with those growing on the serpentine site. Five families with seven species grow only on the serpentine soil and were not found by the IUCN study (IUCN 2004) in the Ussangoda region (Table 2). Of these Violaceae occurs on the plains and species of the other four families occur as shrubs or trees on the serpentine site. The diversity of families and their species was low on the serpentine soil. The survey of species up to now has identified 16 species growing only on the serpentine soil (Table 2) and 44 species growing on serpentine and non-serpentine soil in Ussangoda. The habit of these species were climbers, herbs, shrubs and trees. Monocotyledons were confined to Cyperaceae and Poaceae with four species. Of the 31 families on serpentine soil, Fabaceae had six species, Capparaceae and Malvaceae five species each and the rest had three species or less (Table 2). In contrast, the diversity of species within the families was greater on the non-serpentine region of Ussangoda (Table 2). Fabaceae had the most with 14 species while 10 families had three or more species (Table 2). A complete survey of the families and species on the serpentine soil is continuing.

Table 2: Plant species and their families found on serpentinite soil and non-serpentine regions in Ussangoda (Habit: H – herb, S – shrub, C – climber, T – tree). Weerasinghe and Iqbal (2011)

Families	Habit	Species	Only on Serpentine soil	On serpentinite and non-serpentine soils	Source (Ref no.) P = present survey
APOCYNACEAE	H	<i>Carissa spinarum</i>		X	P
ASCLEPIADACEAE	S	<i>Calotropis gigantean</i>		X	P
ASPARAGACEAE	C	<i>Asparagus racemosus</i>		X	P
ASTERACEAE	H	<i>Eupatorium odoratum</i>		X	P
	H	<i>Vernonia cinerea</i>		X	P
BORAGINACEAE	S	<i>Ehretia laevis</i>	X		P
CACTACEAE	H	<i>Opuntia sp.</i>		X	1, P
CAPPARACEAE	S	<i>Capparis pedunculosa</i>		X	P
	S	<i>Capparis rotundifolia</i>		X	P
	S	<i>Capparis sepiaria</i>		X	P
	S	<i>Capparis zeylanica</i>		X	P
	S	<i>Maerua arenaria</i>	X		P
CELASTRACEAE	S	<i>Maytenus emarginata</i>		X	P
CONVOLVULACEAE	H	<i>Evolvulus alsinoides</i>		X	1,2,3, P
	H	<i>Ipomoea pes-caprae</i>	X		P
CYPERACEAE	H	<i>Fimbristylis falcata</i>	X		2,3, P
	H	<i>Fimbristylis monticola</i>	X		P
	H	<i>Fimbristylis ovata</i>	X		P
EUPHORBIACEAE	H	<i>Euphorbia hirta</i>		X	P
	H	<i>Euphorbia thymifolia</i>		X	P
	S	<i>Flueggea leucopyrus</i>		X	P
FABACEAE	C	<i>Acacia caesia</i>		X	P
	T	<i>Cassia auriculata</i>		X	3, P
	H	<i>Cassia kleinii</i>	X		P
	H	<i>Crotolaria tecta</i>		X	P
	H	<i>Desmodium sp.</i>		X	3, P
FLACOURTIACEAE	S	<i>Dichrostachys cinerea</i>		X	P
		<i>Casearia zeylanica</i>	X		P
	S	<i>Flacourtia indica</i>	X		P
	T	<i>Scolopia acuminata</i>		X	P
LINACEAE	T	<i>Hugonia mystax</i>		X	P
LORANTHACEAE	S	<i>Dendrophthoe falcata</i>		X	P
MALVACEAE	H	<i>Abutilon indicum</i>		X	P
	H	<i>Pavonia odorata</i>		X	P
	H	<i>Sida acuta</i>		X	P
	H	<i>Sida cordifolia</i>		X	P
	H	<i>Sida rhombifolia</i>	X		P

MELASTOMATACEAE	S	<i>Memecylon umbellatum</i>		X	P
MELLIACEAE	T	<i>Azadirachta indica</i>		X	P
MENISPERMACEAE	C	<i>Pachygone ovata</i>	X		P
OLACACEAE	S	<i>Olax imbricata</i>	X		P
OLEACEAE	C	<i>Jusminum angustifolium</i>		X	P
POACEAE	H	<i>Eragrostis tenella</i>	X		P
RHAMNACEAE	S	<i>Ziziphus oenoplia</i>		X	P
RHIZOPHORACEAE	H	<i>Cassiopourea ceylanica</i>	X		P
RUBIACEAE	T	<i>Canthium dicoccum</i>		X	P
	T	<i>Morinda tinctoria</i>		X	P
	T	<i>Tarenna asiatica</i>		X	3, P
RUTACEAE	S	<i>Glycosmis mauritiana</i>		X	P
	T	<i>Limonia acidissima</i>		X	P
	C	<i>Toddalia asiatica</i>		X	3, P
SALVADORACEAE	T	<i>Azima tertacantha</i>		X	P
	T	<i>Salvadora persica</i>		X	P
SAPINDACEAE	T	<i>Allophylus cobbe</i>		X	P
	T	<i>Lepisanthes tetraphylla</i>		X	P
	T	<i>Sapindus emarginatus</i>		X	P
VERBENACEAE	S	<i>Lantana camara</i>		X	P
	H	<i>Stachytarpheta jamaicensis</i>		X	P
VIOLACEAE	H	<i>Hybanthus enneaspermus</i>	X		2, 3, P
VITACEAE	H	<i>Cissus quadrangularis</i>		X	P

The plant species on the Ussangoda serpentine site were identified from our present study (P) and previous cited studies. The species on the non-serpentine regions in Ussangoda are based on the IUCN survey (IUCN 2004). The cited studies are:

1. Brooks R.R. (1987). *Serpentine and its Vegetation. A multidisciplinary approach*. Dioscorides Press, Portland OR, USA, 224 p.

2. Seneviratne A.S., Nandadasa H.G., Fernando W.S., Sanjeevani H.H.V.M. & Rajapakse R.I.H.R. (2000). The serpentine vegetation of Ussangoda (Hambantota district) and nickel accumulating plant species. Proceedings of the Sixth Annual Forestry and Environmental Symposium, Kandy Sri Lanka 29-30 December 2000.

3. Rajakaruna N. & Bohm B.A. (2002). Serpentine and its vegetation: a preliminary study from Sri Lanka. *Journal of Applied Botany* 76: 20-28.

Adaptation of the plant species to the climatic and edaphic conditions of the serpentinite site

Growth and adaptation by *Vernonia cinerea* (Family: Asteraceae)

Introduction

To determine the morphological and physiological adaptations to the serpentine soil, we selected the species *Vernonia cinerea*, which grows on the serpentinite soil. This was the only species which could be propagated by seeds to conduct parallel experiments on non-serpentine soil to determine the adaptations of the plant to serpentine soil. An experiment was conducted to determine the adaptations by *Vernonia cinerea* growing on serpentinite soil.

Materials and methods

The *Vernonia cinerea* plants on the Ussangoda serpentine soil were stunted with elongated and thick leaves and an extensive root system. The species was identified as *Vernonia cinerea* from herbarium specimens at the National Herbarium, Peradeniya. According to Grierson (1980) it is an erect or decumbent annual herb that grows up to 15-30 cm tall. However, the species growing on the Ussangoda serpentinite soil was morphologically different from the same species growing elsewhere.

Five randomly selected *Vernonia cinerea* plants naturally occurring on the serpentinite soil and another five plants grown in the greenhouse in non-serpentine soil, from seeds of serpentinite plants, were used to determine and compare the shoot/root ratio. Seeds of *Vernonia cinerea* plants from the Ussangoda serpentinite soil were germinated on wet filter papers. Five seedlings each were planted on non-serpentine soil in the greenhouse in pots, and replicated. All the pots were watered regularly in the same manner. After 3 months the plants were removed to determine the shoot and root biomass, along with plants from the serpentinite site.

Results

The shoot/root ratio of *Vernonia cinerea* occurring naturally on serpentinite plain soil was low (0.8) than that grown on non-serpentine soil in the green house soil in Kandy (3.17). The variation was almost similar in both (Fig.5).

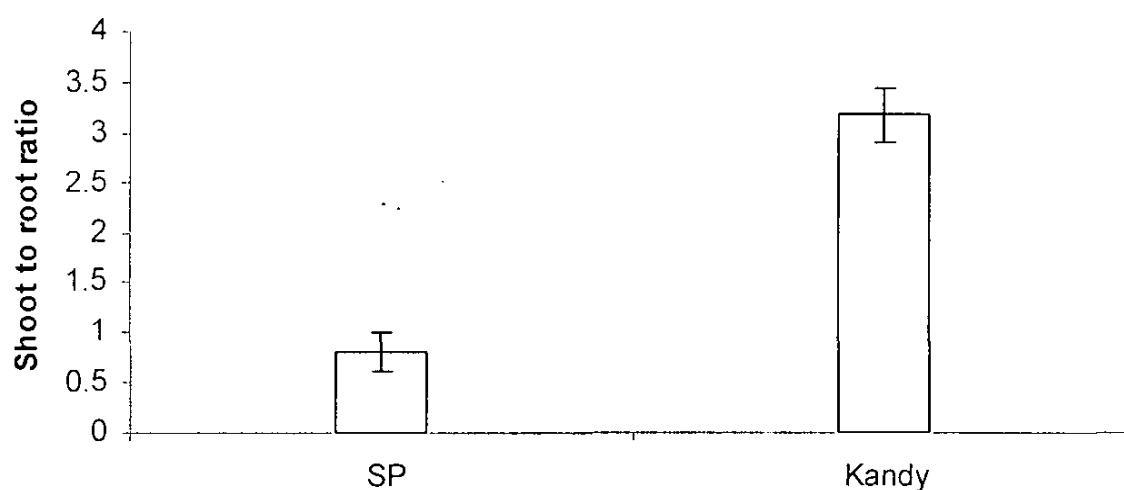


Fig 5. Shoot/root ratio of *Vernonia cinerea* under two soil types (n = 5). SP: plants from the serpentinite plains, Kandy: non-serpentine soil in the green house.

The plants on the serpentinite plains showed a stunted growth and did not grow beyond 4 inches (Fig 6). The plants grown on non-serpentinite soil showed a better growth with elongated internodes (Fig 7).



Fig 6. *Vernonia cinerea* plants growing on the Ussangoda serpentinite deposit.



Fig 7. Initial growth stages of *Vernonia cinerea* on non serpentinite garden soil.

Discussion

Vernonia cinerea plants have a well developed root system than the above ground biomass in its natural condition on the Ussangoda serpentinite soil. This is an adaptation to survive the unfavourable climate, which is dry and hot for most of the year compounded by the adverse and unfavourable soil conditions of the serpentinite soil. Reduced above ground biomass would prevent evapo-transpiration and thereby enable the plant to survive long dry periods supported by the extensive root system. The plants showed normal growth on non-serpentinite soil.

Similar to *Vernonia cinerea*, the other species also showed similar adaptations. The species are prostrate, have an extensive root system, thick and reduced leaves, reduced shoots, and leaves are covered with trichomes.

Metal uptake by the plant species

Metal uptake by flora on the serpentinite plains

Plant species on the serpentinite plains show morphological adaptations to the high available metal content in the soil. These species though few (10 -15 species) occupy more than 90% of the Ussangoda serpentinite soil with the rest occupied by shrubs and trees – the pockets of Shrub-dominated patches.

Analysis of the species on the serpentinite plains showed high levels of heavy metal accumulation including Mg. Of the nine species analysed, three species *Euphorbia*, *Evolvulus*, and *Vernonia cinerea* were hyper-accumulators of Ni (>1000 µg/g). Two species, *Cassia kleinii* and *Desmodium* sp. accumulated over 900 µg/g Ni. All the species showed a high accumulation of Fe exceeding 1000 µg/g, while *Eragrostis tenella* accumulated over 800 µg/g (Table 3).

Mg is present in high amounts in the soil from the Mg containing serpentinite minerals. The plant species showed different levels of Mg uptake with *Cassia kleinii* showing the least uptake of 1518 µg/g (Table 3).

The plants have developed different mechanisms to prevent the excess of heavy metals in the soil from interfering with the cellular metabolism. The metals are either absorbed and sequestered within the plant some species have avoided uptake. *Fimbristylis falcate* and the unidentified grass species absorbed the least heavy metals as shown by their total metal content (Table 3).

Metal uptake by shrub species

The shrub species on the serpentinite soil occupy less than 5% of the total serpentinite area. However, these species have developed on isolated patches of the soil on the serpentinite site, which has different properties physically and chemically. This has apparently enabled these species to colonise the serpentinite soil, but are nevertheless exposed to the high content of heavy metals and Mg relative to non-serpentinite soil.

Nickel: Hyper-accumulation was shown by *Olax imbricate*, *Flacourtia elliptica* and *Toddalia asiatica* (Table 4).

Iron: All the shrub species accumulated less than 500 µg/g. This is in contrast to the species on the serpentinite plains (Table 4). This also provides further evidence for the heterogeneity of the soil within the serpentinite site, resulting in the two types of vegetation: prostrate and shrub species.

Magnesium: All the species tolerated a high Mg content in their tissues of over 3000 µg/g.

The total metal content in the shrub species was also high.

	Ni		Fe		Mn		Ca		Mg		Total metal (mg/g) ²	Ca/Mg in plant Tissues
	µg/g	%	µg/g	%	µg/g	%	µg/g	%	µg/g	%		
	945.80	6.19	3375.00	22.10	144.80	0.95	9285.00	60.81	1518.00	9.94	15.27	6.12
	486.80	2.63	1730.60	9.35	77.40	0.42	8154.00	44.03	8070.00	43.58	18.52	1.01
	914.09	4.43	2540.91	12.32	203.64	0.99	11154.91	54.09	5809.09	28.17	20.62	1.92
<i>illa</i>	544.60	2.37	8215.20	35.78	317.60	1.38	11543.24	50.28	2337.00	10.18	22.96	4.94
	1208.80	8.02	1458.20	9.67	117.60	0.78	5292.00	35.09	7005.00	46.45	15.08	0.76
<i>oides</i>	1016.25	3.98	3287.50	12.87	151.25	0.59	13148.35	51.45	7950.00	31.11	25.55	1.65
<i>ass</i>	307.40	2.27	1552.20	11.46	102.20	0.75	9078.12	67.04	2502.00	18.48	13.54	3.63
<i>ea</i>	1007.80	4.41	3472.40	15.19	133.40	0.58	14250.00	62.35	3993.00	17.47	22.86	3.57
<i>cata</i>	535.90	4.15	3099.70	23.99	117.90	0.91	6849.36	53.01	2317.50	17.94	12.92	2.96

of total from Ni, Fe, Mn, Ca and Mg

um of Ni, Fe, Mn, Ca and Mg

Table 4. Metal content in leaves of shrubs species

Species	Ni	Fe	Mn	Ca	Mg	Ca/Mg in plant Tissues
	µg/g	µg/g	µg/g	µg/g	µg/g	
<i>Acaciae caesia</i>	67	160	65	20943	5490	3.81
<i>Allophylus cobbe</i>	354	435	20	17825	9408	1.89
<i>Canthium dicoccum</i>	62	84	608	8658	3816	2.27
<i>Cassia auriculata</i>	56	177	78	6282	5688	1.10
<i>Flacourtia elliptica</i>	684	271	495	8618	10470	0.82
<i>Flacourtia indica</i>	1165	64	393	4503	5532	0.81
<i>Glycosmis</i>	272	262	26	6468	5658	1.14
<i>Hugonia mystax</i>	23	206	320	4488	6654	0.67
<i>Lantana camara</i>	79	221	92	6262	4942	1.27
<i>Mimosa pudica</i>	58	231	87	2337	5010	0.47
<i>Morinda tinctoria</i>	91	149	159	11128	10701	1.04
<i>Olax imbricata</i>	1081	441	159	7482	7752	0.97
<i>Pachygone ovata</i>	18	82	12	5743	4294	1.34
<i>Tarenna asiatica</i>	142	102	33	7998	5496	1.46
<i>Toddalia asiatica</i>	1063	249	236	6195	7221	0.85
<i>Ziziphus oenoplia</i>	52	257	1105	12312	6911	1.78

Physical and chemical parameters of the serpentinite soil

Introduction

The elemental composition of serpentinite soils are affected by pedogenic processes, slope and parent material composition (Cheng et al., 2009). Weathering of serpentinite rocks release varied concentrations of Mg to the overlying soil and thereby lead to spatial heterogeneity in Ca/Mg ratio (Brooks, 1987). There is little information regarding the spatial distribution of chemical properties across serpentinite sites. Research done by scientists has shown that the Ca/Mg ratio is typically higher in the A horizon (~ 1.0) than in the sub-soil where it can be as low as 0.1 (Alexander et al., 1989; Graham et al., 1990). A reason behind the variation in chemical composition between soils can be due to the mineralogical differences in their parent material. The Ca in soil varies with the parent minerals such as hornblende and tremolite (Lee et al., 2001). A study carried out in the Klamath Mountain (California) showed that its serpentine soil had a low level of K because it lacked K bearing minerals. The same site showed a variation in the concentrations of Ca and Mg across the soil profiles (Alexander et al., 1989; Graham et al., 1990). The pre-dominance of Mg on exchange sites are typical for serpentinite soils but the natural cycling will lead to an increase in the Ca/Mg ratio on the surface soils (Cleaves et al., 1974; Rabenhorst et al., 1982). In addition, the distribution patterns of soil organic C and total N have significant feedbacks to plant establishment, growth and survival (Hook et al., 1991). Among the micro-elements, Ni is considered mobile and shows a tendency to leach from the surface soils (Gasser et al., 1995). Another study indicated that Ni, Fe and Mn are mobile in the reducing environment and concentrated in the oxidizing environment (Lee et al., 2001), while Grasser and Dahlgren (1994) showed that the Ni concentration increases with organic carbon and CEC in serpentinite soils.

Materials and methods

Soil samples were collected during two seasons (dry and wet) according to the stratified random sampling method. Soil samples were taken from 40 locations excluding the boundary area to represent all different strata identified in the study site. Soil samples were taken from serpentinite plains (17), SDP1 (8), SDP2 (6), SDP3 (5) and SDP4 (4). The boundary area was sampled only during the wet season and the main sampling locations are given in Fig 8.

The following abbreviations are used below for the heterogeneity of the soil:

- SP serpentinite plain
- SDP shrub dominated patches 1 to 4 (see Fig. 3A)

Soils were sampled and analyzed for physical and chemical parameters as described previously.

The temporal changes include seasonal variation between dry and wet seasons.

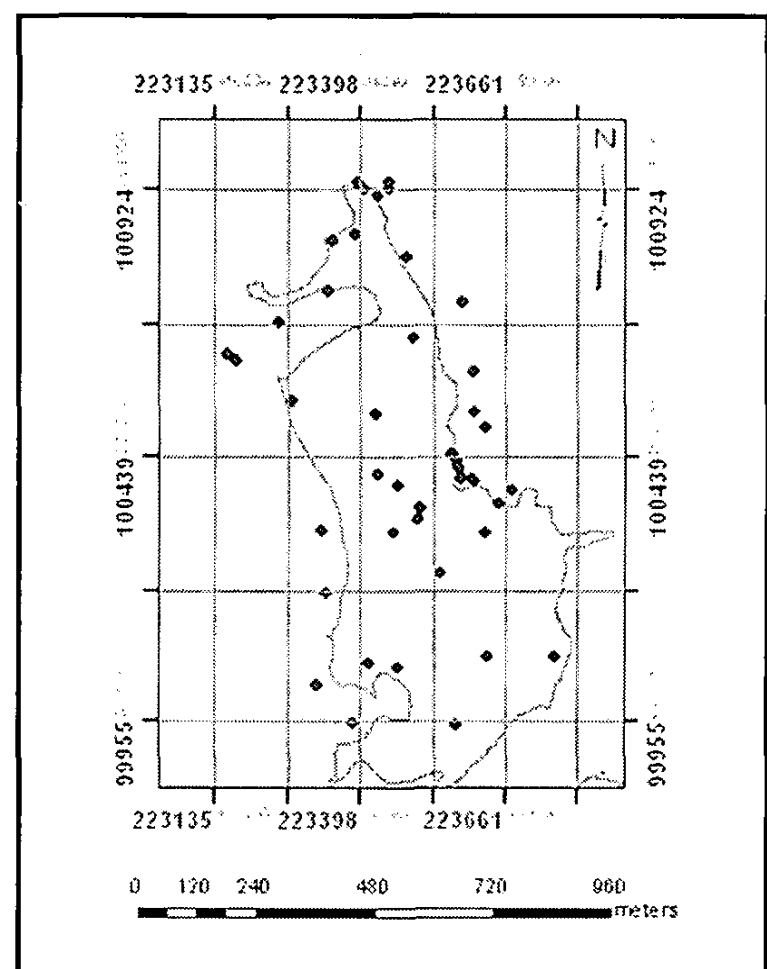


Fig 8: Soil sampling locations at the Ussangoda serpentinite deposit.

Results

Physical soil properties

Soil profile

The soil profile in the south-eastern part of the study site showed a shallow fine top soil underlying by a soil layer with small to large granules, stones and rock particles. Serpentinite bedrock was observed at a depth of 180 cm. Further, serpentinite rocks were observed at the surface of the plain as superficial outcrops (Fig 9). However the profile showed variation within the site.

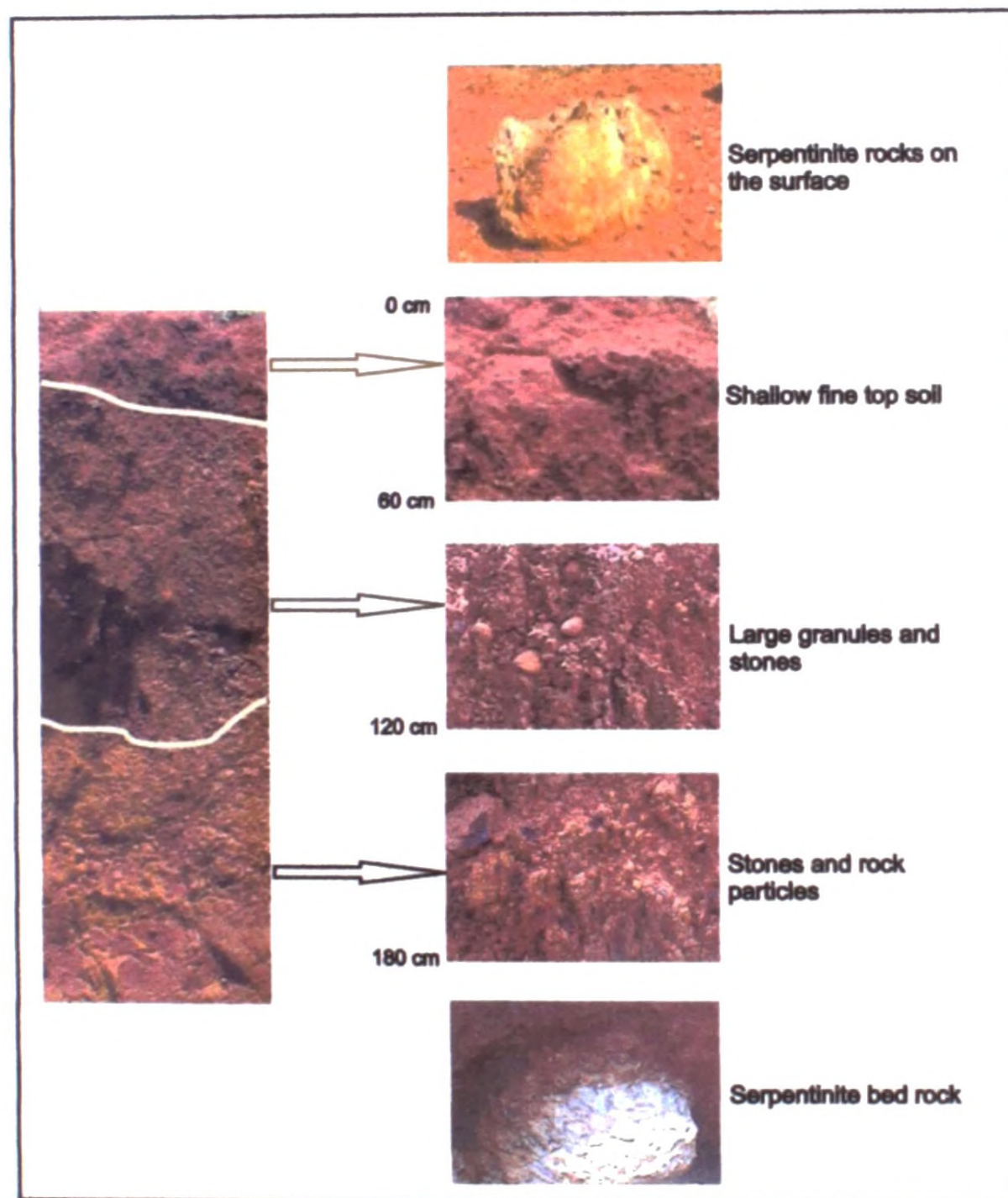


Fig 9. Soil profiles depicting different strata at the Ussangoda serpentinite deposit.

After the mechanical analysis was completed in the laboratory a percentage was obtained for each of the soil separates. These were added up for sand from the very coarse through to the very fine, to determine the total sand content. Total sand was used, along with silt and clay contents, to determine the soil textural name from the ISSS textural triangle (Fig.10).

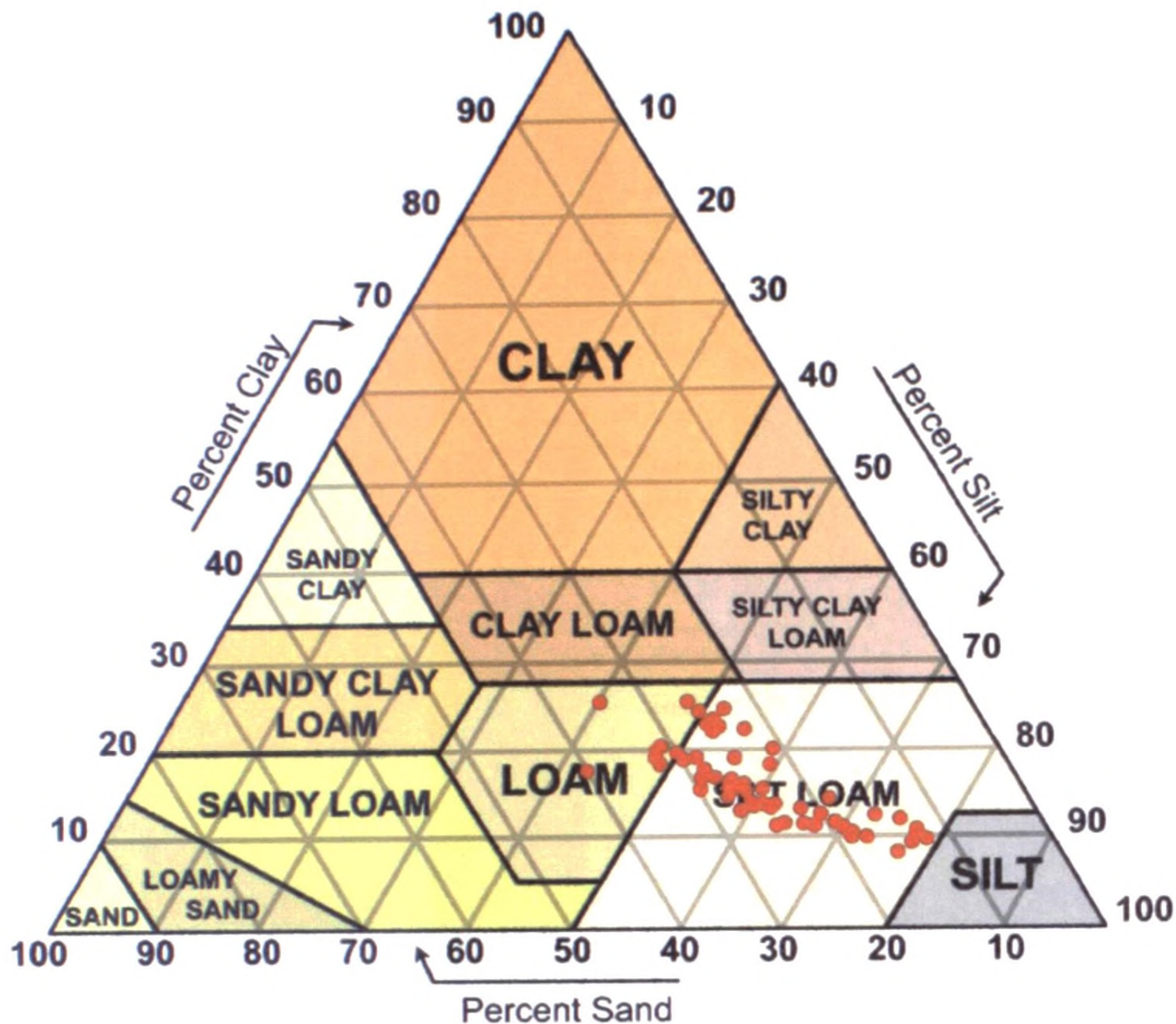


Fig.10: Classification of the Ussangoda serpentine soils According to ISSS Textural Triangle

As shown by the red dots in Fig.10, soil samples from serpentinite land falls in to 'Silt Loam' category. Silt loam has rather small amounts of sand and clay and is composed mostly of silt-sized particles. When dry, it is often rather cloddy in the field; but the lumps are easily broken between the fingers, and the soil then feels soft and floury. When moistened and squeezed between the fingers it feels soft and smooth. It will not "ribbon out" but break into small bits. Dark reddish brown, dark brown and dusky red colours were obtained with the Munsell colour chart. Those are very common colours observed in serpentinite soils. This dark colour is caused by the high iron content and is not related to a high humus level. The highest percentage of soil fraction present in the serpentinite soil was fine sand and silt (Fig. 11). Clay was present at very low levels in the serpentinite soil, where it tends to have lower clay content than "normal" soils Fig.10. Percentages of clay and fine sand of the Ussangoda soil

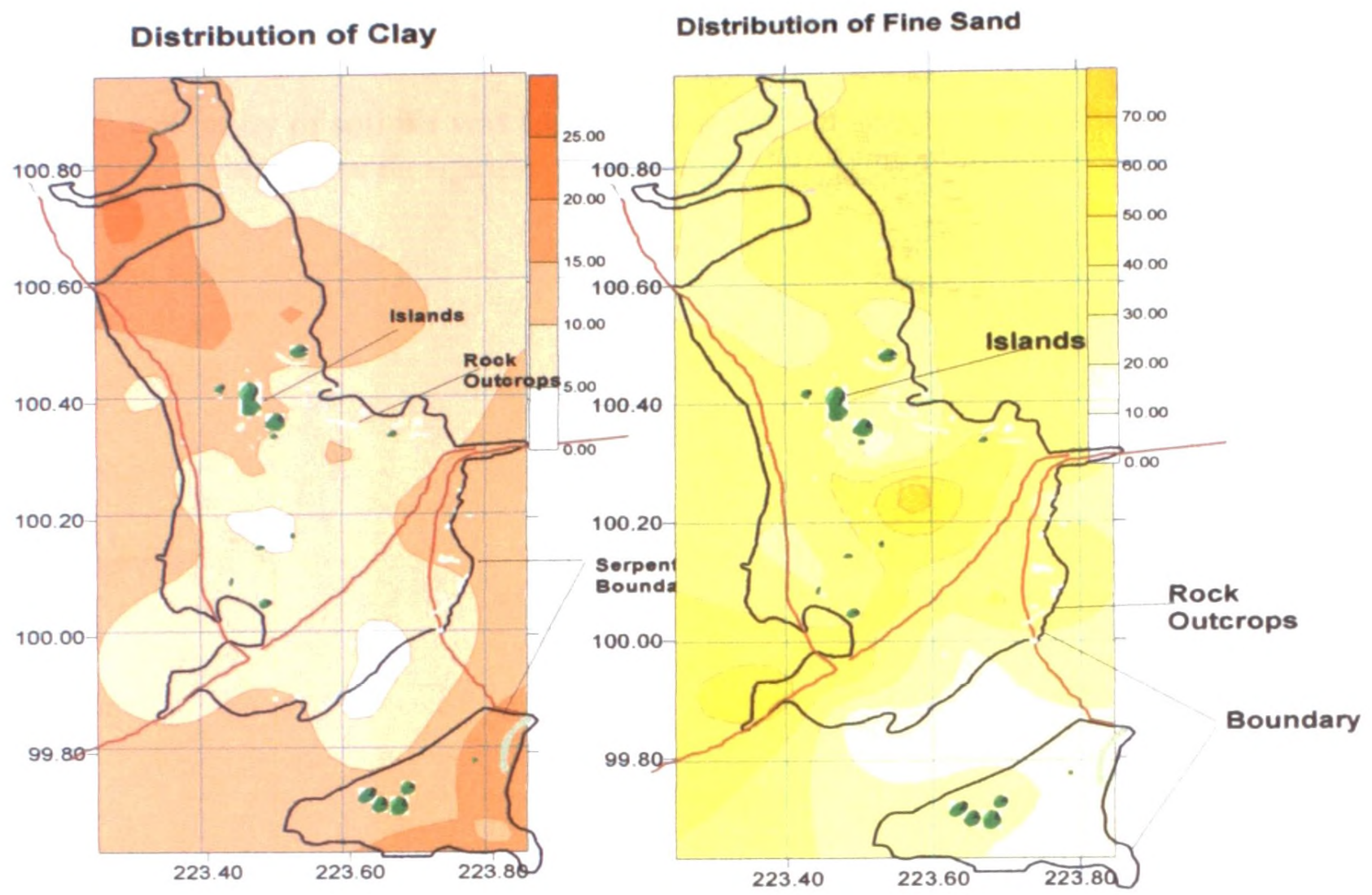


Fig. 11: Percentages of clay and fine sand of the Ussangoda serpentinite soil

Chemical soil properties

Soil pH

The temporal variability of soil pH was higher during the wet season than in the dry season at all locations (Fig 12). There were no significant differences between the seasons.

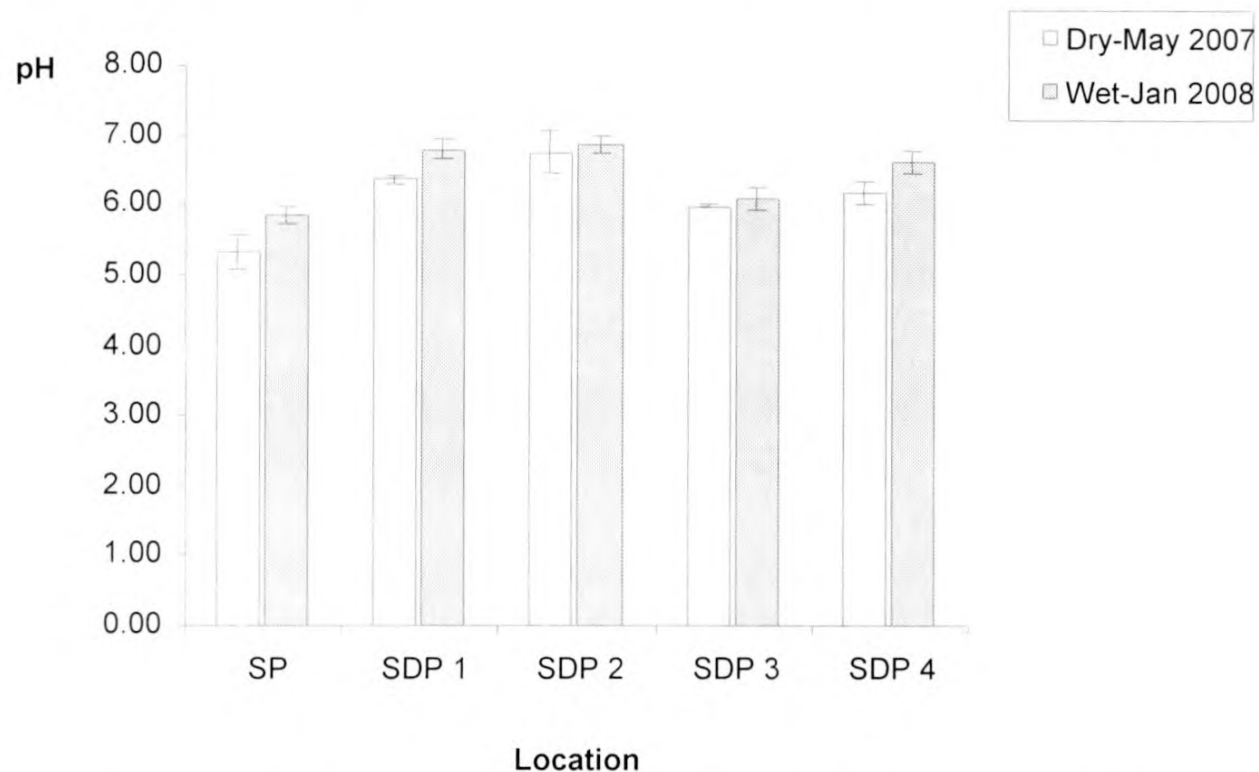


Fig 12. Soil pH in the Ussangoda serpentinite deposit during dry and wet seasons (\pm SE).

The mean soil pH in the two seasons showed little variation among the locations. An average pH level of 5.59 was observed in the serpentinite plains and it was significantly lower than SDP1 and SDP2 ($P < 0.0001$). The soil of the shrub dominated patches had pH values between 6 and 6.8. In addition the boundary area had a pH of 6.11. The plains tended towards an acidic pH than the shrub dominated patches.

Calcium

The soil Ca concentration was high in all four shrub dominated patches than in the serpentinite area (Fig 13). The northeast area beyond the boundary showed a high soil Ca concentration. In general there were many patches on the serpentinite plains with less soil Ca.

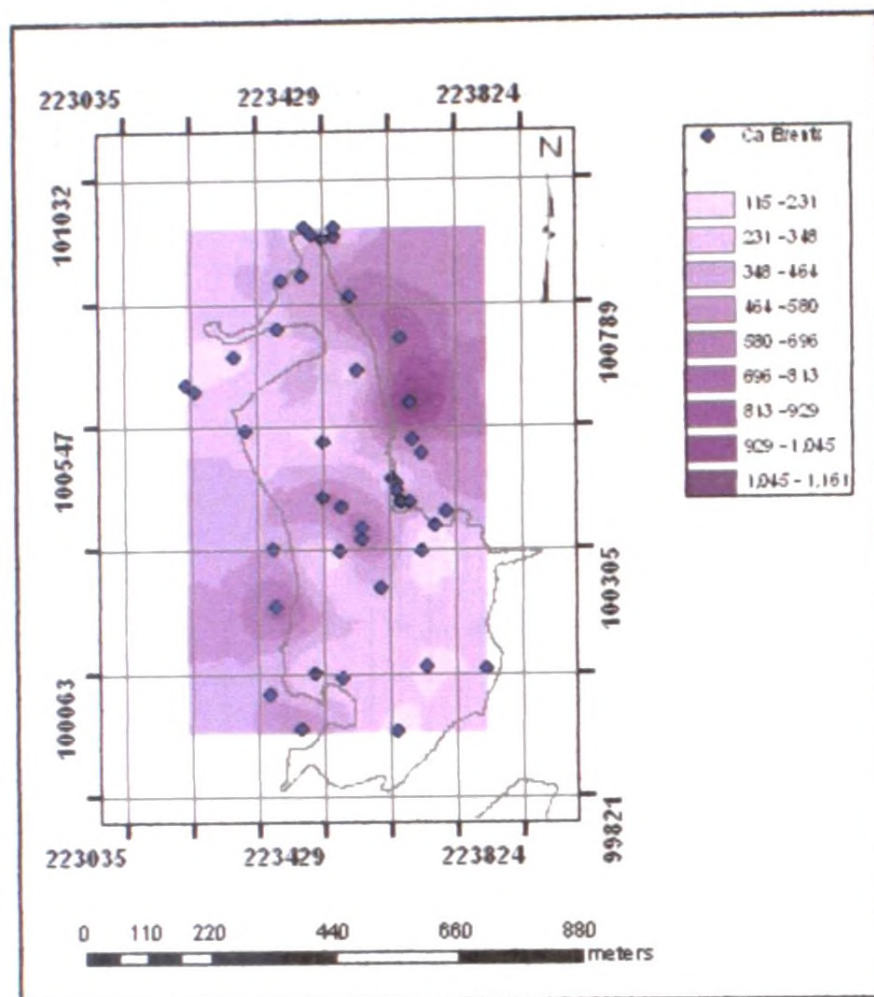


Fig 13. Spatial distribution of soil Ca levels at Ussangoda

The temporal variability showed variations among the selected locations (Fig 14). The SDP2, SDP3 and SDP4 showed a significant difference ($P=0.013$, $P<0.000$ and $P=0.046$ respectively) between the dry and wet seasons. The SDP3 and SDP4 (smaller in size) showed a sharp increase in Ca concentration during the wet season than in the dry season while SDP1 and SDP2 remained low. The Ca concentration in the serpentinite plains during the wet season was significantly higher than in the dry season ($P=0.019$). It shows that the soil in the newly originating small shrub dominated patches (SDP3 and SDP4) have high levels of Ca than the remaining serpentinite plains.

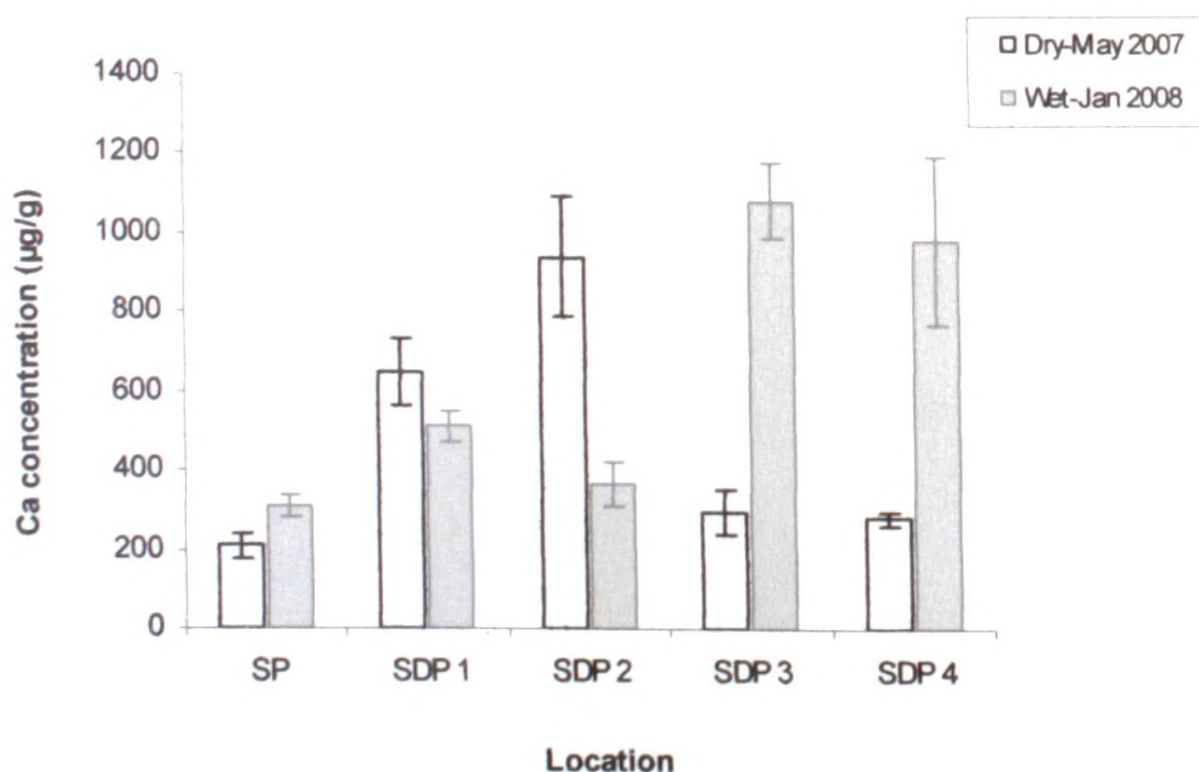


Fig 14. Soil Ca concentration (\pm SE) in selected locations at the Ussangoda serpentinite deposit during dry and wet seasons.

The mean Ca concentrations of both seasons were compared between sites to identify any trends. The soil Ca concentrations vary from 68 $\mu\text{g/g}$ to a maximum of 1568 $\mu\text{g/g}$ within the entire serpentinite area along with its boundary (Fig 15). The serpentinite plains had the significantly lowest mean soil Ca concentration (268 $\mu\text{g/g}$) with the lowest individual range of 448. The four shrub dominated patches had significantly higher soil Ca concentrations than the serpentinite plains ($P < 0.0001$). The soil Ca concentration of the boundary area did not exhibit significant difference from that of shrub dominated patches and serpentinite plains.

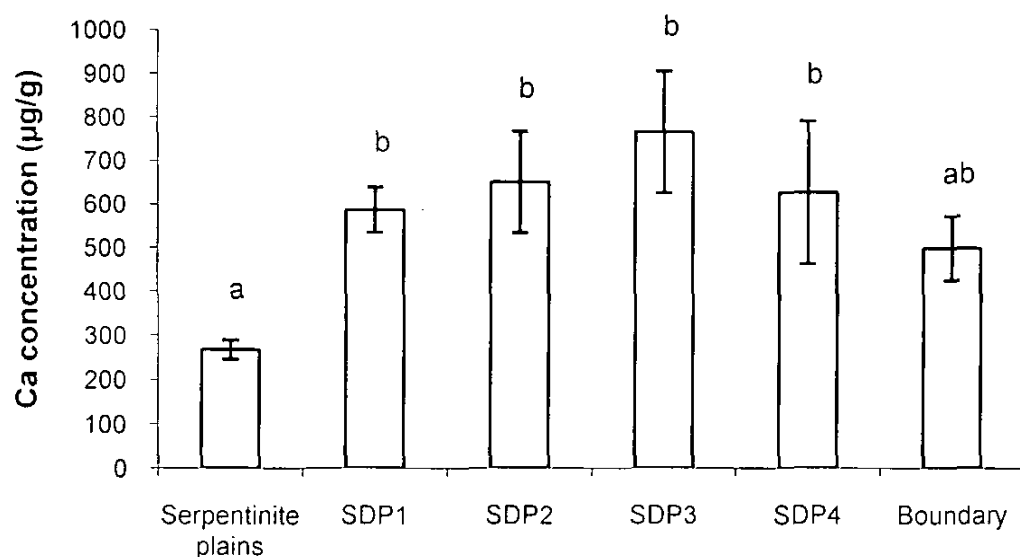


Fig 15. Mean soil Ca concentration (\pm SE) in selected locations at the Ussangoda serpentinite deposit ($n = 34, 16, 12, 10, 8, 15$ respectively).

Magnesium (Mg)

The soil Mg concentration was high at the centre (shrubs dominated patch area) than on serpentinite plains (Fig 16). The map also shows that at two locations just outside the boundary the soil Mg concentrations were higher than the serpentinite soils. This could be due to the higher elevation of the serpentinite site from the surrounding area, leading to leaching of the Mg.

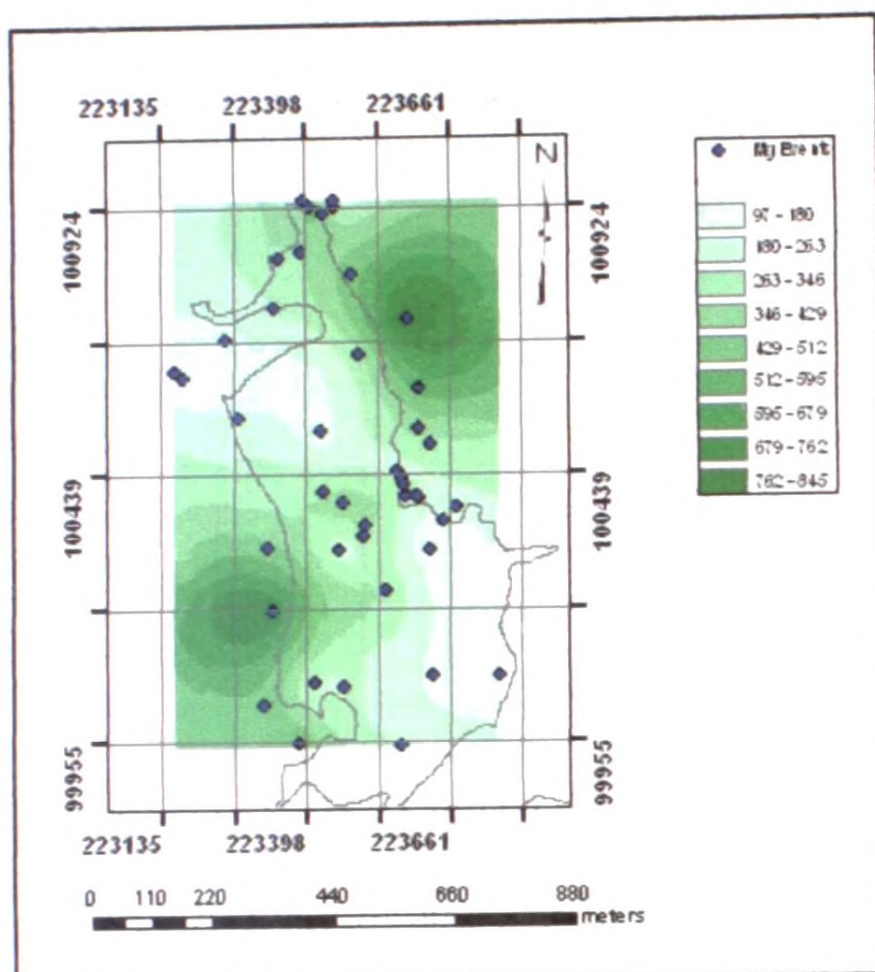


Fig 16. Spatial distribution of soil Mg levels at the Ussangoda serpentinite deposit.

The temporal variability showed no consistent trend between wet and dry seasons among stratified locations identified at Ussangoda serpentinite deposit (Fig 17). The serpentinite plain area has a higher Mg concentration during the dry season than the wet season. This was observed in only SDP2 while SDP1, SDP3 and SDP4 showed a higher value in the wet season. The Mg concentration in SDP2 was significantly higher ($P=0.022$) in the dry season than in the wet season and for SDP3 it was significantly higher in the wet season ($P<0.0001$). The variation between seasons was high in SDP3 and SDP4.

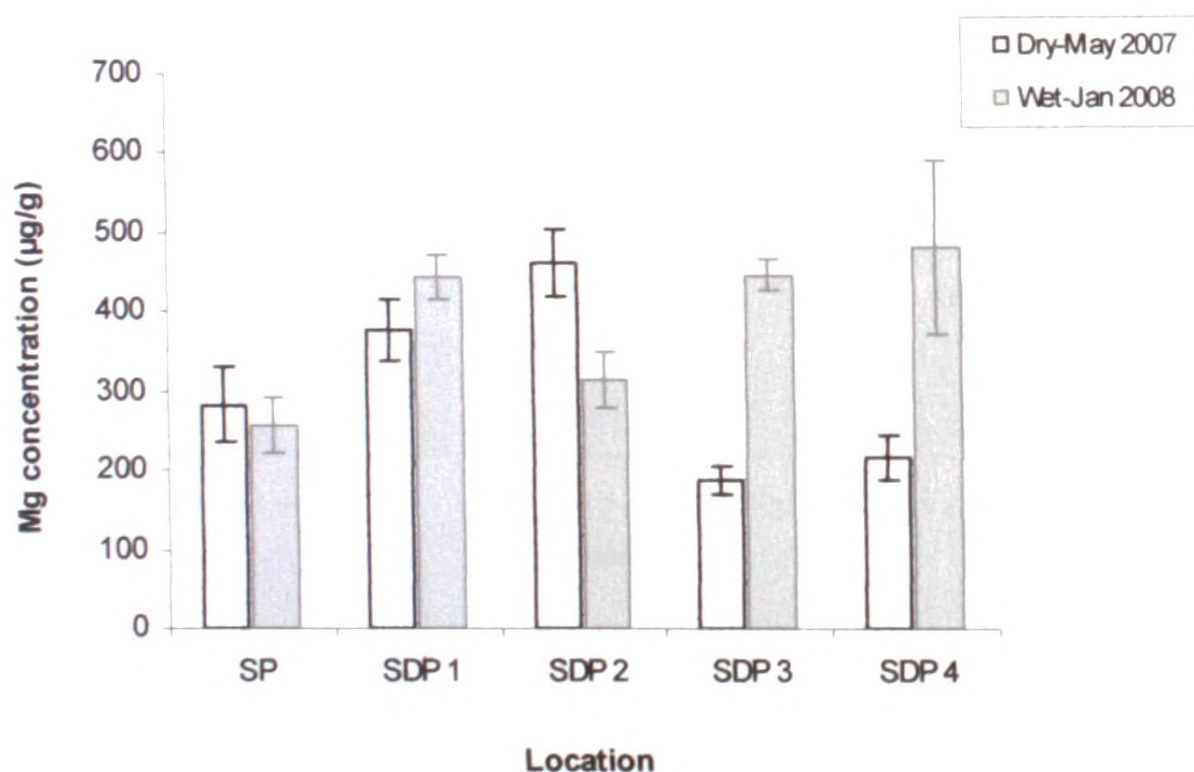


Fig 17. Soil Mg concentration in selected locations at the Ussangoda serpentinite deposit during the dry and wet seasons (\pm SE).

The Mg concentrations of the two seasons were averaged to identify possible relationships (Fig 18). The soil Mg concentration of all the shrub dominated patches were higher than that of the serpentinite plains however only the soil Mg concentration of the largest SDP1 was significantly higher than that of the serpentinite plains ($P = 0.045$).

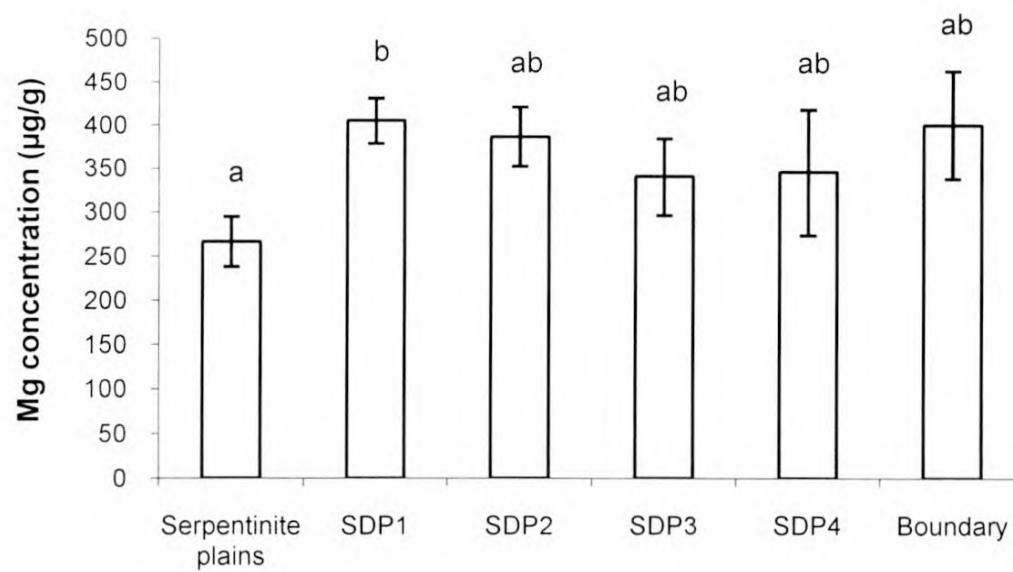


Fig 18. Mean soil Mg concentration in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 34, 16, 12, 10, 8, 15$ respectively).

Calcium to Magnesium ratio

The serpentinite plains, SDP3 and SDP4 had lower Ca/Mg ratios (0.81, 1.57 and 1.36 respectively) during dry seasons than in the wet season (1.48, 2.41 and 2.05 respectively). In contrast, the two larger SDP1 and SDP2 had a higher Ca/Mg ratio in the dry period (Fig 19).

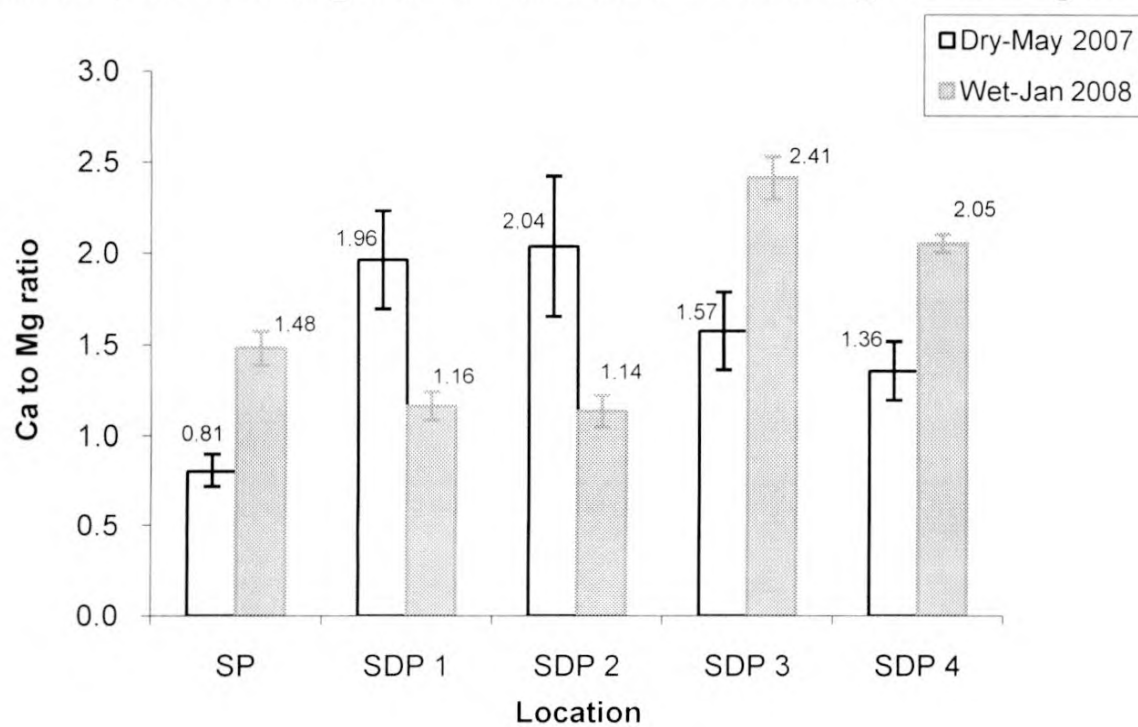


Fig 19. Soil Ca/Mg ratio in selected locations at the Ussangoda serpentinite deposit during the dry and wet seasons (\pm SE).

The Ca/Mg ratio of the two seasons was averaged to identify possible relationships (Fig 20). The average Ca/Mg ratio in the serpentinite plains was 1.17 and it was the lowest value observed among the stratified locations within the entire study site. The minimum and the maximum values observed within the serpentinite plains were 0.4 and 1.87 respectively. All four shrub dominated patches had a mean Ca/Mg ratio ranging from 1.53 to 2.07 and the boundary area had a mean value of 1.29. The SDP3 showed a Ca/Mg ratio which was significantly higher than that of serpentinite plains and the boundary area ($P < 0.0001$).

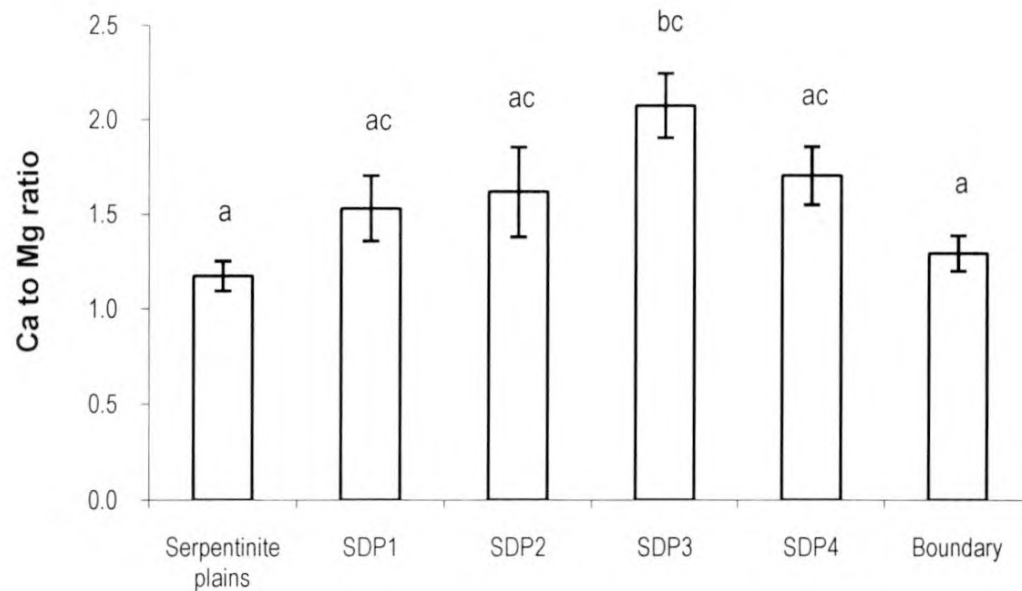


Fig 20. Mean soil Ca/Mg ratio in selected locations at the Ussangoda serpentinite deposit ($n = 34, 16, 12, 10, 8, 15$ respectively).

Total Nitrogen

The serpentinite plains had a total N content of 708 $\mu\text{g/g}$ and it was significantly lower ($P < 0.0001$) than the SDP1, SDP2 and SDP4 which contained N levels of 1892, 2031 and 1609 $\mu\text{g/g}$ respectively (Fig 21).

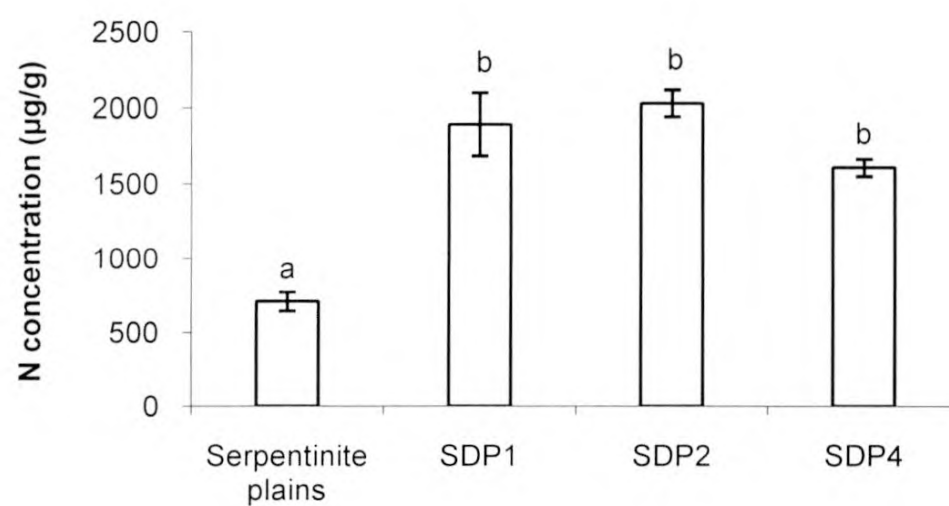


Fig 21. Mean soil N in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 14, 7, 6, 4$ respectively).

Soil Organic Carbon

The mean soil organic C was high in the shrub dominated patches than in the serpentinite plain area (Fig. 22).

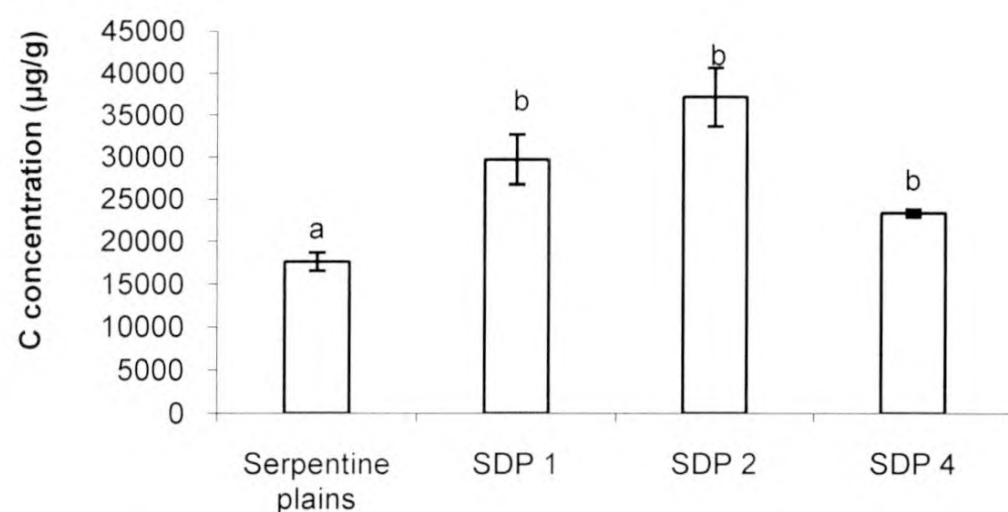


Fig 22. Mean soil organic C in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 14, 7, 6, 4$ respectively).

Soil Carbon to Nitrogen ratio

The mean C/N ratio of the serpentinite plain was 26 and it was significantly higher ($P < 0.0001$) than that of SDP1, SDP2 and SDP4 whose C/N ratios were 15, 18 and 14 respectively (Fig 23).

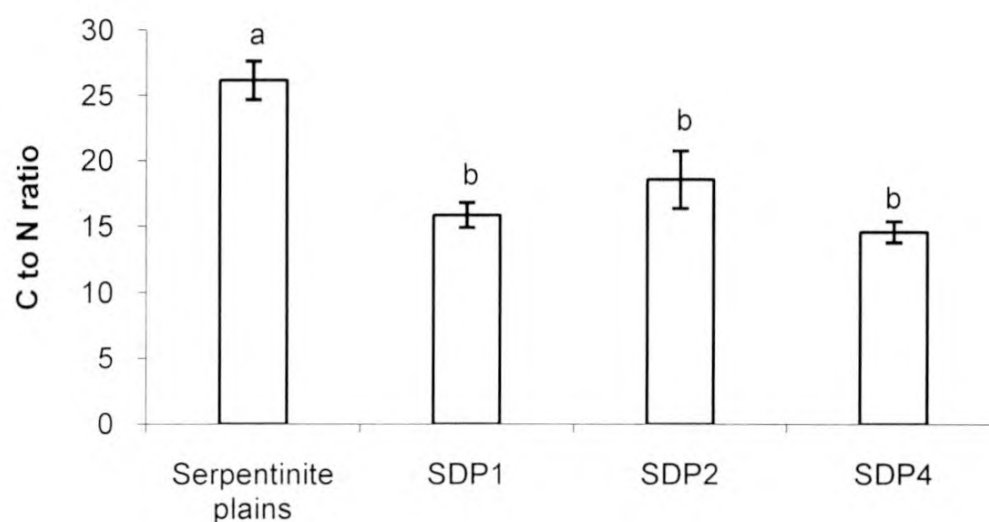


Fig 23. Mean soil C/N ratios in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 14, 7, 6, 4$ respectively).

Soil Phosphorous

The soil phosphorous level (383 $\mu\text{g/g}$) on the serpentinite plains was significantly lower ($P=0.004$) than that of SDP1 and SDP2, which contained 474 and 482 $\mu\text{g/g}$ respectively (Fig 24).

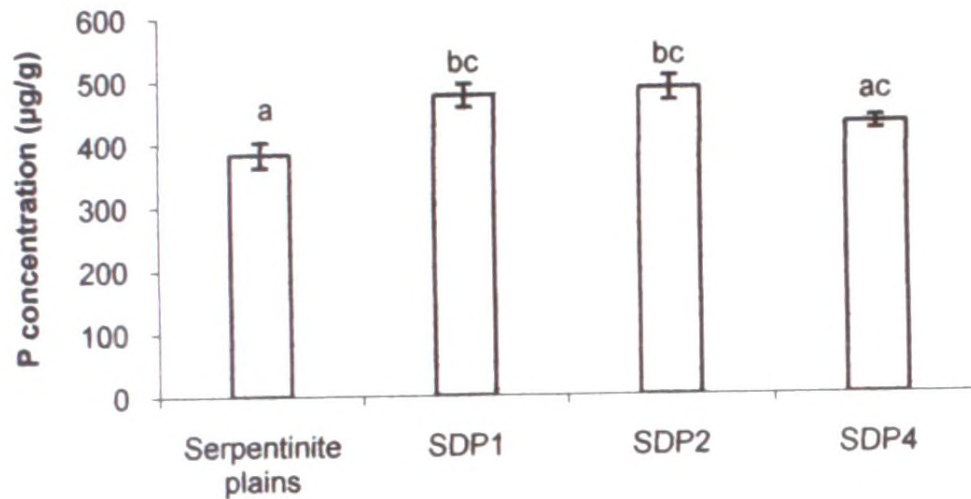


Fig 24. Mean soil P concentration in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 14, 7, 6, 4$ respectively).

Potassium

The soil K concentration ranged between 230 and 300 $\mu\text{g/g}$ at the centre of the serpentinite site near the shrub dominated patches than the rest of the serpentinite plains (Fig 24). The K concentration was also high in the south west region outside the boundary area.

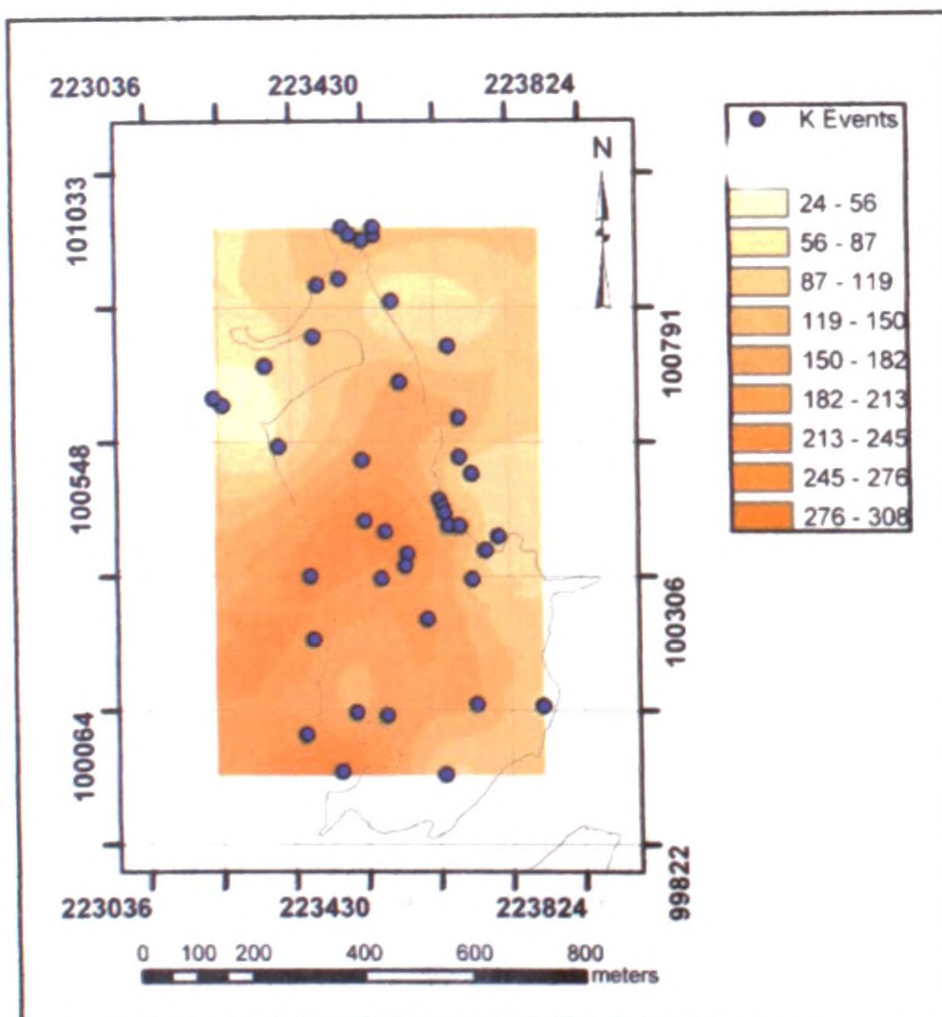


Fig 24. Spatial distribution of soil K levels at the Ussangoda serpentinite deposit.

The serpentinite plain and the boundary area had the lowest K concentrations of 138.2 and 123.3 $\mu\text{g/g}$ respectively (Fig 25). The shrub dominated patches had an average concentration of K

higher than 230 $\mu\text{g/g}$ and each was significantly higher than the serpentinite plains and the boundary area ($P < 0.0001$). The variation within the shrub dominated patches was low (CV values < 40) compared to the serpentinite plains and the boundary area which had CV values of 49 and 85 respectively. These results indicate that the K concentration is highly variable in the serpentinite plains and the boundary area.

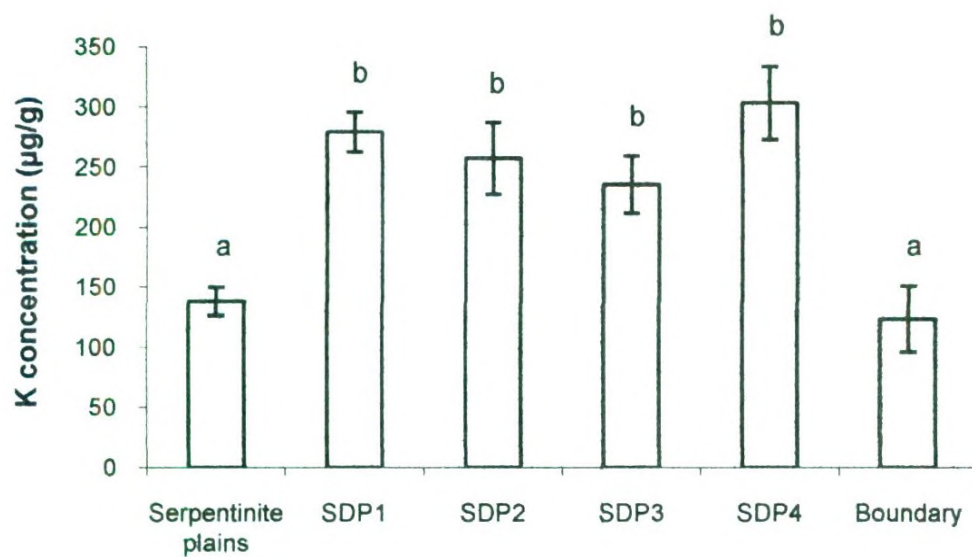


Fig 25. Mean soil K concentration in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 34, 16, 12, 10, 8, 15$ respectively).

Nickel

The soil Ni concentration is low at the centre and it has concentrated towards the North and North East area and in the South West area (Fig 26).

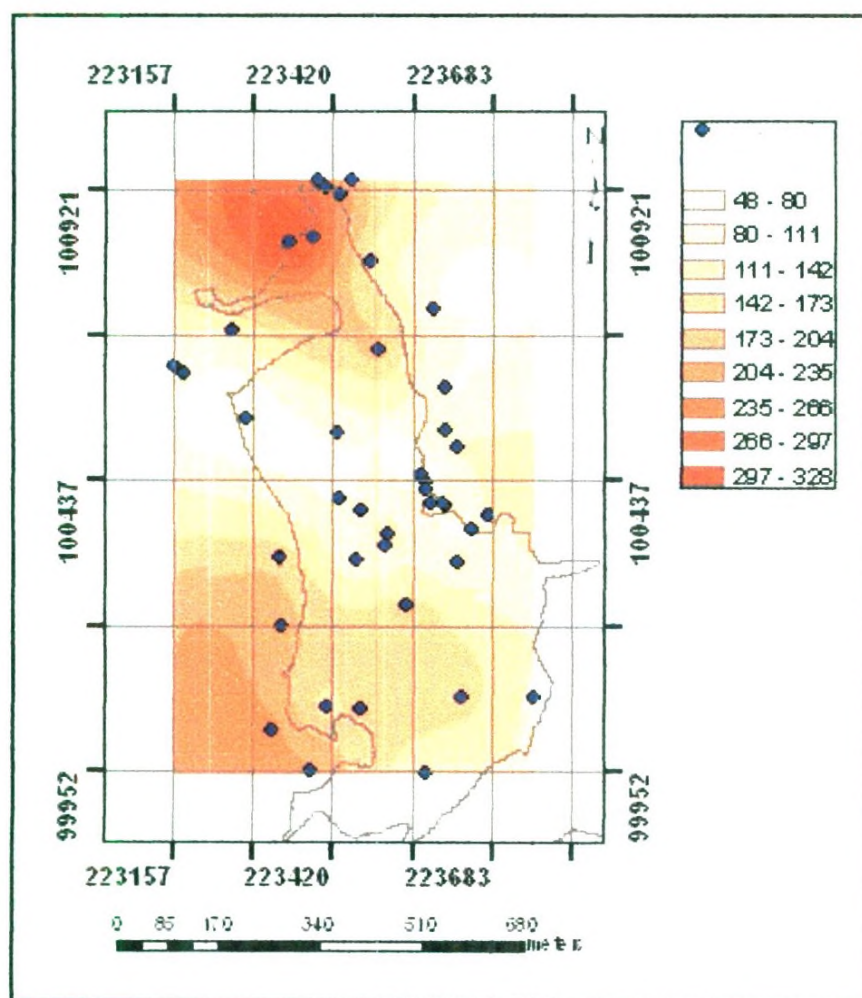


Fig 26. Spatial distribution of soil Ni levels at the Ussangoda serpentinite deposit.

The mean Ni concentrations for the wet and dry seasons the nickel concentration in the serpentinite plains and the boundary area was 131 $\mu\text{g/g}$ and 145 $\mu\text{g/g}$ respectively (Fig 27). The Ni concentration in the shrub dominated patches were variable with SDP2 showing the significantly highest concentration. The SDP3 and SDP4 contained very low Ni concentrations of 75 $\mu\text{g/g}$ and 45 $\mu\text{g/g}$ respectively. The serpentinite plains and the boundary area was significantly higher than the SDP4, which had the least Ni ($P < 0.0001$).

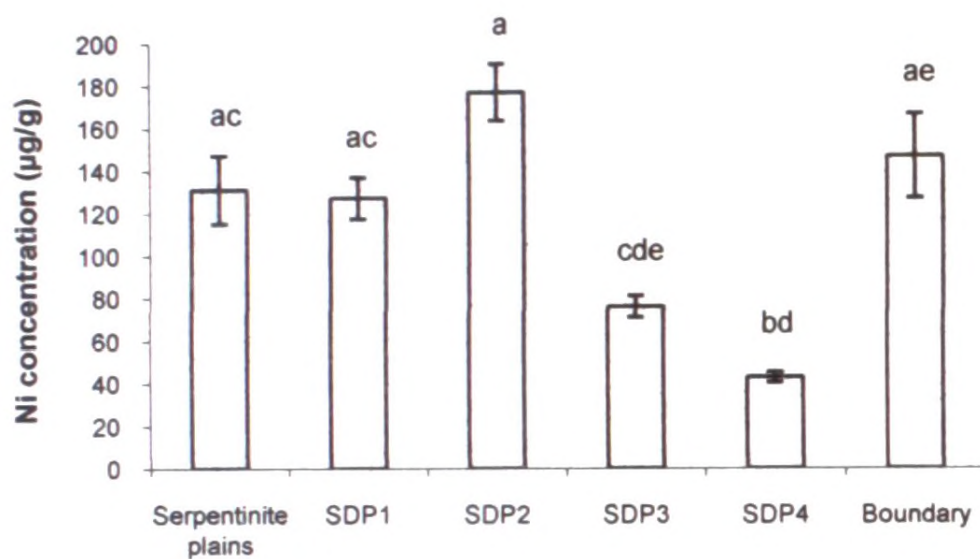


Fig 27. Mean soil Ni concentration in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 34, 16, 12, 10, 8, 15$ respectively).

Ferrous

The soil Fe concentration is low at the centre and it has concentrated towards the North East and South West areas (Fig 28).

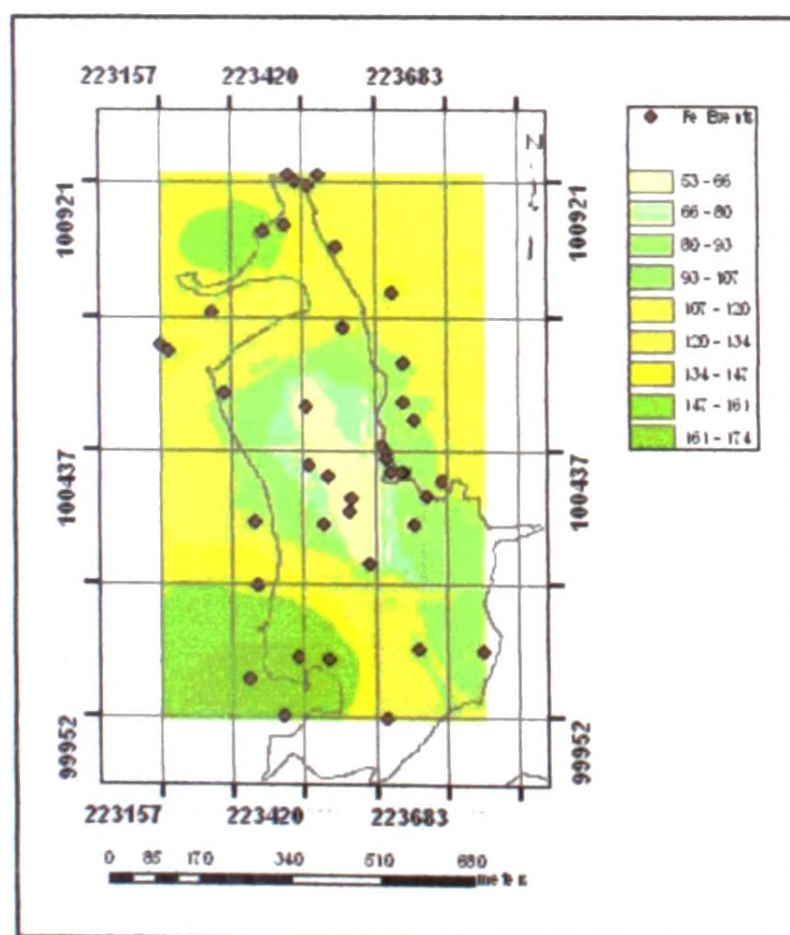


Fig 28. Spatial distribution of soil Fe levels at the Ussangoda serpentinite deposit.

The serpentinite plains and SDP2 showed significant differences between the dry and wet seasons ($P=0.025$ and $P=0.007$ respectively, Fig. 29). The Fe concentration was higher during the wet season than the dry season, except in SDP3.

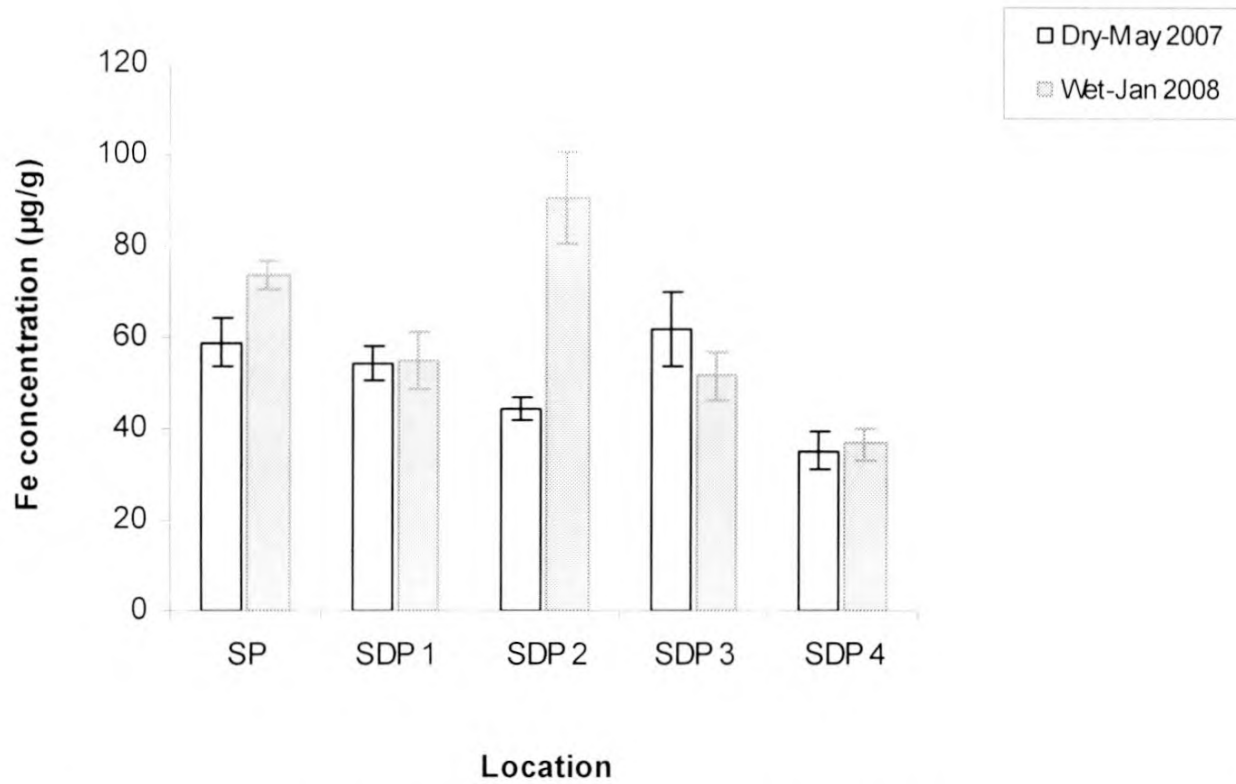


Fig 29. Soil Fe concentration in selected locations at the Ussangoda serpentinite deposit during dry and wet seasons (\pm SE).

The boundary area and the serpentinite plains contained higher mean Fe concentrations of $148 \mu\text{g/g}$ and $67 \mu\text{g/g}$ respectively than the other locations and they were significantly higher than the SDP4 ($P<0.0001$, Fig 30).

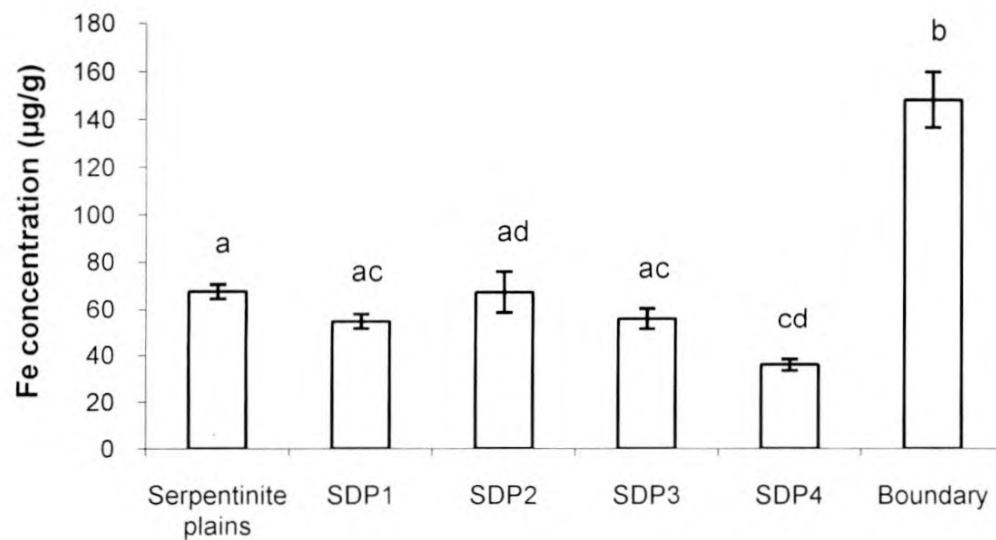


Fig 30. Mean soil Fe concentration in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 34, 16, 12, 10, 8, 15$ respectively)

Total and available metals in the soil

Although the total availability of the metals are high, the bio-availability is much less to the plants. Mg is an available of nearly 1/3 of the total available content in the soil (Table 5). The absorption of excess Mg by the plants is reflected on the morphological changes to adapt to the serpentinite soil.

Table 5. The total and bio-available forms of the major serpentine elements in the Ussangoda soil (mean \pm SD).

Soil moisture

The temporal variability of soil moisture shows a variation in the stratified locations (Fig 31). The moisture % in serpentinite plains, SDP1, SDP2, SDP3 and SDP4 were significantly higher during the wet season than the dry season ($P < 0.0001$, $P = 0.004$, $P < 0.0001$, $P = 0.004$ and $P = 0.001$ respectively). A high variation was observed in SDP3 during the dry season.

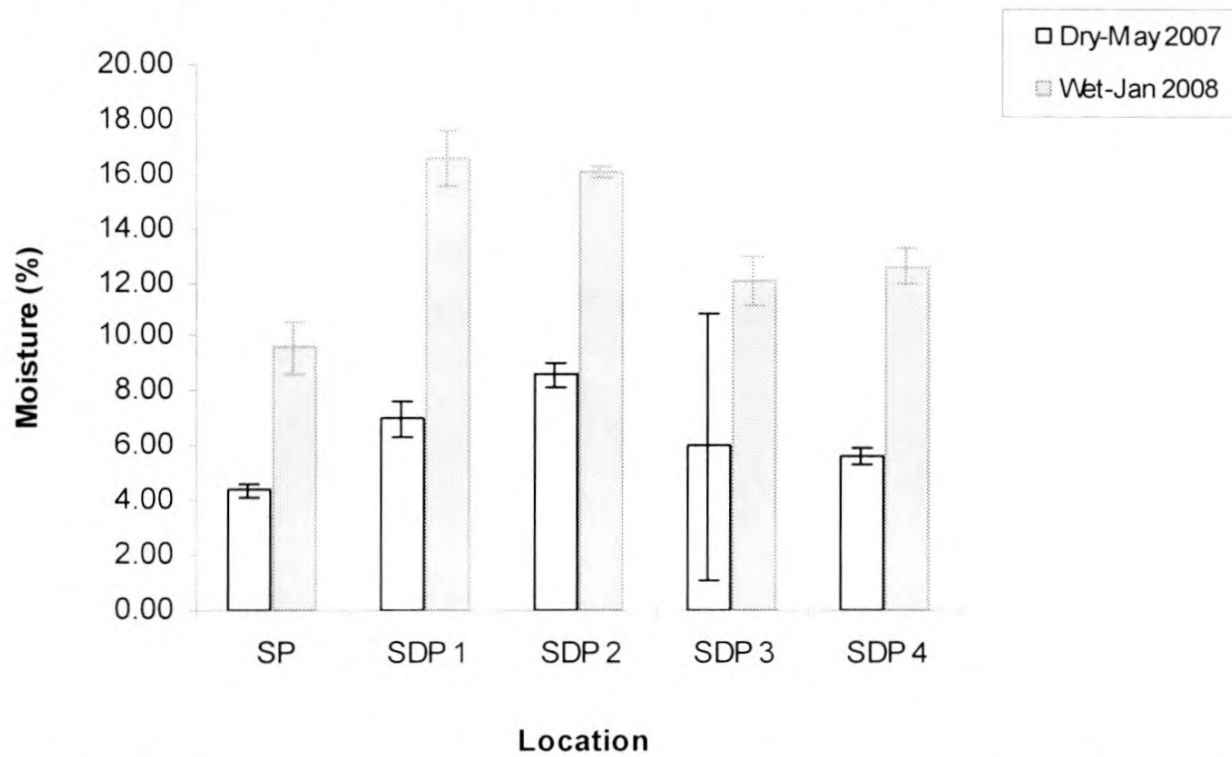


Fig 31. Soil moisture content in selected locations at the Ussangoda serpentinite deposit during dry and wet seasons.

Soil organic matter

The soil organic matter levels varied significantly between locations (Fig 32). The soil organic matter was higher in the wet season than in the dry season in all locations though only serpentinite plains, SDP1, SDP2 and SDP4 showed significant differences between wet and dry seasons ($P < 0.0001$, $P = 0.017$, $P = 0.024$ and $P = 0.01$ respectively).

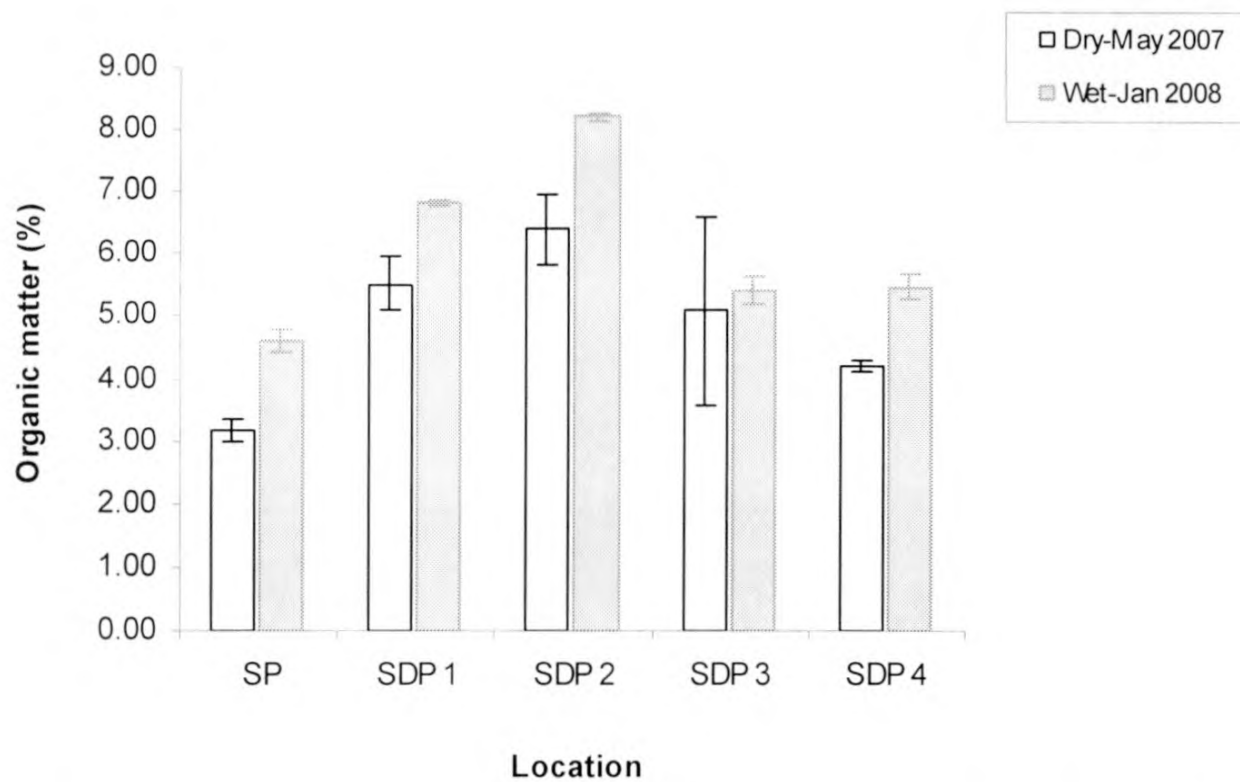


Fig 32. Soil organic matter in selected locations at the Ussangoda serpentinite deposit during dry and wet seasons (\pm SE).

When considering wet and dry seasons together, the lowest organic matter content (3.9 %) was observed in the serpentinite plains, which was significantly lower than the boundary area, SDP1 and SDP2 (6.87, 5.84 and 6.86 respectively; Fig 33). The SDP4 too had significantly lower organic matter level than that of the boundary area ($P < 0.0001$).

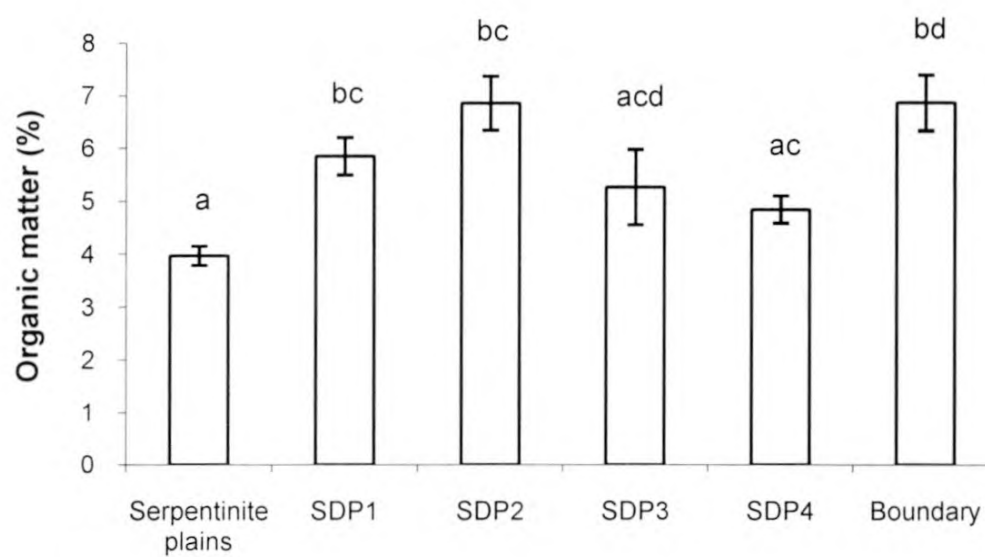


Fig 33. Mean soil organic matter content in selected locations at the Ussangoda serpentinite deposit (\pm SE; $n = 31, 12, 9, 8, 8, 15$ respectively).

Soil Conductivity

The soil conductivity of the serpentinite plain was higher in the dry season than the wet season (Fig 34). In contrast, the soil conductivity in SDP1, SDP2, SDP3 and SDP4 were high during the wet season. The soil of the serpentinite plain contained an average conductivity of 87 which was the lowest among all sites and it also showed the highest variation. All other locations had high soil conductivity than the above except the SDP3.

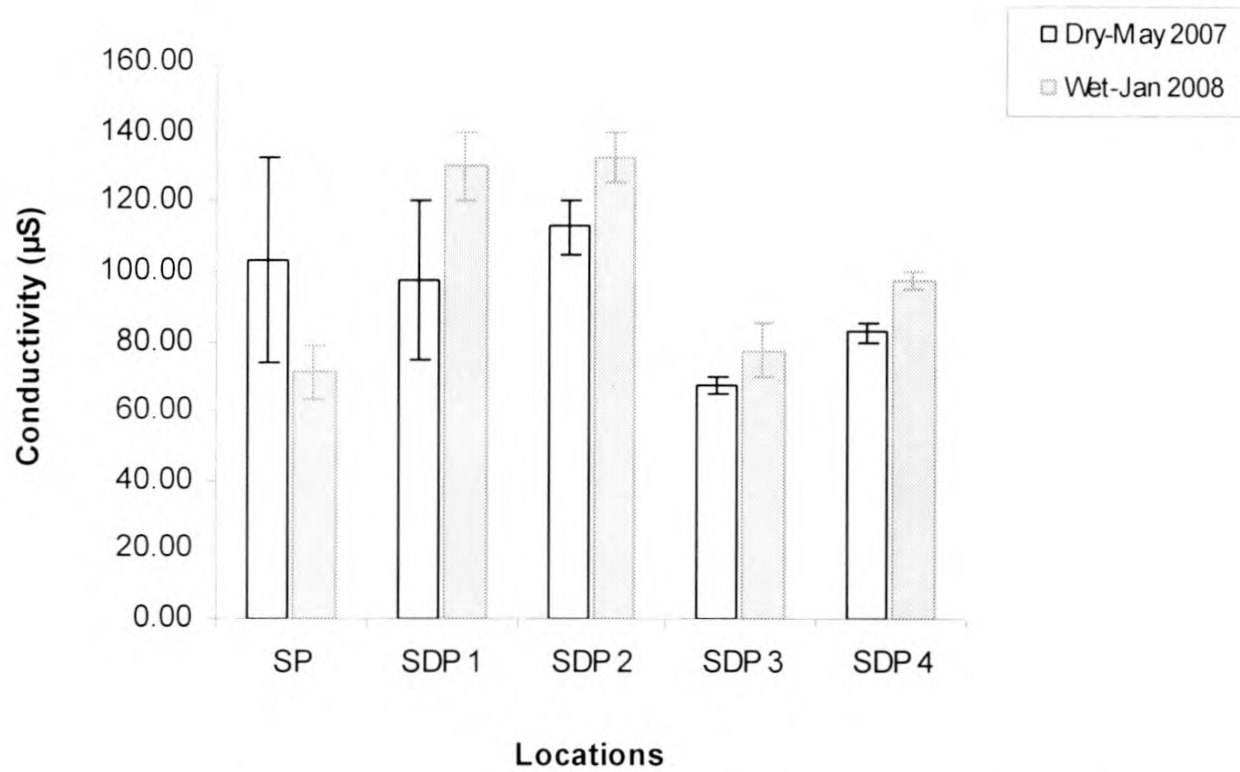


Fig 34. Soil conductivity in selected locations at the Ussangoda serpentinite deposit during dry and wet seasons (\pm SE).

Soil Cation Exchange Capacity (CEC)

The Soil CEC was very high during the wet season than the dry season in all the locations (Fig. 35). The CEC in the wet season showed the serpentinite plains, SDP1, SDP2 and SDP4 were significantly higher than in the dry season. ($P < 0.0001$, $P = 0.025$, $P = 0.025$ and $P = 0.036$ respectively).

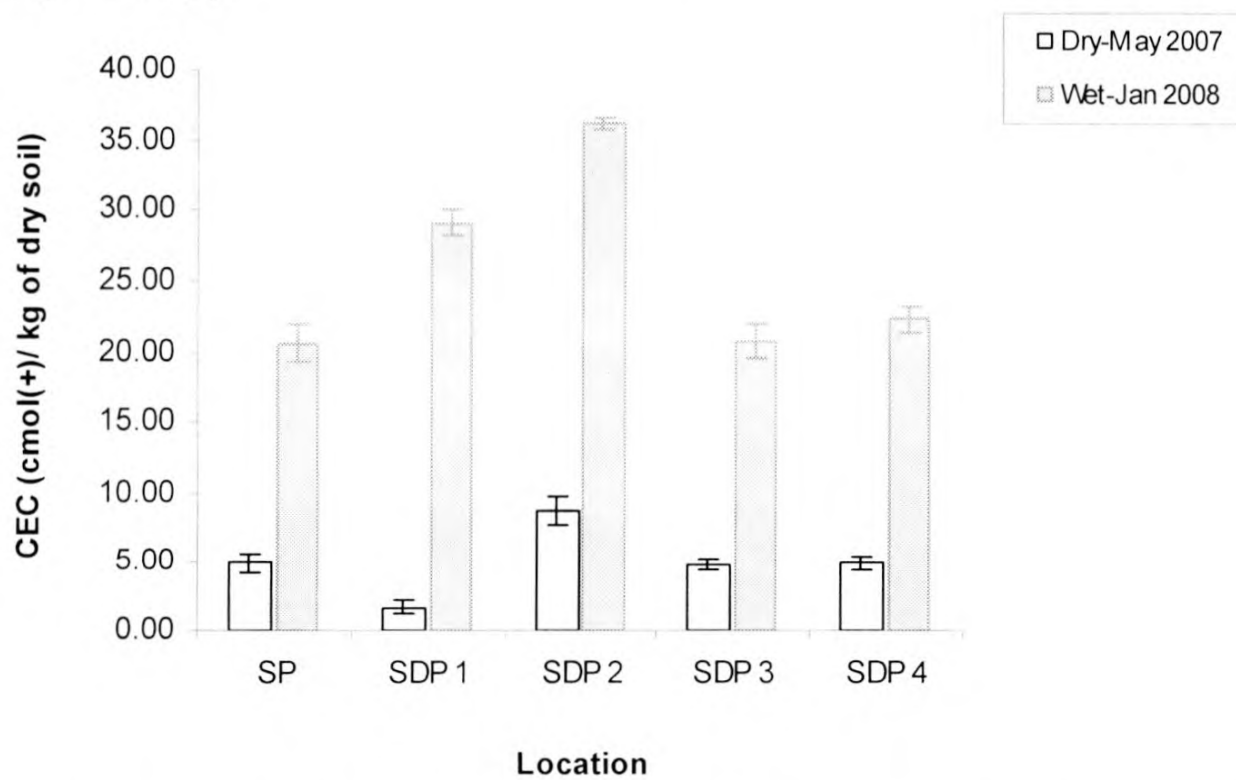


Fig 35. Mean soil CEC in selected locations at the Ussangoda serpentinite deposit during dry and wet seasons (\pm SE).

The mean CEC of 12.7 in the serpentinite plains was significantly lower ($P = 0.027$) than the boundary area with the highest CEC of 31.5 (Fig 36). The SDP1 and SDP2 had high values however they showed very high variation among them.

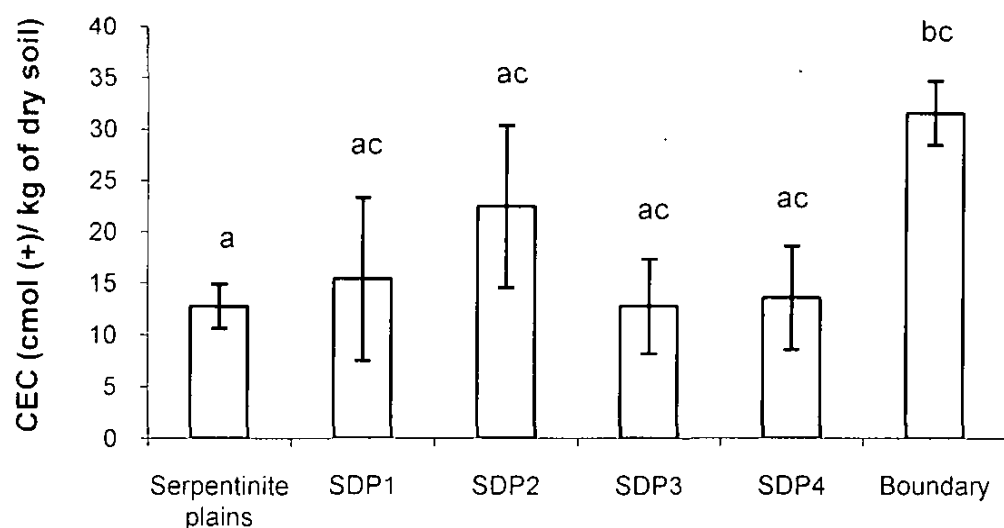


Fig 36. Mean soil CEC in selected locations, for both seasons, at the Ussangoda serpentinite deposit (\pm SE; $n = 16, 4, 4, 4, 4, 5$ respectively).

Discussion

The spatial variability of the soil parameters can be attributed to the differences in the parent material whose weathering over time determines the overlying soil. The temporal changes of soil characteristics reflect the changes over time (seasonal changes). This occurs mainly due to the climate parameters especially rainfall. Increase of rainfall affects the soil by changes of the soil moisture content.

Spatial variability

The mean pH of the serpentinite plain soil was 5.5 and in the shrub dominated patches it ranged between 6 and 7. The results of this study show that there is a variation in pH between the serpentinite plains and shrub dominated patches. However the previously recorded pH value for the Ussangoda serpentinite deposit by Rajakaruna and Baker (2004) was highly acidic at the level of 4.6. The obtained pH values are close to neutral pH levels and according to Rajakaruna et al., (2009) it shows similarities to world wide serpentinite soils. The pH values at Ussangoda shows similarities to other serpentinite sites in Canada (Roberts and Proctor, 1992), New Caledonia (Proctor, 2003), South Africa (Reddy et al., 2009) and Tropical East Asia (Proctor et al., 2003).

The mean values of Ca, Mg, N, C, K, Moisture, organic matter and cation exchange capacity in the shrub dominated patches were greater than in the serpentinite plains. Although both Ca and Mg were high in the shrub dominated patches, the Ca/Mg ratio was high in the shrub dominated patches (1.53 - 2.07) than the serpentinite plains (0.4 - 1.87). The serpentinite plains at Ussangoda showed that it has a mean Ca/Mg ratio of 1.17, which is higher than the value of 0.7 defined for serpentinite soils by Brooks (1987). The low Ca content of the serpentinite plain reflects the underlying lithology with low Ca minerals. This indicates that the soils were derived

from underlying serpentinite rocks which has low Ca values. The shrub dominated patches reflect the presence of Ca rich lithology which is typical to regional ecology of the area. Higher Mg values are typical in most serpentinite locations in the world. The Ca/Mg ratio identified by Rajakaruna and Baker (2004) is close to the upper limit of the values obtained for the serpentinite plains. The results at the Ussangoda serpentinite deposit show similarities to sites in West Italian Alps (Lazaro et al., 2006) and Sabah, Malaysia (Proctor et al., 2003).

The major plant nutrients C, N, P and K were high in shrub dominated patches in comparison to the serpentinite plains. The serpentinite plain soil at Ussangoda was deficient in N, P and K. This is the first recorded information on soil N, organic C and P values for the Ussangoda serpentinite deposit. The previously identified levels of K by Rajakaruna and Baker (2004) were close to the values of shrub dominated patches. According to Brady et al., (2005) and Brooks (1987) these results show similarities to other serpentinite sites in the world. These parameters are considered important because they relate with the concept 'serpentine syndrome' as suggested by Brady et al. (2005).

The C/N ratio in the serpentinite plain (close to 30) was significantly higher than that of the shrub dominated patches (< 20). The high C/N ratio in the serpentinite plain increases the immobilization rate of N, by storage in its organic form in the soil. The low C/N ratio in the shrub dominated patches (< 20) result in mineralization of N that favours release of N to the soil. This positively influences plant growth (Hook et al., 1991).

The results of the soil Na levels is probably a consequence of the sea-spray during the dry season where it has concentration over the higher elevation area including the shrub dominated patches. During the wet season the soil Na decreases due to leaching.

The average soil Ni concentration of large shrub dominated patches (1 and 2) is similar or higher than the serpentine plains. However, the small shrub dominated patches (3 and 4) have comparatively low soil Ni concentrations. This suggests that the origin of shrub dominated patches may have occurred initially at sites with low soil Ni. The soil Ni values obtained by Rajakaruna and Baker (2004) were as low as concentrations in smallest shrub dominated patches.

Temporal variability

Considering the changes over time (seasonal), organic matter has increased with the increase of the soil moisture content. It is due to the favourable conditions preventing organic matter degradation. The increase of organic matter helps to increase the cation binding sites in the soil. Thereby it increases the ability of the soil to retain more cations and tends to increase the soil cation exchange capacity. The increase of the moisture content in soil during the wet season contributed to a small increase in the soil pH. In certain patches the concentration of Ca and K increased during the wet season. The increase of Ca mobility during the wet season was prominent in the newly emerging shrub dominated patches. This is not prominent in the large shrub dominated patches (1 and 2). The increase of the Ca/Mg ratio creates a favourable environment for plant growth. It is presumed that these small patches behave as sites which provided the basic needs of the soil environment for plant growth for the origination of new shrub dominated patches.

V General discussion

The Ussangoda serpentinite deposit is identified as one of the five serpentinite deposits close to the Precambrian suture zone between the Vijayan and Highland Complex of Sri Lanka.

The Ussangoda serpentinite deposit commonly known as 'Ussangoda' is famous in the history of Sri Lanka due to myths associated with this site. One is that a meteorite struck and burnt the vegetation and some also say that it is an area where a fierce battle had occurred and the spilled blood has made the soil red. According to ancient Hindu legend, the emperor king Ravana landed his special chariot at this point. These myths persisted over the years in the absence of a scientific explanation. This study should dispel these myths and establish the science of this unusual habitat.

This site was first identified as a serpentinite deposit during early geological surveys carried out in Sri Lanka. However, the first scientific botanical observation of a serpentinite deposit was described in the book "Serpentine and its vegetation - a multi disciplinary approach" by Brooks (1987). This documented only two plant species at Ussangoda. Thereafter studies by Seneviratne et al. (2000) and Rajakaruna and Bohm (2002) documented 14 and 9 species respectively. The study by Rajakaruna and Baker (2004) highlighted the soil conditions at Ussangoda. The present work is an extension to the study by Iqbal et al., (2006).

The influence of edaphic factors on serpentine vegetation is mainly due to chemical parameters followed by physical and biological parameters (Brady et al., 2005). The physical parameters contribute in variable extents to maintain characteristic chemical properties of the soil. The main results of this study were compared with the preliminary study of Rajakaruna and Baker (2004) and are summarized below (Table 6).

Soil pH has an inverse relationship with metal bioavailability (Maier et al., 2000). The pH at the serpentinite plains varies between 5-6 and at the shrub dominated patches it varies between 6 – 6.8. The serpentinite plains are acidic than the shrub dominated patches and these values are greater than the values obtained by Rajakaruna and Baker (2004) (Table 6). Soil pH showed a significant ($P < 0.01$) positive relationship with soil cation exchange capacity. The pH level of serpentinite plains favour metal bioavailability than the shrub dominated patches, however, the difference in pH was between 5 and 6.8. The pH range between 5-7 was observed worldwide except in sites at France, Western Newfoundland (Canada), Aosta Valley (Italy) and Mount Kinabalu (Malaysia) (Proctor 2003, Shellari et al. 1998).

The Ca/Mg ratio of less than 0.7 is a characteristic attribute of serpentinite soils (Brooks, 1987). During the initial survey the mean Ca/Mg ratio in serpentinite plain soil was determined as 0.6 but in the subsequent detailed study the mean Ca/Mg ratio was 1.17, ranging from 0.4 to 1.87. The mean Ca/Mg ratio of 1.17 of this study is lower than 1.83 identified by Rajakaruna and Baker (2004). The results showed that Ca/Mg ratio varies spatially and temporally. According to the results of Ca/Mg ratio, the site at Ussangoda is similar to sites at Aosta Valley (West Italian Alps – 1.14) and Mount Kinabalu (Malaysia – 1.14) (Proctor 2003, Shellari et al. 1998).

Table 6. Summarized mean data of soil parameters at the Ussangoda serpentinite deposit (Mean \pm standard error) and compared with the study of Rajakaruna and Baker (2004).

Element	SP	SDP 1	SDP 2	SDP 3	SDP 4	Boundary	Rajakaruna and Baker (2004)
pH (H ₂ O)	5.5 (\pm 0.1)	6.5 (\pm 0.1)	6.8 (\pm 0.1)	6 (\pm 0.07)	6.4 (\pm 0.1)	6.1 (\pm 0.1)	4.6 (\pm 0.1)
Moisture *	7 (\pm 0.7)	9 (\pm 1)	10 (\pm 1)	9 (\pm 1)	9 (\pm 1)	12 (\pm 2)	ND
Conductivity (μ S)	87 (\pm 15)	114 (\pm 13)	122 (\pm 7)	73 (\pm 4)	90 (\pm 5)	96 (\pm 10)	ND
Ca **	268 (\pm 21)	587 (\pm 52)	651 (\pm 117)	766 (\pm 140)	627 (\pm 164)	499 (\pm 74)	166 (\pm 13.9)
Mg **	266 (\pm 28)	405 (\pm 26)	386 (\pm 34)	340 (\pm 44)	346 (\pm 72)	400 (\pm 62)	94.6 (\pm 10.4)
Ca/Mg	1.01	1.44	1.68	2.25	1.81	1.24	1.83
N **	708 (\pm 65)	1892 (\pm 207)	2031 (\pm 86)	ND	1609 (\pm 57)	ND	ND
C/N	26 (\pm 1)	16 (\pm 1)	19 (\pm 2)	ND	15 (\pm 1)	ND	ND
P **	383 (\pm 20)	474 (\pm 18)	482 (\pm 19)	ND	424 (\pm 10)	ND	ND
K **	138 (\pm 11)	278 (\pm 16)	257 (\pm 29)	235 (\pm 23)	302 (\pm 30)	123 (\pm 27)	224.2 (\pm 27)
Ni **	131 (\pm 16)	127 (\pm 9)	176 (\pm 13)	75 (\pm 5)	42 (\pm 2)	145 (\pm 19)	45.6 (\pm 5.9)
Fe **	68 (\pm 3)	55 (\pm 3)	67 (\pm 9)	56 (\pm 5)	36 (\pm 3)	148 (\pm 12)	16.2 (\pm 0.6)
Mn **	34 (\pm 3)	19 (\pm 1)	27 (\pm 5)	41 (\pm 5)	27 (\pm 5)	31 (\pm 4)	63.8 (\pm 8.2)
CEC ***	13 (\pm 2)	15 (\pm 8)	22 (\pm 8)	13 (\pm 5)	14 (\pm 5)	32 (\pm 3)	8.5 (\pm 0.8)
OM *	4 (\pm 0.1)	6 (\pm 0.3)	7 (\pm 0.5)	5 (\pm 0.7)	5 (\pm 0.2)	7 (\pm 0.5)	ND

ND = Not determined, * = (%), ** = (μ g/g), *** = cmol(+)/kg of dry soil

The adsorption affinities to soil particles are similar among Ca and Mg next to Al (FitzPatrick, 1983). Therefore the most adsorbed cations to soil particles at the study site will be Ca and Mg followed by K and micro-nutrients. The variation of soil Ca and Mg within the study site is therefore related with heterogeneity of minerals in the weathering bed rock.

The amount and transport of plant nutrients, metals and other organic chemicals in soil are determined by 'adsorption' on to soil particles and is related with cation exchange capacity and organic matter of soil (Sparks, 2003). The results show that cation exchange capacity and organic matter are high in the shrub dominated patches than the serpentinite plains mainly during the wet season. The maximum CEC during the dry season was close to 10 and during the wet season was above 35 (cmol(+)/kg of dry soil). Therefore shrub dominated patches favour high retention of nutrients at the Ussangoda serpentinite deposit. The cation exchange capacity of this study is higher than the results obtained by Rajakaruna and Baker (2004) (Table 6). Soil moisture and organic matter exhibit a significant ($P < 0.01$) positive relationship with soil cation exchange capacity and this signifies their inter-relationship.

The soil organic C and N increases due to greater accumulation of organic matter in soil and thereby C/N ratio influence on plant growth (Zuo et al., 2009; Hook et al., 1991). The shrub dominated patches have a comparatively high accumulation of organic matter (Table 5) which favours high levels of soil organic C, soil N and a low C/N ratio than the serpentinite plains which favours mineralization of N and thereby release N to the soil. There was a significant ($P < 0.01$) negative relationship between soil N and C/N ratio.

Nickel is an important trace element available in serpentinite soils (Brooks, 1987). The two small shrub dominated patches (3 and 4) have a low Ni concentration than the larger shrub dominated patches (1 and 2) (Table 5). It is likely that origination of shrubs took place at locations with low Ni concentrations. Only the Ni concentration of the smallest shrub dominated patch was close to the result obtained by Rajakaruna and Baker (2004). The low Ni could be due to its mobility and tendency to leach from surface soils as observed by Grasser et al., (2005). The Ni concentration did not clearly show an increasing relationship with cation exchange capacity as observed by Grasser and Dahlgren (1994).

The soil moisture content was favourable in the shrub dominated patches than the serpentinite plains even during the dry season (Table 6). Thus shrub dominated patches have a suitable level of soil moisture for seed germination and plant growth. The large shrub dominated patches have a soil moisture content that is twice that of the serpentinite plains during the dry season. Further, it also shows less retention of soil moisture in the serpentinite plains where the surface soil is exposed to environment. The plant cover prevents evaporation in the shrub dominated patches and its favourable soil physical parameters contribute to suitable levels of chemical parameters. In the serpentinite plains, the soil hardness increases with low moisture conditions and this may prevent seedling germination and growth.

Plants on this serpentinite site are adapted to tolerate the unfavourable soil and climate conditions. The plants on the serpentinite plains are prostrate and have a low shoot/root ratio, an indication of the extensive root system of the prostrate plants to search for water. The plants on the shrub dominated patches are well established showing good adaptability to the environment and are expanding their area gradually, especially during the wet season.

The soil solution, as defined by Sparks (2003), is the aqueous medium that contains its solutes. The soil solutions of the shrub dominated patches are rich in nutrients suitable for plant growth (N, P and K) than in the serpentinite plain area (Table 5). It is a proportion from the nutrient concentration of the soil solution that is accumulated by plants. Continuous uptake of soil nutrients, accumulate in the plants. Therefore the plant nutrient concentration is higher than the available nutrient concentration in the soil solution.

The average soil Ni concentration in shrub dominated patches 1 and 2 was 150 $\mu\text{g/g}$, however, only six species out of the 16 analysed from the shrub dominated patches had concentrations higher than 100 $\mu\text{g/g}$ of Ni. This shows that the plants on the shrub dominated patches have the ability to tolerate the soil Ni concentrations with minimum plant Ni accumulation. These plants are referred to as metallophytes (Whiting et al. 2004). Metal hyper-accumulation (Brady et al., 2005 and Baker et al., 2000) was observed in many of the species on the plains. *Hybanthus*

enneaspermus was one of the hyper-accumulators (1800 µg/g). This genus is also a Ni hyper-accumulator in New Caledonia with above 3000 µg/g (Jaffre et al., 1979; Reeves et al., 1999). Three of the shrub species showed hyper-accumulation of Ni.

Our results agrees with two facts (poor plant productivity and distinct vegetation) from the three highlighted by Whitaker (1954) regarding the 'serpentine problem'. The other fact of high rate of endemism was not observed at the Ussangoda serpentinite deposit. The problem at Ussangoda is based on many edaphic factors and as pointed out by Kruckeberg (1986), it can be referred to as geo-edaphics since these characteristics have a geological influence. The most important edaphic characteristics at the Ussangoda serpentinite deposit include organic matter, Ca/Mg, Ni, C/N, N, P and K.

Soil in the Ussangoda serpentinite deposit is varied in its characteristics with space and season. The behaviour of plant growth is a result of adapting to both the edaphic and climate conditions. The soil of serpentinite plains and shrub dominated patches are different in certain characteristics and it gives an indication of the impact of edaphic characteristics on plant growth. The soil in Ussangoda serpentinite deposit show typical indications with low Ca/Mg ratio which varied within the site. The mean Ca/Mg ratio in this soil was above 0.7; however, there were many individual results below the 0.7 level. The major nutrients required by a plant (N, P and K) are comparatively low and may be the other factor influencing plant growth. The immobilization and mineralization of N determines the N content in the serpentinite soil.

The plants growing in the Ussangoda serpentinite deposit have evolved to tolerate the harsh edaphic characteristics or accumulate metals from the substrate. Almost all the plants are facultative metallophytes due to the absence of site specific endemics. A combination of edaphic and climate conditions has lead to the stunted growth of plants on the plains.

VI CONCLUSION

From this study we conclude that:

The Ussangoda serpentinite soil shows typical characteristics of serpentinite soil elsewhere in the world, however, with variations. The peculiar vegetation is due to the soil characteristics that have arisen from the weathering of the serpentinite parent material. The serpentinite soil has significant different characteristics from non-serpentine soil, in its physical and chemical properties.

Plant species have adapted and evolved on this soil to give a unique assemblage of plants with unusual morphological and physiological adaptations.

The heterogeneity of the soil within the serpentinite site is a result of apparent differences in the minerals in the bed-rock. This has resulted in favourable composition of minerals in the soil for plant growth in selected locations such as the shrub dominated patches.

We also speculate that people may have settled on the plains in ancient times resulting in subsequent changes in the soil. These altered locations could be the shrub dominated patches. There is evidence of such settlements from the identification of tools used by humans in ancient times by the Dept. of Archaeology.

Finally, it is imperative that this unique ecological habitat be conserved for posterity, which is a living laboratory to study plant adaptation under a peculiar regime of unfavourable soil and climate conditions and the geological significance of this site.

VII REFERENCES

- AESL. (1999). Methods for the analysis of soil, plant, water and environmental samples. Agricultural and Environmental Services Laboratories, College of Agriculture and Environmental Sciences, University of Georgia. (<http://aesl.ces.uga.edu/protected/methods/detailsstl-soil/or7.html>)
- Alexander, E.B., Coleman, R.G., Keeler-Wolf, T. and Harrison, S.P. (2007). Serpentine geocology of Western North America: geology, soils and vegetation. Oxford University Press. New York, 512.
- Alexander, E.B., Adamson, C., Zinke, P.J. and Graham, R.C. (1989). Soils and conifer forest productivity on serpentinized peridotite of Trinity Ophiolite, California. *Soil Sci.* 148, 412-423.
- Anderson, J.M. and Ingram, J.S.I. (1993). Tropical soil biology and fertility: A hand book of methods (2nd edition), CABI Publishing, Wallingford Oxon, 240.
- Arabas, K.B. (2000). Spatial and temporal relationships among fire frequency, vegetation and soil depth in an eastern North American serpentine barren. *Journal of the Torrey Botanical Society* 127(1), 51-65.
- Baker, A.J.M., McGrath, S.P., Reeves, R.D. and Smith, J.A.C. (2000). Metal hyperaccumulator plants: A review of the ecology and physiology of a biological resource for phytoremediation of metal polluted soils. In *Phytoremediation of contaminated soil and water*, eds. N. Terry and G. Banuelos. Lewis, Boca Raton, FL, USA, 85-108.
- Brady, K.U., Kruckeberg, A.R. and Bradshaw Jr, H.D. (2005). Evolutionary ecology of plant adaptation to serpentine soils. *Annual review of ecology, evolution and systematics* 36, 243-266.
- Brearley, F.Q. (2005). Nutrient limitation in a Malaysian ultramafic soil. *Journal of tropical Forest Science* 17(4), 596-609.
- Brooks, R.R. (1987). Serpentine and its vegetation. A multidisciplinary approach. Dioscorides Press, Portland OR, USA, 454.
- CCD (2003). Revised Coastal Zone Management Plan, Sri Lanka. Coast Conservation Department, Colombo (Unpublished).
- Chapin, F.S., Walker, L.R., Fastie, C.L. and Sharman, L.C. (1994). Mechanisms of primary succession following deglaciation at Glacier Bay, Alaska. *Ecol. Monogr.* 64, 149-175.
- Cheng, C.H., Jien, S.H., Tsai, H., Chang, Y.H., Chen, Y.C. and Hseu, Z.Y. (2009). Geochemical element differentiation in serpentine soils from the Ophiolite complexes, Eastern Taiwan. *Soil Sci.* 174, 283-291.
- Cleaves, E.T., Fisher, D.W. and Bricker, O.P. (1974). Chemical weathering of serpentinite in the eastern piedmont of Maryland. *Geol. Soc. Am. Bull.* 85, 437-444.
- Coleman, R.G. (1971). Petrologic and geophysical nature of serpentinites. *Bull. Geol. Soc. Am.* 82, 897-918.

- Cooray, P.G. (1994). The Precambrian of Sri Lanka: a historical review. *Precambrian Res* 66, 3-18.
- Deraniyagala, S. (1992). The prehistory of Sri Lanka Part I. Memoirs of the Archaeological Survey of Ceylon, V. 8. Sri Lanka Department of Archaeological Survey.
- Dissanayake, C.B. (1982). The geology and geochemistry of the Uda Walawe serpentinite, Sri Lanka. *Journal of the National Science Council of Sri Lanka* 10(1), 13-34.
- Dissanayake, C.B. & Van Riel B.J. (1978). Petrology and geochemistry of a recently discovered nickeliferous serpentinite from Sri Lanka. *Journal of the Geological Society of India* 19, 464-471.
- Fernando, G.W.A.R. (2001). Genesis of metasomatic sapphirine-corundum-spinel-bearing granulites in Sri Lanka, an integrated field, petrological and geochemical study, University of Mainz, Germany, 175 (<http://ArchiMeD.uni-mainz.de/pub/2001/0029>).
- FitzPatrick, E.A. (1983). Soils, their formation, classification and distribution. IBM press, Longman group (FE) ltd, UK.
- Grasser, U.G., Juchler, S.J., Hobson, W.A. and Sticher, H. (1995). The fate of chromium and nickel in subalpine soils derived from serpentine. *Can. J. Soil. Sci.* 75, 187-195.
- Grasser, U.G. and Dahlgren, R.A. (1994). Soil-phase speciation and surface association of metals in serpentinitic soils. *Soil Sci.* 158, 409-420.
- Graham, R.C., Diallo, M.M. and Lund, L.J. (1990). Soils and mineral weathering on phyllite colluvium and serpentinite in northwestern California. *J. Soil Sci. Soc. Am.* 54, 1682-1690.
- Grierson, A.J.C. (1980). Family Compositae. In A Revised handbook to the Flora of Ceylon – Vol 1, eds. M.D. Dassanayake, F.R. Fosberg. Amerin publishing Co. Pvt Ltd, New Delhi, 132-135.
- Hook, P.B., Burke, I.C. and Lauenroth, W.K. (1991). Heterogeneity of soil and plant N and C associated with individual plants and openings in North American shortgrass steppe. *Plant Soil* 138, 247-256.
- Iqbal M.C.M., Kulasekara, L., Rajakaruna, N. & Iqbal, S.S. (2006). Plant-soil relations of a serpentine site in the Southern coast of Sri Lanka. Proceed. of the Fifth International Conference on Serpentine Ecology, Siena 9-13 May 2006.
- IUCN (2004). The Environmental profile of the Rekawa, Ussangoda and Kalametiya (RUK) Coastal Ecosystems. Coast Conservation Department, Sri Lanka.
- Jaffre, T., Kersten, W.J., Brooks, R.R. and Reeves, R.D. (1979). Nickel uptake by the Flacourtiaceae of New Caledonia. Proceed. of the Royal Society of London B205, 385-394.
- Jaffre, T., Brooks, R.R., Lee, J. and Reeves, R.D. (1976). *Sebertia acuminata*: a hyperaccumulator of nickel from New Caledonia. *Science* 193, 579-580.
- Kalra, Y.P. and Maynard, D.G. (1991). Methods manual for forest soil and plant analysis. Information report NOR-X-319. Forestry Canada, Northwest region, Edmonton, Alberta, Canada, 116.

- Kröner, A., Cooray, P.G. and Vitanage, P.W. (1991). Lithotectonic subdivision of the Precambrian basement in Sri Lanka. In: The crystalline crust of Sri Lanka. Summary of research of the German-Sri Lanka Consortium, ed. A. Kröner. Geol. Surv. Dep. Sri Lanka Prof. Pap. 5, 5-21.
- Krückeberg, A.R. (1986). An essay: The stimulus of unusual geologies for plant speciation. *Systematic Botany* 11, 455-463.
- Krückeberg, A.R. (1984). California serpentines: Flora, vegetation, geology, soils and management problems. University of California publications in botany, Univ. of California press, Berkeley, CA, 78.
- Lazaro, J.D., Kidd, P.S. and Martinez, C.M. (2006). A phytogeochemical study of the Tras-os-Montes region (NE Portugal): Possible species for plant-based soil remediation technologies. *Science of the Total Environment* 354(2-3), 265-277.
- Lee, B.D., Graham, R.C., Laurent, T.E., Amrhein, C. and Creasy, R.M. (2001). Spatial distributions of soil chemical conditions in a serpentinitic wetland and surrounding landscape. *J. Soil Sci. Soc. Am.* 65, 1183-1196.
- Maier, R.M., Pepper, I.L. and Gerba, C.P. (2000). Environmental Microbiology, Academic press, California 92101-4495, USA.
- McIntosh, J.L. (1969). Bray and Morgan soil test extractants modified for testing acid soils from different parent materials. *Agronomy Journal* 61, 259-265.
- Munasinghe T. & Dissanayake C.B. (1980). Is the highland-eastern Vijayan boundary in Sri Lanka a possible mineralized belt? – A Reply. *Economic Geology* 75, 775-777.
- Munasinghe T. & Dissanayake C.B. (1979). Is the highland-eastern Vijayan boundary in Sri Lanka a possible mineralized belt? *Economic Geology* 74, 1495-1496.
- Nelson, D.W. and Sommers, L.E. (1996). Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America and American Society of Agronomy, Madison, USA.
- Proctor, J. (2003). Vegetation and soil and plant chemistry on ultramafic rocks in the tropical Far East. *Perspectives in Plant Ecology, Evolution and Systematics*. 6/1,2, 105-124.
- Rabenhorst, M.C., Foss, J.E. and Fanning, D.S. (1982). Genesis of Maryland soils formed from serpentine. *J. Soil Sci. Soc. Am.* 46, 607-616.
- Rajakaruna, N., Harris, T.B. and Alexander, E.B. (2009). Serpentine geocology of Eastern North America: A review. *Rhodora* 111, 21-108.
- Rajakaruna, N. and Boyd, R.S. (2008). The edaphic factor. In: *The Encyclopedia of Ecology*, S. E. Jorgensen (Ed), Elsevier, Oxford, United Kingdom, 1201-1207.
- Rajakaruna, N. and Baker, A.J.M. (2004). Serpentine: A model habitat for botanical research in Sri Lanka. *Ceylon Journal of Science* 32, 1-19.
- Rajakaruna, N. & Bohm B.A. (2002). Serpentine and its vegetation: a preliminary study from Sri Lanka. *Journal of Applied Botany* 76; 20-28.

- Ratnayake, R.R., Seneviratne, G. and Kulasooriya, S.A. (2007). A modified method of weight loss on ignition to evaluate soil organic matter fractions. *International Journal of Soil Science* 2 (1), 69-73.
- Reddy, R.A., Balkwill, K. and McLellan, T. (2009). Plant species richness and diversity of the serpentine areas on the Witwatersrand. *Plant Ecology* 201, 365-381.
- Reeves, R.D., Baker, A.J.M., Borhidi, A. and Berazain, R. (1999). Nickel Hyperaccumulation in the Serpentine Flora of Cuba. *Annals of Botany* 83, 29-38.
- Roberts, B.A. and Proctor, J. (1992). The ecology of areas with serpentinized rocks. A world view. Kluwer Academic Publishers, Netherlands, 420.
- Seneviratne A.S., Nandadasa H.G., Fernando W.S., Sanjeevani H.H.V.M. & Rajapakse R.I.H.R. (2000). The serpentine vegetation of Ussangoda (Hambantota district) and nickel accumulating plant species. Proceed. of the Sixth Annual Forestry and Environmental Symposium, Kandy Sri Lanka 29-30 December 2000.
- Shellari, S., Schwartz, C., Hasko, A. and Morel, J.L. (1998). Heavy metals in soils and plants of serpentine and industrial sites of Albania. *The Science of the Total Environment* 209, 133-142.
- Siritunge, H.W.S., Dharmasiri, K.A.N., Ranatunge, C.L. and Pannila, A.S. (1987). An unusual deposit of red ochre at Ussangoda. Proceed. of the Sri Lanka Association for the Advancement of Science. 9th December 1987.
- Soltanpour, P.M. and Schwab, A.P. (1977). A new soil test for simultaneous extraction of macro and micro nutrients in alkaline soils. *Communications in Soil Science and Plant Analysis* 8, 195-207.
- Sparks, D.L. (2003). Environmental soil chemistry. Academic Press, California 92101-4495, USA, 315.
- Tennakone, K., Senevirathna, M.K.I. and Kehelpannala, K.V.W. (2007). Extraction of pure metallic nickel from ores and plants at Ussangoda, Sri Lanka. *J.Natn.Sci.Foundation Sri Lanka* 35(4): 245-250.
- Weerasinghe, H.A.S. and Iqbal, M.C.M. (2011). Plant diversity and soil characteristics of the Ussangoda serpentine site. *Journal of the National Science Foundation* (in press).
- Wickramaratne, S.N. (2000). Preliminary survey of serpentine vegetation in Uda walawe area. Proceedings of the Sixth Annual Forestry and Environmental Symposium, Kandy Sri Lanka 29-30 December 2000.
- Whiting, S.N., Reeves, R.D., Richards, D., Johnson, M.S., Cooke, J.A., Malaisse, F., Paton, A., Smith, J.A.C., Angle, J.S., Chaney, R.L., Ginocchio, R., Jaffre, T., Johns, R., McIntyre, T., Purvis, O.W., Salt, D.E., Schat, H., Zhao, F.J. and Baker, A.J.M. (2004). Research priorities for conservation of metallophyte biodiversity and their potential for restoration and site remediation. *Restoration ecology* 12 (1), 106-116.
- Whittaker, R.H. (1954). The ecology of serpentine soils: *Ecology* 35, 258-259.
- Zuo, X., Zhao, X., Zhao, H., Zhang, T., Guo, Y., Li, Y. and Huang, Y. (2009). Spatial heterogeneity of soil properties and vegetation-soil relationships following vegetation restoration of mobile dunes in Horqin Sandy Land, Northern China. *Plant Soil* 318, 153-167.

VIII Problems encountered during the implementation of the project

- The contract of the Principal Investigator was discontinued for a period of eight months from Oct 2007 to April 2008, which disrupted the continuity of the project.
- The Research Assistant resigned from the project in May 2009 and a new RA was recruited on 28 Sept 2009.
- The frequent breakdown of the AAS at the IFS interfered with sample analysis for heavy metals in plants and soil.

IX Major findings and follow-up activities

The major findings are given under Conclusions, above. To conserve and maintain this unique site it is necessary to involve the local inhabitants. This can be achieved through the creation of a Geo-Park, which is already underway through the National MAB committee of the NSF. This should be expedited by finding the necessary funds and also consulting the administrative processes through the local authorities of the area. The findings of this project could contribute to explain the significance of the site to the general public.

Section 4

Impact of Research results

Impact of Research results

- i) Relevance of results achieved to scientific advancement

This is the first detailed study of the soil and plants of one of the six serpentinite sites in Sri Lanka. It contributes to understanding the scientific background to the unusual plant characteristics on this soil, and thereby dispels the myths and folklore surrounding this site. The results identified many plant species which are hyper-accumulators of heavy metals.

- ii) Relevance of results achieved to national/socio-economic development

- iii) Dissemination/application of research output

The results from this study are contributing towards setting up a Geo-Park in Ussangoda, through the MAB Committee of the NSF. Such a Geo-Park would integrate the local population in the conservation and maintenance of the proposed Ussangoda Geo-Park to regularize visitors to the Park and derive an income through direct and indirect activities associated with managing the Park.

Section 5
Miscellaneous

Miscellaneous

- i) List of major equipment acquired during the project period and their functionality

A horizontal shaker and GPS was purchased which are in use for ongoing research activities in Ussangoda and other research projects.

- ii) List of publications/communications arising from the project and/or presentations made at seminars, workshops etc. (Please attach copies)

Published in a journal

H.A.S. WEERASINGHE and **M.C.M. IQBAL** (2011). Plant diversity and soil characteristics of the Ussangoda serpentine site. Journal of the National Science Foundation (in press).

Published in conferences and proceedings

SAMITHRI, Y.A.S., D.S.A. WIJESUNDERA and **M.C.M. IQBAL** 2007. A preliminary study of the Ussangoda Serpentine Flora. 12th International Forestry and Environment Symposium, 30th November-1st December 2007, Kalutara Sri Lanka.

H.A.S. WEERASINGHE and **M.C.M. IQBAL** 2007. Soil nutrient contents in the Ussangoda serpentine soil. Page 76, Proceedings of Sri Lanka Association for the Advancement of Science, Part I. 63rd Annual Sessions. Sri Lanka Association for the Advancement of Science, Colombo.

SAMITHRI, Y.A.S., D.S.A. WIJESUNDERA and **M.C.M. IQBAL** 2008. Floral diversity and Conservation of the Ussangoda serpentine site in Sri Lanka. Sixth International Conference on Serpentine Ecology, June 16-23, 2008, Maine USA.

WEERASINGHE, H.A.S., S. M. WEERASINGHE, G.W.A.R. FERNANDO and **M.C.M. IQBAL** 2008. Soil and vegetation heterogeneity on a serpentine site in Ussangoda Sri Lanka. Sixth International Conference on Serpentine Ecology, June 16-23, 2008, Maine USA.

IQBAL, M.C.M. and S. RAJARATNAM 2008. Nickel accumulation by *Fimbristylis ovata* (Cyperaceae) growing on Ultramafic soil in Ussangoda Sri Lanka. Sixth International Conference on Serpentine Ecology, June 16-23, 2008, Maine USA.

IQBAL, M.C.M. and D.S.A. WIJESUNDERA 2008. Conservation of the Ussangoda serpentine plain in Sri Lanka as a Geo-park. Annual meeting of the British Ecological Society, September 3-5, 2008, London United Kingdom.

SAMITHRI, Y.A.S., D.S.A. WIJESUNDERA and **M.C.M. IQBAL** (2008). Morphological and physiological adaptations on a serpentine ecosystem in Ussangoda, Sri Lanka. p39. Annual meeting of the British Ecological Society, September 3-5, 2008, London United Kingdom.

Plant Diversity and Soil characteristics of the Ussangoda Serpentine site

H.A.S. WEERASINGHE and M.C.M. IQBAL*

Plant Reproductive Biology, Institute of Fundamental Studies, Hantana Road
Kandy, Sri Lanka

*Corresponding author (Email: mcmif2003@yahoo.com)

Telephone: 081 2232002

Fax: 081 2232131

Abstract

Serpentine soils are derived from the weathering of serpentine and ultramafic rocks, which have a high content of ferromagnesian minerals. The soil is enriched with heavy metals, which alters the physical and chemical properties of the soil creating a hostile environment for plant growth. There are six serpentine sites in Sri Lanka and the Ussangoda site is on the southern coast in Hambantota. The moisture content, organic matter and CEC were low in the serpentine soil. The available calcium (Ca) was low and magnesium (Mg) content relatively high which gave a Ca to Mg ratio of 0.60, typical for serpentine soils. Two distinct forms of vegetation grow on the Ussangoda serpentine soil. The large plain is covered by stunted, prostrate species with an extensive root system. Patches of shrubs and trees occur on the plains in small islands. The serpentine flora is sharply demarcated from the surrounding non-serpentine flora by their growth habit. The diversity of families and species is lower on the serpentine soil than the adjacent non-serpentine flora. Four families and their six species grew only on the serpentine soil and not in the adjacent non-serpentine region. Five species on the serpentine soil contained 560 – 830 ppm of nickel in their tissues and *Hybanthus enneaspermus* had 1800 ppm. Two species *Vernonia zeylanica* and *Scolopia acuminata* are endemic to Sri Lanka.

Keywords: Serpentine, Ussangoda, heavy metals, metal uptake, biodiversity, *Evolvulus alsinoides*, *Hybanthus enneaspermus*

INTRODUCTION

Serpentine soils occur in isolated patches all over the world particularly along continental margins. They are derived from serpentine rocks composed of serpentine minerals and ultramafic rocks, which have a high content of ferromagnesian minerals (Brooks, 1987). The weathering of these rock types enriches the soil with Mg, Fe and other heavy metals such as Ni, Co etc. These contribute to changing the physical and chemical properties of the soil towards an unfavourable and hostile environment for plant growth. Over time, plant species have adapted to these unusual soil conditions producing a unique association between the soil and plants. They can be regarded as a living laboratory for studying evolutionary biology and adaptations by the plant species to the extreme environment peculiar to serpentine soils.

Very little is known of the geology and flora of serpentine sites in Southeast Asia. In India, an ultramafic site was reported in the Orissa state of Calcutta (Brooks, 1987). The serpentine areas in the Malay Archipelago are well documented and many endemic species were identified (Brooks, 1987; Proctor 2003). The soil characteristics of the ultramafic sites in Malaysia, Indonesia and The Phillipines were also compared by Brearley (2005). Geological studies in Sri Lanka have shown six serpentinite bodies at Ussangoda, Indikolapelessa, Ginigalpelessa, Katupota, Yodagannawa and Rupaha. These lie close to a Precambrian suture zone between the lithotectonic units, the Vijayan and Highland series (Dissanayake & Van Riel, 1978; Munasinghe & Dissanayake, 1979; Munasinghe & Dissanayake, 1980). Of these sites the geochemistry of the Uda-Walawe serpentine site has been described (Dissanayake & Van Riel, 1978; Dissanayake, 1982).

Ultramafic soils are generally shallow with a high Mg to Ca ratio, deficient in essential plant nutrients and contain potentially toxic concentrations of heavy metals (Proctor & Woodell, 1975; Brooks 1987). The rocky nature of the soil, low clay and organic matter content provides a highly permeable soil with low water holding capacity. In the soil, the exchangeable Mg concentrations are high and exchangeable Ca concentrations are low and are deficient in the essential plant nutrients N, P and K (Kruckeberg, 1984). Plant life

on serpentine soils have adapted morphologically and physiologically to this environment. Morphologically plants are dwarf with narrow, glaucescent thick leaves, strong sclerenchyma development and enlarged root system (Kruckeberg, 1984). Physiologically they are able to tolerate the heavy metal presence in the soil by absorption and sequestration or exclusion. Thus serpentine soils provide a unique ecological niche which is poor in diversity of plant species.

The flora of Ussangoda was first described by Brooks (1987), who on a visit to the island referred to the Ussangoda serpentine site: "At Welipatanwila, the heavily laterised ultramafics are almost completely devoid of vegetation except for a scattering of a small blue-flowered herb, *Evolvulus alsinoides*. The boundary of the serpentine is marked by low thorn bushes interspersed with *Opuntia* species". In a subsequent study (Seneviratne *et al.*, 2000), 14 plant species were identified all of which accumulated over 100 ppm of Ni. Rajakaruna and Bohm (2002) studied nine plant species growing on the Ussangoda serpentine soil and the soil chemistry from their root zones. Their study found three species which hyperaccumulated over 1000 ppm of Ni from the soil. In a recent study (Iqbal *et al.*, 2006) 29 species of flowering plants which included trees, shrubs, vines and prostrate plants growing within the Ussangoda serpentine site were identified and *Cassia kleinii* as a Ni hyper-accumulator. Thus in the last 20 years, few studies were devoted to study this unique habitat and much work remains to be done.

For a comprehensive study of the Ussangoda serpentine site, it is necessary to determine the diversity of plant species, their physiological adaptations to the adverse soil environment and the soil characteristics contributing to their adaptations. This would subsequently assist in the study of the other serpentine sites in Sri Lanka and potentially contribute towards identifying heavy metal hyper-accumulating species. The objective of this study is to determine the important physical and chemical characteristics of the Ussangoda soil, its consequence on the flora and diversity of the flora in relation to the surrounding non-serpentine areas.

MATERIAL AND METHODS

Site description: The serpentine study site in Ussangoda (Fig. 1) is a flat plain (approximately 1 km²) located close to the Nonagama junction on the Matara – Hambantota highway (lat 06° 05' N, long 80° 59' E). The southern boundary of the plain is a cliff, approximately 30 m amsl, overlooking the Indian Ocean. The highest point on the plain is 34.5 m amsl.

Climate: the mean annual temperature is 27.9 °C with a mean range of 31.1 °C to 24.6 °C. Daytime temperature during field visits reached 35.8 °C. The annual rainfall is less than 1250mm (mainly from October – January) with more than 5 dry months with less than 50 mm rainfall (IUCN, 2004).

Soil analysis: Soil samples were collected according to the stratified random sampling technique to represent the 10 m, 20 m and 30 m contours. Each sample was collected from below the soil surface to a depth of 10 cm and stored in labeled polythene bags. All the samples were analyzed separately. The samples were air-dried for one week at room temperature and passed through a 2 mm sieve. Soil moisture was determined by drying five grams of soil to a constant mass in an oven at 105 °C for 24 h and cooling it in a desiccator for 30 min. To determine pH, 20 ml of de-ionized water or calcium chloride was added to 10 g of soil and stirred 4-5 times within 30 min. The suspension was allowed to settle for 30 minutes and the pH of the supernatant determined. Soil conductivity was measured in a suspension from mixing 40 g of soil and 80 ml de-ionized water. The above methods are described in Kalra & Maynard ((1991).

Cation Exchange Capacity of the soil was determined according to Anderson & Ingram (1993). Air-dried soil was shaken with 1M potassium chloride for 5 min and repeatedly centrifuged until the supernatant was clear. Ethanol was added to the filtrate and centrifuged until the supernatant was clear which was discarded. To this 1M ammonium acetate was added, shaken and centrifuged until the supernatant was clear. The supernatant volume was made up to 100 ml with ammonium acetate the potassium concentration was measured by the Atomic Absorption Spectrophotometer (AAS). Soil organic matter was determined by percentage Loss-On-Ignition (LOI) after heating five grams of oven-dried soil in a crucible to 375°C in a muffle furnace for 16 hours (Kalra & Maynard, 1991). Soil Exchangeable Cations (Ca, Mg, Na & K) were extracted by

shaking five grams of air-dried soil with 25 ml of neutral 1N ammonium acetate for 30 min, filtered (Whatman no.42) and the filtrate analyzed by AAS (AESL, 1999). Soil micronutrients were extracted by adding 50 ml of diethylene triamine penta acetic acid (DTPA) to 2.5 g of air dried soil in 250 ml open conical flasks and filtered. The micronutrients in the filtrate were measured by AAS (Amacher, 1996).

Plant material: Plants with their reproductive structures were identified in the National Herbarium of the Royal Botanic Gardens, Peradeniya and herbarium sheets prepared of the collected species. Plant samples for analysis were bagged and labeled in polythene bags.

Plant analysis: Plant samples were cleaned with a nylon brush under running tap water to remove adhered soil and then washed with ethylene diamine tetra-acetic acid (EDTA) for 1min and rinsed thrice with de-ionized water to remove any surface bound metals. The samples were dried at 80 °C for 24 h in a forced air oven and ground in a plant grinder and stored in air tight bags. Samples of 500 mg were ashed in a muffle furnace at 550 °C for 8 h and the ash dissolved in 5ml of concentrated HCl and volume made up to 50 ml with distilled water. The macro- and micro nutrients were determined by AAS.

Statistical Analysis: Statistical analysis was carried out using the Minitab 14 statistical software package. One-way ANOVA along with multiple comparison of means using Tukey's test was performed.

RESULTS

The serpentine plain has isolated patches of dense shrubs and trees, and rocky outcrops. The plants on the plains are prostrate, stunted with an extensive root system. The plain is clearly demarcated from the surrounding non-serpentine area by large shrubs and trees. The surface soil is a fine reddish dust with small lateritic stones.

Soil characteristics

The serpentine and non-serpentine soil showed a significant difference in their physical and chemical properties. Within the serpentine site there are two contrasting vegetation types, the prostrate stunted species and the patches of shrubs and trees. The available moisture was low on the serpentine soil while the shrub patches had significantly higher moisture approaching that of the non-serpentine soil. This was not associated with the organic matter content of the soils (Table 1). The Cation Exchange Capacity of the serpentine soils were also significantly lower. The pH of the serpentine soil tended towards acidity and the non-serpentine soil was significantly neutral (Table 1). The conductivity of the non-serpentine soil was significantly higher than the serpentine soil and the shrub patches.

The chemical properties of the serpentine soil showed highly significant differences from the non-serpentine soil. The Ca content of the non-serpentine soil was 3 to 15 times higher than that on the shrub patches and the serpentine soil respectively. Although Mg content of the different soils were comparably similar, the difference in Ca was reflected in the Ca:Mg ratio (Table 1). The serpentine soil has a characteristic value of 0.60. The shrub patches with a higher Ca content of 3 to 4 times that of the serpentine soil have a Ca:Mg ratio higher than that of the serpentine soils. Similarly the Ni content was much higher than in the non-serpentine soils. Fe does not show a significant difference between the soil types and Mn was only high in the serpentine soil (Table 1).

Flora

In this study the diversity of plant families and species in Ussangoda is based on a field survey of the flora on the serpentine soil and a previous survey conducted by the IUCN (2004) on all the species in the Ussangoda region.

This study has identified to-date 26 plant families on the serpentine soil. Of these nine families with 12 species occur on the serpentine plain (Table 2). These species are prostrate, dwarf or stunted, with small leaves, thick sclerenchymatous stems and

extensive root systems. The prostrate species *Evolvulus alsinoides*, had three colour morphs: white, pale purple and dark blue. They occurred either in close proximity or spread apart on the plains. The dominant family on the serpentine plains was Fabaceae with three species. The other families occur in the patches of shrubs and trees on the serpentine plain.

The occurrence of species from the IUCN plant survey was compared with those growing on the serpentine site. Five families with seven species grow only on the serpentine soil and were not found by the IUCN study (IUCN 2004) in the Ussangoda region (Table 3). Of these Violaceae occurs on the plains (Table 2) and species of the other four families occur as shrubs or trees on the serpentine site. The diversity of families and their species was low on the serpentine soil. The survey of species up to now has identified 16 species growing only on the serpentine soil (Table 2) and 44 species growing on serpentine and non-serpentine soil in Ussangoda. The habit of these species were climbers, herbs, shrubs and trees. Monocotyledons were confined to Cyperaceae and Poaceae with four species. Of the 31 families on serpentine soil, Fabaceae had six species, Capparaceae and Malvaceae five species each and the rest had three species or less (Table 2). In contrast, the diversity of species within the families was greater on the non-serpentine region of Ussangoda (Table 3). Fabaceae had the most with 14 species while 10 families had three or more species (Table 2). A complete survey of the families and species on the serpentine soil is continuing.

Five species growing on the serpentine soil showed nickel accumulation. The species *Evolvulus alsinoides*, *Euphorbia thymifolia*, *Cassia kleinii*, and *Vernonia cinerea* accumulated 560 – 830 µg/g (dry weight) of nickel in their tissues while *H. enneaspermus* was a hyperaccumulator (Table 2). Although *Fimbristylis ovata* showed a low nickel accumulation on the serpentine soil, under experimental hydroponic conditions with Ni, levels of 2000 µg/g (dry weight) were detected (unpublished data).

DISCUSSION

A defining characteristic of a serpentine soil is a Ca: Mg ratio of less than 0.6 (Brooks, 1987). The Ussangoda serpentine soil on the plains showed a ratio of 0.6 and soil under the shrubs and trees a ratio of 1.8 to 1.9. This was significantly below that of the non-serpentine soil. Although the Mg content was not significantly different between the serpentine and non-serpentine soils, the Ca content was almost 15 times less on the serpentine plains. In a previous study on the soil chemistry of Ussangoda (Rajakaruna & Bohm 2002) the Ca concentration determined in the root zones of six species ranged from 112 – 210 $\mu\text{g/g}$ (dry weight), which compares well with a mean value of 187 $\mu\text{g/g}$ (dry weight) in this study. However, the Mg content determined in this study was 3- 5 times that determined by Rajakaruna and Bohm (2002). In their study of four serpentine soils in Sri Lanka, Ussangoda showed the highest Ca:Mg ratio of 1.3 to 2.4 while the other three sites had Ca:Mg as low as 0.07 (in Ginigalpelessa) due to a high Mg content. A serpentine site in Malaysia showed a similar ratio of 0.6 (Brearley 2005) and a serpentine site in Portugal (Lázaro *et al.*, 2006), showed similar high values of exchangeable Mg over Ca in the soil to give a Ca:Mg ratio of 0.7 whereas the non-serpentine sites were 2.4 to 6.9. In a serpentine site in Italy similarly low values of 0.3 were found (Chiarucci, 1998) due to the high Mg content in the soil. The Ussangoda site falls within the basic definition for a serpentine soil based on Ca:Mg ratio.

The CEC determined in this study is similar to that obtained previously on the same site (Rajakaruna & Bohm 2002). The other serpentine sites in Sri Lanka in Indikolapelessa and Ginigalpelessa had a higher CEC (Rajakaruna & Bohm 2002) of 25-50 $\text{cmol}(+)/\text{kg}$ of soil. Higher CEC values of 16 $\text{cmol}(+)/\text{kg}$ was also shown by a temperate serpentine soil (Lázaro *et al.*, 2006). The soil pH in Ussangoda determined previously (Rajakaruna & Bohm 2002) were more acidic (4.3 to 4.9) than that determined in this study, which could be due to time of sampling and determination of the pH. In Malaysia, a pH value of 5.3 similar to Ussangoda was determined (Brearley 2005). Acidic pH values were also obtained in serpentine soils in temperate conditions (Lázaro *et al.*, 2006). The Loss of Ignition determined in a serpentine site in Italy of 10.8 to 23.7% (Chiarucci 1998) was much higher than the 2.9 recorded in Ussangoda. This could be accounted for by the

cooler temperate climates while Ussangoda is exposed to continuously warm temperatures. However, high Loss of Ignition values of 12.6% were determined in a Malaysian serpentine soil (Brearley 2005). The soil physical and chemical properties of the Ussangoda serpentine soil are similar to that elsewhere. However, there is a wide range of values depending on the time and location of sampling within the site.

Brooks (1987) first identified three species on the Ussangoda (*E. alsinoides*) and Uda-Walawe (*Cymbopogon flexuosus* and *Morinda tinctoria*) serpentine sites in Sri Lanka. He concluded that the serpentine flora was impoverished in species number and endemism without further potential for botanical research. Further studies (Seneviratne *et al.*, 2000) on the flora of Ussangoda identified 14 species confined to specific areas on the serpentine plain and of limited distribution. In a preliminary survey of four serpentine sites in Sri Lanka Rajakaruna and Bohm (2002) reported on the flora, soil characteristics and heavy metal uptake by the plants.

Flora on serpentine soils are generally poor in species diversity and show a high degree of endemism. While the flora on the Ussangoda soil is poor in species and families compared to the surrounding non-serpentine region, attention has been drawn to the fact that although Sri Lanka has a greater degree of biodiversity per unit area than other Asian countries, endemic species were not found on the serpentine soils (Rajakaruna & Bohm, 2002).

From a previous study of the flora of four serpentine sites in Sri Lanka, Rajakaruna & Bohm (2002) concluded that the floristic composition was typical of tropical serpentine habitats. Their study added at least 23 new genera from Sri Lanka to the list of plants known to occur on serpentine soils. Of the 51 species identified in this study, upto now, growing on the plains and as patches of shrubs and trees on the Ussangoda serpentine soil, two species *Vernonia zeylanica* (Grierson, 1980) and *Scolopia acuminata* (Verdcourt, 1996) were found endemic to Sri Lanka while *Cassia kleinii* (Rudd, 1991) is apparently endemic to Sri Lanka and Southwest India.

Colour polymorphism of the flowers of *Evolvulus alsinoides* growing on the serpentine soil was previously reported (Seneviratne *et al.* 2000; Rajakaruna & Bohm, 2002). Both studies refer to two colours, while this study identified three colour morphs. The non-serpentine species is also known to have two colours (Austin, 1980). Rajakaruna and Baker (Rajakaruna & Baker 2004) speculate if the colour morphs could be due to edaphic differences in their micro-habitat. However, in this study, the three flower types were observed in plants growing very close to each other as well as far apart. Seneviratne *et al.*, (2000) found distinct flavonoid profiles and suggest they are “flavonoid races”.

The plant tissue concentration of heavy metals (Ni, Fe, Mn) growing on the serpentine soil were above that considered to be normal found in non-serpentine plants (Greger, 2004). Such accumulation of heavy metals is a characteristic of serpentine adapted plants Brooks (1987). Plants capable of accumulating over 1000 µg metal/g dry leaf tissue are considered as hyperaccumulators (Baker & Brooks (1989). *Hybanthus enneaspermus* accumulated over 1000 ppm nickel and three other species accumulated 500 – 800 ppm nickel (Table 2). The different Ni contents in the different species suggests that the plants have varied mechanisms of overcoming Ni toxicity in the soil by increased uptake and sequestering the Ni (hyperaccumulators) or by excluding from uptake (species with low Ni). Previous studies (Seneviratne *et al.*, 2000) found, in addition to *H. enneaspermus*, four other species also able to hyperaccumulate nickel. Rajakaruna and Bohm (2002) also found *H. enneaspermus* as a nickel hyperaccumulator besides *Evolvulus alsinoides* and *Crotolaria biflora*. While the status of *H. enneaspermus* is unequivocal as a nickel hyperaccumulator, the differences in the other species could be due to time and location of sampling or analytical methods. Since surface contamination of the plant tissue with the metal rich soil is a problem, in this study, plant tissues were washed with EDTA to remove surface bound metals, which may account for the lower values determined. According to Rajakaruna and Bohm (2004), *H. enneaspermus* and *E. alsinoides* occur in serpentine sites in Queensland, Australia but are not nickel hyperaccumulators. They suggest that since many varieties of both species are known, the Sri Lankan species may represent a physiologically distinct form, perhaps an edaphic race.

After the primary mineralization of the serpentine rock, the elemental composition of the soil is also altered by the colonization of vegetation, which along with climate determines the present mineral composition (Chiarucci *et al.*, 1998). There is a dynamic interaction between the soil and the vegetation determining the physical and chemical characters of the soil at a given time. Tropical serpentine soils are different from temperate soils, primarily due to the cooler climate and vegetation. However, more studies on tropical serpentine sites are necessary to better understand the tropical serpentine soils and their interaction with the flora that is established on these soils. The Ussangoda serpentine site has the basic soil attributes of a typical serpentine soil and has a particularly low Ca content. The floral diversity is restricted and shows adaptation to the soil conditions morphologically and physiologically. Amongst the species are hyperaccumulators as well as excluders of Ni.

Acknowledgements

We thank the Director of Archaeology, Dept. of Archaeology for permission to take field samples from the Ussangoda serpentine site. We wish to acknowledge Dr. D.S.A. Wijesundera Director General of the National Botanic Gardens, Peradeniya for permitting us the use of the Herbarium for identification of the species. We thank Dr. G.W.A.R. Fernando Dept. of Physics, Open University of Sri Lanka and Ms. Y.A.S. Samithri in the preparation of this manuscript and Mr. R.B. Hapukotuwa for field assistance. Financial assistance provided by the British Ecological Society, Institute of Fundamental Studies, and a research grant from the NSF (RG/2006/EB/08) is gratefully acknowledged.

References

AESL (Agricultural and Environmental Services Laboratories) (1999). Methods for the analysis of soil, plant, water and environmental samples. Agricultural and Environmental Services Laboratories, College of Agriculture and Environmental Sciences, University of Georgia. (<http://aesi.ces.uga.edu/protected/methods/detailsstl-soil/or7.html>)

Amacher, M.C. (1996). Nickel, Cadmium and Lead. In: *Methods of soil analysis: chemical methods, Part 3*. Soil Science Society of America and American Society of Agronomy, Madison USA.

Anderson, J.M. and Ingram, J.S.I. (1993). Tropical soil biology and fertility: A hand book of methods. CABI Publishing, Wallingford, United Kingdom.

Austin, D.F. (1980). Convolvulaceae. In: *In a Revised Handbook to the Flora of Ceylon*. Vol.I. (Eds. M.D. Dassanayake and F.R. Fosberg) pp.288-363. Amerind Publishing Co. New Delhi, India.

Baker, A.J.M. & Brooks, R.R. (1989). Terrestrial higher plants which accumulate metallic elements – a review of their distribution, ecology and phytochemistry. *Biorecovery* **1**: 81-126.

Brearley, F.Q. (2005). Nutrient limitation in a Malaysian ultramafic soil. *Journal of Tropical Forest Science* **17** (4): 596-609.

Brooks, R.R. (1987). *Serpentine and its Vegetation. A multidisciplinary approach*. Dioscorides Press, Portland OR, USA, 224 p.

Chiarucci, A., Riccucci, M.; Celesti, C. & de Dominicis, V. (1998). Vegetation-Environment relationships in the ultramafic area of Monte Ferrato, Italy. *Israel Journal of Plant Sciences* **46**: 213-221.

Dissanayake, C.B. & Van Riel, B.J. (1978). Petrology and geochemistry of a recently discovered nickeliferous serpentinite from Sri Lanka. *Journal of the Geological Society of India* **19**: 464-471.

Dissanayake, C.B. (1982). The geology and geochemistry of the Uda Walawe serpentinite, Sri Lanka. *Journal of the National Science Council of Sri Lanka* **10**(1): 13-34.

Greger, M. (2004). Metal availability, uptake, transport and accumulation in plants. In: *Heavy Metal stress in Plants* (Ed. M.N.V. Prasad) pp. 462. Narosa Publishing House, New Delhi India.

Grierson, A.J.C. (1980). Compositae. In: : *In a Revised Handbook to the Flora of Ceylon*. Vol.I. (Eds. M.D. Dassanayake and F.R. Fosberg) pp. 111-278. Amerind Publishing Co. New Delhi, India.

International Union for the Conservation of Nature (2004), *The Environmental Profile of Rekawa, Ussangoda and Kalametiya (RUK) Coastal Ecosystems*. IUCN Sri Lanka.

Iqbal, M.C.M., Kulasekara, L., Rajakaruna, N. & Iqbal, S.S. (2006). Plant-soil relations of a serpentine site in the Southern coast of Sri Lanka. Fifth International Conference on Serpentine Ecology, Siena 9-13 May 2006.

- Kalra, Y.P. & Maynard, D.G. (1991). Methods manual for forest soil and plant analysis. Information report NOR-X-319. Forestry Canada. Northwest region, Edmonton, Alberta, Canada.
- Kruckeberg, A.R. (1984). *California Serpentine: Flora, Vegetation, Geology of Soils, and Management Problems*. University of California press. Berkeley, California, USA 180 p.
- Lázaro, J.D., Kidd, P.S., Martínez, C.M. (2006). A phytogeochemical study of the Trás-os-Montes region (NE Portugal): Possible species for plant-based soil remediation technologies. *Science of the Total Environment* **354**: 265-277.
- Munasinghe, T. & Dissanayake, C.B. (1979). Is the highland-eastern Vijayan boundary in Sri Lanka a possible mineralized belt? *Economic Geology* **74**: 1495-1496.
- Munasinghe, T. & Dissanayake, C.B. (1980). Is the highland-eastern Vijayan boundary in Sri Lanka a possible mineralized belt? – A Reply. *Economic Geology* **75**: 775-777.
- Proctor, J & Woodell, S.R.J. (1975). The ecology of serpentine soils. *Advances in Ecological Research* **9**: 255-366.
- Proctor, J. (2003). Vegetation and soil and plant chemistry on ultramafic rocks in the tropical Far East. *Perspectives in Plant Ecology, Evolution and Systematics* **6**: 105-124.
- Rajakaruna, N. & Bohm, B.A. (2002). Serpentine and its vegetation: a preliminary study from Sri Lanka. *Journal of Applied Botany* **76**: 20-28.
- Rajakaruna, N. & Baker, A.J.M. (2004). Serpentine: A model habitat for botanical research in Sri Lanka. *Ceylon Journal of Science* **32**: 1-19.
- Rudd, V.E. (1991). Fabaceae. In: : *In a Revised Handbook to the Flora of Ceylon*. Vol.VII. (Eds. M.D. Dassanayake and F.R. Fosberg). pp. 34-381. Amerind Publishing Co. New Delhi, India.
- Seneviratne, A.S., Nandadasa, H.G., Fernando, W.S., Sanjeevani, H.H.V.M. & Rajapakse, R.I.H.R. (2000). The serpentine vegetation of Ussangoda (Hambantota district) and nickel accumulating plant species. Proceedings of the Sixth Annual Forestry and Environmental Symposium, Kandy Sri Lanka 29-30 December 2000.
- Verdcourt, B. (1996). Flacourtiaceae. In: *In a Revised Handbook to the Flora of Ceylon*. Vol.X. (Eds. M.D. Dassanayake and W.D. Clayton). pp. 199-235. Oxford and IBH Co. New Delhi, India.

Figure 1

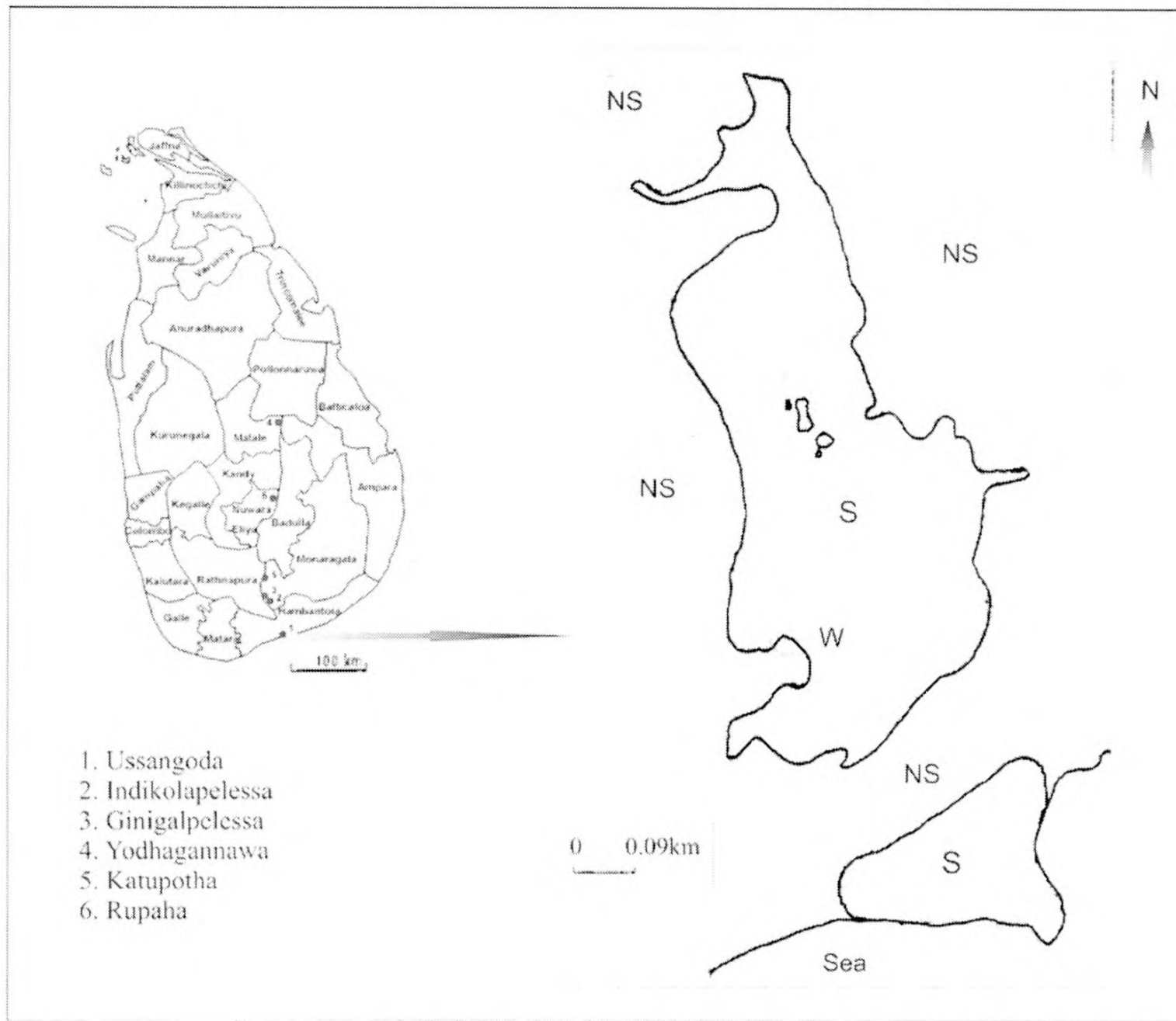


Table 1. Physical and chemical properties of the serpentine soil in Ussangoda and the adjacent non-serpentine soil (mean values \pm SE).

Soil parameter	Serpentine (Area = 1km ²)	Island ¹ 1 (Area = 2141m ²)	Island ¹ 2 (Area = 764m ²)	Non-serpentine
n	14	9	7	6
Moisture (%)	4.4 \pm 0.26 ^a	7.01 \pm 0.64 ^b	8.92 \pm 0.42 ^{b,c}	10.61 \pm 1.6 ^c
Organic Matter (%)	2.96 \pm 0.26 ^a	5.46 \pm 0.42 ^b	5.84 \pm 0.23 ^{b,c}	4.31 \pm 0.24 ^{a,b}
CEC (cmol(+)/kg of dry soil)	6.76 \pm 0.85 ^a	6.29 \pm 1.59 ^a	9.72 \pm 1.57 ^{a,b}	13.44 \pm 1.23 ^b
n	6	4	4	5
pH	5.32 \pm 0.21 ^a	5.95 \pm 0.13 ^{a,b}	6.23 \pm 0.21 ^b	7.3 \pm 0.19 ^c
Conductivity (micro-siemens)	61 \pm 6.54 ^a	55.8 \pm 9.54 ^a	130 \pm 28 ^b	162.4 \pm 10.9 ^b
<i>Exchangeable cations</i>				
n	29	9	7	8
Ca (μ g/g)	187 \pm 27.5 ^a	645 \pm 84.8 ^b	905 \pm 135 ^b	2911 \pm 650 ^c
Mg (μ g/g)	311 \pm 48.3 ^a	352 \pm 50.3 ^a	456 \pm 35.7 ^a	519 \pm 53.2 ^a
Ca/Mg	0.601	1.832	1.984	5.608
K (μ g/g)	140 \pm 12.2 ^a	321 \pm 38.3 ^b	314 \pm 21.7 ^b	338 \pm 93.9 ^b
Na (μ g/g)	67 \pm 16.8 ^a	50 \pm 9.44 ^a	67 \pm 10.1 ^a	636 \pm 207 ^b
<i>Available micro-elements</i>				
n	31	9	7	8
Ni (μ g/g)	101 \pm 12.1 ^a	137 \pm 12.14 ^a	151 \pm 7.8 ^a	4 \pm 1.13 ^b
Fe (μ g/g)	65 \pm 4.61 ^a	56 \pm 3.19 ^a	46 \pm 3.35 ^a	62 \pm 15.2 ^a
Mn (μ g/g)	42 \pm 6.96 ^a	15 \pm 1.73 ^b	10 \pm 0.94 ^b	19 \pm 4.18 ^{a,b}

¹ Island refers to the patches of shrubs and trees on the serpentine plains

Figures followed by different letters in the same row are significantly different at P<0.05. (n = number of samples).

Table 2. Nickel (Ni) content (mean \pm SE) in some prostrate plants on the Ussangoda serpentine plain.

Name of the Plant	Family	Plant part	Nickel ($\mu\text{g/g}$ dry weight)
<i>Hybanthus enneaspermus</i>	Violaceae	Lvs+sh	1828 \pm 106
<i>Evolvulus alsinoides</i>	Convolvulaceae	Lvs+sh	828 \pm 36
<i>Euphorbia thymifolia</i>	Euphorbiaceae	Lvs+sh	745 \pm 67
<i>Cassia kleinii</i>	Fabaceae	Lvs+sh	652 \pm 23
<i>Desmodium triflorum</i>	Fabaceae	not determined	
<i>Crotolaria</i> sp.	Fabaceae	not determined	
<i>Vernonia cinerea</i>	Asteraceae	Lvs+sh	561 \pm 14
<i>Eragrostis</i> sp.	Poaceae	Lvs	233 \pm 8
<i>Frimbristylis ovata</i>	Cyperaceae	Lvs	220 \pm 2
<i>Frimbristylis falcata</i>	Cyperaceae	Lvs	73 \pm 19

Lvs = Leaves, sh = shoots

Table 3: Plant species and their families found on serpentine soil and non-serpentine regions in Ussangoda (Habit: H – herb, S – shrub, C – climber, T – tree).

Families	Habit	Species	Only on Serpentine soil	On serpentinite and non-serpentinite soils	Source (Ref no.) P = present survey
APOCYNACEAE	H	<i>Carissa spinarum</i>		X	P
ASCLEPIADACEAE	S	<i>Calotropis gigantean</i>		X	P
ASPARAGACEAE	C	<i>Asparagus racemosus</i>		X	P
ASTERACEAE	H	<i>Eupatorium odoratum</i>		X	P
	H	<i>Vernonia cinerea</i>		X	P
BORAGINACEAE	S	<i>Ehretia laevis</i>	X		P
CACTACEAE	H	<i>Opuntia</i> sp.		X	1, P
CAPPARACEAE	S	<i>Capparis pedunculosa</i>		X	P
	S	<i>Capparis rotundifolia</i>		X	P
	S	<i>Capparis sepiaria</i>		X	P
	S	<i>Capparis zeylanica</i>		X	P
	S	<i>Maerua arenaria</i>	X		P
CELASTRACEAE	S	<i>Maytenus emarginata</i>		X	P
CONVOLVULACEAE	H	<i>Evolvulus alsinoides</i>		X	1,10,11, P
	H	<i>Ipomoea pes-caprae</i>	X		P
	H	<i>Fimbristylis falcata</i>	X		10, 11, P
CYPERACEAE	H	<i>Fimbristylis monticola</i>	X		P
	H	<i>Fimbristylis ovata</i>	X		P
	H	<i>Euphorbia hirta</i>		X	P
EUPHORBIACEAE	H	<i>Euphorbia thymifolia</i>		X	P
	S	<i>Flueggea leucopyrus</i>		X	P
	S	<i>Dichrostachys cinerea</i>		X	P
FABACEAE	C	<i>Acacia caesia</i>		X	P
	T	<i>Cassia auriculata</i>		X	11, P
	H	<i>Cassia kleinii</i>	X		P
	H	<i>Crotolaria tecta</i>		X	P
	H	<i>Desmodium</i> sp.		X	11, P
FLACOURTIACEAE	S	<i>Casearia zeylanica</i>	X		P
	S	<i>Flacourtia indica</i>	X		P
	T	<i>Scolopia acuminata</i>		X	P
LINACEAE	T	<i>Hugonia mystax</i>		X	P
LORANTHACEAE	S	<i>Dendrophthoe falcata</i>		X	P
MALVACEAE	H	<i>Abutilon indicum</i>		X	P
	H	<i>Pavonia odorata</i>		X	P
	H	<i>Sida acuta</i>		X	P
	H	<i>Sida cordifolia</i>		X	P

	H	<i>Sida rhombifolia</i>	X		P
MELASTOMATACEAE	S	<i>Memecylon umbellatum</i>		X	P
MELLIACEAE	T	<i>Azadirachta indica</i>		X	P
MENISPERMACEAE	C	<i>Pachygone ovata</i>	X		P
OLACACEAE	S	<i>Olax imbricata</i>	X		P
OLEACEAE	C	<i>Jusminum angustifolium</i>		X	P
POACEAE	H	<i>Eragrostis tenella</i>	X		P
RHAMNACEAE	S	<i>Ziziphus oenoplia</i>		X	P
RHIZOPHORACEAE	H	<i>Cassiopourea ceylanica</i>	X		P
RUBIACEAE	T	<i>Canthium dicoccum</i>		X	P
	T	<i>Morinda tinctoria</i>		X	P
	T	<i>Tarennia asiatica</i>		X	11, P
RUTACEAE	S	<i>Glycosmis mauritiana</i>		X	P
	T	<i>Limonia acidissima</i>		X	P
	C	<i>Toddalia asiatica</i>		X	11, P
SALVADORACEAE	T	<i>Azima tertacantha</i>		X	P
	T	<i>Salvadora persica</i>		X	P
SAPINDACEAE	T	<i>Allophylus cobbe</i>		X	P
	T	<i>Lepisanthes tetraphylla</i>		X	P
	T	<i>Sapindus emarginatus</i>		X	P
VERBENACEAE	S	<i>Lantana camara</i>		X	P
	H	<i>Stachytarpheta jamaicensis</i>		X	P
VIOLACEAE	H	<i>Hybanthus enneaspermus</i>	X		10, 11, P
VITACEAE	H	<i>Cissus quadrangularis</i>		X	P

The plant species on the Ussangoda serpentine site were identified from this and the cited studies. The species on the non-serpentine regions in Ussangoda are based on the IUCN (2004) survey.

Figure legends.

Figure 1. Map of Sri Lanka showing the serpentine sites and an enlarged view of the Ussangoda serpentine site. (S = Serpentine, NS = Non-serpentine, W = Water hole).

Abstract Submission Form
(Deadline: January 31, 2008)

Theme: Applied Ecology

Oral Presentation OR Poster: Oral

AV needs: Multimedia projector connected to laptop

Title: Floral diversity and conservation of the Ussangoda serpentine site in Sri Lanka

Author list, affiliations and email of corresponding author:

Y.A.S. Samithri¹, D.S.A. Wijesundera² and M.C.M. Iqbal^{1*}

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

² Department of National Botanic Gardens, Peradeniya Road, Peradeniya, Sri Lanka.

* Email: mcmif2003@yahoo.com

Keywords: Ussangoda, endemic plants, serpentine soil, serpentine vegetation, MAB.

Abstract (250 words maximum).

Ussangoda is one of the five geologically identified serpentine sites in Sri Lanka located on the southern coast overlooking the Indian Ocean. The site has a deep red color due to the highly lateritic soil and is a popular location for recreation.

This extensive plain of approximately 1 km² is sparsely populated with <15 plant species from 7 families. All these species are prostrate with reduced leaf size, internodes, and thick extensive root system confined to the surface soil layer. Isolated patches of thorny deep-rooted shrubs occupy <5% of the plains. These patches consist of 41 plant species belonging to 26 families. The biomass per unit area on the plain is much less than that of the shrubs. Metal accumulation in the shoots was found in both vegetation types. The most dominant family on this ecosystem was Fabaceae followed by Capparaceae, Salicaceae, Rutaceae and Rubiaceae. Salicaceae, Menispermaceae, Rhizophoraceae and Violaceae were recorded only from the serpentine ecosystem, and not in the adjacent non-serpentine vegetation.

Of these species *Vernonia zeylanica* (Asteraceae) is endemic to Sri Lanka and *Cassia kleinii* (Fabaceae) is found only in Sri Lanka and Southwest India. All the species are tolerant to high metal content in the soil either by accumulation or exclusion. Some of the prostrate species are hyper-accumulators of nickel.

Conservation measures integrating the local population, is imperative, to preserve this site.

This site has been identified as a geo-park by the National Man and Biosphere committee of the UNESCO.

Abstract Submission Form

(Deadline: January 31, 2008)

Theme: Geology-Soils

Oral Presentation OR Poster: Oral Presentation

AV needs: Multimedia projector connected to a Laptop computer

Title: Soil and Vegetation Heterogeneity on a Serpentine Site in Ussangoda, Sri Lanka

Author list, affiliations and email of corresponding author:

H. Asiri S. Weerasinghe¹, S. Madawala Weerasinghe², G.W.A.R. Fernando³, M.C.M. Iqbal^{1*}

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

² Dept. of Botany, University of Peradeniya, Peradeniya, Sri Lanka.

³ Dept. of Physics, Open University of Sri Lanka, Nawala Road, Sri Lanka.

*mcmif2003@yahoo.com

Keywords: ultramafic soil, calcium magnesium ratio, Ussangoda, Sri Lanka

Abstract (250 words maximum).

Weathered ultra-mafic rocks crop out as a serpentinite bearing lateritic cap on a flat plain at Ussangoda on the southern coast of Sri Lanka. Two distinct forms of vegetation grow on this soil: the plain is dominated by prostrate species producing very low biomass per unit area, and small isolated patches of thorny shrubs of higher biomass, occupying less than 5% of the total area. This area receives <1250 mm annual rainfall, with daytime temperatures of 36 °C and 40% relative humidity.

Soil samples were collected (0-10cm) by stratified random sampling from the plains and shrubs and their physical and chemical parameters determined. The soil physical characteristics on the plains and under the shrub were similar with 90–95% sand and 5–10% silt and clay. The mean magnesium content was similar on the plains (315 µg/g) and under the shrubs (329 µg/g). The mean calcium content was significantly higher under the shrubs (593 µg/g) than on the plains (208 µg/g) giving a Ca:Mg ratio of 1.8 and 0.6 respectively. Organic nitrogen was significantly higher under the shrubs (1874 µg/g) than on the plains (708 µg/g). The soil moisture content and organic matter were also higher under the shrubs.

Chemical heterogeneity of ultra-mafic rocks during their formation may perhaps have contributed to the differences observed in the soil chemistry, which is reflected in the distinct forms of vegetation, species composition, and biomass production of the surface flora.

Abstract Submission Form
(Deadline: January 31, 2008)

Theme: Applied Ecology

Oral Presentation OR Poster: Poster

AV needs: None

Title: Nickel accumulation by *Fimbristylis ovata* (Cyperaceae) growing on ultramafic soil in Ussangoda, Sri Lanka.

Author list, affiliations and email of corresponding author:

M.C.M. Iqbal^{1*} and S. Rajaratnam²

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

² Department of Biological Sciences, Vavuniya Campus, University of Jaffna, Sri Lanka.

* Email: mcmif2003@yahoo.com

Abstract (250 words maximum).

Nickel (Ni) accumulating plants are commonly found on ultramafic soils. Of the Ni accumulating species on the ultramafic soil in Ussangoda, *Fimbristylis ovata* (Cyperaceae) is fast growing and easily propagated. It has a stunted growth habit with a shoot/root ratio of 0.23 which when grown on non-ultramafic soil increased to 1.52. The plant available Ni content in the soil was variable (84 – 170 ppm). Ni uptake in the ultramafic soil is determined by available Ni, soil moisture regime, and other soil chemical characters which influence uptake by the roots. *F. ovata* plants were grown under experimental hydroponic conditions to determine the translocation, uptake and tolerance to Ni under different concentrations. Plants grown in hydroponic solution supplemented with 100 – 900 μM of Ni for two weeks accumulated over 3000 $\mu\text{g/g}$ dw of Ni, of which 30% was found in the shoots. In a time-course study, over 50% of the Ni was taken up by the roots in the first 24 hours, reaching a peak after 3 days. The transfer of the absorbed Ni to the shoots reached a maximum after 5 days. *F. ovata* is able to hyperaccumulate and tolerate Ni in its tissues. Although *F. ovata* accumulated low levels of Ni on the ultramafic soil, it was able to uptake much higher levels under experimental conditions.

purposes have varied from obtaining the basic knowledge on their ecological importance to industrial or other uses. However most investigations based on the isolation and identification of fungus species from plant litter have been reported from temperate situations and remarkably little has been published from tropical forest ecosystems. The present investigation was carried out in order to isolate and identify the fungal species involved in the decomposition of mixed leaf litter in Mulawella research area in the Sinharaja forest. Since Sri Lanka has no proper records of soil and litter inhabiting fungal spp. a database will be compiled with information on fungal spp. associated with the leaf litter in Sinharaja forest.

Five study plots (50m x 50m) were located in this site, 1km above the trail to the research station. Mixed leaf litter samples from each of the 5 study plots were collected during a rainy season using random quadrates (1m x 1m) and transported to the laboratory in clean polythene bags. Fungal isolation from the leaf material collected from each of the 5 study plots were carried out using standard methods. 12 leaf discs from each of the 5 replicate samples were obtained by the means of sterilized cork borer. These discs were washed serially and 2 pieces (1mm) of leaf litter were taken from each disc and plated on 2% MEA. Fungi growing from these pieces of leaves were isolated and pure cultures were prepared. Preliminary fungal identifications were carried out using identification keys. Confirmations of these identifications to species level were done using the available reference cultures in the department of Botany, University of Kelaniya. The frequency of occurrence of each fungus was estimated using standard equations. After 6 months from the initial collection date second sampling of leaf litter was carried out from the 5 study plots and same procedures were applied for isolations and identifications of fungi.

Among the fungi isolated from the study site *Trichoderma harzianum* was isolated in the highest frequencies (20.8% and 37.5%) respectively from first and second samplings. The other fungi isolated in higher frequencies from the initially collected leaf materials were *Acremonium strictum* (10%), *Penicillium variabile* (7.5%), *Monosporium* sp. (2.5%), *Cylindrocladium* sp. (3.3%), *Broomella acuta* (5.8%), *Chaetomium globosum* (9.2%), *Geotrichum candidum* (6.7%), *Glomerella cingulata* (3.3%), *Diplorhinotrichum* sp. (2.5%), *Fusarium* sp. (2.5%) and many of dark and hyaline sterile fungal species. In addition, *Glomerella cingulata* (6.7%), *Fusarium* sp. (3.3%), *Beltrania rhombica* (4.2%), *Acremonium* sp.2 (2.5%) and some of sterile, dark and hyaline species were isolated in higher frequencies from the second sample (6 months after the first collection date) of leaf litter materials. *Menisporopsis* sp., *Apiospora phaeospermum*, *Menisporopsis* sp., *Cylindrocarpon magnusianum*, *Acremonium* sp1, *Diplorhinotrichum* sp., *Paecilomyces* sp., *Acremonium kiliense*, *Cylindrocladium parvum* were some of the fungi isolated in low frequencies (1%-2%) from both litter samples.

The result obtained for the fungal community structure and its changes during the two sampling times of mixed leaf litter in Sinharaja forest indicated the presence of fungi species (*Trichoderma harzianum*, *Acremonium strictum*, *Glomerella cingulata*... etc) that were common to the leaf litter collected at both sampling times. *Trichoderma harzianum* which was isolated in higher frequencies is the dominant fungal species associated with the decomposition of leaf litter in this site.

The identified fungal cultures isolated during this study could be used as reference cultures for future identifications of micro fungi from different ecosystems in Sri Lanka. In addition to maintaining the live cultures, a database could be maintained where all the information on this collection of fungal isolates is available.

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A Preliminary Study of the Ussangoda Serpentine Flora

Y. A. S. Samithri¹, D. S. A Wijesundara² and M. C. M. Iqbal¹

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Kandy, Sri Lanka

² Royal Botanical Gardens, Peradeniya, Sri Lanka.

Serpentine soils are derived from ultramafic rocks, which have a high concentration of Magnesium (Mg), Iron (Fe) and heavy metals such as Nickel, Manganese and Cobalt. They are deficient in essential plant nutrients such as Calcium, Nitrogen, Potassium and Phosphorous. There is also an imbalance in the Calcium to Magnesium ratio in these soils. Consequently the physical and chemical properties of the serpentine soil are hostile to plant life and hence hosts a distinctive flora adapted to these extremities. Generally, serpentine plants are dwarf with xeromorphic, chlorotic, narrow, glaucous leaves and enlarged root system. Often serpentine outcrops are characterized by distinct vegetation, poor productivity and high rate of endemism.

In Sri Lanka there are five reported serpentine bodies, which occur roughly along the boundary of the Vijayan and Highland series. Of these, Ussangoda is the only serpentine outcrop on the coast while the rest are on the mainland. Ussangoda is characterized by a deep red colour of the soil. The area is a relatively flat plain with herbaceous prostrate plants and patches of trees and shrubs. A unique type of vegetation on the plains characterizes the outcrop; the vegetation is sharply demarcated with the adjacent non-serpentine dense forest cover.

Plant specimens with identifiable reproductive structures were collected for identification and to study their adaptations.

There were eleven prostrate species belonging to eight families on the plains. In contrast to the species on the plains, the patches of shrubs and trees were high in diversity of families (25) and species (52). The adjacent non-serpentine region, however, had the most diversity with 47 families and 116 species. Fabaceae was the dominant family on serpentine and non-serpentine soil with 6 and 12 species, respectively. Four families, Flacourtiaceae, Menispermaceae, Rhizophoraceae, and Violaceae were recorded only from the serpentine area. Though the number of species is restricted on the serpentine area, *Vernonia zeylanica* (Astereaceae) is endemic to Sri Lanka and *Cassia kleinii* (Fabaceae) is endemic to Sri Lanka and South West India. None of these were recorded from the non-serpentine habitat. Only one endemic species, *Cassine glauca* (Celastraceae), was found in the non-serpentine habitat.

Conservation of this ecosystem is important because of the ecological significance of the site in terms of rich biodiversity and providing habitats for endemic and threatened species. Presently the site is seriously threatened by uncontrolled recreational activities. In addition there is a heavy erosion of soil due to driving of vehicles. These conditions have caused a major impact on the natural habitat and the plants growing on this ecosystem. Therefore it is imperative to adopt appropriate conservation measures to protect this unique and rare habitat.

Keywords: Serpentine flora, Ussangoda,

311

Floristic Survey of Kaudulla National Park

M.S. Rakeeb, P.R. Attygalle, B.M.P. Singhakumara.

UNIVERSITY OF SRI JAYEWARDENPURA

Gangodawila, Nugegoda, Sri Lanka.

Kaudulla National Park is one of the Protected Areas declared in April 2002 and managed by the Department of Wildlife Conservation. It is located in the dry zone of Sri Lanka. The objective of the study is to identify major plant communities in different habitats in the Park and study the structure and composition of these communities.

Twelve plots were demarcated in four different habitats for sampling of trees. Three sub plots were demarcated within each main plot for the sampling of saplings. All woody plants with a diameter = 10 cm at breast height were measured using a diameter tape and the height was estimated. Herbarium specimens were prepared from each species which are new to the sampling location within the plots and also plant species found in surrounding areas.

A total number of 417 individual tree species (= 10 cm) belong to 20 families and 38 genera were recorded in main plots while 2012 saplings in 36 families and 87 genera were recorded in the sub plots representing all four different habitats. Euphorbiaceae and Combretaceae were the dominant families of trees while Rutaceae, Euphorbiaceae and Fabaceae were the dominant families of saplings. Identified communities were *Chloroxylon*, *Drypetes*, *Pterospermum* community (old growth forest); *Pterospermum*, *Bauhinia*, *Cordia* community (secondary forest); *Terminalia*, *Nauclea*, *Haldina* community (riverine forest) and *Vitex*, *Mitragyna*, *Dichrostachys* community (abandoned shifting cultivation land). Eight endemic and threatened plant species belonged to six families were recorded from all four habitats.

The highest Important Value Indices were recorded for *Terminalia arjuna* and *Drypetes sepiaria* found in the Rivrine Forest and Old Growth Forest habitats. The highest diversity was recorded from the secondary forest while the lowest was recorded from the old growth forest.

The present study proved that the use of combination of chemical and structural characters would be more pragmatic in developing phenograms which indicate reliable inter-specific relationships in taxonomic revisions of the genus *Pandanus*.

*priyangi@kln.ac.lk

Tel: 033-2290914

425/D

Soil nutrient contents in the Ussangoda serpentine soil

H A S Weerasinghe and M C M Iqbal *

Plant reproductive biology project, Institute of Fundamental Studies, Kandy

Serpentine soils result from weathering of ultramafic rocks which contain high concentrations of Mg and Si. These soils are deficient in plant nutrients such as N, P, K and Ca. In addition, Mg, Fe and Ni occur in high concentrations. The ratio of Ca to Mg is <0.7 in serpentine soils, which is an important parameter to distinguish these from non-serpentine soils. Serpentine soils are sandy, shallow and well drained containing very low moisture. In addition they have a poor soil structure. All these factors present a hostile environment to plant life. This study is an attempt to assess the plant available elements at this site.

Ussangoda is one of the five serpentine sites in Sri Lanka, located on the southern coast of the island. The soil of this site is red in colour and has a plain area of 1 km² with a few interspersed islands of vegetation. The plain area consists of prostrate plants and the islands contain shrubs. The highest point is 34.5 m from sea level. Soil samples were collected according to the stratified random sampling technique representing three contours (10-20 m, 20-30 m and above 30 m) at a depth of 5 cm below the soil surface where most of the roots were present. Plant available micro-elements (DTPA method) and macro-elements (ammonium acetate method) were determined using the Atomic Absorption Spectrophotometer. The results were analyzed using one way ANOVA.

The available micro-elements, Fe and Mn were low at the higher elevation (69 µg/g and 27 µg/g respectively) than at the lower elevation (82 µg/g and 45 µg/g respectively). The other available micro-elements, Cu and Zn were detected at less than 2 µg/g. The macro-elements, Ca, Mg and K show high variability. However the obtained result for Ca was significantly lower in the plains in comparison to the non serpentine areas (p=0.000). The Ca/Mg was less than 0.7 in the serpentine site and about 3 in non-serpentine. In addition, available Ni (non-essential element) was significantly higher (p=0.001) in the serpentine site in contrast to the non serpentine sites. Our preliminary results show that the Ussangoda serpentine site has the major characteristics of a typical serpentine soil (Ca/Mg ratio, presence of high Ni) and other features of its own.

*mcmif2003@yahoo.com

Tel: 081-2232002

426/D

Hypoglycemic and anti-hyperglycemic activities of *Phyllanthus debilis* in mice

K K Wanniarachchi, L D C Peiris* and W D Ratnasooriya

Dept. of Zoology, Faculty of Science, University of Colombo, Colombo 03, Sri Lanka

Abstract Submission Form
(Deadline: January 31, 2008)

Theme: Applied Ecology

Oral Presentation OR Poster: Oral

AV needs: Multimedia projector connected to laptop

Title: Floral diversity and conservation of the Ussangoda serpentine site in Sri Lanka

Author list, affiliations and email of corresponding author:

Y.A.S. Samithri¹, D.S.A. Wijesundera² and M.C.M. Iqbal^{1*}

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

² Department of National Botanic Gardens, Peradeniya Road, Peradeniya, Sri Lanka.

* Email: mcmif2003@yahoo.com

Keywords: Ussangoda, endemic plants, serpentine soil, serpentine vegetation, MAB.

Abstract (250 words maximum).

Ussangoda is one of the five geologically identified serpentine sites in Sri Lanka located on the southern coast overlooking the Indian Ocean. The site has a deep red color due to the highly lateritic soil and is a popular location for recreation.

This extensive plain of approximately 1 km² is sparsely populated with <15 plant species from 7 families. All these species are prostrate with reduced leaf size, internodes, and thick extensive root system confined to the surface soil layer. Isolated patches of thorny deep-rooted shrubs occupy <5% of the plains. These patches consist of 41 plant species belonging to 26 families. The biomass per unit area on the plain is much less than that of the shrubs. Metal accumulation in the shoots was found in both vegetation types. The most dominant family on this ecosystem was Fabaceae followed by Capparaceae, Salicaceae, Rutaceae and Rubiaceae. Salicaceae, Menispermaceae, Rhizophoraceae and Violaceae were recorded only from the serpentine ecosystem, and not in the adjacent non-serpentine vegetation.

Of these species *Vernonia zeylanica* (Asteraceae) is endemic to Sri Lanka and *Cassia kleinii* (Fabaceae) is found only in Sri Lanka and Southwest India. All the species are tolerant to high metal content in the soil either by accumulation or exclusion. Some of the prostrate species are hyper-accumulators of nickel.

Conservation measures integrating the local population, is imperative, to preserve this site. This site has been identified as a geo-park by the National Man and Biosphere committee of the UNESCO.

Abstract Submission Form
(Deadline: January 31, 2008)

Theme: Geology-Soils

Oral Presentation OR Poster: Oral Presentation

AV needs: Multimedia projector connected to a Laptop computer

Title: Soil and Vegetation Heterogeneity on a Serpentine Site in Ussangoda, Sri Lanka

Author list, affiliations and email of corresponding author:

H. Asiri S. Weerasinghe¹, S. Madawala Weerasinghe², G.W.A.R. Fernando³, M.C.M. Iqbal^{1*}

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

² Dept. of Botany, University of Peradeniya, Peradeniya, Sri Lanka.

³ Dept. of Physics, Open University of Sri Lanka, Nawala Road, Sri Lanka.

* mcmif2003@yahoo.com

Keywords: ultramafic soil, calcium magnesium ratio, Ussangoda, Sri Lanka

Abstract (250 words maximum).

Weathered ultra-mafic rocks crop out as a serpentinite bearing lateritic cap on a flat plain at Ussangoda on the southern coast of Sri Lanka. Two distinct forms of vegetation grow on this soil: the plain is dominated by prostrate species producing very low biomass per unit area, and small isolated patches of thorny shrubs of higher biomass, occupying less than 5% of the total area. This area receives <1250 mm annual rainfall, with daytime temperatures of 36 °C and 40% relative humidity.

Soil samples were collected (0-10cm) by stratified random sampling from the plains and shrubs and their physical and chemical parameters determined. The soil physical characteristics on the plains and under the shrub were similar with 90–95% sand and 5–10% silt and clay. The mean magnesium content was similar on the plains (315 µg/g) and under the shrubs (329 µg/g). The mean calcium content was significantly higher under the shrubs (593 µg/g) than on the plains (208 µg/g) giving a Ca:Mg ratio of 1.8 and 0.6 respectively. Organic nitrogen was significantly higher under the shrubs (1874 µg/g) than on the plains (708 µg/g). The soil moisture content and organic matter were also higher under the shrubs.

Chemical heterogeneity of ultra-mafic rocks during their formation may perhaps have contributed to the differences observed in the soil chemistry, which is reflected in the distinct forms of vegetation, species composition, and biomass production of the surface flora.

Abstract Submission Form
(Deadline: January 31, 2008)

Theme: Applied Ecology

Oral Presentation OR Poster: Poster

AV needs: None

Title: Nickel accumulation by *Fimbristylis ovata* (Cyperaceae) growing on ultramafic soil in Ussangoda, Sri Lanka.

Author list, affiliations and email of corresponding author:

M.C.M. Iqbal^{1*} and S. Rajaratnam²

¹ Plant Reproductive Biology, Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

² Department of Biological Sciences, Vavuniya Campus, University of Jaffna, Sri Lanka.

* Email: mcmif2003@yahoo.com

Abstract (250 words maximum).

Nickel (Ni) accumulating plants are commonly found on ultramafic soils. Of the Ni accumulating species on the ultramafic soil in Ussangoda, *Fimbristylis ovata* (Cyperaceae) is fast growing and easily propagated. It has a stunted growth habit with a shoot/root ratio of 0.23 which when grown on non-ultramafic soil increased to 1.52. The plant available Ni content in the soil was variable (84 – 170 ppm). Ni uptake in the ultramafic soil is determined by available Ni, soil moisture regime, and other soil chemical characters which influence uptake by the roots. *F. ovata* plants were grown under experimental hydroponic conditions to determine the translocation, uptake and tolerance to Ni under different concentrations. Plants grown in hydroponic solution supplemented with 100 – 900 μM of Ni for two weeks accumulated over 3000 $\mu\text{g/g}$ dw of Ni, of which 30% was found in the shoots. In a time-course study, over 50% of the Ni was taken up by the roots in the first 24 hours, reaching a peak after 3 days. The transfer of the absorbed Ni to the shoots reached a maximum after 5 days. *F. ovata* is able to hyperaccumulate and tolerate Ni in its tissues. Although *F. ovata* accumulated low levels of Ni on the ultramafic soil, it was able to uptake much higher levels under experimental conditions.

- 3 **MITSCHUNAS, N.¹, FILSER, J.¹, WAGNER, M.²** (1 University of Bremen, Germany, 2 University of Sheffield, UK)
On the use of fungicides in seed burial studies
 Seed burial studies investigating fungal-induced seed mortality vary with respect to number and identities of fungicides used. Here, we show that by combining several fungicides, a more comprehensive seed protection may be achieved. Captan, the fungicide most commonly used in such experiments, increased dormancy in one of the tested species.
- 4 **GREEN, I.D. SHEPHERD, R. DIAZ, A. SMITH, M.** (Bournemouth University, UK)
Heathland restoration by soil acidification – predicting phytoavailable aluminium levels.
 Aluminium phytoavailability is a key driver of vegetation change during restoration of acid grassland/heathland by soil acidification. However, the relationship between available Al and soil pH is not linear. We report the efficacy of methods for determining the extent to which chemical treatment has increased available Al concentrations in soil.
- 5 **JESSET, J.¹, PECK, M.², DIAZ, A.¹** (1 Bournemouth University, 2 University of Sussex)
Camera trapping as a tool for rapid assessment of incidence of mammals in Ecuadorian cloudforest.
 Movement-activated Wild View Xtreme 2 camera traps were tested for their ability to provide a rapid assessment of the presence of charismatic mammals using the forest floor. Traps set along paths were able to successfully capture images of puma, oncilla, spectacled bear, opossums and agoutis within days of being deployed.
- 6 **STAJEROVA, K.¹, KOLAR, F.¹, KUBESOVA, M.², SEKERKA, L.¹, MOLEM, K.³, LEPS, J.¹** (1 University of South Bohemia, CZ, 2 Charles University of Prague, CZ, 3 The New Guinea Binatang Research Center, PNG)
The role of alien plants in a shifting agriculture in Papua New Guinea.
 The study compares different successional stages of abandoned tropical fields in the lowland rainforest area. Alien species dominate in early successional stages, then both the number of alien species and their total abundance decreases in the course of succession. Alien species are virtually absent from the undisturbed primary forest.
- 7 **BURNET, K.M.** (University of Sheffield, UK)
Developing and testing density structured models of arable weed populations.
 A novel method based on discrete density classes and rapidly collected data may allow much improved exploration of large spatial scales in weed population models. Detailed field experiments will be conducted in order to construct and analyse demographic and density-structured models, revealing the comparative advantages of both methods.
- 8 **BURNS, F.¹, BOLTON, M.², SZEKELY, T.¹, MCCULLOCH, N.³** (1 University of Bath, UK, 2 RSPB, UK, 3 Environment and Heritage Service, UK)
The ecological, demographic and genetic bases for decline in the globally endangered St Helena Wirebird *Charadrius sanctaehelenae*.
 The global population of the St Helena Wirebird was estimated as 208 adults in 2005. This marked a reduction of 43% in five years. Results are presented from the first field season investigating the demography of this species and the drivers of the recent population decline.
- 9 **GOLDBERG, E. TOWNSHEND, D.** (Natural England, UK)
Summary of Natural England's "State of the Natural Environment" report.
 Natural England's State of the Natural Environment report brings together evidence on biodiversity, landscapes and access. We provide baseline evidence and information on condition, and details on the primary drivers of change and effectiveness of these responses made to reduce or remove the impact of those pressures.
- 10 **FALCONER, F. WHEATLEY, R. KARLEY, A.** (SCRI, UK)
Nitrification rates in soils of potato and barley fields receiving carbon amendments.
 Nitrification by soil microbes was estimated in three fields of potatoes and barley, with different carbon amendments, throughout the growing season. Significant differences in nitrification rates were found between crops in the same field and in response to the different inputs. Some of these results are presented and discussed.
- 11 **CHRISTIAN, L.¹, SNEDDON, J.C.²** (1 Liverpool John Moores, UK, 2 Liverpool John Moores)
An investigation into Copper (Cu) & Molybdenum (Mo) transfer between soil, heather and feather of red grouse (*Lagopus lagopus scoticus*) in the Highlands of NE Scotland
 This study investigated correlations in Cu & Mo transfer between soil -heather-feather in Red Grouse. There were positive though non significant correlations in the transfer path for Cu and negative correlations for Mo indicating competitive inhibition in uptake. Studies at sites with higher soil element concentrations are planned.
- 12 **PRESSLAND, C.P.** (University of Bristol, UK)
The impact of game management on invertebrate biodiversity.
 Game management involves a large proportion of the UK rural landscape and its effects on biodiversity are largely unknown. This project looks at the impact of releasing pheasants on invertebrates in and around farmland woodlands to try to establish the effects and mechanisms involved in this popular countryside sport.
- 13 **IQBAL, M.C.M.¹, WIJESUNDERA, D.S.A.²** (1 Institute of Fundamental Studies, Hantana, Kandy, Sri Lanka, 2 Royal Botanic Gardens, Peradeniya, Sri Lanka)
Conservation of the Ussangoda serpentine plain in Sri Lanka as a geo-park.
 The Ussangoda plain has geological, ecological and cultural values to be nominated as a geopark. Its serpentine soil has heavy metal tolerant, prostrate plant species. The site is threatened by alternative economic uses, due to ignorance of its significance. Establishing a geopark could integrate the local population to derive economic benefits and conserve the flora.

- 18:10 **NIELSEN, U.N.¹, OSLER, G.H.R.¹, VAN DER WAL, R.², CAMPBELL, C.D.¹, BURSLEM, D.F.R.P.³**
 (1 The Macaulay Institute, UK, 2 Aberdeen Centre for Environmental Sustainability, UK, 3 School of Biological Sciences, Aberdeen University, UK)
The effect of habitat heterogeneity on species richness of soil mites and microbes.
 Belowground foodwebs are highly species rich, but in contrast to other terrestrial and aquatic ecosystems we know little of what structures richness in soils. We present data from a large study and an experiment showing strong positive relationships between species richness of several groups of soil biota and habitat heterogeneity.

Ecosystem Processes I ⁵⁴² ^{Eng} ^{resh.}

Session 32: Location: G16, Sir Alexander Fleming Bldg
 Chair: Prof David Raffaelli

- 08:30 **COOMES, D.A. BENTLEY, W. GAXIOLA, A.**
 (University of Cambridge, UK)
What causes the decline phase of successions?
 Soil-phosphorus depletion is often considered responsible for the decline phase of succession, characterised by decreases in plant biomass and ecosystem productivity. We show that podzolisation of older soils within a New Zealand chronosequence has led to poor drainage, with consequences for ecosystem processes that surpass those of P depletion.
- 08:50 **ORWIN, K.H.¹, BUCKLAND, S.², JOHNSON, D.³, BARDGETT, R.D.¹** (1 Lancaster University, UK, 2, 3 University of Aberdeen, UK)
Relationships between plant traits and soil properties.
 It has been suggested that plant traits might be good predictors of how soil functions. We tested this idea by measuring changes in soil properties in long-term monoculture plots containing a range of grassland plant species. Results showed significant species effects, but few strong relationships with plant traits.
- 09:10 **JONES, J.M. POWER, S.A.** (Imperial College, UK)
Investigating nitrogen deposition signals in Calluna-dominated lowland heathland systems in England.
 This study investigated the relationships between modelled N deposition and a suite of heathland soil and plant characteristics. Thirty-two lowland heath sites across England were surveyed along an N deposition gradient (13.3 – 30.8 kg ha⁻¹ yr⁻¹). Tissue, soil and litter N&P, and enzyme activity were all significantly related to N deposition. The N deposition signal is detectable at heathlands across England.
- 09:30 **DJOHAN, T.S.** (Gadjah Mada University, Indonesia)
Post-fire forest regrowth in the catchment area at southern slope of Mount Merapi Yogyakarta, Java.
 I studied the tree of tropical-rain forest regrowth after post-fire of 2002 and 1994 at the southern slope of Mount Merapi. The fires burned all the vegetation, except Kinah (*Chinchona rubra*) and Puspa (*Schima noronhae*). The forest regrowth consisted of forest fire survivor trees, and seedlings of new colonists trees.
- 09:50 **FINN, J.A.¹, KIRWAN, L.², BROPHY, C.³, SEBASTIA, M.T.⁴, LUESCHER, A.⁵, CONNOLLY, J.³** (1 Teagasc, Ireland, 2 WIT, Ireland, 3 University College Dublin, Ireland, 4 University of Lleida, Spain, 5 ART, Switzerland)
Agronomic diversity increased aboveground biomass and reduced weed invasion in experimental grassland swards over three years across 12 European sites.
 A common experiment across 12 European sites (360 plots) systematically varied the relative abundance of two grasses and two legumes. Average yield of mixtures was greater than that of monocultures. Community evenness improved production of aboveground biomass and resistance to weed invasion. Effects persisted for at least three years.
- 10:10 **IQBAL, M.C.M.¹, SAMITHRI, Y.A.S.¹, WIJESUNDERA, D.S.A.²** (1 Institute of Fundamental Studies, Hantana, Sri Lanka, 2 Royal Botanic Gardens, Peradeniya, Sri Lanka)
Morphological and physiological adaptations on a serpentine ecosystem in Ussangaoda, Sri Lanka.
 Serpentine soil at Ussangoda is low in Ca and contains toxic levels of heavy metals. Plants have low diversity, low shoot/root ratio and are tolerant to heavy metals. Over 95% of the soil is covered by prostrate species of low biomass and the rest with isolated patches of high biomass shrubs.
- 10:30 **TYOKUMBUR, E.T** (University of Ibadan, Nigeria)
Bioconcentration of trace elements in Alaro Stream Ecosystem, Ibadan.
 The physical, biological, chemical properties and trace metal levels were investigated at five study sites and the ecological effects of industrial effluents from Steelworks, Sumal and 7UP factories discharged into the stream were determined. Bioconcentration in the fauna and flora showed significant relationship with their habitats.

Evolution and Genetics – Animals

Session 33: Location: 542, Mechanical Engineering Bldg
 Chair: Steven White

- 14:10 **RANKIN, D.J.¹, DIECKMANN, U.², KOKKO, H.³**
 (1 University of Bern, Switzerland, 2 International Institute of Applied Systems Analysis, Austria, 3 University of Helsinki, Finland)
Sexual conflict and the evolutionary tragedy of the commons.
 Males and females often have different mating optima, and multiple mating acts to the benefit of males whilst inflicting a cost on females. With a model coupling both evolutionary and ecological dynamics, we show that male harassment can evolve to an extreme level which results in the population going extinct. We further explore which factors, such as eco-genetic feedbacks, which may prevent such runaway evolution to self-extinction.

Section 6

Summary Statement of Expenditure

The financial position of grant No. RG/2006/EB/08 as at 29.04.2011 awarded to Dr. M.C.M. Iqbal by National Science Foundation is as follows.

		Funds received by the Univ./ Institution	Total expenditure Rs.	Balance available Rs
Personnel -	Research Student	555,000.00	844,238.71	(289,238.71)
	Technical Assistant	-	-	-
	Other	-	-	-
Equipment - Reciprocating Shaker (Model :SHR - 2 D)	Foreign	350,000.00	183,680.00	166,320.00
	Local	-	-	-
Consumables -	Foreign	195,000.00	142,101.50	52,898.50
	Local	-	-	-
Travel & Subsistence		90,150.00	10,656.25	79,493.75
Miscellaneous		50,000.00	25,972.35	24,027.65
Total		1,240,150.00	1,206,648.81	33,501.19

Unspent balance of the funds received -

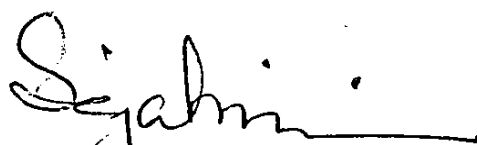
Fund received Rs. 1,240,150.00

Actual expenditure 1,206,648.81

Balance 33,501.19

Cash Imprest/Cash advance -

Balance as at 29.04.2011 33,501.19



.....
Bursar/Accountant

ACCOUNTANT

Institute of Fundamental Studies
HANTANA ROAD,
KANDY.

Date: 29/04/2011

Section 7

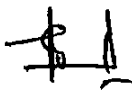
Signatures of grantees and Head of Institution

Section 7

i) Grantees' signatures

Principal Investigator Dr. M.C.M. Iqbal 


Co-Investigators Dr. D.S.A. Wijesundera

Dr. G.W.A.R. Fernando 

ii) Comments of the Head of the Department/signature

Highly commendable

iii) Head of the Institution's signature


**Director
Institute of Fundamental Studies
Hantana Road
Kandy**

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