The ecology of ultramafic areas in Sabah: threats and conservation needs

A. van der Ent

Centre for Mined Land Rehabilitation, Sustainable Minerals Institute,
The University of Queensland, Brisbane, QLD 4072, Australia
a.vanderent@uq.edu.au

ABSTRACT. Ultramafics are characterised by high concentrations of magnesium and nickel, low concentrations of calcium, low water retention capacity and low concentrations of essential plant nutrients in soils derived from this substrate. These extreme chemical soil condition force plants to adapt to survive. Sabah is one of the richest areas in the world for plant diversity on ultramafic substrates. A range of species, including a number of pitcher plants (Nepenthaceae), orchids (Orchidaceae) and trees and shrubs are endemic to ultramafic areas in Sabah, often occurring on a few, or even just a single, site. Ultramafic vegetation types in Sabah are severely threatened by land-clearing activities. Although only a small minority of the geological substrates in Sabah are ultramafic, ecosystems on these substrates have a disproportionately high number of endemic and rare plant species. Destruction of these types of ecosystems, in particular, can potentially result in extinction of plant species.

Keywords. Endemism, Mount Kinabalu, rare species, Sabah, serpentine, ultramafics

Introduction

Preliminary research suggests that the Malaysian state of Sabah may be one of the richest areas in the world for plant diversity on ultramafic substrates. Kinabalu Park, covering approximately 1200 square kilometres, has in excess of 900 plant species occurring on ultramafics. This extremely high diversity is a consequence of the immense biodiversity of the Malesian region itself, as well as the locally diverse edaphic and climatic conditions. Generally in the Malesian region, ultramafic vegetation types have lower stature and different species composition compared to lowland dipterocarp-forest (Proctor & Nagy 1992). The edaphic stresses that ultramafic substrates exert on plant survival have resulted in high numbers of endemic species on these substrates.

Ultramafic rocks and substrates

Ultramafic (or 'ultrabasic') substrates are found all around the world. The often-used geological term 'serpentine' refers to lizardite, antigorite and chrysotile, but ecologists use it to describe the ecology of soils derived from ultramafic substrates (Coleman & Jole 1992). Ultramafics are found in tectonic chunks ('ophiolite suites'), which are fragments of the upper mantle obducted in continental margins on ocean floors (Coleman & Jole 1992). In Sabah, ultramafics (predominantly in the form of the mineral peridotite) that have been raised above sea level weather to iron- and nickel-rich laterites (Baillie et al. 2000). Such soils are characterised by very high concentrations of magnesium and nickel, both of which may be phytotoxic, have low water retention capacity, low available phosphorus concentrations (partly due to phosphorus-immobilising ferric sesquioxides) and low concentrations of other essential plant nutrients such as nitrogen and potassium (Baillie et al. 2000).

The ultramafic effect ('serpentine syndrome')

The evolutionarily challenging selection forces that ultramafics exert on plants is a result of the extraordinary geochemistry (Rajakaruna & Baker 2006). The excess of magnesium, and specifically the very low calcium to magnesium ratio (<1) in soils derived from ultramafic substrates, is an important factor in determining species composition and structure of vegetation on ultramafic substrates (Brooks 1987). The foliar concentration of magnesium is often significantly higher in plants growing on ultramafics, while calcium concentrations are often significantly lower (Brady et al. 2005). Extremely high nickel concentrations in such soils can also be limiting to the growth of many plant species. The bioavailable and thus potentially phytotoxic concentration of nickel in the soil depends on soil clay content, organic exudates in the rooting zone, soil moisture pH and the presence of other divalent ions such as calcium and magnesium.

Another important factor defining the structure and species composition of ultramafics is water stress. Many plants found on ultramafics have morphological adaptations to minimise water requirements and water loss in order to survive in drought conditions (Brady et al. 2005). Such adaptations include a generally low stature, small-crowned growth-form and other characteristics such as glaucous leaves and sclerophyllous and microphyllous morphologies. Examples of vegetation types in which many plants clearly display such adaptations are the graminoid vegetation on higher elevations on Mt. Tambuyukon and the stunted vegetation at Mt. Silam (Bruijnzeel et al. 1993). Morphological adaptations that evolved to reduce transpiration are also likely to minimise nickel and magnesium uptake. The low water retention capacity of most ultramafic soils might induce water stress, but may also increase the toxicity of magnesium and nickel by the concentration effect in the soil solution (Proctor & Nagy 1992). In addition, water stress and drought can increase the susceptibility of vegetation to fire. Prolonged dry periods that may occur due to the El Nino effect often result in fires affecting the ultramafic vegetation communities of Mt. Kinabalu. Aiba & Kitayama (2002) showed that the growth rates of trees on ultramafics are lower than those at equivalent altitudes on non-ultramafics, but they have also shown that the mortality rate during droughts is distinctly lower on ultramafics. The recurrence of fires delays succession and therefore prevents development of tall vegetation types. Furthermore, the burning of leaf litter during fire could also have an effect on the soil nutrient status by increasing the availability of phosphorus and mineralising organic matter.

The environmental and edaphic factors mentioned in the proceeding paragraph have, taken together, been termed the 'serpentine syndrome' (Jenny 1980), a 'syndrome' expressed through the combined characteristic morphology, physiology and ecology of these plant communities that likely results from a dynamic interplay of the above-mentioned factors (Brady et al. 2005). Besides the geochemical anomalies, other prevailing environmental and edaphic conditions may also be important in determining the specific vegetation composition and structure of such plant communities. Soil depth and the degree of exposure to wind, for example, may also be contributing factors that restrict the successful survival of plants on ultramafics.

Hyperaccumulators of nickel in Sabah

Some plants have the remarkable physiological capacity to accumulate shoot nickel at levels 100-10,000-fold greater than levels in non-accumulators (Lasat 2001). Such 'hyperaccumulators' are confined to ultramafics because that substrate is the largest and most widespread metal-enriched habitat on a global scale. It is an exceptionally rare phenomenon with only 1–2% of plant species found on ultramafics being classed as hyperaccumulators. As of 2010, some 400 nickel hyperaccumulator species have been described (Baker 1981, Baker & Smith 2000). Nickel hyperaccumulators are found in many different genera across at least 45 plant families (Baker et al. 1999). As such, nickel hyperaccumulators have a great variety of growth forms, ecophysiological characteristics and ecological requirements (Pollard et al. 2002). The plant families that are most represented are Euphorbiaceae, Brassicacea, Asteraceae, Flacourtiaceae (Salicaceae), Buxaceae and Rubiaceae (Reeves 2003), illustrating that this phenomenon has independently developed multiple times on ultramafics. Nickel hyperaccumulators are relatively easy to identify by chemical analysis of dried foliage in the laboratory or in the field by pressing fresh leaves against white test paper impregnated with dimethylglyoxime ('DMG'), which is a nickel-specific colorimetric dye (Baker et al., 1992a).

A number of hyperaccumulators have been found in Sabah, including: *Rinorea bengalensis* (Wall.) Kuntze, *Phyllanthus balgooyi* Petra Hoffm. & A.J.M.Baker, *Dichapetalum gelonioides* (Roxb.) Engl. ssp. *tuberculatum* Leenh. and *Shorea tenuiramulosa* P.S.Ashton. The small tree or scrambler, *Dichapetalum gelonioides ssp. tuberculatum*, has up to 25 mg/g nickel in its dried foliage (Reeves 2003). While hyperaccumulators are typically recognised on the basis of the concentrations of metals in the foliage, other plant parts may have very different metal concentrations. For instance, Reeves (2003) cites values for phloem tissues of the shrub *Phyllanthus balgooyi* of up to 90 mg/g nickel on a dry weight basis. This is a widespread shrub on ultramafics in Sabah (as well as in the Philippines) and it has only recently been described formally (Hoffmann et al. 2003). Prior to this, it was provisionally recognized as *Phyllanthus 'palawanesis'* (Baker et al. 1992b).

Epiphytes on ultramafics

Epiphytes are an ecologically important part of the plant diversity on ultramafics in Sabah, particularly at higher altitudes. Epiphytes may be sensitive to the chemical composition in the host tissues and may absorb elements, such as nickel, from their host. However, the precise ecological relationship between epiphytes and their host is very poorly understood. In New Caledonia, Boyd et al. (2009) found that epiphytes (mosses and liverworts) growing on nickel hyperaccumulator hosts contained higher levels of nickel than those growing on non-hyperaccumulator hosts. Even more so, the epiphyte nickel concentrations often exceeded the threshold of nickel hyperaccumulation (Boyd et al. 2009). This indicates that the capacity of epiphytes to grow on hyperaccumulators depends on their capability to tolerate high nickel concentrations, which may in turn define the spatial and ecological attributes of epiphyte community composition (Boyd et al. 2009). There is limited evidence from Mt. Kinabalu were several epiphytic orchids are known only from ultramafic substrates, suggesting important correlations between the chemical composition of substrate and host. In addition to potential chemical relationships, the open and low-statured structure (with, as a result, higher sunlight intensity, higher surface temperatures, lower humidity and higher wind exposure) of many ultramafic vegetation types is undoubtedly important for the distribution and relative abundance of epiphytes on ultramafics.

Endemism on ultramafic substrates

Whittaker (1954) categorised three general characteristics common among vegetation types on ultramafics: (a) low stature and biomass production; (b) high levels of endemism; and (c) distinct differences from vegetation in surrounding areas. Based on these characteristics, Whittaker (1954) attributed the ‘serpentine syndrome’ to three causes: the edaphic or geochemical; the plant species-level (autecology); and the plant community-level (synecology). The preponderance of endemism of species occurring on ultramafic substrates in Sabah differs strongly between areas. High levels of endemism are generally associated with especially isolated areas, either geographic or altitudinal. Some species may have a high affinity for ultramafic substrates, being more abundant or even solely confined to such areas, while others have wide ecological amplitudes and occur on different substrates. Species endemic to ultramafics may be paleo-endemics; species for which their population have become confined to ultramafics due to competition elsewhere (Baker & Whiting 2002), or neo-endemics which have evolved *in-situ* from closely-related species.

Ultramafics in Sabah

The geology of Sabah, Malaysia, is mainly composed of sedimentary rock, such as sandstone and shale, but about 3500 square kilometres (4.6% of total landmass) of

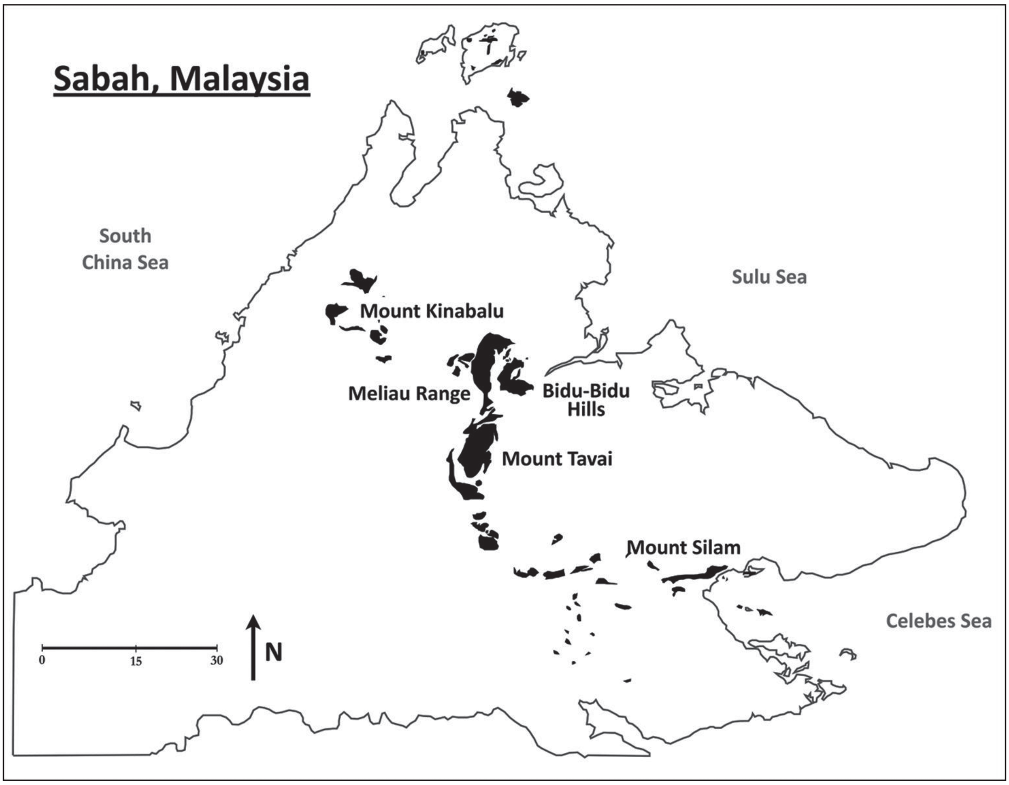

Fig. 1. Delimitation of ultramafic outcrops based on the map 'Igneous Rocks of Sabah, Malaysia' by Geological Survey, Borneo Region, Malaysia, 1965. In the map, the most extensive ultramafic outcrops are featured, including Mount Kinabalu, Mount Silam, Mount Tavai, Meliau Range and Bidu-Bidu Hills.

ultramafics occur (Proctor et al. 1988, Repin 1998). The most extensive ultramafic outcrops are found in the Meliau Range, at Mt. Tawai, the Bidu-bidu Hills, Mt. Silam and around Mt. Kinabalu (Collenette 1964) (Fig. 1). Ultramafics are found from sea level (on islands in the Darvel Bay area) up to nearly 2900 metres above sea level (on Mt. Kinabalu). Studies of the plant diversity on ultramafics are extremely limited in Sabah. The Sabah Forestry Department (2005) has undertaken some general site reconnaissance at Mt. Tawai and the Bidu-Bidu Hills and described three main types of ultramafic vegetation: (1) lowland ultramafic forest, in which dipterocarps dominate; (2) hill forest in which *Casuarinaceae* dominate but also some dipterocarps are found; and (3) hill and lower montane mixed dipterocarp forest. Mt. Silam near the town of Lahad Datu has extensive ultramafic vegetation and has been the subject of more extensive research (Proctor et al. 1988, Proctor et al. 1989, Bruijnzeel et al. 1993). Although this mountain is only 884 m high, it ranges from lowland dipterocarp-dominated forest to stunted *Myrtaceae*-dominated vegetation (Proctor & Nagy 1992). Ultramafics on the islands in Darvel Bay are often composed of mono-specific stands of *Casuarina nobilis* Whitmore (Fox & Hing 1971). The plant diversity of Mt. Kinabalu has been the subject of extensive research (see Beaman & Beaman 1990; Beaman et al. 2003), but the ecology of ultramafics has so far only been studied specifically by Repin (1998).

Ultramafics around Mt. Kinabalu

Barthlott et al. (2007) lists the northern part of Sabah as one of the top five global plant diversity centres, with more than 5,000 species per 10,000 square kilometres. Extensive research at Mt. Kinabalu, has revealed that the plant diversity is as high as 5000–6000 species (excluding mosses and liverworts but including ferns), comprising over 200 families and 1000 genera (Beaman et al. 2003). Given that this plant diversity occurs in an area approximately only 1200 square kilometres, Mt. Kinabalu probably represents the most floristically biodiverse place in the world (Beaman et al. 2003). The high biodiversity at Mt. Kinabalu is mainly the result of the different climatic zones, due to altitudinal differences, the large array of soils including ultramafics (‘geodiversity’), the distinctiveness of habitats and the proximity of older mountain ranges (Mt. Kinabalu is geologically very young), which provide a ‘species dispersion base’ (Beaman et al. 2003). At elevations of 1700 m and above, ultramafic vegetation is characterised by the dominance of (1) *Tristaniopsis elliptica* Stapf, (2) *Leptospermum javanica* Sm.– *Tristaniopsis elliptica* Stapf, and (3) *Leptospermum recurvum* Hook.f. - *Dacrydium gibbsiae* Stapf (Kitayama 1991). On lower elevations, *Gymnostoma sumatranum* (Jungh. ex de Vriese) L.A.S.Johnson and *Centhostoma terminale* L.A.S.Johnson are distinctive (Beaman & Beaman 1990). High on Mt. Kinabalu (around 2900m) the vegetation on ultramafics is rather bare and consists only of herbs such as *Schoenus curvulus* F. Muell., *Euphrasia borneensis* Stapf and *Machaerina falcata* (Nees) Koyama. The graminoid vegetation types on the summit of Mt. Tambuyukon and at the spur of Marai Parai are another characteristic of local ultramafic vegetation types, with endemic species such as the pitcher plant *Nepenthes rajah* Hook.f. and the herb *Scaevola verticillata* Leenh..

Mt. Kinabalu’s ultramafic vegetation is typified by endemics from the Nepenthaceae family, which are confined to ultramafics such as the earlier mentioned *Nepenthes rajah* Hook.f. , as well as *N. burbidgeae* Hook.f. ex Burb. and *Nepenthes macrovulgaris* J.R.Turnbull & A.T.Middleton and a number of endemic orchids such as *Paphiopedilum rothschildianum* (Rchb.f.) Stein, *Paphiopedilum hookerae* (Rchb.f.) Stein *var. volonteanum* (Sander ex Rolfe) Kerch., *Paphiopedilum dayanum* (Lindl.) Stein, *Corybas kinabaluensis* Carr, *Arachnis longisepala* (J. J. Wood) Shim & A. Lamb and *Platanthera kinabaluensis* Kraenzl. ex Rolfe in Gibbs.

In addition, a range of trees, shrubs and herbs are ultramafic endemics at Mt. Kinabalu, including: *Magnolia persuaveolens subsp. rigida* Noot., *Embelia cordata* Philipson, *Syzygium dasyphyllum* Merr. & L.M.Perry, *Syzygium exiguifolium* Merr. & L.M.Perry, *Syzygium myrtillus* (Stapf) Merr. & L.M.Perry, *Eriobotrya aff. bengalensis* (Roxb.) Hk.f., *Hedyotis protrusa* Stapf, *Lasianthus membranaceus var. firmus* Stapf, *Urophyllum subanurum* Stapf, *Wikstroemia indica* (L.f.) C.A.Meyer and *Elatostema bulbothrix* Stapf (Beaman & Anderson, 2004).

Only a few tree species are currently understood as true ultramafic endemics. These include *Borneodendron aenigmaticum* (Meijer 1964), *Dacrydium gibbsiae*

Stapf and *Pittosporum silamense* J.B.Sugau. Some other species, such as *Buchanania arborescens* (Blume) Blume, and dipterocarps such as *Dipterocarpus lowii* Hook.f., *Dipterocarpus ochraceus* Meijer, *Dipterocarpus geniculatus* Vesque, *Shorea tenuiramulosa* and *Shorea kunstleri* King are typical of ultramafics, but are not entirely confined to this substrate (Ashton 1982; Proctor, 2003)

Threats to ultramafic vegetation in Sabah

Ultramafic vegetation types in Sabah are severely threatened by land clearing activities, such as in the Meliau Range, Bidu-Bidu Hills, Mt. Silam and Mt. Tawai and a range of smaller sites. Despite the status of a protected forest reserve of these ultramafic localities, encroachment remains a problem, and many sites without legal protection have disappeared in recent years, such as Morou Porou and the Lohan Valley. Mt. Kinabalu and ultramafic sites within national park boundaries, such as Mt. Tamboyukon are safeguarded, but land clearing has made the national park a virtual 'island'. Although only a small minority of the geological substrates in Sabah are ultramafic, these areas have a disproportionately high number of endemic and/or rare plant species. Many plant species occur on only a few sites or even a single site and habitat destruction, if it occurred, could therefore potentially result in extinction.

Conservation and research priorities

Only very limited research on the ecology of ultramafics in Sabah has been undertaken to date. According to Baker & Brooks (1988), *"... the ultramafic regions of Asia are generally the least explored and poorly described of such regions in the world".* Due to the lack of scientific information, it is difficult to formulate conservation strategies and priorities, although given the history of, and potential risk for further, habitat destruction, it is evident that many species endemic to ultramafics are threatened. The need for conservation and research has been made strongly by Repin (1998) who emphasised that scientific research and preservation of ultramafics in Sabah needs to be given utmost priority, particularly in those areas without legal protection, before there is any further destruction and loss.

ACKNOWLEDGEMENTS. The author wishes to thank Prof. David Mulligan and Dr. Peter Erskine from the Centre for Mined Land Rehabilitation (CMLR) at the University of Queensland for generous support and the opportunity to participate in the Flora Malesiana Symposium in Singapore. Thanks also to Dr. Andrew Fletcher from the CMLR for critical comments on the manuscript.

References

Aiba, S. & Kitayama, K. (2002) Effects of the 1997–98 El Nino drought on rain forests of Mount Kinabalu, Borneo. *J. Trop. Ecol.* 18: 215–230.

Ashton, P.S. (1982) Dipterocarpaceae. *Flora Malesiana* Ser. I, 9(2): 237–600
Baillie, I., Evangelista, P. & Inciong, N. (2000) Differentiation of upland soils on the Palawan ophiolitic complex, Philippines. *Catena* 39: 283–299.
Baker, A. (1981) Accumulators and excluders-strategies in the response of plants to heavy metals. *J. Pl. Nutr.* 3: 643–654.
Baker, A. & Brooks, R. (1988) Botanical exploration for minerals in the humid tropics. *J. Biogeogr.* 15, No 1: 221–229.
Baker, A. & Smith, A. (2000) Metal hyperaccumulator plants: biological resources for exploitation in the phytoextraction of metal contaminated soils, pp. 3–5. *Proc. InterCost Workshop for Bioremediation. Sorrento, Italy.*
Baker, A. & Whiting, S. (2002) In Search of the Holy Grail: A Further Step in Understanding Metal Hyperaccumulation? *New Phytol.* 155: 1–4.
Baker, A.J.M., Proctor, J., Balgooy, M.M.J. van, & Reeves, R.D. (1992a) Hyperaccumulation of nickel by the ultramafic flora of Palawan, Republic of the Philippines. In: Proctor, J., Baker, A.J.M. & Reeves, R.D. (eds) *The Vegetation of Ultramafic (Serpentine) Soils.* Andover, U.K.: Intercept Ltd.
Baker, A.J.M., Proctor, J., Balgooy, M.M.J. van & Reeves, R.D. (1992b) Hyperaccumulation of nickel by the ultramafic flora of Palawan, Republic of the Philippines. In: Proctor, J., Baker, A.J.M. & Reeves, R.D. (eds) *The Vegetation of Ultramafic (Serpentine) Soils.* Andover, U.K.: Intercept Ltd.
Barthlott, W., Hostert, A., Kier, G., Küper, W., Kreft, H., Mutke, J., Rafiqpoor, M. & Sommer, J. (2007) Geographic patterns of vascular plant diversity at continental to global scales. *Erdkunde* 61: 305–315.
Beaman, J.H., Anderson, C. & Beaman, R.S. (2003) Biodiversity of Mount Kinabalu. *CBD Technical Series* 8: 58.
Beaman, J.H. & Anderson, C. (2004) *The Plants of Mount Kinabalu. 5: Dicotyledon families Magnoliaceae to Winteraceae*. Kota Kinabalu: Natural History Publications (Borneo) Sdn. Bhd. & Kew: Royal Botanic Gardens, Kew.
Beaman, J.H. & Beaman, R.S. (1990) Diversity and distribution patterns in the flora of Mount Kinabalu. In: Baas, P., Kalkman, K. & Geesink, R. (eds) *The Plant Diversity of Malesia.* Dordrecht: Kluwer Academic Publishers.
Boyd, R., Wall, M. & Jaffre, T. (2009) Do tropical nickel hyperaccumulators mobilize metals into epiphytes? A test using bryophytes from New Caledonia. *Northeastern Naturalist* 16: 139–154.
Brady, K., Kruckeberg, A. & Bradshaw Jr, H. (2005) Evolutionary ecology of plant adaptation to serpentine soils. *Annu. Rev. Ecol. Evol. Syst.* 36:243–66
Brooks, R.R. (1987) *Serpentine and Its Vegetation: A Multidisciplinary Approach*. Dioscorides Press.
Bruijnzeel, L., Waterloo, M., Proctor, J., Kuiters, A. & Kotterink, B. (1993) Hydrological observations in montane rain forests on Gunung Silam, Sabah, Malaysia with special reference to the ‘Massenerhebung’ effect. *J. Ecol.* 81: 145–167.
Coleman, R.G. & Jole, C. (1992) *Geological Origin of Serpentinites. The Vegetation of Ultramafic (Serpentine) Soils.* Andover: Intercept Limited.

Collenette, P. (1964) A short account of the geology and geological history of Mt. Kinabalu. *Proc. Roy. Soc. London, Ser. B, Biol. Sci.* 161: 56–63.

Fox, J.E.D. & Hing, T.T. (1971) Soils and forest on an ultrabasic hill north east of Ranau, Sabah. *J. Trop. Geogr.* 32: 38–48.

Hoffman, P., Baker, A.J.M., Proctor, J. & Madulid, D. (2003) *Phyllanthus balgooyi* (Euphorbiaceae s.l.), a new nickel-hyperaccumulating species from Palawan and Sabah. *Blumea* 48: 193–199.

Jenny, H. (1980) *The Soil Resource: Origin and Behavior.* New York: Springer-Verlag.

Kitayama, K. (1991) *Vegetation of Mount Kinabalu Park, Sabah, Malaysia*. Honolulu: Environment and Policy Institute, East-West Center and Department of Botany, University of Hawaii at Manoa.

Lasat, M.M. (2001) Phytoextraction of toxic metals: a review of biological mechanisms. *J. Environm. Qual.* 31:109–120.

Meijer, W. (1964) Forest botany in North Borneo and its economic aspects. *Econ. Bot.* 18: 256–265.

Pollard, A., Powell, K., Harper, F., Andrew, J. & Smith, C. (2002) The genetic basis of metal hyperaccumulation in plants. *C.R.C. Crit. Rev. Pl. Sci.* 21: 539–566.

Proctor, J. (2003) Vegetation and soil and plant chemistry on ultramafic rocks in the tropical Far East. *Perspect. Plant Ecol.* 6: 105–124.

Proctor, J. & Nagy, L. (1992) Ultramafic rocks and their vegetation: an overview. In: Baker, A., Proctor, J. & Reeves, R.D. (eds) *The Vegetation of Ultramafic (Serpentine) Soils: Proceedings of the First International Conference on Serpentine Ecology.* Andover, U.K.: Intercept Ltd.

Proctor, J., Lee, Y., Langley, A., Munro, W. & Nelson, T. (1988) Ecological studies on Gunung Silam, a small ultrabasic mountain in Sabah, Malaysia. I. Environment, forest structure and floristics. *J. Ecol.* 76: 320–340.

Proctor, J., Phillipps, C., Duff, G., Heaney, A. & Robertson, F. (1989) Ecological studies on Gunung Silam, a small ultrabasic mountain in Sabah, Malaysia. II. Some forest processes. *J. Ecol.* 77: 317–331.

Rajakaruna, N. & Baker, A.J.M. (2006) Serpentine: a model habitat for botanical research in Sri Lanka. *Ceylon J. Sci.* 32: 1–19.

Reeves, R. (2003) Tropical hyperaccumulators of metals and their potential for phytoextraction. *Pl. & Soil* 249: 57–65.

Repin, R. (1998) Serpentine ecology in Sabah, Malaysia. *Sabah Parks Nat. J.* 1: 19–28.

Sabah Forestry Department (2005) *Sabah Forestry Department* [Online]. URL:http://www.forest.sabah.gov.my/caims/Class%20I/A_FR1/bidu%20bidu.htm [Accessed August 30 2010].

Whittaker, R.H. (1954) The ecology of serpentine soils. *Ecology* 35: 258–288.