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Chapter ten:

Revegetation and Stabilisation of Mine Dumps and other Degraded Terrain

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Introduction

It is only during the past two decades that real concern has been shown for the extensive areas of degraded and contaminated land that exist in most parts of the world. This degradation springs largely from mining activities, particularly opencast, and from other causes such as pastoral over-exploitation, or industrial activities in which enterprises such as smelters can blanket the surrounding countryside with toxic dust and fumes. Although a certain amount of window dressing could be seen in half-hearted attempts at remediation in the immediate post-war years, it was only the emergence of the "green movements" in the 1960s and 1970s that have compelled industries and governments to recognise the real concerns of their citizens to preserve the environment.

The situation has now changed radically and virtually all mining companies, smelters and other "dirty" industries operating in the western world now have environmental programmes that attempt to rehabilitate the damage that they now cause and at the same time even push back the clock to remediate previous devastation caused by their predecessors. This movement is especially strong in the USA where the "Superfund" regulations (see Chapter 1) now compel owners of contaminated land to remediate it, even if they had not originally caused the problem. The cost of such land restoration will be so great that this has spawned the development of many new remediation techniques purporting to provide ever less costly and ever "greener" alternatives to the classical remediation techniques.

The extent to which industrial concerns are prepared to undertake remediation is largely a question of geography. In many Third World countries, little or no effort is devoted to remediation due to the lack of public opinion that would enforce reform. An example of this can be seen in Fig.10.1 which is a view of the effects of opencast mining at Macedo near Niquelândia in Goiás State Brazil. The mine produces nickel from the huge Tocantins Ultramafic Complex and has no programme for revegetation of the area.

If one were to attempt to pinpoint a date at which the first steps were made towards an attempt at rehabilitation of polluted environments, we need to look no further than the work of Bradshaw (1952) who was one of the first to realise that abandoned mine sites support metal-tolerant populations of common grasses such as *Festuca rubra* and *Agrostis tenuis* that could be used to revegetate other mine dumps and colliery spoil heaps. Bradshaw's pioneering work led to the appearance of an important benchmark paper by Antonovics *et al.* (1971) that summarised much of this earlier work and set the scene for the significant advances that were made thereafter.

Fig.10.1. View of opencast mining for nickel at Macedo in Goiás State, Brazil. Photo by R.R.Brooks.

The emphasis of this book is of course on hyperaccumulators and it must freely be admitted that these specialised plants are no more adapted than other metal-tolerant species for the purpose of revegetation of degraded and contaminated terrain. They do however have one advantage over their non-accumulating cousins. If they are annuals that can be harvested and resown, or if they are perennials that can be cropped and recropped on an annual basis, there is thereby an opportunity not only to revegetate, but also to remove some of the metal burden of the soil. The removed biomass, if ashed, will have perhaps 15 times more of the metal than the dry material and might even provide a saleable

sulphur-free *bio-ore* (see Chapters 14 and 16).

This chapter is divided into three sections. The first of these describes the inadvertent colonisation of anthropogenic environments by hyperaccumulating plants. The second examines the potential of fertilisation of naturally occurring metal-tolerant plants in order to accelerate the restoration of contaminated and degraded land. The final section examines the progress and technology of land restoration in New Caledonia where several hyperaccumulators of nickel and manganese have a potential role.

Inadvertent Colonisation of Anthropogenic Environments by Hyperaccumulators

Introduction

Colonisation of anthropogenic environments by plants has been described by Brooks and Malaisse (1985) in connection with the metal-tolerant flora of Shaba Province, Zaïre in Central Africa. Much of the material in this section is derived from this work. Colonisation of these man-made environments is either *advertent* or *inadvertent* depending on whether or not humans have been directly or indirectly responsible for the introduction.

Inadvertent processes involve colonisation of mining areas, roadsides dressed with gangue from mining activities, roads and railways contaminated by spillage from ore-carrying vehicles or wagons, and lastly, archaeological sites. The latter opens up the possibility of discovering such sites by the nature of their metal-tolerant vegetative cover (see Chapter 7). Advertent processes involve the intentional vegetating of unsightly mine dumps or industrial sites by selection of suitable metal tolerant plant species. This is a rapidly developing field in view of the current interest of conservationists in preserving and improving the environment. Both of the above types of colonisation of man-made environments will now be discussed.

Colonisation of mining sites

In examining the question of colonisation of mining sites, a clear distinction must be made between the natural vegetation existing at the site before exploitation of the mineral resources, and the subsequent adventive flora which colonised the site after human modification of the environment. In Shaba Province, Zaïre and in nearby Zambia, exploitation of copper deposits has in many places led to the destruction of most of the characteristic vegetation, so that all that remains is carpets of colonisers of sterile mine dumps such as those that occur in Shaba at Karavia, Kasombo, Kambove, Kakanda, Luiswishi and Lukuni (see Fig.7.12). These carpets are dominated by *Eragrostis boehmii, Rendlia cupricola* and *Haumaniastrum katangense*. The last two are hyperaccumulators of copper and/or cobalt. The *Haumaniastrum* is one of the most remarkable colonisers of copper deposits in Southcentral Africa and its behaviour has been documented by Malaisse and Brooks (1982).

Good examples of colonisation of modified mining environments are to be found over old mines in Shaba. For example, Malaisse and Grégoire (1978) studied vegetation over the Mine de l'Etoile near Lubumbashi which closed in 1926 and has since had a period of nearly 60 years to undergo the dynamics of changing vegetation patterns. The above authors reported distinct communities over mine tailings as opposed to the pre-existing natural vegetation. Common members of this adventive community include *H.katangense* together with *Cryptosepalum dasycladum, Pteris vittata, Rendlia cupricola, Bulbostylis mucronata* and *Crepidorhopalon dambloni*. Only the *Cryptosepalum* and *Pteris* are non-accumulators.

One of the best examples of disturbed mining ground is to be found at Mindigi about 100 km west of Likasi (see Fig.7.12) in Shaba Province, Zaïre (Duvigneaud, 1959). The area is riddled with pre-European workings and more recent excavations have brought to the surface small pebbles highly enriched in both copper and cobalt. The highly-toxic soils (3700 μg/g copper and 1900 μg/g cobalt) exposed by mining support a carpet of *Eragrostis boehmii* containing in addition, several highly metallicolous species such as members of the genera: *Ascolepis, Sopubia, Bulbostylis, Gladiolus, Icomum, Vernonia, Triumfetta* etc. many of whose constituent species are hyperaccumulators of copper and/or cobalt.

One of the most remarkable examples of the ability of metal-tolerant hyperaccumulators to colonise new metalliferous environments is demonstrated by the discovery of *Haumaniastrum katangense* at copper deposits near Kela (Malaisse and Brooks, 1982) some 25 km west of Kakanda (see Fig.7.12). The mining company Gécamines has opened up a network of roads crossing the open forest and leading to about 20 deposits between Kakanda and Kela. These deposits are usually situated on the flanks or at the summits of rocky hills. The presence of *H.katangense* at Kela can only be explained by transport of this species via supply lorries from a mine where this plant exists naturally. The nearest of such stations is some 60 km distant from Kela.

Colonisation of rail tracks and roadsides

In Zaïre, the extraction of copper from its minerals involves production of a large volume of sterile waste which is usually deposited near the sites of extraction and which forms large dumps. A secondary usage of this material is for the dressing of dirt roads during the wet season. During the dry season, the road traffic deposits dirt on both sides of the road creating a band of lightly-mineralised substrate. Malaisse and Brooks (1982) have reported the presence of a metal-tolerant community upon these road verges which includes the hyperaccumulators *Cryptosepalum maraviense, Bulbostylis mucronata, H.katangense* and *Crepidorhopalon dambloni* which are all annual cuprophytes.

The above authors have followed the west-northwest axis of the road from Lubumbashi for a distance of 8 km beyond the city limits and have observed these four taxa along a band of 50 km at 1 km intervals. A carpet of *Crepidorhopalon dambloni* along the roadside is shown in Fig.10.2.

Malaisse and Brooks (1982) have also observed the presence of *H.katangense* along railway tracks near Lubumbashi. At the beginning of the colonial epoch, a railway was built to connect the Etoile and Ruashi mines with the processing plant at Elizabethville (Lubumbashi). The minerals were transported in open wagons and today bands of *H.katangense* can be observed locally along the route of this railway for about 20 km as it crosses the city. The line was in operation from 1911 to 1926 when the mines were shut down. Along the Lubumbashi-Kipushi railway, traces of malachite are still to be found in the ballast.

Fig.10.2. Rose-coloured carpet of *Crepidorhopalon dambloni* colonising a metal-rich roadside near Lubumbashi, Shaba Province, Zaïre. Photo by R.R.Brooks.

An interesting example of inadvertent colonisation of a roadside is shown in Fig.10.3. which represents a carpet of the nickel hyperaccumulator *Alyssum euboeum* growing over an access road to a magnesite mine on the island of Euboea in Greece. The road was constructed from the nearby mine tailings and provides an ideal habitat for this plant which is not found away from the verges of the road.

Fig.10.3. The nickel hyperaccumulator *Alyssum euboeum* growing over a mine access road on the island of Euboea, Greece. The road was constructed from waste from the nearby magnesite mine and has provided an ideal habitat for this plant. Photo by W.Krause.

Colonisation of sites polluted by industrial effluent

It is well known that metal-tolerant taxa will readily colonise sites affected by industrial effluent. A good example of this is found in Central Europe where *Thlaspi rotundifolium* subsp. *cepaeifolium* is often found over river gravels heavily contaminated with zinc and lead (Reeves and Brooks, 1983).

A classical example of inadvertent colonisation of a former industrial site is to be found near the city of Lille in northern France. This is shown in Fig.10.4. The terrain had been contaminated by effluent from a nearby zinc smelter and the soil contains a very elevated concentration of this metal. The site has been colonised by a pink carpet of *Armeria maritima* subsp. *halleri* among which is interspersed stands of the zinc hyperaccumulator *Cardaminopsis halleri*.

Fig.10.4. Carpet of the metal-tolerant *Armeria maritima* subsp. *halleri* growing over soil contaminated by a zinc smelter near Lille in northern France. Interspersed within this carpet is the zinc hyperaccumulator *Cardaminopsis halleri*. Photo by B.H.Robinson.

In Shaba Province, Zaïre, the copper hyperaccumulator *Rendlia cupricola*, a hemicryptophyte, is now found outside of its original area and grows on alluvial sands enriched in heavy metals derived from water used at the Likasi ore treatment plant. The plant has also been found in grey colluvia near the River Mulunguishi, a site likewise polluted by metalliferous muds from the treatment plant. Another plant found in areas subject to industrial pollution is the non-accumulator *Bulbostylis mucronata* which is found on temporarily waterlogged soils rich in minerals, as on muds from concentration plants or even on soils subjected to extensive pollution from aerial fallout of zinc, lead, and copper from the Gécamines treatment plant.

A spectacular example of inadvertent colonisation of industrial effluent again comes from Zaïre. A carpet of *Haumaniastrum katangense was found to* colonise soil contaminated with copper derived from the fallout from the giant stack of the copper smelter at Lubumbashi, Zaïre.

Colonisation of archaeological sites

Inadvertent colonisation of archaeological sites in Zaïre and elsewhere has already been fully covered in Chapter 7. Only the very bare details will therefore be repeated here.

One of the most remarkable aspects of the distribution of *Haumaniastrum katangense* and other metallophytes in Zaïre is their presence over sites of furnaces traditionally used in precolonial days for the production of small copper crosses (Plaen *et al.*,1982).

The artisans used copper smelters which were constructed on ancient termite hills which thereby provided a gradient suitable for the flow of molten copper. They were surrounded by earth walls about a metre high which must have contaminated the moulds and smelting conduits. The furnaces were situated near dambos (periodically-inundated savanna) or near rivers which provided the necessary water. The sites were also near stands of *Pterocarpus tinctorius* which were also used to produce charcoal.

These 14th century artisans brought copper ore to the smelter sites and abandoned the activities after a few seasons. After a long period of time the old smelters weathered to ground level and were colonised by *H.katangense* and other plants that served as indicators for the sites and for artefacts buried beneath them. The artefacts include pottery, ancient pipes used for smelting and copper "*croisettes*" (crosses) that were used for currency at that time (see Chapter 7 for further details of these discoveries).

Revegetation of Degraded and Polluted Land by Fertilisation of Native Plants

Introduction

The problem of vegetating old mine dumps is one which is receiving a great deal of attention today. Mine dumps are not only unsightly, but provide unwelcome publicity for the mining industry as well as polluting the environment with wind-blown toxic waste which can affect agriculture as well as animal and human health.

Degradation of metalliferous environments does not necessarily always result from mining or industrial activity. Failed agricultural programmes in which the original vegetation cover was removed and the land abandoned after unsuccessful attempts at cropping, can also result in impoverished land that could take decades to be restored to its original condition. In some cases these attempts failed because the agronomists did not recognise the basic infertility of serpentine soils.

Most degraded sites are situated over ultramafic (serpentine) soils because these represent much greater areas (1% of the earth's surface) than the far smaller extent of other forms of mineralization such as sulphides. The most obvious way to restore degraded vegetation would seem to be fertilisation of the soil in order to increase plant productivity.

There are however, very few examples of employment of such a strategy except some fertilisation experiments on natural serpentine vegetation in Scotlaand (Carter *et al.*,1988; Looney and Proctor, 1989), California (Koide *et al.*,1988; Huenneke *et al.*,1990), and Tuscany (Robinson *et al.*,1997; Chiarucci, 1994; Chiarucci *et al.*,1994, 1997a, 1997b). There is clearly a need for such studies

because increasing the biomass of the plant community by fertilisation might have the result of decreasing plant diversity by elimination of rarer species and encouraging the appearance of weeds that would not normally have tolerated the extreme edaphic conditions of unfertilised serpentine soils.

Fertilisation experiments over Tuscan serpentine soils

Introduction

Chiarucci *et al.* (1997a) have recently studied the effect of fertilisation on species richness and cover in two serpentine sites of southern Tuscany. In one of these sites, located in the Ombrone Valley near Murlo south of the city of Siena, the influence of fertilisation on biomass production was also investigated (Chiarucci *et al.*,1997b). The vegetation community belongs to the *Armerio-Alyssetum* phytosociological association which is the most typical vegetation of ultramafic soils of Tuscany (Chiarucci *et al.*,1995). This vegetation type, mainly formed by chamaephytes and hemicryptophytes is illustrated in Chapter 3 (Fig.3.2). This figure shows both of the type species: *Armeria denticulata* (bottom left) and the nickel hyperaccumulator *Alyssum bertolonii* (top right).

Thirty-five 1 m^2 quadrats were selected randomly in a gentle slope covered by the *Armerio-Alyssetum bertolonii* association and 5 replicates of each were fertilised with the following treatments:

1 - control;
2 - nitrogen at 10 g/m^2 as ammonium nitrate;
3 - phosphorus at 10 g/m^2 as sodium dihydrogen phosphate;
4 - combined nitrogen and phosphorus as above;
5 - nitrogen and phosphorus as above, and potassium (the latter at 10 g/m^2 as potassium chloride;
6 - calcium at 100 g/m^2 as calcium carbonate;
7 - calcium, nitrogen, phosphorus and potassium as above.

The plots were fertilised in October 1994 and 1995 and cover data were collected in Spring 1994, 1995 and 1996 by the points-quadrat method (Moore and Chapman, 1986) in which the intersections of the vegetation were recorded with a square grid of 441 points/m^2. After harvesting, a soil sample was taken over each plot and the soluble fractions of each soil determined by extraction into 1M ammonium acetate.

After the collection of cover data, the plants were harvested at ground level and sorted by species. The material was dried at 80°C for 48 h and then weighed. Total biomass and the biomass of each species and life form were transformed logarithmically and submitted to an analysis of variance (ANOVA).

Effect of fertilisers on the plant-availability of various elements

Soil pH and element availability data are summarised in Table 10.1 below. The pH showed a significant reduction where nitrogen was added and a significant increase after amendment with calcium. The availability of calcium and potassium increased in the quadrats where they had been added, whereas sodium appeared to be reduced in such plots. The availability of nickel was relatively constant except where the pH had been raised after addition of lime. Manganese availability increased in the NKP- and to a lesser extent in the N- and NP-treated plots. The copper increased in the NPKCa- and NP- and NPK-treated quadrats.

Table 10.1. Mean (n=5) availability at pH 7 of elements (μg/g in original soil) of fertilised and control experimental quadrats (35) over serpentine soils in the Murlo district, Tuscany, Italy. Letters after each value indicate statistically significant differences of the means from other quadrats for the same element.

Element/pH	O	N	P	NP	NPK	NPKCa	Ca
pH	7.37a	7.05bc	7.41ab	6.93c	6.86c	7.75d	7.94d
Ca	837.5a	790.2a	817.0a	822.3a	959.0a	3718.4b	3800.7b
Co	0.095a	0.082a	0.084a	0.088a	0.072a	0.090a	0.072a
Cr	0.048a	0.026a	0.036a	0.012a	0.026a	0.012a	0.034a
Cu	0.078a	0.090a	0.076a	0.138ab	0.138ab	0.194b	0.092a
Fe	0.988a	0.480a	0.426a	0.190a	0.236a	0.470a	0.228a
K	27.9a	27.4a	24.4a	23.0a	81.8b	57.3ab	22.8a
Mg	1555a	1702a	1918a	1856a	1808a	1148a	1274a
Mn	2.08a	2.68ab	2.12a	2.98ab	3.59b	1.93a	1.86a
Na	1990a	1643a	1871a	1808a	2024a	1105b	1238b
Ni	4.43a	4.51a	3.53ab	3.64ab	4.37a	2.40b	2.23b
V	0.373a	0.380a	0.378a	0.378a	0.386a	0.382a	0.386a
Zn	0.103a	0.130a	0.176a	0.216a	0.140a	0.310a	0.344a

Source: Chiarucci *et al.* (1997a).

Effects of fertilisation on species richness and ground cover

Fertilisation induced marked increases in total ground cover and in the cover of some species, especially in the plots fertilised with at least nitrogen and phosphorus together, which showed a threefold increase in total ground cover.

The addition of potassium to the two other fertilisers induced another increase in ground cover, whereas calcium did not induce any significant effect. Species richness as slightly promoted in the fertilised plots. Although extremely strong changes were shown in the ground cover of the vegetation, species composition had not changed significantly after two years of fertilisation. The species present in the plots increased in abundance after fertilisation but there was no significant colonisation by other species. On average the hyperaccumulator *Alyssum bertolonii* increased its cover tenfold (from 0.9-9.6 %) in the NPK fertilised plots.

Effect of fertilisers on biomass production

The effect of different fertiliser treatments on the total biomass of each quadrat

is reported in Table 10.2. The biomass data give a good reflection of the results of the cover measurements. Total ground cover and biomass were, in fact, very highly mutually correlated ($P<0.001$). Significant differences in biomass production were seen for fertiliser treatments involving at least nitrogen and phosphorus.

Addition of fertilisers also reduced the coefficients of variation within the plots submitted to the same treatments, implying a more homogeneous biomass production. The life forms showing the highest increase in biomass were woody species (chamaephytes and shrubs) and annual graminoids and forbs. Although perennial graminoids and forbs showed an apparent increase in biomass after fertilisation, these increases were not statistically significant. There was enhanced biomass of geophytes only in NPKCa-treated plots.

The hyperaccumulator *Alyssum bertolonii* gave the second-highest increase in biomass, increasing sixfold with the NPK treatment. In other experiments described in Chapter 15, pure stands of cultivated plants of this species can increase their biomass by a factor of three. This is of supreme importance for phytomining with this plant.

Table 10.2. Geometric mean of the total biomass (g) and biomass of different life forms (g) in fertilised and control experimental quadrats (35) over serpentine soils in the Murlo district, Tuscany, Italy. Letters after mean values indicate statistically significant ($P<0.05$) differences of the means from other quadrats as determined by the SNK test. The geometric mean of the biomass of the hyperaccumulator *Alyssum bertolonii* is also shown.

	O	N	P	NP	NPK	NPKCa	Ca
Total plant	40.01a	51.02a	83.75a	186.46b	282.52b	303.85b	72.60a
Woody plants	19.88a	35.22ab	40.41ab	89.59bc	196.15c	166.15c	40.87ab
Per. grasses	7.87	4.84	9.46	5.24	12.47	16.46	11.05
Per. forbs	2.67	0.68	2.48	6.88	17.02	2.54	5.99
Geophytes	0.02a	0.02a	0.11a	0.06a	0.18a	1.04b	0.06a
Ann. grasses	0.31a	2.61ab	2.79ab	17.84b	8.23b	9.51b	0.43a
Ann. forbs	0.86a	4.34ab	10.86bcd	19.2bd	15.47bcd	27.78d	3.06c
A. bertolonii	2.95ab	5.63abc	1.67a	4.71abd	19.79cd	14.76bc	3.79ab

Source: Chiarucci *et al.* (1997b).

The most significant increases in biomass production were by the following species in descending order: *Aira elegantissima*, *Alyssum bertolonii*, *Centaurea aplolepa* subsp. *caruleana*, *Helychrysum italicum*, *Herniaria glabra*, *Psilurus incurvus*, *Sedum rupestre* and *Thymus acicularis* subsp. *ophioliticus*. The hyperaccumulator *Alyssum bertolonii* gave the second greatest increase in biomass.

Conclusions

It is clear from the above experimental work, that fertilisation of natural stands of native metal-tolerant plants can greatly increase the biomass and provide a means of quickly restoring degraded terrain. It is however less clear what effect fertilisation will have on species composition. In fact, annual species showed the highest growth after fertilisation, probably because of their seed availability in the soil. This might adversely affect the performance of perennial species. The significant increase of biomass of woody species, among which *Alyssum bertolonii* was the most important, was performed by plants already growing in the plots and not by colonisation by new individuals. To promote the abundance of this species for phytomining or phytoremediation might therefore require that it be sown and thereby reduce the growth of annual species.

The experiments reported above have only extended over a three-year period and have not taken into account the possibility of invasion by weeds once the fertility of the ultramafic soils has been improved by the fertilisation regime. However, a rapid colonisation by weeds or other undesirable species after fertilisation is unlikely because of the lack of plant propagules in the surroundings of the plots. A longer term of fertilisation together with a shorter distance from potential propagules would be required to colonise these fertilised plots by non-serpentinic species.

Advertent Colonisation of Anthropogenic Environments by Hyperaccumulators in New Caledonia

Introduction

New Caledonia is one of the world's largest producers of nickel, derived from lateritic *garnierite* (hydrated nickel silicate) mineral. About one third of the 16,600 km^2 of the main island and its subsidiary the Ile des Pins is covered with ultramafic rocks (Fig.10.5) that are hosts for 56 hyperaccumulators of nickel (see Table 3.3).

This total comprises the world's second highest abundance of nickel hyperaccumulators in a single country or territory: i.e. after Cuba. It is not surprising therefore that revegetation programmes in that country include several hyperaccumulators.

There is a pressing need for revegetation of opencast mine sites in New Caledonia because of the widespread devastation caused by mineral exploitation on that island (Fig.10.6).

In an attempt to revegetate opencast mining sites in New Caledonia, the mining company *Société Métallurgique le Nickel* (SLN) in collaboration with the French research institutes *ORSTOM and CIRAD Forêts* is undertaking an ambitious programme of reclamation (Fig.10.7).

This programme has been described by Jaffré et al. (1993,1994), Jaffré and Pelletier (1992), Jaffré and Rigault (1991) and Pelletier and Esterle (1995). Most

of the material in the remainder of this chapter is derived from these and other papers.

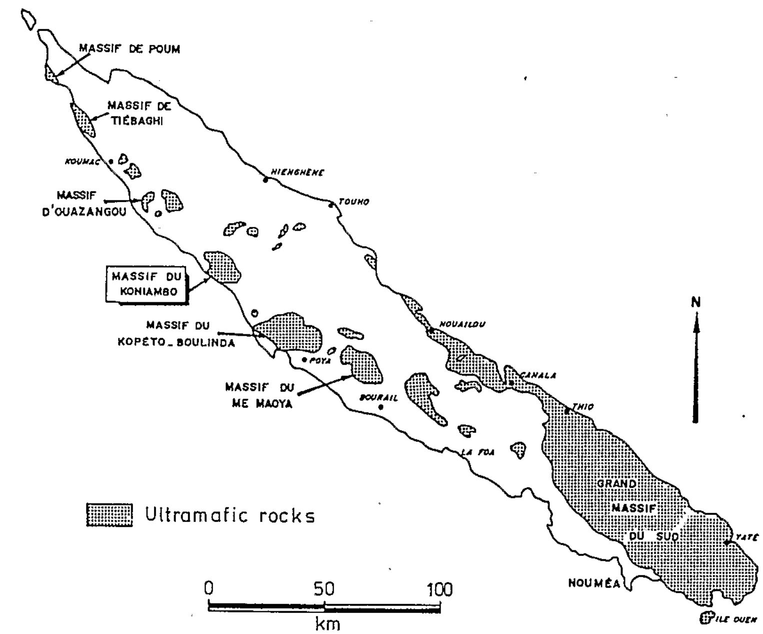

Fig.10.5. Map of New Caledonia showing the principal ultramafic massifs. Source: Brooks (1987).

Physical reconstitution and stabilisation of degraded terrain

The usual method of physical reconstitution of the environment consists of terracing the lateritic spoil from the opencast mining operations. The toxicity of the lateritic material is a result largely of its high magnesium content that produces a low Ca/Mg quotient that is highly unfavourable for plant nutrition. Although magnesium is the dominant element in the natural waters of the region, its actual concentration in these waters (typically 15 μg/mL) is not unduly high for an ultramafic environment and has not been increased by mining activities.

The terraces (see Fig.10.8) have a slope not exceeding 30° and have allowed the stabilisation of some 132 million tonnes of gangue formed in the period 1975-1990.

The base of the terraces is formed of a rocky drain over which the laterites are placed in compacted layers. The front walls of the terraces are composed of large rock boulders that retain the laterites in place. In front of the base of the terraces a rocky dam retains the percolating water in a diversion channel that leads the water away for safe disposal.

A channel just above the terraces diverts fresh water from above, in order to reduce the amount supplied for disposal through the diversion. The surface of the terraces is revegetated with appropriate plants as can be shown from Fig.10.9.

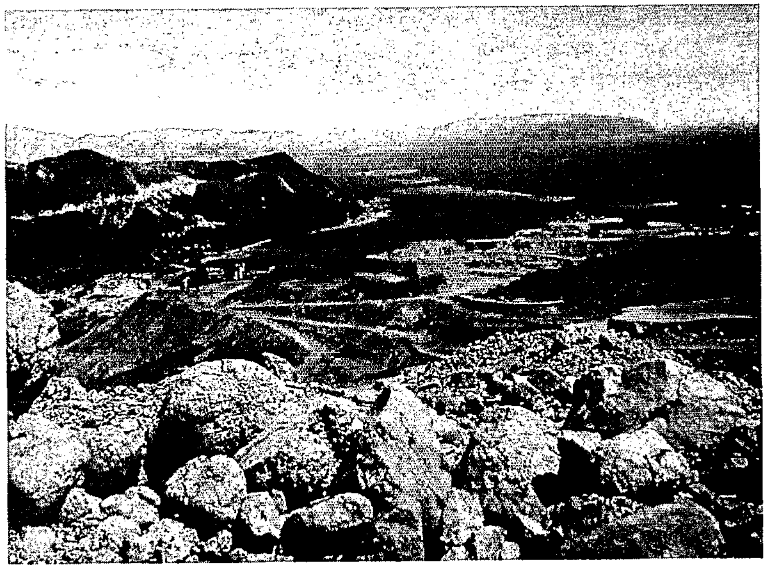

Fig.10.6. View of destruction caused by opencast mining in New Caledonia. Source: Jaffré and Rigault (1991).

Strategies of revegetation in New Caledonia

The two main problems of revegetation of opencast mine sites in New Caledonia are related to the poor nutrient status of the gangue coupled with the high content of magnesium (causing an unfavourable Ca/Mg quotient in waters and soil solutions - see above) and other phytotoxic metals such as nickel. Strategies that can be employed for revegetation and stabilisation are detailed below.

1 - Use of native plants that have a high resistance to unfavourable edaphic conditions and that can be put to good use. These include various pioneer species associated with nitrogen-fixing symbiotic bacteria, such as *gaïac* (*Acacia spiroorbis*) and *Casuarina collina* that will grow on the degraded material with very little extra attention.

2 - Amelioration of the substrate. In some cases, the sites can be remediated by adding fertile soils from other areas, or else lime can be added that will serve

to provide a favourable substrate for sowing with rapidly growing plants of economic use such as grasses and legumes. This strategy works well in flat areas but is useless for mountainous regions.

Techniques of revegetation

There are two main techniques of revegetation of mining sites in New Caledonia.

The first of these involves transplanting plants grown from seeds or as cuttings in some form of plant growth unit such as a greenhouse or shade house. This is by far the more costly of two procedures. Planting is performed manually in steep terrain or by machine in flat areas.

The young plants are surrounded by straw or a plastic film to preserve humidity in the early stages. About 6-8 months are required for the establishment of plants over the mine wastes.

Some of the plants used in revegetation are legumes such as "*gaiac*", *Storckiella*, *Archidendropsis* and *Serianthes* and various species of Casuarinaceae such as *Casuarina collina* as well as several species of *Gymnostema*. Planting densities range from about 1 per m^2 for small trees or large shrubs and up to 5-10 per m^2 for the smaller cyperaceous species.

Fig.10.7. View of revegetation of degraded terrain in New Caledonia. Source: Jaffré *et al.* (1993).

Direct seeding is also feasible but less frequently used than direct planting. Use can be made of hydroseeding with a "seed cannon" in which a powerful pump projects a pulp composed of seeds and cellulose (finely chopped hay for example), as well as fertilisers and other materials. The cannon can project the seed as far as 500 m. A team of two persons can treat 1-5 ha/day.

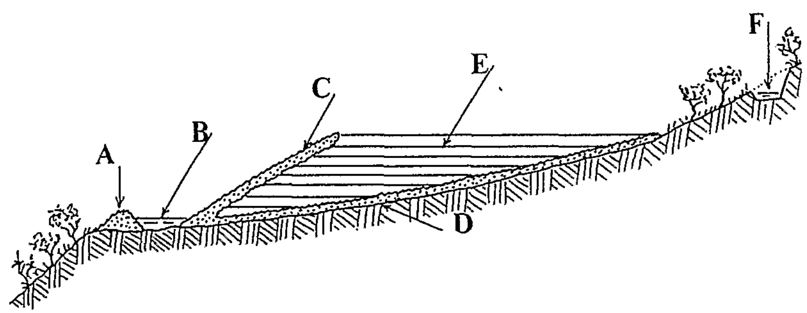

Fig.10.8. Sketch of a scheme for stabilisation of lateritic gangue derived from opencast mining in New Caledonia. A - rocky dam to retain and divert water percolating through the laterite, B - water-diversion channel, C - terrace wall composed of large rock boulders, D - rocky drain below the laterites, E - layers of compacted laterite, F - channel to divert fresh water away from the system. Source: Jaffré and Pelletier (1992).

Table 10.3. Growth characteristics of seven New Caledonian nickel hyperaccumulators that could be used for revegetating mine dumps and other degraded terrain.

Characteristic	GP	AL	BA	PA	PC	AD	HC
Ni content (% dry weight)	0.66	0.19	0.54	0.21	0.12	0.25	0.88
PREFERRED SOILS							
magnesian	3	1	2	1	2	3	3
ferralitic	1	-	-	1	1	-	-
alluvial volcanic/sedimentary	-	-	-	-	1	-	-
humid	2	0	0	2	1	1	1
dry	1	2	2	1	1	2	2
ALTITUDE (m)	0-700	nd	0-500	50-1000	0-1000	0-500	0-500
SEED							
maturation (month)	J,F	nd	J,F,M	nd	nd	J	J,F
latency (days)	6-12	nd	nd	nd	nd	nd	nd
germination	60%	nd	nd	nd	nd	nd	nd
CUTTINGS							
strike time (days)	nd	nd	nd	nd	nd	80	100
success rate	nd	nd	nd	nd	nd	45%	10%

GP - *Geissois pruinosa*, AL - *Argophyllum laxum*, BA - *Baloghia alternifolia*, PA - *Phyllanthus aeneus*, PC - *P.chrysanthus*, AD - *Agathea deplanchei*, HC - *Hybanthus caledonicus*.
nd - no data, 0-3 ability to tolerate edaphic conditions where 0 = poor and 3 = very good. After Jaffré and Pelletier (1992).

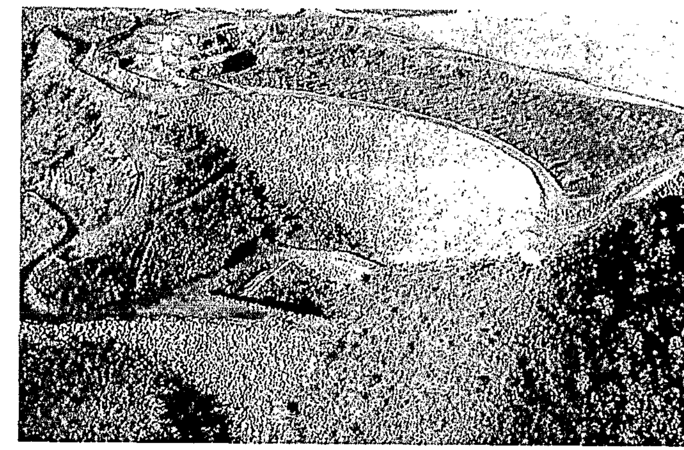

Fig.10.9. Aerial view of terracing of a lateritic mine discharge at Kongouhaou, New Caledonia. The surface of the laterite has been planted with *gaïac* and *bois de fer* (ironwood), both indigenous species adapted to mining environments. Source: Jaffré and Pelletier (1992).

A typical pulp would have the following composition: seed, 50-100 kg/ha (5000-8000 seeds); mulch, 2000 kg/ha; NPK fertiliser, 360 kg/ha; stabiliser (alginate), 200 kg/ha; lime (for pyritic gangue), 600 kg/ha; bacterial cultures. The purpose of the mulch is to increase the surface humidity, to even out the daily variation in temperature, to protect the microflora and microfauna, and to provide a reservoir of organic material from which the plants will derive nutrients.

Nickel hyperaccumulators that can be used for revegetation in New Caledonia

Jaffré and Pelletier (1992) have presented a large table of characteristics of 104 herbs, shrubs and trees that lend themselves to being grown for remediation of degraded land in New Caledonia. This list includes 7 nickel hyperaccumulators, details of which are shown in Table 10.3 above. Two of these plants (*Geissois pruinosa* and *Hybanthus caledonicus*) are illustrated in Figs 10.10 and 10.11.

It is perhaps fitting that this chapter should end with the above description of the rehabilitation work currently being carried out in New Caledonia. Where once this beautiful island was synonymous with human destruction of the environment, it has now become an example of what may be achieved when industry and governments work together to remediate a polluted and damaged land. The extent of the devastation is such that it would be difficult to believe that full remediation will ever be carried out, but at least a start has been made.

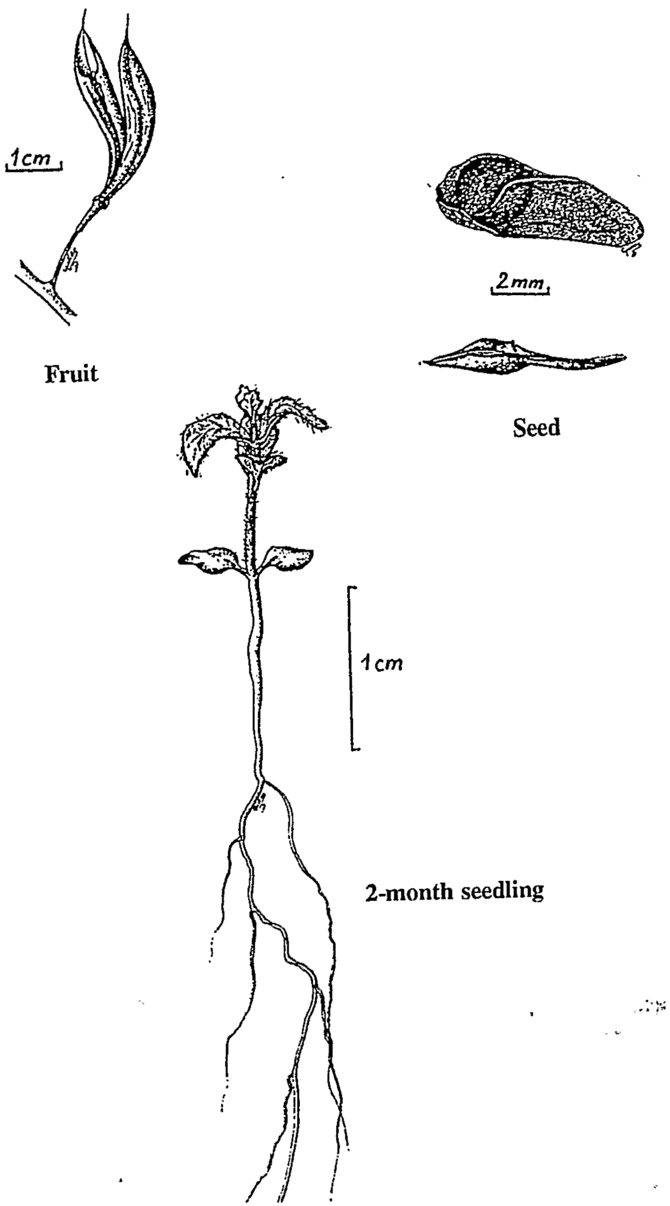

Fig.10.10. Sketch of the nickel hyperaccumulator *Geissois pruinosa*. This plant may be used for revegetating mine waste and contains about 0.60% nickel in its dry biomass. Source: Jaffré and Pelletier (1992).

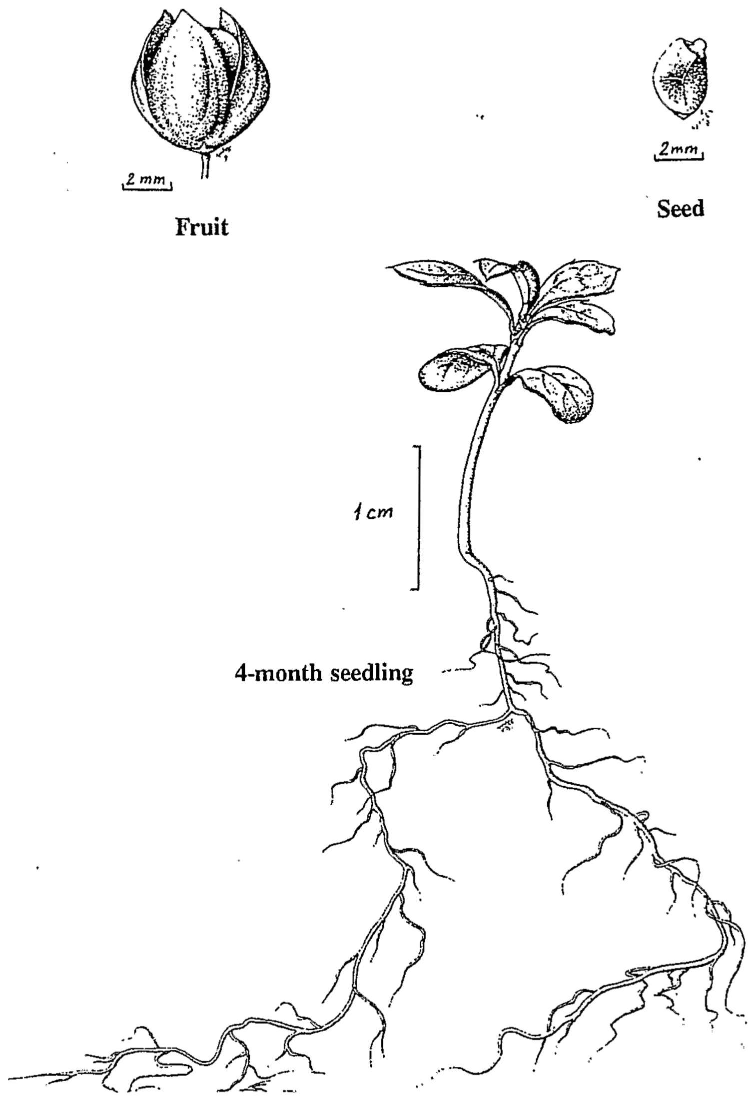

Fig.10.11. Sketch of the nickel hyperaccumulator *Hybanthus caledonicus* that can contain nearly 1% of this metal on a dry-weight basis. This plant has potential for revegetation of mine sites. Source: Jaffré and Pelletier (1992).

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