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SOIL CRUST LICHENS AND MOSSES ON CALCRETE-DOMINANT SOILS AT MARALINGA IN ARID SOUTH AUSTRALIA

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Abstract

A total of 23 lichen and six moss taxa were collected from soil crusts at 15 sites on calcrete-dominant landscapes in the Maralinga area. Apart from two vagant lichens *Chondropsis semiviridis* (F. Muell. ex Nyl.)Nyl. and *Xanthoparmelia convoluta* (Krempehl.)Hale, soil lichens were dominated by crustose and squamulose types. Three families, Verrucariaceae, Peltulaceae and Lecideaceae accounted for 57% of the genera found at Maralinga. No liverworts, and only six moss species were collected. Sites with varying disturbance history were used to examine the recovery of crust cover and floristics over time. Across all quadrats, crust cover (± standard error of the mean) averaged 38.0 ± 3.6%. Total crust cover and lichen species richness increased significantly as time since disturbance increased ($P<0.001$). Field results suggest that recovery of crust cover to levels necessary for protection against water erosion (30–40% cover) is achievable within 30–40 years.

Introduction

Maralinga lies between the Nullarbor Plain and the Great Victoria Desert approximately 800 km north-west of Adelaide. In the mid 1950s the area around Maralinga was used for nuclear testing, and for the past 40 years, access has been restricted. The landscape comprises a mosaic of semi-arid woodland and low shrubland, which, apart from small areas immediately adjacent to the nuclear test sites, has been altered very little by europeans. The soils are rich in calcareous sediments, and exposed calcrete is common on the surface. The combination of winter-dominant rainfall, highly calcareous soils and low levels of disturbance has supported the growth and establishment of an extensive microphytic crust cover over large areas of the landscape. This crusted surface protects the soil against wind and water erosion (Williams *et al.*,1995; Eldridge and Kinnell, 1997), and is essential for the maintenance of vital soil and ecological processes (West, 1990; Eldridge and Greene, 1994a).

Because of its extreme isolation and restricted access, relatively few plant collections have been made from the area. Although soil crust lichens and mosses abound, there are few collections of non-vascular organisms from the Maralinga area, and specimens from the Nullarbor and North-western Regions are poorly represented in herbarium holdings.

In August 1996 a visit was made to the area to examine recovery of disturbed soil crusts in order to predict their recovery rates after the current cleanup of contaminated soils. This paper describes the lichens and mosses found during a systematic survey of soil crusts at 15 sites north of Maralinga Village across a range of disturbance histories.

The Study site

Maralinga is located approximately 800 km north-west of Adelaide in the North-western and Nullarbor Regions. The area lies midway between the Great Victoria Desert in the north, and the Nullarbor Plain in the south-west and consequently includes a mixture of plain and dunefield landscapes. Since the early 1950s, access to the area has been severely restricted due to its history of nuclear testing. Prior to that time much of the area was under traditional ownership by the local Maralinga-Tjarutja aborigines. Due to the relatively low

rainfall, lack of reliable surface water and location outside the Dog Fence, the area has not been used for cattle grazing or sheep grazing respectively.

i) Climate

The Maralinga area is typical of arid Australia in that it receives approximately 200 mm yr^{-1} (Meigs, 1953). This rainfall is extremely spatially and temporally variable. To the south the township of Cook has an average annual rainfall of 172 mm yr^{-1}. Winds at Maralinga are generally light to moderate, and the area receives some cool W-SW winds from the Great Southern Ocean 150 km to the south. Climate ranges from cool winters with overnight dews and frosts to hot summers where diurnal temperatures in excess of 40°C are not uncommon (Trefry, 1979).

ii) Geomorphology

Most of the area is underlain by calcrete, derived from Middle Miocene Tertiary limestone. Consequently, soils are highly calcareous, with pH levels often in excess 9.0. The relatively open areas where most of the nuclear testing was carried out comprise low, gently undulating plains dominated by loamy calcareous soils, often with exposed calcrete at the surface. To the north, these plains merge into the southern limits of the Great Victoria Desert which comprises linear, west-east trending sand dunes which rise up to 8 m above the surrounding landscape. The dunes are separated by moderately wide swales to 2 km wide with local slopes to 1–2%. The dune soils are predominantly uniform sands and loamy sands, with little or no profile development. The swales (or dongas) represent shallow, subcircular depressions with gentle slopes and flat valley floors. These swales are frequently arranged in chains, parallel to the neighbouring dune systems, but elsewhere appear to have a random spatial pattern (Jennings, 1967). The swales comprise a mixture of calcareous loams and sandy loams, often with weak pedological development (Mitchell *et al.*, 1979), grading to sands and loamy sands at the margins of the dunes.

iii) Vascular vegetation

The predominant vegetation on calcareous soils is a semi-arid low woodland dominated by mulga (*Acacia aneura*), bullock bush (*Alectryon oleifolius*), sugarwood (*Myoporum platycarpum*), mallees (*Eucalyptus gracilis*, *E. foecunda*, *E. socialis*), *Senna artemesioides* and numerous acacias (*A. burkittii*, *A. colletioides*, *A. kempeana*, *A. oswaldii*, *A. papyrocarpa*). The sand dunes are dominated by mallees as well as isolated bullock bush and shrubs of the Chenopodiaceae (*Atriplex* spp., *Maireana* spp.).

Methods

In August 1996 a field trip was made to the Maralinga area to examine natural regeneration of microphytic crust surfaces in relation to disturbance history, and to make collections of soil crust lichens, bryophytes and cyanobacteria. Fifteen sites were visited, each with a known disturbance history. These sites included areas never disturbed (or relatively undisturbed) by Europeans, tracks constructed during nuclear testing operations in 1956 and left to regenerate, sites disturbed in 1967 during Operation Brumby and left to regenerate, and an area disturbed in 1993. Sites were chosen on the basis of local knowledge and information held in unpublished and published reports and files. At each of the 15 sites, a 100 m transect was laid out perpendicular to the road, and ten 0.5 m^2 quadrats were laid down to form the basis for data and soil crust collection. Within each quadrat, measurements were made of soil surface condition, microtopography, landscape element, slope, type and degree of erosion, cover and relative composition of lichens and bryophytes, cover and type of vascular plants, and cover and type of litter. Relationships between surface morphology, vascular plants and lichen and bryophyte taxa are reported elsewhere. Samples of soil crust were collected from each quadrat and transported to the

laboratory to enable the lichens and bryophytes in the samples to be identified. Sufficient material was collected to provide voucher material for lodgement in various herbaria. Additional samples of taxa recorded at a site, but not collected in the 10 quadrats, were also made.

Soil samples were sieved in the laboratory using a 2 mm sieve. Lichens and bryophytes were identified using keys in Filson (1988, 1992), Filson and Rogers (1979), McCarthy (1991a), Catcheside (1980) and Scott and Stone (1976), as well as more recent generic revisions. Nomenclature follows Streimann and Curnow (1989) and McCarthy (1991b).

Results

i) Crust floristics

Apart from one site which was disturbed in 1993, surfaces supported a rich flora of terricolous lichens. Across the 15 sites (150 quadrats), 23 lichen and 6 moss species were recorded. Three lichen families, Verrucariaceae, Peltulaceae and Lecideaceae accounted for 57% of the genera found at the 15 sites. Nine species, *Catapyrenium lacinulatum* (Ach.)Breuss, *C. squamulosum* (Ach.)Breuss, *Collema coccophorum* (Tuck.), *Eremasterella crystallifera* (Taylor)G. Schneider, *Fulgensia subbracteata* (Nyl.)Poelt, *Heppia despreauxii* (Mont.)Tuck., *Peltula patellata* (Bagl.)Swinscog & Krog ssp. *australiensis* (Muell.-Arg.)Büdel, *Psora crenata* and *Lecidea* sp. aff. *ochroleuca* Pers. were collected at ten or more of the sites. Apart from the two foliose and vagant lichens *Chondropsis semiviridis* and *Xanthoparmelia convoluta*, the soil crust was dominated by crustose and squamulose lichens. Other terricolous lichens found in the general area but absent from the 150 quadrats included: *Xanthoparmelia constipata* (Kurokawa & Filson)Elix & Johnston, × *alternata* Elix & Johnston, infertile *squamules* of *Cladonia* sp. and *Neofuscelia luteonotata* (J. Stein)Esslinger. The saxicolous lichens *Buellia subalbula* (Nyl.)Muell.-Arg., *Peltula omphaliza* (Nyl.)Wetmore, *Diploschistes gypsaceus* (Ach.)Zahlbr., *Lecanora sphaerospora* Muell.-Arg., *Acarospora glaucocarpa* (Ach.)Korber and *Caloplaca* sp. aff. *cinnabarina* (Ach.)Zahlbr. were common components of calcareous rocks at many sites.

Six moss species were collected from the 150 quadrats. Many of the mosses came from the families Pottiaceae and Bryaceae (Table 1). Three of these, *Desmatodon convolutus*

	*No. of quadrants	Years since disturbance			
		3	30	40	99
LICHENS					*
Acarospora nodulosa (Dufour)Hue	5		*	*	*
A. novae-hollandiae H. Magn.	8			*	*
Aspicilia calcarea (L.)Mudd.	19				*
Caloplaca sp.	1		*	*	*
Catapyrenium lacinulatum (Ach.)Breuss	36			*	*
C. pilosellum Breuss	2		*	*	*
C. squamulosum (Ach.)Breuss	60				*
Chondropsis semiviridis (F. Muell. ex Nyl.)Nyl.	8		*	*	*
Collema coccophorum Tuck.	134				*
Diploschistes thunbergianus (Ach.)Lumbsch & Vezda	3			*	*
Endocarpon helmsianum Muell.-Arg.	6		*	*	*
E. pusillum Hedw.	18		*		
E. rogersii P.M. McCarthy	1		*	*	*
Eremastrella crystallifera (Taylor)G. Schneider	47		*	*	*
Fugensia subbracteata (Nyl.)Poelt	45		*	*	*

Table 1. Relationships between time since disturbance and presence or absence of lichens and mosses averaged over the relevant number of quadrats at each site. *maximum = 150.

Table 1 cont.

	*No. of quadrants	Years since disturbance			
		3	30	40	99
LICHENS cont.					*
Heppia despreauxii (Mont.)Tuck.	95		*	*	*
Lecidea sp. aff. *ochroleuca* Pers.	40				*
Peltula imbricata R. Filson	1		*	*	*
P. patellata (Bagl.)Swinscow & Krog subsp. *australiensis* (Muell.-Arg.)Büdel	48		*	*	*
Psora crenata (Taylor)Reinke	71		*		*
Toninia sedifolia (Scop.)Timdal	8				*
Xanthoparmelia convoluta (Krempelh.)Hale	3				
MOSSES					
Acaulon leucochaete Stone	6		*	*	*
Bryum eremaeum Catches. ex Spence & Ramsay	49		*	*	*
Crossidium davidai Catches.	3		*	*	*
C. geheebii (Broth.)Broth.	11		*	*	*
Desmatodon convolutus (Brid.)Grout	70		*	*	*
Stonea oleaginosa (Stone)R.H. Zander	36		*	*	*

(Brid.)Grout, *Stonea oleaginosa* (Stone)R.M. Zander and *Bryum eremaeum* (Catch. ex Stone & Ramsay were collected from 10 or more sites. *Desmatodon convolutus* and *Bryum eremaeum* were the most abundant mosses in the area. Other mosses collected within the quadrats included *Crossidium geheebii* (Broth.)Broth., *Crossidium davidai* Catches., *Acaulon leucochaete* Stone and a sterile unidentified *Pottia* sp. Other species found outside the quadrats, usually as isolated individuals, included *Goniomitrium enerve* Hook. & Wils., *Didymodon torquatus* (Tayl.)Catches. and *Tortula princeps* De Not. Small tufts of *Bryum* argenteum Hedw. were found amongst building debris at the Maralinga Village. Despite exhaustive searching in suitable habitats, and moderate rainfall prior to and during the collecting trip, no hepatics were collected in either the quadrats or in adjacent areas.

Species richness of lichens on their own was a useful indicator of disturbance history (Table 2). There was a significant increase in the total number of lichen species as time since disturbance increased ($F_{1,148}$=132.45, P<0.001), and time since disturbance explained 47% of the variation in number of species. Adding the number of mosses to lichens failed to explain any more of the unexplained variability in time since disturbance.

Years since disturbance	Number of quadrats	Number of taxa	
		Mean	SEM
3	10	0.0	0.0
30	50	5.08	0.36
40	40	7.48	0.41
100	50	9.55	0.37

Table 2. Mean and standard error of the mean (SEM) number of lichen taxa for sites of varying disturbance history on calcrete soils at Maralinga.

ii) Crust cover

Total cover of microphytic soil crust ranged from zero to 90% across the 150 quadrats. Across all sites and quadrats, mean cover (± standard error of the mean) of microphytic crusts was 38.0 ± 3.6 %. There was a significant effect of time since disturbance on crust cover ($F_{3,146}$=14.56, P<0.001) with crust cover increasing with time since disturbance (Figure 1). However, time since disturbance accounted for only 28% of the variation in

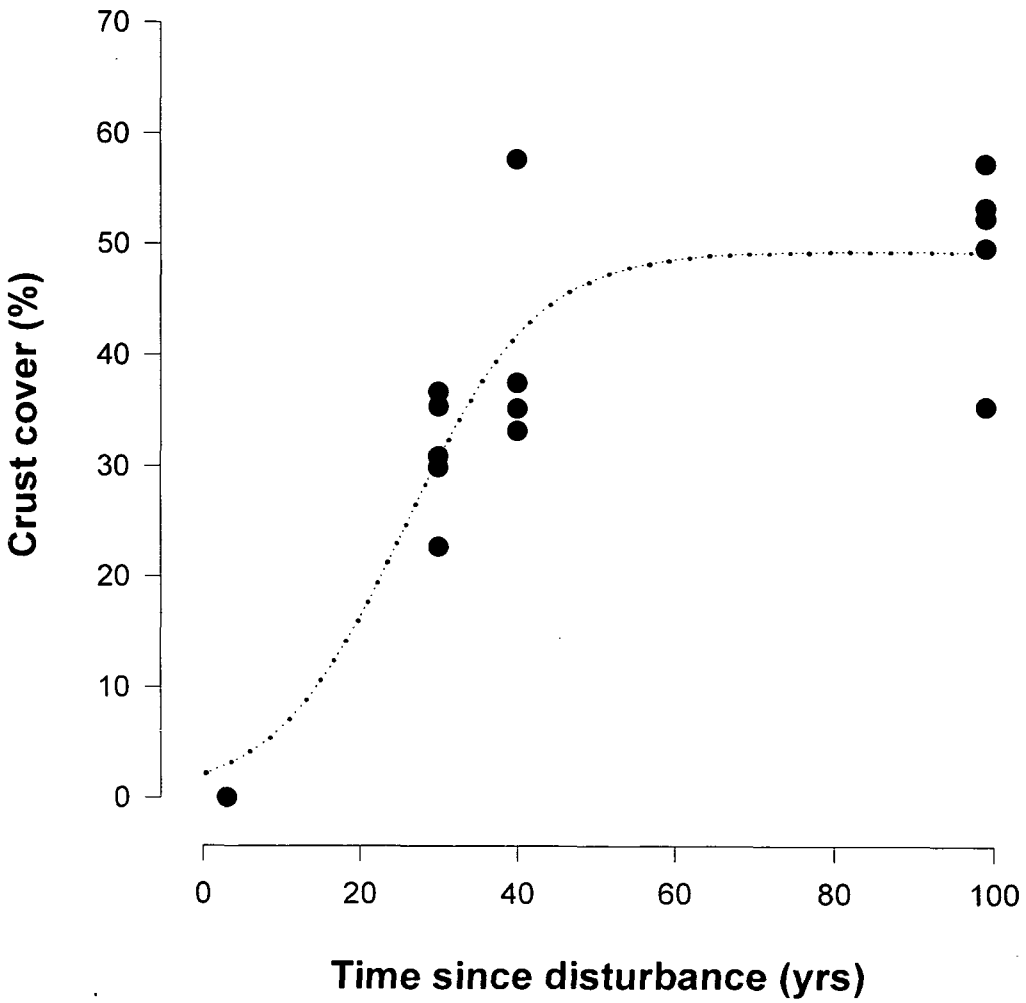

Fig. 1. Changes in crust cover (%) with changes in time since disturbance.

crust cover. This was probably due to the fact that there is a rapid increase in cover of cyanobacteria and cyanolichens such as *Peltula* and *Collema* shortly after disturbance so that examination of cover alone is a poor indicator of the dynamics of soil crust recovery.

Discussion

The Maralinga soils yielded a rich suite of 22 lichen taxa, nine of which occurred at ten or more sites (Table 1). Surprisingly the bryophyte flora was dominated by only four moss species, and no liverworts were found at the sites. Six terricolous lichens were found only in areas which have not been disturbed. These included the foliose lichens *Chondropsis semiviridis* and *Xanthoparmelia convoluta*, and the crustose and squamulose lichens *Caloplaca* sp., *Peltula imbricata* R. Filson, *Acarospora nodulosa* (Dufour)Hue and *Diploschistes thunbergianus* (Ach.)Lumbsch & Vezda.

The high surface coverage of the crusts in the Maralinga area is attributed to a combination of high soil pH levels and low levels of disturbance. In other semi-arid and arid regions, calcareous soils also support extensive areas of crust, often with a large number of species. For example Eldridge (1996) showed that in western NSW, the largest number of lichen and bryophyte species (up to 16 per 0.5 m^2 quadrat) occurred on calcareous earth soils. Similarly, Anderson *et al.* (1992) and St Clair *et al.* (1993) demonstrated the importance of soil pH in explaining the distribution of bryophytes and lichens in soil crusts in the western United States. In western NSW, Downing and Selkirk (1993) showed that calcareous soils along the Lake Mungo shoreline, and the belah-rosewood woodlands, supported the greatest number of bryophyte species.

Soil crusts are known to be susceptible to physical disturbances such as trampling by humans, livestock and off-road vehicles (Rogers and Lange, 1971; Mack and Thompson, 1982; Johansen and St Clair, 1986; Beymer and Klopatek, 1992; Jeffries and Klopatek, 1987; Harper and Marble, 1989; Klopatek, 1993). Due to the extreme remoteness of the Maralinga site, the absence of above-ground water, and its location outside the dingo fence, the area has not supported permanent sheep and cattle grazing. Apart from feral camels which are known to inhabit the area, the soil surface has been relatively unimpacted by europeans or introduced animals. Only small areas were used for the atomic tests in the mid-1950s. Similarly the lack of reliable surface water means that the Maralinga-Tjarutja community traditional owners lead a semi-nomadic lifestyle, making only a localised impact upon the soil crust community. Consequently, the soil crust organisms in this area are probably indicative of pristine crust communities.

The lichen crust was dominated by six species *Psora crenata*, *Collema coccophorum*, *Catapyrenium squamulosum*, *Catapyrenium lacinulatum*, *Heppia despreauxii* and *Fulgensia subbracteata* which have large continental and intercontinental distributions. They are common components of crusts in North America (Nash *et al.*, 1977; St Clair *et al.*, 1993), Israel (Galun and Reichert, 1960) and North Africa (Faurel *et al.*, 1953). Two species, *Eremastrella crystallifera* and *Peltula patellata* subsp. *australiensis* are endemic to Australia, and were significant components of the soil crust both in terms of abundance and cover. Three of the six mosses found in the Maralinga area were collected within more than 25% of quadrats. *Stonea oleaginosa* is a small reddish-coloured moss which is often overlooked in soil crust studies (Eldridge and Tozer, 1996). The red apices of the leaves often blend in with the red sand grains on which it grows, and it is often found partially buried in the soil. It is usually associated with stable, uneroded, well-vegetated calcareous soils (Eldridge and Tozer, 1997a). Lipids in the leaves (Stone, 1978) as well as the reddish coloured leaf tips, may assist in thermoregulation. *Desmatodon convolutus* is a common moss associated with soil crusts, and has a large continental distribution ranging from arid winter rainfall-dominant environments to semi-arid, summer rainfall-dominant landscapes (Eldridge and Tozer, 1996). Extensive surveys from western NSW suggest that it is one of the mosses most strongly associated with lichen-dominated soil crusts (Eldridge and Tozer, 1997b). Similarly, *Bryum eremaeum* was found on most surfaces, and is remarkable in that it is restricted almost exclusively to desert regions (Spence and Ramsay, 1996). Underground stem tubers are thought to enable this moss to survive periods of drought (Spence and Ramsay, 1996).

Apart from the present study, there have been few collections from the area. Symon and Copley (1986) recorded 14 bryophyte and 4 lichen species (Table 3) from the Eastern Great Victoria Desert region. Of those recorded, *Heterodea muelleri* (Hampe)Nyl. was the only lichen not found in the present study. The reason for the low number of mosses found in the present study may relate to the relatively homogeneous landscapes on which the study was conducted. No depressions were sampled which may have yielded *Riccia* spp. and *Funaria* spp. which favour saline swamps and saltmarshes (Catcheside, 1980). Census records from the State Herbarium of South Australia for the Nullarbor and North-western Regions (unpublished data) reveal a relatively species poor flora of 27 mosses, 11 liverworts and 21

lichens associated with soil surfaces. Of particular interest is the large number of *Riccia* spp. (9 species) collected from this arid region of South Australia. Many of these were collected during an Adelaide Herbarium expedition to the Birksgate-Tomkinson Ranges in 1978.

LICHENS	MOSSES	LIVERWORTS
Acarospora schleicheri (Ach.)Massal.[1]	*Bryum argenteum* Hedw.	*Riccia lamellosa* Raddi
Heterodea muelleri (Hampe)Nyl.	*B. eremaeum* Catch. ex Spence and Ramsay	
Psora decipiens (Hedw.)Hoffm.	*B.* sp. aff. *pachytheca*	
Xanthoparmelia sp.	*Crossidium davidai* Catches.	
	C. geheebii (Broth.)Broth	
	Desmatodon convolutus (Brid.)Grout	
	Didymodon torquatus (Tayl.)Catches.	
	Funaria hygrometrica Hedw.	
	F. salsicola C. Muell.	
	Gigaspermum repens (Hook.)Lindb.	
	Goniomitrium acuminatum Hook. & Wils.	
	Tortula pagorum (Milde)De Not	
	T. princeps De Not	

Table 3. Lichens, mosses and liverworts collected in the Great Victorian Desert (after Symon and Copley 1986). [1]syn. *Acarospora citrina*.

Apart from the species found on calcareous soils, a number of mosses and lichens were also common on sands associated with mallee (*Eucalyptus* spp.) sandplains and dunefields at Maralinga. Although no objective assessment of abundances was carried out, systematic searches at six sites revealed a rich crust in some areas supporting up to 15 taxa (Table 4). Most sandplain sites were dominated by *Barbula calycina* Schwaegr, *Didymodon torquatus* and *Collema coccophorum*, and crust cover was greatest on the southern side of the trees and shrubs. *Neofuscelia luteonotata* (J. Stein)Esslinger was found at four sites dominated by *Triodia irritans*.

LICHENS	MOSSES
Acarospora citrina (Taylor)Zahlbr. ex Rech.*	*Barbula calycina* Schultz
Catapyrenium squamulosum (Ach.)Breuss	*Bryum eremaeum* Catches. ex Spence & Ramsay
Cladonia sp.	*Didymodon torquatus* (Tayl.)Catches.
Collema coccophorum Tuck.	*Tortula princeps* De Not
Heppia despreauxii (Mont.)Tuck.	
Lecidea sp.	
Neofuscelia luteonotata (J. Stein)Esslinger	
Peltula patellata (Bagl.)Swinscog & Krog	
Psora crenata (Taylor)Reinke	
Xanthoparmelia alternata Elix & Johnston	
X. constipata (Kurokawa & Filson)Elix & Johnston	

Table 4. Mosses and lichens found on sandy soils associated with mallee (*Eucalyptus* spp.) plains and dunefields. *Single specimen only.

Soil crusts and land stability

During the past decade, research in eastern Australia has shown that soil crusts are important for preventing water erosion in rangelands (Eldridge and Greene 1994a,b; Eldridge and Kinnell 1997). Crusts reduce erosion in two main ways. Firstly, soil fungi

associated with crusts glue together small soil particles with their organic gels and polysaccharides, making them relatively stable. Secondly, crusts organisms provide a physical barrier on the soil surface which reduces the erosive energy of raindrops, and densely-packed lichens create small depressions which trap runoff water and allow it to infiltrate into the soil.

Crusts also influence, and this depends on crust composition and soil conditions. Recent research (Eldridge 1993, Eldridge *et al.* 1997) suggests that water flow through soil crusts depends on the physical condition of the soil under the crusts. On well-managed soils with abundant large air pores (macropores), which are usually created by soil animals and plant roots, infiltration is likely to be unaffected by crust cover. However, on degraded soils, fungal hyphae and the roots (rhizines) of lichens help to stabilise the small entry points through which water can enter the soil.

Lichens having cyanobacteria as their fungal partner produce nitrogen which is used by either plants (Belnap 1995) or small soil animals. Crusts also produce organic carbon which is important for binding soil particles together. This increased stability and the fact that crusts trap water and plant seeds, and produce nitrogen, means that crusted soils are good sites for germination and establishment of seedlings (Harper and St Clair 1985) and as refugia for invertebrates such as springtails and mites (Scarlett 1994).

Crusts are often destroyed by livestock trampling and human activities. The lack of disturbance over a large area of the Maralinga site contributes to the extensive crust cover and large number of lichen species found (Table 1). Although sites with 30 or 40 years of recovery have still not recovered their full complement of species, i.e. lacking the foliose lichens *Chondropsis semiviridis* and *Xanthoparmelia convoluta*, they are nevertheless floristically rich. Areas disturbed by the current rehabilitation process are likely to exhibit high rates of erosion before a sufficient vascular and non-vascular plant cover has restabilised. Given the observed pattern of crust recovery over time (Figure 1), it is suggested that recovery to 30–40% cover, a level necessary to protect the soil against water erosion in the absence of vascular plants (Eldridge and Kinnell, 1997), will take from 30 to 40 years.

Annotated list of soil crust taxa

This list includes a frequency score and relevant notes. Species frequency is described as follows: infrequent, less than 5 occurrences i.e. recorded in less than 5 quadrats; relatively infrequent, 5–20 occurrences; common 21–70 occurrences; abundant, >60 occurrences.

Lichens

Acarospora nodulosa (Dufour)Hue Relatively infrequent; found in five quadrats at four of the undisturbed sites. Squamules typically dark cream to light brown coloured, in colonies up to 5 cm across. Fertile squamules characterised by punctiform dark black immersed apothecia were commonly observed. This species has been recorded infrequently on non-calcareous loams in western New South Wales, and also occurs in Western Australia.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3513,* 23.viii.1996, calcareous rocky ridge approximately 18 km N Maralinga Village, with dense *Acacia aneura* and *Casuarina cristata*, in association with *Toninia sedifolia*, *Eremastrella crystallifera* and *Heppia despreauxii*.

Acarospora novae-hollandiae H. Magn. Relatively infrequent. Large patches of this typically yellow-green crustose lichen occurred on calcareous soil at five of the fifteen sites across a range of disturbance histories (Table 1).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3536*, 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Acacia colletioides* and *Maireana astrotricha* with *Peltula* patellata ssp. *australiensis*, *Catapyrenium* lacinulatum and Psora crenata, 1 km S of junction of Left St and Second St, approx 35 km N Maralinga Village.

Aspicilia calcarea (L.)Mudd Relatively infrequent. Although *Aspicilia calcarea* was generally restricted to undisturbed sites, it was also recorded on one site with 40 years recovery. Specimens were typically grey to greyish-white, tubular to coral-like, varying to sub-fruticose in some areas. Sub-fruticose forms were typically attached to rock as well as soil. No fertile specimens were observed.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3543*, 25.viii.1996, calcrete plains at the junction of Boona Radial and 2nd Ave, approximately 38 km N Maralinga Village, with dense *Acacia aneura*, *Maireana astrotricha* and *Atriplex vesicaria*, in association with *Acarospora nodulosa* and *Diploschistes thunbergianus*.

Caloplaca sp. Infrequent. This crustose lichen is characterised by orange apothecia which provide a vivid contrast with the underlying substrate. Although *Caloplaca* sp. is common on calcrete pebbles, in association with *Buellia subalbula* (Nyl.)Muell.-Arg., *Peltula omphaliza* (Nyl.)Wetmore, *Verrucaria* sp. and *Diploschistes* sp., it was found on soil overlying rock at only one location which is essentially undisturbed. This species can probably be ascribed to *C. cinnabarina* (Ach.)Zahlbr.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3472*, 20.viii.1996, approximately 5 km N of the Forward Gate 12 km N Maralinga Village, on calcrete ridge with Casuarina cristata, Eucalyptus spp., with Psora *crenata*, *Diploschistes thunbergianus* and *Chondropsis semiviridis*.

Catapyrenium lacinulatum (Ach.)Breuss Common; found within 36 of the 150 quadrats at Maralinga. Although relatively inconspicuous within the crust, it occurred in small colonies of up to 50 squamules. It is distinguished from the closely-related *Catapyrenium squamulosum* (Ach.)Breuss and *C. pilosellum* Breuss by the presence of thick white rhizines and from *Endocarpon* spp. by the eight hyaline spores. *C. lacinulatum* also occurred on sandy substrates but characteristically as isolated squamules.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3534*, 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Acacia colletioides* and *Maireana astrotricha* with *Peltula patellata* ssp. *australiensis*, *Desmatodon* convolutus and *Psora crenata*, 1 km S of junction of Left St and Second St, approx 35 km N Maralinga Village.

Catapyrenium pilosellum Breuss Infrequent; occurred in small colonies of up to a centimetre across. Separated from *C. lacinulatum* by the presence of marginal perithecia.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3518*, 23.viii.1996, on plains of scattered *Casuarina cristata* and *Acacia aneura* with calcrete overlying sand, with *Catapyrenium squamulosum*, junction of 5th St. and Central Ave., approx 39 km N Maralinga Village.

Catapyrenium squamulosum (Ach.)Breuss Common. Abundant on calcrete soils at Maralinga. Characterised by laminal perithecia on the thallus; erhizinate. Occurred commonly with the closely-related *C. lacinulatum* which has thick whitish rhizines.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3482*, 20.viii.1996, 'Roadside', approximately 20 km N Maralinga Village. on open plains with *Alectryon oleifolius* and *Casuarina cristata*, with *Psora crenata*, *Eremastrella crystallifera* and *Peltula* sp.

Chondropsis semiviridis (F. Muell. ex Nyl.)Nyl. Relatively infrequent. Like *Xanthoparmelia convoluta*, this lichen was common at two of the four undisturbed sites. It was characterised by a foliose dichotomously branched thallus which rolls into a ball when dry. Dry specimens up to 20 mm in diameter were found in the area, often attached to vegetation and small stones. This lichen is common over large areas of South Australia (Rogers, 1972). In New South Wales it is relatively uncommon (Eldridge, 1996), and is probably susceptible to clearing and overgrazing.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3475*, 20.viii.1996, approximately 5 km N of the Forward Gate 12 km N Maralinga Village, on calcrete ridge with *Casuarina cristata*, *Eucalyptus* spp., with *Psora crenata*, *Diploschistes thunbergianus* and *Caloplaca* sp.

Collema coccophorum Tuck. Abundant. This squamulose to sub-fruticose lichen was the most commonly occurring soil lichen, and was collected in 134 of the 150 quadrats in the survey area. *Collema coccophorum* is a common component of soil crusts on rangeland soils in the southern hemisphere (Filson and Rogers, 1979, Rogers, 1974, Eldridge, 1996) and in North America (Nash *et al.*, 1977) and the Middle East (Galun and Reichert, 1960; *Faurel et al.*, 1953). It was also common on sandy soils, often in association with *Synalissa symphorea* and the moss *Bryum eremaeum*. Specimens were commonly fertile, and specimens were often partially buried in the soil.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3486*, 20.viii.1996, on calcrete plains of dense *Senna artemesioides* and *Dodonaea* spp., with *Desmatodon convolutus*, *Fulgensia subbracteata*, *Collema coccophorum* and *Bryum eremaeum*, Tufi test site, approximately 32 km N Maralinga Village.

Diploschistes thunbergianus (Ach.)Lumbsch & Vezda Infrequent. Although found within only one quadrat at each of three undisturbed sites, *Diploschistes thunbergianus* was locally abundant in some areas, often occupying about 5% of the ground cover in some quadrats. Specimens occurred in large colonies up to 8 cm across, and were typically fertile with dark-brown to black immersed apothecia. *Diploschistes thunbergianus* is a common soil lichen over large areas of semi-arid pastoral country in NSW, Queensland, Victoria and Western Australia.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3539*, 25.viii.1996, calcrete plains at the junction of Boona Radial and 2nd Ave, approximately 38 km N Maralinga Village, with dense *Acacia aneura*, *Maireana astrotricha* and *Atriplex vesicaria*, in association with *Acarospora nodulosa* and *Aspicilia calcarea*.

Endocarpon helmsianum Muell.-Arg. Relatively infrequent. Single squamules were found in six quadrats at four of the 15 sites (Table 1), usually in association with *Endocarpon pusillum*, *Eremastrella crystallifera*, *Fulgensia subbracteata* and *Psora crenata*. This species is separated from other *Endocarpon* spp. by the bisporous asci, the black rhizines and the large (5–20 mm wide) thallus, and from *Catapyrenium* spp. by the number of spores. This species has been recorded in the North-western Botanical region of South Australia (McCarthy, 1991a).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3532*, 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Acacia colletioides* and *Maireana astrotricha* with *Peltula patellata* ssp. *australiensis*, *Catapyrenium lacinulatum* and *Psora crenata*, 1 km S of junction of Left St and Second St, approx 35 km N Maralinga Village.

Endocarpon pusillum Hedw. Relatively infrequent. This species is a common component of rangelands soils in Australia (Rogers, 1974; Rogers and Lange, 1972; Eldridge, 1996; McCarthy, 1991a). It is characterised by strongly-developed black rhizines and

distinguished from other *Endocarpon* spp. principally by spore characteristics and thallus size (McCarthy, 1991a).This lichen often occurs in degraded sites and in colonies a few centimetres across, and may be regarded as a pioneer species.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3471,* 20.viii.1996, approximately 5 km N of the Forward Gate 12 km N Maralinga Village, on calcrete ridge with *Casuarina cristata, Eucalyptus* spp., with *Psora crenata, Diploschistes thunbergianus* and *Chondropsis semiviridis.*

Endocarpon rogersii P.M. McCarthy Infrequent. This light-coloured species is characterised by bi-septate spores and light coloured rhizines. It is distinguished from *Catapyrenium lacinulatum* by the number of spores. This species is common in areas further to the east (Rogers, 1970; Eldridge, 1996) and has been collected in the North-western and Regions of South Australia (McCarthy, 1991a).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3472,* 21.viii.1996, West radial, approximately 1 km from Taranaki ground zero, on limestone plain with scattered *Acacia aneura, Senna artemesioides* and *Maireana sedifolia.*

Eremastrella crystallifera (Taylor)G. Schneider Common. One of the most conspicuous components of the soil crust community at Maralinga. *Eremastrella crystallifera* has an upper thallus structure resembling a mass of pyramidal-shaped crystals. This shape is thought to aid in thermoregulation, and may be useful for channelling water into the thallus. This species was found in 47 of the 150 quadrats, often in large colonies to 5 cm across. This species is relatively uncommon in NSW (Eldridge, 1996), and anecdotal evidence suggests that it increases in abundance with decreasing rainfall.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3518,* 23.viii.1996, rocky site approximately 18 km N Maralinga Village, with dense Acacia aneura and *Casuarina cristata,* in association with *Catapyrenium lacinulatum* and *Heppia despreauxii.*

Fulgensia subbracteata (Nyl.)Poelt Common. *Fulgensia* is a very common crustose lichen of calcareous soils is characterised by a distinctive citric-yellow to orange thallus which may become sorediose or granular. Like *Eremastrella crystallifera,* this species appears to be more common as annual rainfall declines. In rangelands in western NSW and western United States (St Clair *et al,.* 1993), it is virtually restricted to soils with a high gypsum (calcium sulphate) content (Eldridge, 1996).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3489,* 20.viii.1996, on calcrete plains of dense Senna *artemesioides* and *Dodonaea* spp., with *Desmatodon convolutus, Psora crenata, Collema coccophorum* and *Bryum eremaeum,* Tufi test site, approximately 32 km N Maralinga Village.

Heppia despreauxii (Mont.)Tuck. Abundant; occurring on calcrete and aeolian landscapes in 95 of the 150 quadrats at Maralinga. Thalli are olive-green to grey-green in colour, and generally occurred as small rosettes to 5 mm across (Rogers, 1974). In other disturbed environments, typical squamules have partially segmented lobes, which are often buried in the soil, indicating that active erosion has occurred (Eldridge, 1996). Immature thalli resemble *Peltula patellata* ssp. *australiensis,* from which it cannot reliably be separated except without fertile material. *Heppia* differs from *Peltula* spp. in the presence of 8 non-septate, hyaline spores approximately 15 µm across compared with many (often >100) smaller, hyaline spores in *Peltula* spp.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3516,* 23.viii.1996, rocky site approximately 18 km N Maralinga Village, with dense *Acacia aneura* and *Casuarina cristata*, in association with *Catapyrenium lacinulatum* and *Eremastrella crystallifera.*

Lecidea sp. Common. Sterile thalli of *Lecidea* sp. were collected within 40 quadrats at 13 of the 15 sites. These lichens favour consolidated soils, such as along the edges of tracks and on the surface of above-ground cappings of subterranean termite mounds. Most of this material can probably be ascribed to *Lecidea ochroleuca* Pers. which is known to be common on arid zone soils (Rambold, 1989) or *Lecidea terrena* Nyl. which is also facultatively terricolous.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3561,* 27.viii.1996, on calcrete plains of dense Senna *artemesioides* and *Dodonaea* spp., with *Desmatodon convolutus*, *Psora crenata*, *Collema coccophorum* and *Bryum eremaeum*, Tufi test site, approximately 32 km N Maralinga Village.

Peltula patellata ssp. australiensis (Muell.-Arg.)Büdel Common. This squamulose lichen was widely distributed at Maralinga and collected from 48 of the 150 quadrats at 11 sites. It is characterised by small, circular, greyish squamules upturned at the edges, often with a distinct bluish pruina. Unlike specimens found in western NSW, the squamules from Maralinga were characteristically fertile. *Peltula patellata* ssp. *australiensis* occurred in large colonies up to about 7 cm across, representing a few hundred squamules. It occurred commonly with *Collema coccophorum*, *Heppia despreauxii* and *Catapyrenium squamulosum.*

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3537,* 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Acacia colletioides* and *Maireana astrotricha* with *Desmatodon convolutus*, *Catapyrenium lacinulatum* and *Psora crenata*, 1 km S of junction of Left St and Second St, approx 35 km N Maralinga Village.

Peltula imbricata R. Filson Infrequent. A single sample was collected at one of the undisturbed sites. The species is characterised by the small overlapping squamules (Filson, 1988). has also been recorded from only a few sites in western New South Wales, mostly in areas where grazing has been excluded (Eldridge, 1996).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3520,* 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Maireana astrotricha* and *Atriplex vesicaria*, 3 km E of the junction of 5th and Central, approximately 58 km N Maralinga Village, with *Peltula patellata* ssp. *australiensis*, *Catapyrenium lacinulatum* and *Psora crenata*, 1 km S of junction of Left St and Second St, approximately 35 km N Maralinga Village.

Psora crenata (Taylor)Reinke Abundant. This squamulose lichen is probably the most conspicuous lichen on the Maralinga soils. It is characterised by large pink to pinkish-white squamules to 5 mm across with deeply crenulate margins. Unlike specimens in eastern Australia (Eldridge, 1996; Rogers, 1972), the black and convex marginal apothecia were rarely observed. *Psora crenata* was more abundant at undisturbed sites. Although widely distributed on calcareous soils, it also occurred on sandy soils dominated by mallee (*Eucalyptus* spp.), particularly in sheltered microsites on the southern and eastern side of *Triodia* spp. hummocks. *Psora crenata* occurred in colonies up to 80 mm across with a median size of 35 mm. An analysis of 50 colonies growing on a sandy soil revealed a strong relationship between the total area occupied by individual colonies, and the number of squamules comprising the colonies (R^2=0.859, $F_{1,49}$=305.66, P<0.001). Other data (Eldridge and Ferris, unpublished) demonstrate that colony size is a good indicator of the number of years since disturbance.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3490*, 20.viii.1996, on calcrete plains of dense *Senna artemesioides* and *Dodonaea* spp., with *Desmatodon convolutus*, *Collema coccophorum* and *Bryum eremaeum*, Tufi test site, approximately 32 km N Maralinga Village.

Toninia sedifolia (Scop.)Timdal Relatively infrequent. Found in eight quadrats at only three sites, two of which were undisturbed (Table 1). Characterised by dark-grey, rounded blue squamules, with white to bluish pruina (Filson and Rogers, 1979). Specimens occurred in small colonies up to 5 cm across, often in association with *Psora crenata*, *Eremastrella crystallifera* and *Catapyrenium squamulosum*.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3512*, 23.viii.1996, rocky site approximately 18 km N Maralinga Village, with dense *Acacia aneura* and *Casuarina cristata*, in association with *Catapyrenium lacinulatum* and *Heppia despreauxii*.

Xanthoparmelia convoluta (Krempelh.)Hale Infrequent. This foliose lichen was found at only two sites, both undisturbed. Most specimens were vagrants, though a few were loosely attached to rocks and organic material. It is characterised by elongated, convoluted yellowish-green lobes, varying from smooth in small specimens, to cracked in older specimens. It often occurred in association with *Chondropsis semiviridis*, and its absence from all but the undisturbed sites suggests that in this landscape, it is susceptible to disturbance.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3476*, 20.viii.1996, approximately 5 km N of the Forward Gate north Maralinga Village, on calcrete ridge with *Casuarina cristata*, *Eucalyptus* spp., *Psora crenata*, *Diploschistes thunbergianus* and *Chondropsis semiviridis*.

Mosses

Acaulon leucochaete Stone Relatively infrequent. Isolated patches of a few plants were found at two sites at Maralinga. Collections of this species are not known from the North-western region of South Australia.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3507*, 22.viii.1996, Maralinga Village, on sandy soil under *Callitris glaucophylla* with *Stonea oleaginosa*, *Bryum eremaeum* and *Desmatodon convolutus*.

Bryum eremaeum Catches. ex Spence & Ramsay Common. This moss was the most abundant in terms of individual plants and was commonly associated with soil crust lichens. It was found within 48 of the 150 quadrats, typically in large colonies of more than 50 plants per square centimetre. Species were characterised by stem tubers and a relatively long whitish denticulate hairpoint. This is one of the few Australian mosses which is restricted to arid areas (Spence and Ramsay, 1996).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3508*, 22.viii.1996, Maralinga Village, on sandy soil under *Callitris glaucophylla* with *Stonea oleaginosa* and *Desmatodon convolutus*

Crossidium davidai Catches. Relatively infrequent. Small numbers of *C. davidai* occurred at three of the 15 sites, usually as isolated individuals. This moss closely resembles *Desmatodon convolutus*, and specimens possessing more than one cell on the filaments on the adaxial side of the costa were assigned to *C. davidai*. A revision of the

genus *Crossidium* may place these two species into a single complex (G. Bell, pers. comm. 1996).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3535*, 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Acacia colletioides* and *Maireana astrotricha* with *Peltula patellata* ssp. *australiensis*, *Catapyrenium lacinulatum* and *Psora crenata*, 1 km S of junction of Left St and Second St, approximately 35 km N Maralinga Village.

Crossidium geheebii (Broth.)Broth. Relatively infrequent. Although common on calcareous soils elsewhere in arid Australia (Eldridge and Tozer, 1996; Downing,1992), *Crossidium geheebii* was found within only 11 quadrats at 7 of the 15 sites, and generally as scattered plants.

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3545*, 25.viii.1996, on exposed calcrete ridge supporting open *Acacia aneura*, *Stipa* spp. and *Sclerolaena diacantha*, with *Collema coccophorum*, *Stonea oleaginosa* and *Desmatodon convolutus*, Gona Test site, approximately 28 km N Maralinga Village.

Desmatodon convolutus (Brid.)Grout Abundant. Desmatodon convolutus is one of the most common mosses of dry areas (Eldridge and Tozer 1996). At Maralinga it was found in 70 quadrats at 14 of the 15 sites in loose tufts with *Bryum eremaeum* and *Stonea oleaginosa*. Whilst commonly found on calcareous substrates (Downing, 1992; Downing and Selkirk,1993; Howarth, 1983) it also occurs on a range of soil types (Eldridge and Tozer, 1996).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3584*, 20.viii.1996, in road drain supporting dense *Senna artemesioides*, Tufi Test site, approximately 28 km N Maralinga Village.

Stonea oleaginosa (Stone)R.H. Zander Common; and found within 36 quadrats at ten of the 15 sites. Outside the study area, specimens occurred on sandy soils associated with mallee vegetation and around Maralinga Village (Table 4). Specimens with gemmae were observed on only a few occasions. This moss is often overlooked in collections as it is often half buried under the soil surface, and the red apices of the leaves closely resemble the iron-rich soils on which it is found. Stone (1978) and Catcheside (1980) report that it is not uncommon on desert soils. It has been recorded from a wide variety of landscapes and soil types in western New South Wales (Eldridge and Tozer, 1996).

Selected specimen examined:

SOUTH AUSTRALIA: *D.J. Eldridge 3535*, 25.viii.1996, on calcareous plains of *Casuarina cristata*, *Acacia colletioides* and *Maireana astrotricha* with *Peltula patellata* ssp. *australiensis*, *Catapyrenium lacinulatum* and *Psora crenata*, 1 km S of junction of Left St and Second St, approx 35 km N Maralinga Village.

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