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THE EFFECT OF *GYMNOSTOMA DEPLANCHEANUM* (CASUARINACEAE) LITTER ON SEEDLING ESTABLISHMENT OF NEW CALEDONIAN ULTRAMAFIC MAQUIS SPECIES

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ABSTRACT

Revegetation research on open-cut nickel mines in New Caledonia has identified the potential of the highly diverse native ultramafic flora. Ultramafic substrates contain very high levels of nickel, manganese and magnesium, and are devoid of nitrogen, phosphorus, potassium and calcium, creating difficult conditions for plant establishment. Most revegetation work has focussed on the endemic species Casuarina collina, Acacia spirorbis and Gymnostoma spp. These nurse species produce a deep litter which may alleviate substrate nutrient deficiencies and act as a mulch for colonising seedlings. However, well established plantations of Casuarina and Acacia are poor in species diversity. Natural formations of Gymnostoma spp. appear to possess a higher species diversity and have recently been examined as an alternative nurse species. This glasshouse study examines the seed germination and establishment of six ultramafic species placed above or below Gymnostoma deplancheanum litter.

In general, a slightly higher level of establishment was achieved with seed placed at the contact between litter and soil, followed by seed on bare soil. Seed placed on top of the litter failed to germinate in all species except Dodonaea viscosa, a small-seeded species which apparently washed down the profile. The litter surface appears to dry out too much for seedling establishment and suggests that large seed size may limit penetration through to the bare soil.

A higher number of seedlings established under a daily watering regime than the water stressed regime with the highest mortality recorded for seedlings in the bare soil treatments. The litter treatment reduced soil moisture loss and possibly explains the higher survival rate of seedlings in this treatment under water stress.

1.0 INTRODUCTION

1.1 Location

New Caledonia is located in the south-west Pacific just north of the Tropic of Capricorn and covers a surface area of 19,100 km^2. Approximately one third of the main island (16,900 km^2) is covered by ultramafic substrates derived from a peridotite sheet deposited in the Eocene period (Paris, 1981). These substrates contain high levels of Ni, Cr, Co and Fe which have been mined since the 1870s (Jaffre *et al*, 1995a). The levels of N, P, K are low, and there is a Ca/Mg imbalance due to the high levels of Mg and low levels of Ca (Jaffré 1980). The climate is oceanic sub-tropical with air temperatures ranging between 20°C–30°C. Rainfall ranges from 1,200 to 4,000 mm y^{-1}, mostly during the wet season December to March resulting in heavy leaching on ultramafic substrates.

The rainforest and maquis (heathland) vegetation found on ultramafics contain a highly diverse and endemic flora which has been the focus of botanical research in terms of its biodiversity (Jaffré 1980; Jaffré and Veillon 1991), adaptation to ultramafic soils (Jaffré 1976) and revegetation of existing nickel mines (Cherrier 1990; Jaffré and Rigault 1991; Jaffré *et al.* 1995a; Pelletier and Esterle 1995). The flora has a shared ancestry with Australia in the early Tertiary and many genera are present in both regions (Morat *et al.* 1986).

1.2 History of Revegetation

Prior to the 1970s there was little attempt made to revegetate mine sites in New Caledonia. These heavily eroded and abandoned mines form a conspicuous part of the landscape, with many of these sites remaining bare even for decades. A major problem facing revegetation programs in New Caledonia is the scale of the overburden waste. To obtain 3-4 million tonnes of nickel ore extracted per year in New Caledonia, 10 million tonnes of surface material must be removed and then placed onto waste terraces to be revegetated (Jaffré *et al.* 1995a).

Research into the revegetation of nickel mines in New Caledonia was first carried out in the 1970's by ORSTOM* and CIRAD foret ** (C.T.F.T. 1971; Jaffré and Latham 1976) with the aim of rapidly stabilising overburden waste. Exotic *Pinus caribaea* and two native fast growing nitrogen fixing endemic species, *Acacia spirorbis* and *Casuarina collina* were successfully established on overburden improved with fertiliser (Cherrier, 1990). Concerns that *P. caribaea* would invade native vegetation have discouraged its further use. *Casuarina collina* and *Acacia spirorbis* were chosen because they were fast growing and produced large amounts of litter which could decompose into a nutrient-rich mulch suitable for regeneration of the plantation species, and colonisation of species from the neighbouring maquis (Cherrier 1990). However, it became apparent that these mature plantations were nearly devoid of any regeneration or colonisation. The absence of pioneer maquis species was attributed to the slow decomposing, deep, acidic litter (Jaffré *et al.* 1995a; Pelletier and Esterle 1995), though limited sources of seed may have also restricted colonisation. *Casuarina collina* and *Acacia spirorbis* are naturally found on ultramafic substrates at low altitude. The absence of regeneration of these species is possibly due to the unsuitable substrate properties or the high altitude of many of the mines (Jaffré *et al.* 1995a).

Recent revegetation research has focussed there attention on using ultramafic species to re-establish native communities to nickel mine wastes. To date, 40 ultramafic maquis species belonging to Cyperaceae, Casuarinaceae, Mimosaceae, Myrtaceae and Proteaceae have shown promising results (Table 1) (Jaffré *et al.* 1995a). Nitrogen-fixing endemic *Gymnostoma* spp. (Casuarinaceae) are found on ultramafics in New Caledonia and have been the focus of research as a nurse species in revegetation (Jaffré *et al.* 1995b). *Gymnostoma deplancheanum* is a gregarious species which occurs in vegetation formations ranging from maquis to forest and also appears to facilitate the colonisation by other species after a disturbance by producing a dense litter (Jaffré, 1980; McCoy *et al.* in prep.). The main focus of this study was to assess the physical effect of *G. deplancheanum* litter on the establishment of various pioneer maquis species with different seed sizes. The possible allelopathic nature of Casuarinaceae litter (Story, 1967) was not examined in this experiment. A previous glasshouse experiment examining the allelopathic potential of *G. deplancheanum* litter leachates on ultramafic maquis species showed only a minor difference in growth ($P<0.06$) between leachate watered and the control plants (McCoy unpubl.).

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* ORSTOM — Institut Francais de Recherches pour le Developement en Cooperation.

** CIRAD foret — Centre de cooperation internationale en recherche agronomique pour le developpement.

Table 1. Ultramafic species used in nickel mine revegetation in New Caledonia

Family / Genus	Family / Genus	Family / Genus
Agavaceae	**Dilleniaceae**	**Myrtaceae**
Cordyline (1 sp)	*Hibbertia* (2 sp)	*Myrtastrum* (1 sp)
Caesalpiniaceae	**Euphorbiaceae**	*Tristaniopsis* (1 sp)
Storckiella (2 sp)	*Bocquillonia* (1 sp)	*Xanthostemon* (3 sp)
Casuarinaceae	*Longetia* (1 sp)	**Proteaceae**
Casuarina (2 sp)	*Phyllanthus* (3 sp)	*Grevillea* (3 sp)
Gymnostoma (7 sp)	**Flagellariaceae**	*Stenocarpus* (1 sp)
Celastraceae	*Joinvillea* (1 sp)	**Rhamnaceae**
Peripterygia (1 sp)	**Goodeniaceae**	*Alphitonia* (1 sp)
Cunoniaceae	*Scaevola* (1 sp)	**Rubiaceae**
Geissois (1 sp)	**Mimosaceae**	*Normandia* (1 sp)
Cyperaceae	*Acacia* (1 sp)	**Sapindaceae**
Baumea (1 sp)	*Serianthes* (1 sp)	*Dodonaea* (1 sp)
Costularia (1 sp)	**Myrtaceae**	**Verbenaceae**
Schoenus (2 sp)	*Baeckea* (1 sp)	*Oxera* (1 sp)
Lepidosperma (1 sp)	*Carpolepis* (1 sp)	**Violaceae**
	Cloezia (2 sp)	*Agathea* (1 sp)

(Jaffré & Rigault, 1991)

2.0 METHOD

2.1 Glasshouse Experimental Design

The experiment was designed to examine the germination and early growth of seed placed above or below *Gymnostoma* litter, and subject to either daily watering or water stressed conditions. It was conducted in a glasshouse at ORSTOM Noumea from November 1994 to February 1995. The experimental design consists of 108 pots (750 ml clear plastic) split into two water regimes and three substrate treatments with 20 seed of each of the six species per pot. Each of the replicates was placed in a different block.

2.1.1 Seed selection and treatment

Viable and fresh seed of *Gymnostoma deplancheanum* (Casuarinaceae), *Alphitonia neocaledonica* (Rhamnaceae), *Dodonaea viscosa* (Sapindaceae), *Acacia spirorbis* (Mimosaceae), *Grevillea exul* var. *rubiginosa* (Proteaceae) and *Beccariella baueri* (Sapotaceae) was obtained in November 1994 from ultramafic maquis in the Plaines des Lacs region of southern New Caledonia. Fresh seed was used because seed of *Gymnostoma* and *Beccariella* has a short longevity (several months). Woody dehiscent fruits of *Gymnostoma*, *Alphitonia* and *Grevillea* were opened using heat from infrared lamps. *Alphitonia* fruit was repeatedly soaked in water and then dried using the infrared heat to expose the seed. Seed of *Beccariella* was depulped by hand. Seed of *Acacia* and *Alphitonia* was placed in boiling water and allowed to cool to break the seed dormancy. Details on the, morphology, average weight and size of these seed are given in Table 2.

2.1.2 Experimental media

2.1.2.1 *Gymnostoma deplancheanum* litter

Gymnostoma litter was collected from a maquis woodland and air dried. The average depth of litter in these *G. deplancheanum* dominated formations ranges from 3–7 cm (McCoy *et al.* in prep.). A 5 cm depth (50 grams of *Gymnostoma* litter per pot) was selected for the experiment as being typical of natural conditions. Branches and seed pods of other plant species were removed and the litter was shaken over a 2 mm sieved to remove any seed. Table 3 gives the chemical composition of the litter used in the experiment.

Table 2. Morphology and size of seed species.

Species	Morphology	Average weight per seed (mg)	Average size per seed (mm)
Gymnostoma deplancheanum	winged	2.3	5 x 3
Alphitonia neocaledonica	sub-ovoid	27.5	4 x 4
Dodonaea viscosa	ovoid	1.5	2 x 2
Grevillea exul var. rubiginosa	winged	10.2	12 x 6
Acacia spirorbis	sub-ovoid	30	4 x 4
Beccariella baueri	sub-ovoid	50	6 x 3

2.1.2.2 Soil media

The soil media used in the experiment is a ferritic gravel (sol ferralitique ferritique gravilionnaire) or oxisol (Latham 1986) which occurs as the A horizon in *Gymnostoma* formations of southern New Caledonia. This heavily leached ultramafic substrate has a pH of between 4 and 6.5 and is largely composed of iron-rich pisolite material (Latham 1986). All the species tested naturally occur on this substrate. The chemical composition of this substrate and mine overburden from the Kouaoua (McCoy unpubl.) and Thio nickel mines (Jaffré and Rigault 1991) is given in Table 3. Soil chemistry of both mine overburdens are typical of the substrate conditions encountered in mine revegetation operations in New Caledonia (Table 3).

The test soil was oven dried to 105°C and sieved through a 5 mm mesh sieve. Five hundred and fifty (550) g of ferritic gravel was placed in each pot.

Table 3. Chemical composition (Total %) of *G. deplancheanum* litter and ferralitic gravel used in the trial, and of overburden from two mines.

Chemical component	*Gymnostoma* woodland litter n=12		Ferritic gravel n=12		Kouaoua Laterite overburden n=8		Thio Laterite overburden n=8	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
N	0.59	0.18	0.026	0.01	0.05	-	0.027	-
P (ppm)	122.15	41.32	186.41	37.66	172.86	76.4	161.87	45.99
K	0.05	0.04	<0.01	-	0.03	-	-	-
Na	0.2	0.1	<0.01	-	0.04	0.03	-	-
Ca	0.17	0.01	0.016	-	<0.01	-	<0.01	-
Mg	0.03	<0.01	0.049	0.028	1.8	0.03	1.59	1.04
Mn	0.07	<0.01	0.175	0.14	0.67	0.3	0.52	0.07
Ni	<0.01	-	0.22	0.08	1.38	0.4	1.35	0.2
Fe	0.07	-	48.64	3.43	45.8	4.9	42.10	5.42
Cr	<0.01	-	3.26	1.67	2.26	0.1	2.55	0.21
Co	-	-	0.02	-	0.16	0.05	0.09	0.01
pH in H_2O	6.35	0.7	5.6	0.7	6.4	0.3	6.27	0.3

2.1.3 Watering regime

The watering regimes were to saturate the litter and soil either daily or every third day. Drying curves were determined for the soil + litter treatments by recording the loss in weight from 25 pots of each treatment. After one to three days, the water losses were 30 to 70 ml from the soil but only 10–20 ml from the soil plus litter. Figure 1 shows the mean drying curves obtained for 25 bare soil pots and 25 soil with litter pots. A 1/3 soil saturation level in bare soil was reached after 72 h and used as the watering regime for both treatments. The soil/litter treatment took 132 h to attain a 1/3 soil saturation level due to the reduced evaporation conditions created by the litter. This treatment was watered with less water (50 ml/72 h) than the bare soil treatment (100 ml/72 h).

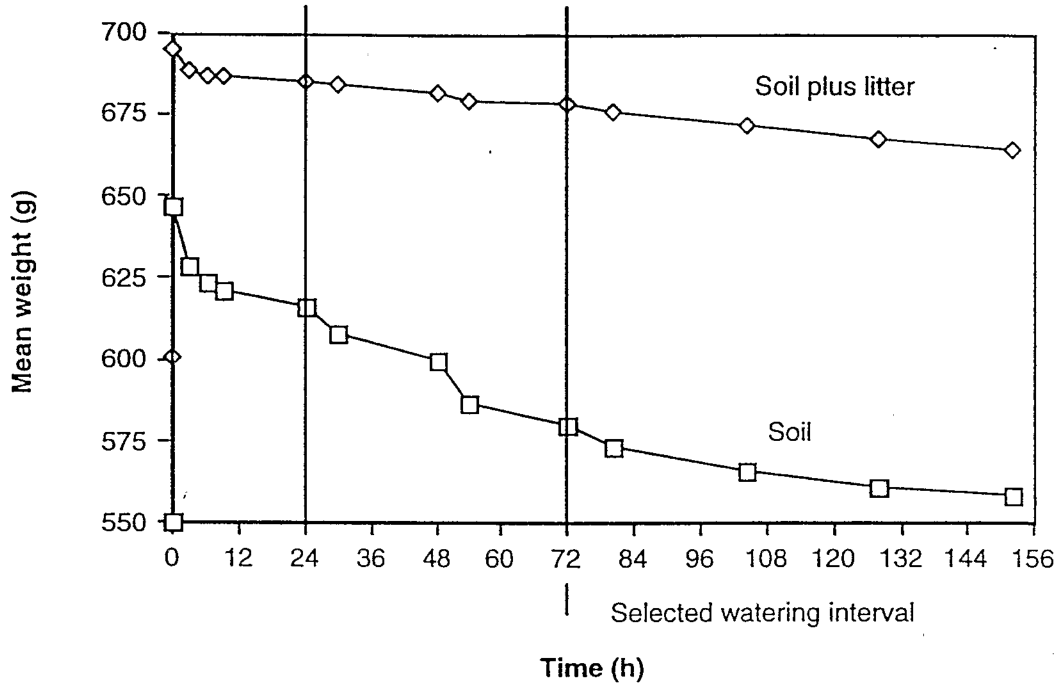

Figure 1. Drying curves of pots containing soil and *Gymnostoma* litter + soil. Pots were initially saturated and were left in the glasshouse to dry. Oven dry weights were 550 g soil and 50 g litter.

3.0 RESULTS AND DISCUSSION

The number of germinations and established seedlings in each pot were recorded weekly over a four month period. Logistic regression and ANOVA, on arc-sine square root transformed data were used to identify the differences within and between species for the various treatments.

3.1 Seedling Establishment Under Different Water Regimes

All species except *Gymnostoma* showed a higher rate of seedling establishment under a daily watering regime. The analysis of deviance indicates a difference in seedling establishment under different water regimes ($P<0.01$); however water regimes were not significant in the ANOVA. Figure 2 shows the number of seedlings established under the two watering regimes.

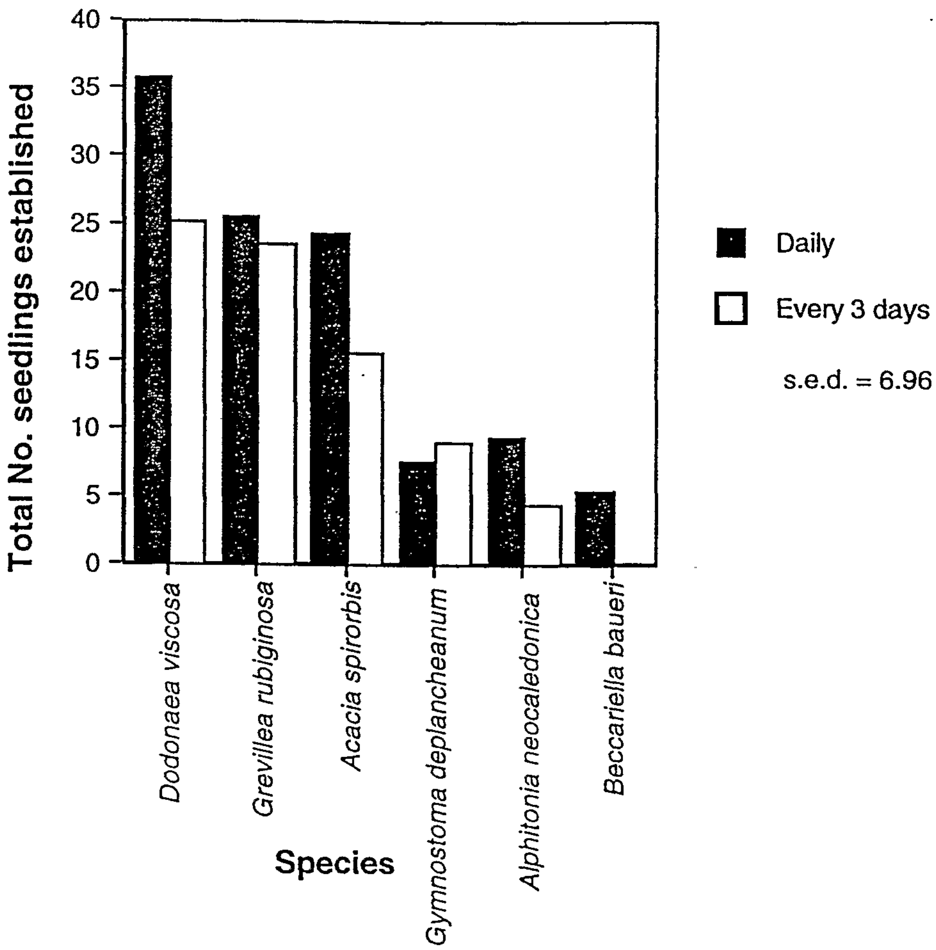

Figure 2. Seedling establishment under daily and 3-day water regimes. A total of 60 seeds was placed in each treatment.

3.2 Seedling Establishment for Soil and Litter Treatments

Figure 3 gives the total number of seedlings established for each species for the bare soil and two litter treatments. The highest level of seedling established was recorded for *Dodonaea* followed by *Grevillea*, *Acacia*, *Gymnostoma*, *Alphitonia* and *Beccariella*. ANOVA showed that seedling establishment was significantly different between species ($P<0.001$). There was also a significant difference between the treatment where seed was placed on top of litter and the two other treatments ($P<0.001$). *Dodonaea* was the only species to establish on treatments where seed was placed on top of the litter.

The small seed (2 mm) of this species was able to penetrate through the litter to the substrate. The top of the litter appeared to dry appreciably under both water regimes and possibly resulted in larger seed and germinants drying out on the litter surface. Large seed sizes of the other species may have also limited passage through the litter to the soil surface.

A lack of difference between seedling establishment on bare soil and at the base of the litter was possibly due to the slow drying of litter treatments. This may have facilitated a greater seedling survival on water-stressed litter treatments. Slightly higher values were recorded for seedling establishment of *Grevillea* and *Dodonaea* on litter treatments than on bare soil. This

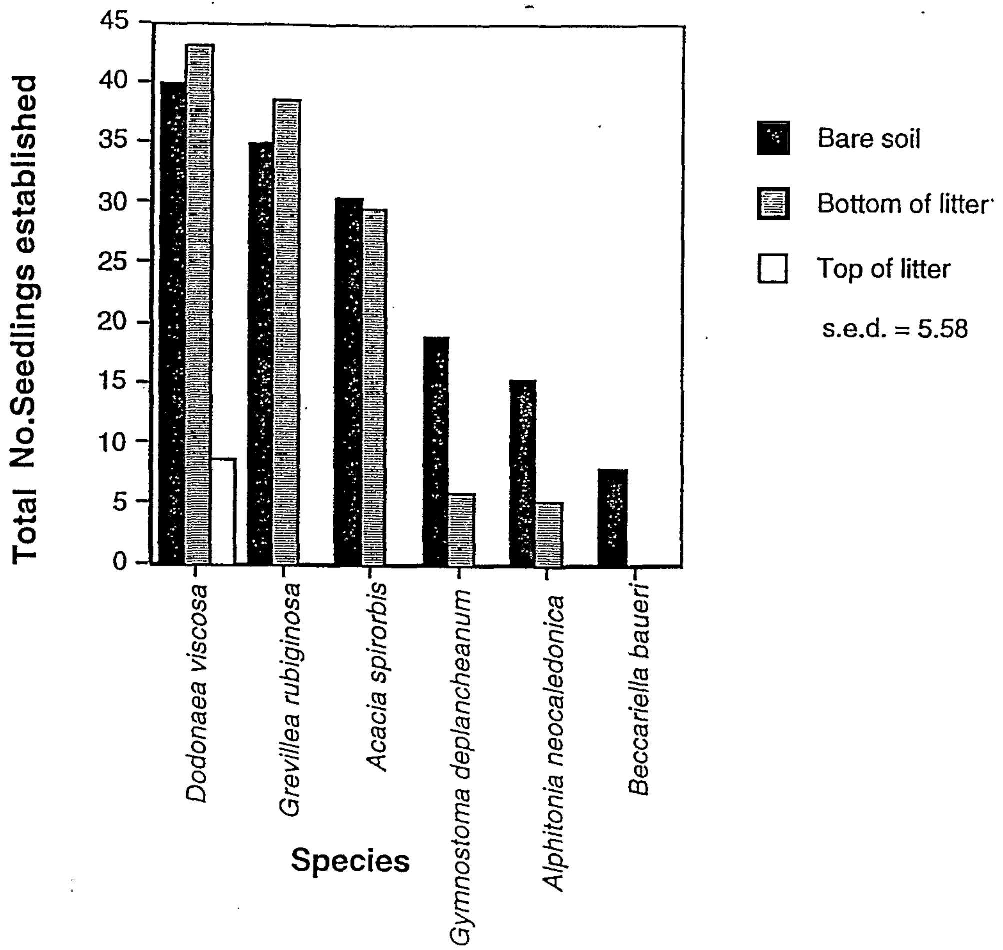

Figure 3. Seedling establishment when seeds placed on bare soil, beneath litter, and above litter.

difference is consistent with broadcast seeding experiments using these species and mulch treatments (Jaffré *et al.* 1995a). Jaffré *et al.* (1995a) recorded more *Grevillea* and *Dodonaea* seedlings on straw mulch treatments than on bare soil. *Grevillea* seed possesses larger reserves which may have assisted seedling shoots to penetrate through the litter. *Dodonaea* has a small seed reserve and was able to establish by germinating and penetrating the 5 cm deep litter layer rapidly (within one month).

The higher establishment values for *Acacia*, *Gymnostoma* and *Alphitonia* on bare soil treatments compared to litter treatments confirm observations of these pioneer species which often colonise disturbed bare ultramafic substrates (Jaffré *et al.* 1995b). Seedlings tend to be slow growing and possibly have difficulty in penetrating deep litter. Table 4 gives the mean height of seedlings for each species after four months.

Table 4. Mean seedling height after four months.

Species	Height (cm)
Acacia spirorbis	4.3
Alphitonia neocaledonica	3.1
Beccariella baueri	1.9
Dodonaea viscosa	4.0
Grevillea exul var. rubiginosa	7.0
Gymnostoma deplancheanum	2.6

3. 3 Established Seedling Mortality

Figure 4 gives the seedling mortality of each species at the end of the experiment. In general, the highest mortality was recorded for seedlings on bare soil treatments which suggests that litter may be beneficial to seedling survival by acting as a mulch. It also hints that allelopathy may not play a role in seedling mortality. Slightly higher mortality values for *Dodonaea* and *Grevillea* on litter treatments were due to fungal attack in the humid litter. The species showing the highest mortality on bare soil are the pioneer species *Gymnostoma* and *Alphitonia* which naturally occur on disturbed substrates. Both of these species produce large quantities of seed.

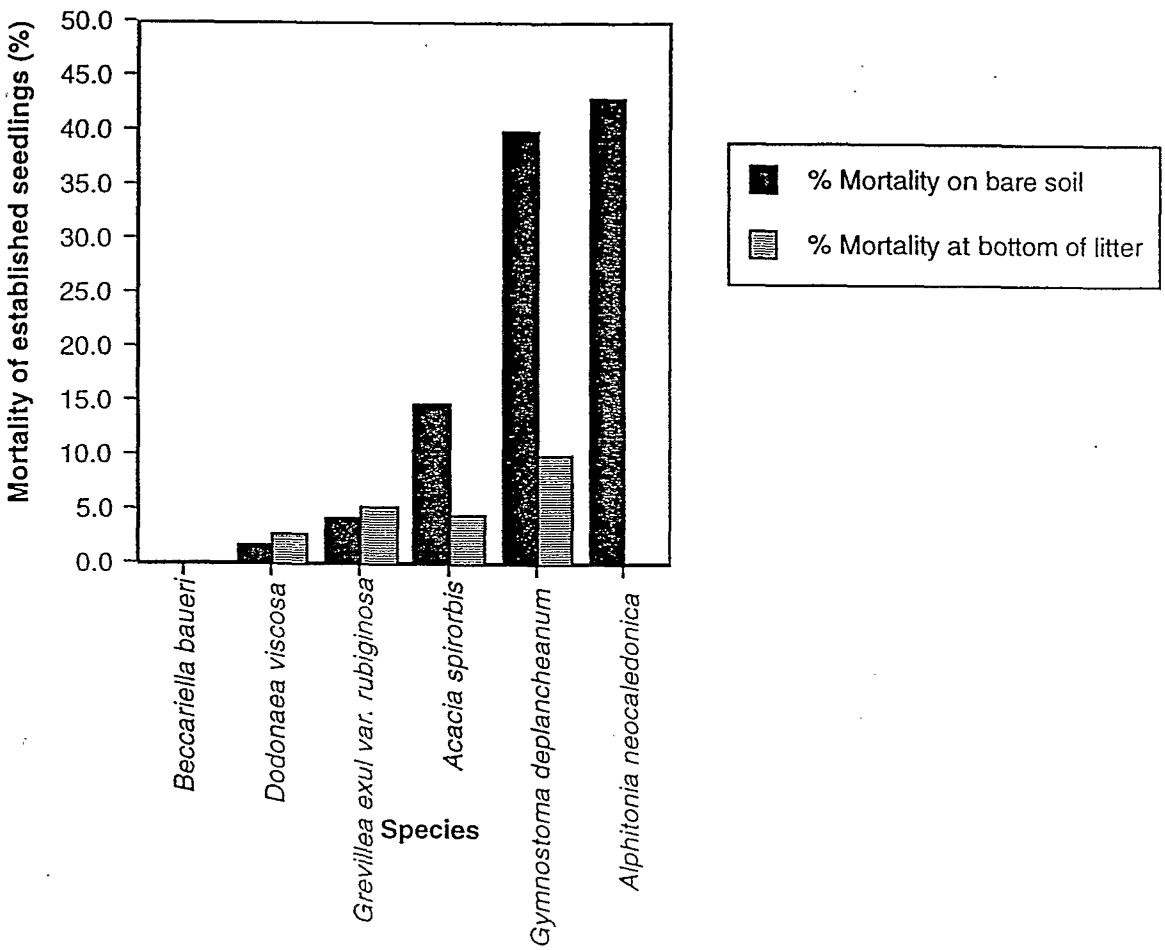

Figure 4. Mortality of established seedlings on bare ground and beneath litter.

4.0 CONCLUSION

The physical effects of litter on the seed of the maquis species tested is highly variable. However, it appears that seed of large seeded species (seed > 6 mm) either fails to germinate in the upper litter or dies after germinating because of the dry conditions and dense matrix of *Gymnostoma* branchlets (needles) which impede passage to the soil. In contrast, small seeds may enter the litter and establish. This phenomena is consistent with the species recorded in natural stands of *Gymnostoma* dominated maquis which are mainly small seeded Myrtaceae, Cunoniaceae and Dilleniaceae (McCoy *et al.* in prep.). From a revegetation perspective, broadcast seeding of future plantations of *Gymnostoma* should include small seeded species.

The lack of difference between seedling establishment on bare soil and at the base of the litter apparently resulted from an incomplete drying of treatments. In this experiment, the bare soil pots lost 30–70% of their moisture while the litter/soil pots lost 10–20% moisture for daily watering and manual watering regimes respectively. A possible solution would be to carry out the litter/soil part of the experiment but with a watering regime which would affect seedling survival. On the basis of the low mortality of seedlings for seed placed at the base of the litter and the moisture retaining properties of the soil/litter treatment, it appears that hydraulic seeding should be followed by an application of mulch (e.g. *Gymnostoma* litter).

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