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TABLE 12. TWO-WAY TABLE OF SPECIES BY CLASSIFICATION GROUP.
Numbers in bold represent the average species richness of each tier.

GROUP		A	B	C	D
	Tier 3 (5–12 m)	**0.00**	**0.06**	**0.00**	**0.25**
G	*Cordyline australis*				1.94
	Pseudopanax arboreus				1.94
	Kunzea ericoides		2.24		
	Tier 4 (2–5 m)	**0.29**	**0.35**	**0.00**	**2.63**
F	*Coprosma propinqua*		0.18		20.00
	Discaria toumatou	0.50			14.06
	Muehlenbeckia astonii		0.18		2.00
	Sophora prostrata		0.91		0.38
	Rosa rubiginosa	0.43			0.44
G	*Kunzea ericoides*				0.81
	Carmichaelia australis				0.13
	Muehlenbeckia astonii		0.18		0.19
	Pseudopanax arboreus				0.38
	Melicytus ramiflorus				0.38
	Cordyline australis		0.03	0.04	0.13
	Cytisus scoparius		0.91		
	Ozothamnus leptophyllus		0.91		
	Ulex europaeus				4.75
	Muehlenbeckia complexa				1.94
H	*Olearia solandri*				0.81
	Tier 5 (0.3–2 m)	**3.14**	**2.65**	**5.83**	**5.38**
A	Exotic grasses	12.57	3.68	31.75	7.88
	Muehlenbeckia complexa	4.07	3.12	4.58	9.44
	Muehlenbeckia astonii	0.29	1.32	2.08	2.25
B	*Coprosma propinqua*		2.26	2.42	18.50
C	*Ozothamnus leptophyllus*	0.43	1.82	3.46	0.13
	Carmichaelia australis	0.57	0.12	0.54	0.63
D	*Coprosma crassifolia*		0.18	5.25	0.13
	Muehlenbeckia australis		0.35	0.58	0.63
	Isolepis nodosus		2.59	0.38	0.06
	Melicytis crassifolius			0.46	
E	*Discaria toumatou*	5.43	0.18		13.00
	Melicytus sp. unnamed	1.43	0.06		0.19
	Rosa rubiginosa	0.79			0.44
	Poa cita	0.93	1.15	0.79	1.56
F	*Clematis afoliata*			0.25	0.88
	Coprosma intertexta				0.44
	Sophora prostrata	0.43	0.91		2.31
	Melicytus sp. unnamed	0.07			0.38
	Cytisus scoparius	0.50	0.18		2.31
	Ulex europaeus		0.18	0.04	4.75
G	*Juncus gregiflorus*	0.43		3.21	
	Kunzea ericoides			0.29	0.50
	Epilobium pubens				0.38
	Cordyline australis		0.06	0.04	0.06
	Ammophila arenaria		2.24		
	Medicago sativa		0.18		
	Cyperus ustulatus			1.29	
	Cirsium vulgare		0.35		
	Echium vulgare		0.18		
	Phymatosorus diversifolius			0.25	
	Lycium ferossimum	0.43		0.25	
	Urtica ferox			0.25	
	Melicytus ramiflorus	0.07			0.38
	Calystegia soldanella			0.25	
	Polystichum richardii			0.25	
	Coprosma repens			0.08	
	Coprosma rhamnoides			0.08	
	Olearia paniculata			1.33	

Table 12 contd.

GROUP		A	B	C	D
G	*Leptospermum scoparium*			0.08	
	Phormium cookianum			0.33	
	Haloragis erecta			0.29	
	Luzula migrata			0.08	
	Clematis forsteri			0.25	
	Rytidosperma petrosum			0.25	
H	*Olearia solandri*	0.07	1.09	0.04	0.50
	Pteridium esculentum			2.58	0.19
	Coprosma robusta				0.81
	Hebe stricta				0.50
	Rubus squarrosus				2.00
	Phormium tenax	0.07			0.44
	Rubus schmidelioides				0.19
	Carex virgata				0.13
	Coriaria arborea				0.13
	Tier 6 (< 0.3 m)	**2.29**	**2.71**	**4.83**	**3.63**
A	Exotic grasses	70.14	45.03	60.29	24.38
	Muehlenbeckia complexa	1.93	2.21	6.46	6.31
	Muehlenbeckia astonii	0.64	0.91	2.08	2.25
B	*Coprosma propinqua*		2.26	1.33	15.06
C	*Ozothamnus leptophyllus*	0.07	1.82	1.17	0.13
	Carmichaelia australis	0.14	0.06	0.29	0.50
D	*Coprosma crassifolia*		0.03	5.00	0.13
	Muehlenbeckia astonii		0.35	0.58	0.25
	Isolepis nodosa		0.18	0.17	0.06
	Melicytus crassifolius			0.46	
E	*Discaria toumatou*	0.57	0.03		5.75
	Melicytus sp. unnamed	1.43			0.19
	Rosa rubiginosa	0.29			
	Poa cita	0.21	1.12	0.58	0.69
F	*Clematis afoliata*			0.04	0.56
	Coprosma intertexta				0.44
	Sophora prostrata		0.91		0.38
	Rytidosperma gracile				1.94
	Melicytus sp. unnamed	0.07			0.06
	Cytisus scoparius	0.14	0.18		2.31
	Ulex europaeus		0.03	0.04	0.38
G	*Juncus gregiflorus*	0.07		1.33	
	Kunzea ericoides			0.29	0.06
	Carmichaelia appressa		0.06		
	Zoysia minima		0.18		
	Cyperus ustulatus				1.94
	Echium vulgare			0.25	
	Rytidosperma sp.		0.35		
	Olearia solandri		0.18		
	Poa anceps			0.04	0.06
	Tetragonia tetragonioides			0.25	
	Asplenium flabellifolium	0.07		0.04	
	Polystichum richardii			0.04	0.06
	Calystegia soldanella			0.04	0.06
	Olearia paniculata			0.25	
	Leptospermum scoparium			0.29	
	Phormium cookianum			0.08	
	Haloragis erecta			0.33	
	Luzula migrata			0.08	
	Rytidosperma petrosum			0.08	
H	*Pteridium esculentum*		0.18	0.25	
	Phormium tenax			4.46	0.19
	Rubus schmidelioides	0.07			0.44

six dryland environment types currently occupied by *M. astonii* (Table 13). Few environmental characteristics distinguish these plots from the other three communities, but plots experience later air frosts, and higher average annual Penman soil water deficits and annual solar radiation inputs than those in other communities.

Community B: Widespread exotic grassland

The 17 plots classified within this widespread exotic grassland community contain between 1 and 72 *M. astonii* plants, which vary widely in height and size (Table 12). The community is present in all six dryland environment types currently occupied by *M. astonii*, including sites: on Kaitorete Spit and in the Hurunui Hills in Canterbury; at Peters Covenant, Cape Campbell airstrip, Mussel Point, Eradus, Awatere Bridge and Seddon Vineyard in Marlborough; and at Sinclair and Baring heads, and in the Ruamahanga River and Orongorongo catchments in Wellington / Wairarapa. The vegetation is species poor and predominantly low statured, but contains scattered emergent trees or shrubs of kanuka, *Cordyline australis*, *Sophora prostrata*, *Ozothamnus leptophyllus*, *Cytisus scoparius*, *Muehlenbeckia australis* and *Coprosma propinqua*. *Ammophila arenaria*, *Cirsium vulgare*, *Medicago sativa*, *Zoysia minima*, *Rytidosperma* sp., and *Carmichaelia apressa* occur in the lower vegetation tiers.

Community C: South Wellington coast shrublands

Plots at Glenburn, Honeycomb, Kupes Sail, Orongorongo, Ruamahanga River, Sinclair Head, and Te Kawakawa Quarry are included in this community. Plots contain between 1 and 7 relatively small (< 1 m in height) plants. The vegetation is short statured (< 2 m in height) and the ground cover is dominated by introduced grasses, but contains occasional stunted trees and shrubs of *Cordyline australis*, *Coprosma crassifolia*, *C. propinqua, Ozothamnus leptophyllus*, *Olearia paniculata,* pohuehue and occasionally *Muehlenbeckia australis, Carmichaelia australis, Melicytus crassifolius* and kanuka (Table 12). Understoreys include bracken (*Pteridium esculentum*), flax (*Phormium tenax, P. cookianum*), silver tussock, the sedges and rushes *Juncus gregiflorus, Cyperus ustulatus* and *Isolepis nodosa,* and the coastal herb *Haloragus erectus*. Being exclusively coastal and restricted to the North Island, this

TABLE 13. OCCURRENCE OF PLOTS IN THE FOUR PLANT COMMUNITIES IN SIX DRYLAND TYPES.

	COMMUNITY				
	A	B	C	D	TOTAL
B		4	5		9
C		3	7		10
D	6	5		2	13
E	1	1		5	7
F		3			3
G		1		1	2

vegetation type experiences the mildest winters, the lowest incidence of frost, the warmest temperatures all year round, the highest growing degree day totals, the least variable rainfall and the lowest atmospheric and soil water deficits of the four vegetation types. Soils are the least indurated, with the lowest fertility in terms of acid-soluble phosphate.

Community D: Tall matagouri-mingimingi shrublands

The eight plots in inland North Canterbury (Balmoral Reserve and Waipara River) and Marlborough (Atkinson Road in the Haldon Hills, The Orchards and Corea) classified in Community D contain between one and nine relatively tall, large *M. astonii* shrubs (height 2.0–3.6 m, average volume 26 m^3). The open vegetation has canopies of *Coprosma propinqua*, matagouri, kanuka and *Olearia solandri* and, occasionally, emergent *Cordyline australis*, *Pseudopanax arboreus*, *Melicytus ramiflorus*, gorse (*Ulex europaeus*) and the liane *Muehlenbeckia complexa*. Lower tiers contain *Coriaria arborea*, bracken, flax (*Phormium tenax*), the sedge *Carex virgata*, the grass *Rytidosperma gracile*, and stunted shrubs of *Coprosma intertexta*, *C. robusta*, *Hebe stricta* and the lianes *Rubus schmidelioides* and *R. squarrosus*. Plots tend to be located on north-facing slopes. The climate is cooler than in other plant communities, reflecting the relatively narrow southern distribution of this community.

9.3.4 Current demography

Of the 174 *M. astonii* plants sampled in the 44 plots, 72 are recorded from one population at Kaitorete Spit and another 18 from Peter's Covenant, Marlborough (Fig. 13). All remaining plants grew in populations of nine or fewer plants, and populations at most sites (27, or 61%) comprised a single plant. This frequency distribution suggests that most if not all populations are relict.

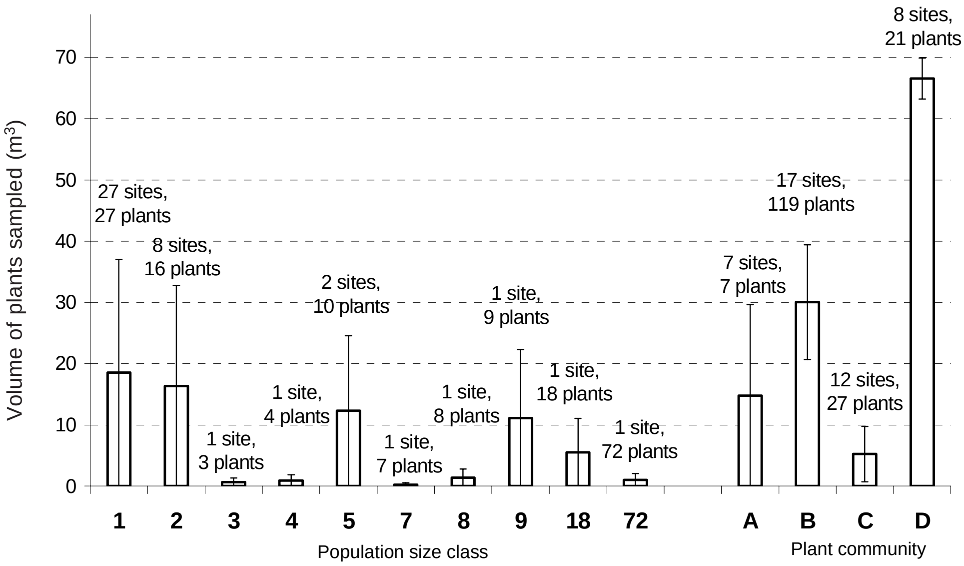

Figure 13. Average volume of plants in population size classes and plant communities.

Plant height ranged from 0.2 m to 3.6 m (Fig. 14A), and there were no seedlings (arbitrarily defined as having height < 0.2 m). Most small plants occurred within the single large population on Kaitorete Spit in Community B (Fig. 13). Plants had a consistent shape across the range of heights (mean height:radius ratio 0.77 (Fig. 14B), although a few smaller plants were outliers with an upright profile (height:radius ratio 1.5–4.0).

There is no consistent trend in canopy volume across population size classes (Fig. 13). However, Community D, with its greater plant richness in the taller tiers, has consistently larger plants (Fig. 13). There was little intrapopulation variation in canopy volume at sites with small plants (Fig.13). This suggests synchronous establishment as cohorts, or simultaneous growth release. Populations with larger canopy volumes tended to show wider variation.

9.4 DISCUSSION

9.4.1 Pre-settlement demography and adaptation

Muehlenbeckia astonii occurs in small numbers in most populations and has a patchy occurrence within locally widespread habitat. This suggests that it was more widespread and frequent in pre-settlement times. Our modelling of the species' environmental envelope supports this conclusion, predicting a wider geographic distribution than that of the present.

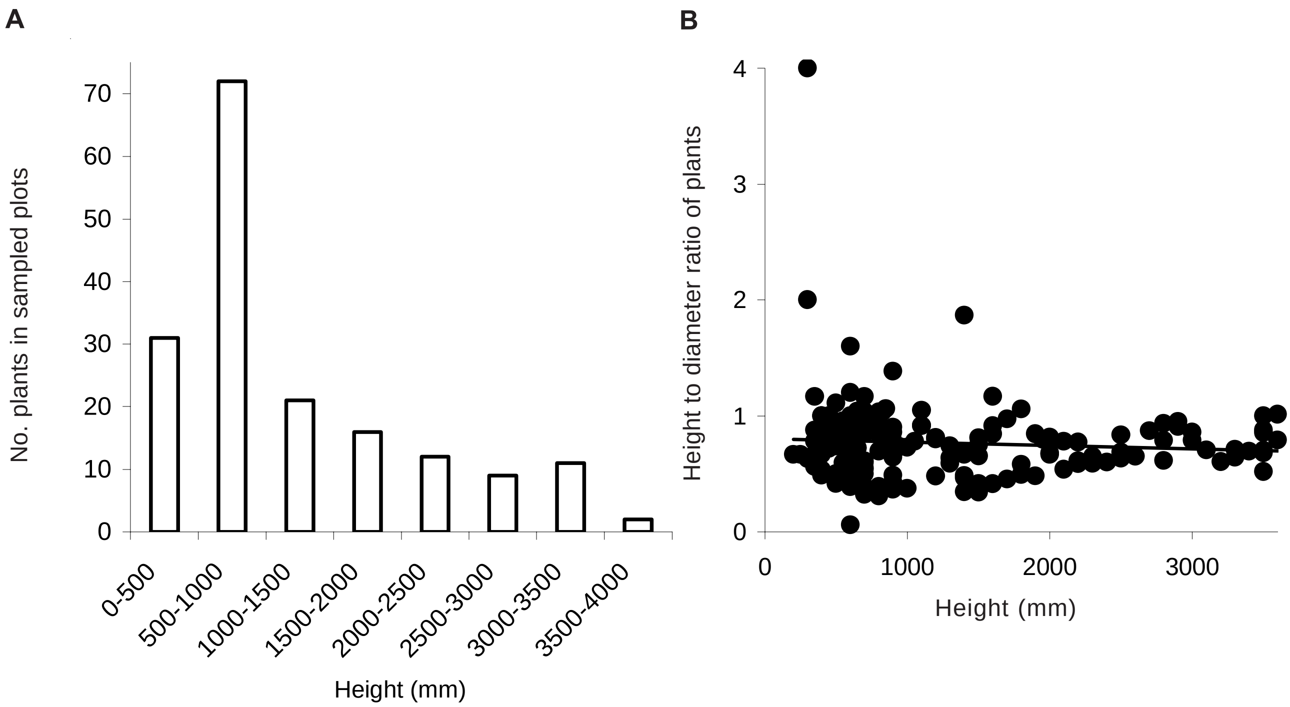

Figure 14. **A**. Number of sampled *Muehlenbeckia astonii* plants in eight height classes. **B**. Height:radius ratios of the 174 sampled plants.

Although *M. astonii* was clearly more widespread previously, the question remains as to whether it was locally abundant within pre-settlement plant communities. Vegetative traits that confer persistence and generalist habitat tolerances suggest a potential for high local abundance in pre-settlement times. The cohort structure of some populations indicates that they may have established in a phase of land clearance within the last 150 years, while the more or less consistently hemispherical profile of canopies points to growth unconstrained by competition for light. Plants are typically larger where *M. astonii* occurs in more woody communities with more complex tier structures (i.e. Community D of the plot classification: Table 12, Fig. 13). This may reflect enhanced vertical growth rates to exploit light gaps and / or microclimate amelioration provided by associated canopy species, or simply that the plants in these taller, later-successional communities tend to be older. The tallest plant (3.6 m) that we recorded occupied an open site with no competition for light. We envisage that *M. astonii* may have attained at least 5 m as a component of closed shrubland or low forest.

Kaitorete Spit plants are characteristically low-statured in comparison with other coastal sites because of browsing by farm stock and the apparently low nutrient status of the coastal sand plain. Nutrient impoverishment may be partly induced by stripping of an uppermost soil horizon in recent sands of the sandplain following clearance of pre-settlement shrubland-low forest.

Muehlenbeckia astonii has tightly interlaced branchlets with high tensile strength and elastic properties. Bond et al. (2004) suggested that these are adaptations in divaricating plants to defend against moa browse. The plant also produces epicormic, erect, monopodial reversion shoots that extend through and then branch above its tightly interlaced canopy. This adaptation might have allowed shoot extension within a shrubland or low-forest community that was subject to browse and mechanical disturbance by moa. The squat profile and heavy body proportions of moa of the eastern guild would have permitted locomotion over and around divaricating canopies, but we suggest that their flattened beaks would not have easily penetrated the divaricating canopies of *M. astonii*. The monopodial shoots of *M. astonii* would also have permitted the plant to breach smothering rubble that would have periodically disturbed plants within accumulating talus on escarpment toeslopes. Moreover, its capacity to sucker and produce monopodial branch extensions would provide architectural flexibility to exploit shifting patterns of light availability in the canopy of woody communities that were constantly disturbed by large birds and other factors.

9.4.2 Heterophylly

Jenkins (1930) offered evidence for distinct juvenile and adult architectural forms of *M. astonii*. However, we encountered no small seedlings, and therefore cannot confirm that heterophylly occurs in the wild.

9.4.3 Environmental and community range

The predicted environmental envelope for *M. astonii* considerably exceeds its present range. This is to be expected, since its edaphically dry habitat has been particularly fire prone since the time of Polynesian land clearance, and there has probably been considerable range contraction and even local extinction. Irrespective of its realised range within the modelled environmental envelope, its present pattern of distribution suggests that *M. astonii* was originally locally abundant and widely dispersed.

We have limited ability to predict the composition of the plant communities that *M. astonii* inhabited in the past. Its characteristically dry habitat is thoroughly modified by fire and by farm use, and pasture grasses invariably dominate now. However, a wide variety of representatives of the likely previous woody flora survive in fire-protected gullies in some of the more mesic environments where *M. astonii* occurs today. Although the environmental envelope of *M. astonii* includes nine different potential tall-forest types of Leathwick et al. (2003), we suggest that its distribution within those forests was quite local, and largely confined to relatively short-statured communities on edaphically dry landforms; we note that the exercise of mapping the environmental envelope of *M. astonii* provides a broad-scale picture, rather than precise microhabitat definition within what heterogeneous environments and communities.

We therefore suggest that in the driest coastal and downland zones, *M. astonii* was probably scattered but widespread within extensive low forest and shrubland canopies. However, as humidity increased, it probably became confined to edaphically dry sites such as escarpments, and to talus and thin soils on ridges and spurs within a matrix of taller forest. The concentration of present-day relicts in low-elevation sites probably reflects its adaptation to aridity where low-statured woody vegetation replaced tall forest rather than an intolerance of cold temperatures with increasing altitude. In other words, *M. astonii* was probably competitive within dry shrubland and low forest, in which stature and productivity are limited by dryness and much less so by frost.

We speculate that more populations remain undiscovered, since four new populations were uncovered in the present study on just one hill-country property in the southern extension of the Lowry Peaks Range south of the Ahuriri River, near the town of Balmoral. Parts of this dry hill-country environment in North Canterbury are poorly botanised.

9.4.4 Regeneration failure

The size-class frequency distribution of *M. astonii* suggests a failure to regenerate, which could result from a loss of seed supply, community competition for germination and establishment microsites, or recruitment failure of juveniles to adult ranks.

The concept of regeneration failure implies a population imbalance, where mortality exceeds recruitment (Allen et al. 2002). The definition of an unbalanced population is influenced by several factors:

- Species' reproductive biology
- How the landscape disturbance regime influences plant demographics
- The spatial and temporal scale at which the population is sampled
- The nature and degree of habitat fragmentation by human agents.

An idealised demographic profile may be assumed to approximate an inverse J-shaped size-class frequency distribution, where the number of juveniles far exceeds that of adults. However, this is predicated on the assumption that populations regenerate continually and independently of landscape-scale disturbances and other factors. We consider how these four factors might bias our judgement of a population imbalance in *M. astonii* in both pre- and post-settlement landscapes.

9.4.5 Reproductive biology

Muehlenbeckia astonii reproduces both asexually (vegetatively) and sexually (seed). Its capacity for vegetative reproduction from suckering and from copious basal resprouting potentially confers multi-generational, clonal survival. Moreover, old roots bear a stout lignotuber-like swelling, which acts as a storage organ that buffers plants against foliage loss or damage from rock avalanche, flood scouring and herbivory. This underground storage organ and the species' suckering habit also allow the plant to clonally migrate in response to shifting patterns of soil and light resources. The divaricate habit of *M. astonii* confers resilience to or resistance against vertebrate browsing and / or desiccating or freezing weather. Its deciduousness is probably an atypical adaptation (in the context of the New Zealand woody flora) to seasonal extremes of climate, in this case winter frost and not summer drought. These biological traits enable long-term vegetative survivorship, as confirmed by the 1941 voucher specimens (CHR 35530 and CHR RARE 1535) of individuals that survive in pasture grass swards to the present day. In other words, the capacity of *M. astonii* for vegetative reproduction counteracts habitat fragmentation and destruction, and provides it with a demographic refuge. The perceived importance of a regeneration failure therefore needs re-evaluation in light of these longevity-promoting reproductive and persistence traits.

This account does not under-recognise the significance of sexual or seed reproduction as an alternative population perpetuation strategy. Clearly, the species' copious fruit production and its potential but unconfirmed attractiveness to birds and lizards would foster widespread and abundant dispersal of propagules. Indeed, naturally recruited seedlings and saplings tens of metres from adult plants in the grounds of Landcare Research, Lincoln, attest to the success of animal vectors and the plant's tolerance of shady forest understoreys.

9.4.6 Landscape disturbance

Our appraisal of disturbance factors in the pre-settlement habitats of *M. astonii* (stony or sandy terraces, fans, basin floors, and dry hill-country) suggest a rather stable environment away from the coast in which physical habitat disturbance such as landsliding, flooding and natural fire were probably spatially and temporally rare. Browsing terrestrial birds were the principal habitat disturbance agent. Accordingly, opportunities for regeneration from seed in understoreys that were heavily trampled by large birds may have been less important than those afforded by vegetative resprouting. Plants probably relied heavily on their erect, monopodial reversion shoots when faced with limited opportunities for seedling regeneration in a heavily bird-disturbed community. We conclude that an imbalanced population needs careful appraisal in terms of the relationship between reproductive modes and disturbance-stimulated regeneration.

9.4.7 Spatial and temporal scale of sampling

An estimate of a species' demographic profile is very much dependent upon the spatial and temporal scale of sampling. For instance, a sample in pre-settlement times that included rare seed-based regeneration on bird-inaccessible microsites or on the fresh pavements provided by infrequent landsliding, flooding, or natural fire, might have differed from samples taken from stable landforms where seed-based regeneration was probably less frequent. Because of the comparative absence of juveniles, today's population profile may be similar to that in its low-disturbance, pre-settlement habitats. A comprehensive impression of the species' population structure and a judgement on a population imbalance therefore depends on the spatial and temporal scale of sampling.

9.4.8 Habitat fragmentation

Finally, the nature and degree of habitat fragmentation also influences ideas of population structure and sustainability. For example, disturbance-stimulated regeneration opportunities may have disappeared because weeds have smothered germination microsites, episodes of land clearance may have fostered successional cohorts only, and alien herbivory may have modified growth patterns. Habitat fragmentation may also distort perceptions of the species' potential stature and community composition. The present hemispherical canopies in its universally degraded, open habitats may poorly reflect canopy shapes and proportions that were typical of plants in taller shrubland communities. In addition, our ability to depict the potential community composition and structure of its habitat may be compromised by local loss of some community constituents.

9.5 CONCLUSIONS

This study did not examine the lack of seedling recruitment in the wild, which could have several causes. However, at this stage of recovery planning, we argue that the concept and importance of reproductive failure in this species requires re-examination. Opportunities for sexual reproduction are now few, but they may have always been limited in the comparatively stable and heavily bird-regulated habitat of *M. astonii*. Ubiquitous ground herbivory by moa and other extinct birds may have restricted seedling recruitment of palatable shrubs and low trees within dry shrubland and low forest to less penetrable lianoid and shrub thickets.

The field evidence for few, recent population losses, life traits that engender resilience (often *M. astonii* is the last native plant of its former community) and multi-generational perpetuation, and no clear evidence for regeneration being disturbance dependant, suggest that community or ecosystem restoration should be a focus for recovery planning, rather than attempts to foster regeneration from seed. This would not be a risk-free strategy, because we cannot confidently predict the population processes that would be restored in successional shrubland or low forest communities. Nevertheless, our emerging knowledge of the landscape history of eastern New Zealand, including the selection pressures imposed on plant evolution by large birds, suggests a need for increased experimental investigation of dry shrubland restoration techniques. Farm stock and rabbits should be excluded from areas in which dryland restoration is attempted, at least in the early stages, since they suppress recruitment of some species of woody plants. In dry systems, the proliferation of sward-forming exotic grasses (Ewans 2004) may be less antagonistic toward recruitment of woody seedlings than in more humid or wet environments. As well as shrubs and trees, a suite of dry-tolerant lianes are candidates for early successional shrubland restoration, particularly *Muehlenbeckia complexa*, *M. axillaris*, *Clematis afoliata*, *Rubus squarrosus* and *R. schmidelioides*. Ultimately, it may be desirable to experiment with a reconstitution of ratite browse pressure in mid-successional shrublands by introducing emu (*Dromaius novaehollandiae*) or ostriches (*Struthio camelus*). These birds may not only graze sward grasses but may scarify ground surfaces and select for native small-leaved woody plants ahead of introduced shrubs based on the vulnerability of plant growth form (Bond et al. 2004).

The argument for a focus on community restoration (ahead of a concern with the loss of disturbance-dependent regeneration opportunities) might be applied to a wider suite of rare shrubs in dry eastern New Zealand, such as *Hebe cupressoides*, *Helichrysum dimorphum*, *Carmichaelia* spp., *Melicytus* spp., *Pimelea* spp. and *Coprosma* spp., of which most reproduce asexually as well as sexually. Much research on plant regeneration has focused on the importance of *de novo* regeneration (seed replacement), rather than plant persistence. However, the persistence niche needs emphasis alongside the regeneration niche (Bond & Midgley 2001).

Although rates of shrub establishment and growth are slow in dry environments, there are potentially great gains to be made from restoring ecosystem structure and function through destocking and rebuilding woody communities. Low intervention management is the only feasible strategy for a large proportion of the rare forbs and grasses of dryland environments, so large is the number, and this may only be possible through shrubland restoration.

At present, conservation of dry lowland ecosystems is in its infancy, and the return of native woody communities to these modified landscapes may be seen only in a few examples on public conservation lands. Nevertheless, there is considerable potential for privately owned initiatives, and this may far outweigh the few opportunities for public ownership of dry lowland New Zealand.

9.6 RECOMMENDATIONS

After prioritising populations requiring protection on the basis of biogeography, demography, community structure and land tenure criteria, threatened species recovery planning by DOC generally follows three courses of action:

- Perpetuating the most at-risk and biogeographically significant gene pools with nursery propagation and land or habitat protection.
- Supplementary planting of priority populations that show limited or no recruitment.
- Restoring community structure and composition where supportive land tenure exists.

For *M. astonii*, recovery action has been no different, in that it has focused on the perpetuation of critical gene pools. Sensibly, planting to supplement truncated populations has concentrated on those sites that offer the best prospects for ecosystem restoration. However, given the species' capacity for almost indefinite vegetative perpetuation, we suggest attention should now shift toward creative initiatives at community restoration, drawing on the insights into its pre- and post-settlement landscape situation (see further treatment on this theme below). Several coastal and inland populations in both the North Island and South Island present opportunities to restore topographical sequences and linkages between forest on deeper and moister soils and shrubland on adjacent drier microsites that would have characterised pre-settlement vegetation patterns. There are already some encouraging examples of the start of ecosystem restoration by de-stocking and some supplementary planting, where native woody vegetation dominates the relict community.

10. General discussion and synthesis

10.1 RESTORATION GOAL SETTING

The restoration of dryland ecosystems in eastern New Zealand is motivated by the need to provide viable habitat for threatened plants and animals, and to replace or repair community composition, structure and function that has been either lost or substantially altered. In many instances, in order to meet these needs, restoration goals for dryland communities of shrub / grassland, grassland and mat herbfield will need to focus on the reconstitution of woody communities. This is because studies of landscape history, relict vegetation and present vegetation trends provide overwhelming evidence that this environment was predominantly woody in pre-settlement times and has been grossly transformed, and that it may not be feasible to maintain grassland vegetation without the imposition of artificial disturbance. Moreover, succession to woody vegetation is likely to sustain more biodiversity than homogeneous grassland owing to the greater complexity in animal food webs. More structurally complex vegetation is also likely to increase ecosystem resilience (Park 2000), improve soil health, restore depleted fertility regimes lost to anthropogenic fire and herbivory, impart greater resistance to alien invasion (Kennedy et al. 2002) and competitively weaken sward-forming grasses.

A full treatment of setting restoration goals for dryland ecosystems is beyond this discussion paper. However, we offer brief comment on some key matters for consideration.

10.1.1 Informing goal setting

All of the plant communities of eastern New Zealand have been considerably modified since human settlement, some key biota and ecotypes have been permanently lost, and some ecosystem changes are probably practically irreversible. Because all New Zealand ecosystems are maladapted to mammalian herbivory, several irreversible changes have probably accrued from 150 years of modification by introduced animals. In combination, compromised indigenousness and perpetuation of irreversible ecosystem trends in tussock grasslands will have parallels with those noted for indigenous forests. Those trends include:

- Palatable species remaining highly browsed even at low stock densities as a result of diet switching.
- Occupation of vacated niches by plant species not eaten or by those tolerant of browse.
- Local extinction of seed sources.
- Fundamental alteration of successional pathways.
- Shifts in ecosystem processes such as from altered fertility states (after Coomes et al. 2003).

The likely former composition of these pre-settlement ecosystems remains difficult to determine with any degree of accuracy, and our understanding of their structure and function remains limited. Therefore, it is not realistic to aim to restore woody ecosystems to states that approximate those of pre-settlement times, or to measure the success of a repair programme against historical conditions (Whisenant 1999).

We suggest that an alternative restoration goal could be based on a contemporary and realistic platform of ecological integrity. Suggested quantifiable components of ecological integrity are:

- Environmental representation and the degree of land protection: for example, the range and percentage land area of environments protected (e.g. using LENZ).
- Native dominance, which has structural and functional components. Structural components could be measured as percentage of native cover in the canopy, subcanopy and ground layers for plants; and for vertebrate animals, their percentage presence compared with introduced animals. Functional dominance may be measured as the contribution of native species to herbivory, carnivory, pollination and seed dispersal. Self-regeneration is an inherent component of native dominance.
- Native occupancy: The degree to which native taxa that would naturally occupy an environment are present (i.e. plants, and vertebrate and invertebrate animal components).

Walker, Lee et al. (2003c) discuss similar objectives for restoration of dryland biodiversity in greater detail.

The condition and composition of vegetation is but one aspect of ecosystem restoration; the properties that should be considered include soil physics, chemistry, hydrology and other biota. In particular, comprehensive appraisal of restoration success would need to include an assessment of animal food webs and their role in ecosystem processes (e.g. the involvement of insects, lizards and birds in pollination, seed dispersal, herbivory and nutrient transfer).

Where degradation is widespread but somewhat-intact relicts remain, these may be used as reference ecosystems to guide planning efforts (Hobbs & Norton 1996). The main attributes of such reference sites for consideration in goal setting include: composition guided by existing species and their abundances;

vertical structure of the vegetation; vegetation pattern; heterogeneity, made up of vegetative, soil and litter components; ecosystem function—energy capture, hydrology, nutrient cycling; and vegetation dynamics such as successions and resilience.

10.1.2 Maximising the woody potential of degraded systems

Our study suggests that disturbance was less important than environmental stress in regulating habitat for our current suite of threatened plants in dry, eastern New Zealand, and that avifaunal herbivory was probably the key ecosystem disturbance process away from riparian sites that experienced flooding and sedimentation. We conclude that the majority of the eastern dryland ecosystems, including those with the highest frequency of rarity, were structurally dominated by woody plants, with grass and forb understoreys. Even cliff and talus habitats were probably fringed and buffered by woody vegetation, as in comparable habitat in relatively intact, wet western regions. We therefore suggest that restoration of threatened plant habitat should increasingly focus on a rebuilding of native woody communities to restore the ecosystem properties of resilience and self-sustainability. It follows that restored native woody vegetation would reduce community susceptibility to exotic plants, accessibility to feral and farm animals, seasonal extremes in vapour pressure and soil moisture deficits, and would restore soil and litter food webs (Norbury 2001).

Across most dry eastern New Zealand hill-country, scattered native woody plants attest to its woody potential. Initially, pragmatic goals of the management of early- and mid-successional woody communities, however depauperate, should be to facilitate increased energy capture and nutrient cycling. Initial efforts will need to focus on sites of greatest successional potential, i.e. those with relatively abundant native woody seed sources and emerging nurse communities. Ecological 'generalists' such as species of *Coprosma*, *Muehlenbeckia*, *Rubus*, *Carmichaelia*, *Phormium, Olearia*, *Ozothamnus*, along with kanuka, manuka, matagouri, bog pine (*Halocarpus bidwillii*), mountain toatoa and *Corokia cotoneaster* may have the best potential to rapidly colonise dry grasslands. Initial increases in ecosystem nutrient budgets may not be rapid, given the browse-avoidance leaf chemistry of these species. In depauperate or relict woody communities, species richness may initially decline as woody structural and functional rebuilding commences, but ecological theory predicts eventual increasing ecological heterogeneity. Our limited knowledge of rates of shrub and tree invasion of grasslands suggests the process is positively correlated with time, site slope, and density and proximity of seed source, and is negatively related to productivity and distance from seed source (Rogers & Leathwick 1994; Wiser et al. 1997). The rate of shrub invasion in red tussock (*Chionochloa rubra*) grasslands in montane, central North Island was slowest far from seed sources, on gentle topography and in wet environments (Rogers & Leathwick 1994); this was probably because tussock vigour inhibited shrub establishment. As a general rule, the greater the density of propagules, the greater the woody potential.

Although matagouri, kanuka and other non-palatable woody species are, in some conditions, capable of regeneration at low to moderate densities of sheep and low rabbit numbers, rates of shrub invasion are generally slowed by mammalian herbivory (see Section 7.5). Two exclosure studies show the control of mammalian herbivores is necessary to maximise the diversity and rate of return of palatable woody plants in degraded short-tussock drylands (Meurk et al. 2002; Walker, Wilson et al. 2003). These studies show that, at least initially, proliferating sward grasses did not compromise the emergence of native woody seedlings and saplings (see also Rose et al. 2004).

To date, fencing and control operations have rid a very few dryland conservation areas of stock, rabbits and goats. At Flat Top Hill Conservation Area in Central Otago, where rabbit numbers have been extremely low for c.10 years, preliminary observations suggest that the exotic subshrub thyme has increased in extent, but that palatable native shrubs (including *Carmichaelia*, *Pimelea* and *Hebe* species) and herbs (*Anisotome* spp.) have increased from local seed sources (S. Walker, unpubl. data; J. Barkla, pers. comm.). Completely mammal-free conditions are difficult to achieve after destocking. Rabbits, hares and possums are seldom controlled and they may selectively inhibit return of palatable woody species. We have very little idea of the effects that these animals plus rodents, hares, hedgehogs and introduced birds may be having, either on the flora or on the invertebrate and vertebrate fauna. Well-designed empirical studies will be required to determine which factors limit woody regeneration, so that managers may formulate appropriate strategies to maximise the indigenous woody potential of degraded systems.

10.1.3 Intervention to rebuild woody ecosystems

In general, the more degraded the ecosystem, the more likely it is to require intervention to initiate woody rehabilitation. We see three broad perogatives for assisted rebuilding of woody communities:

- Reintroduction or perpetuation of threatened trees or forest communities.
- Bolstering the seral scrub component of previously forested landscapes.
- Fostering the equilibrium scrub of the driest and most frost-prone basins and valley floors.

A most pressing need is to maintain the relict gene pool of trees in previously forested landscapes that are now reduced to isolated individuals or groups associated with fire-sheltered gullies or rock outcrops. Almost without exception, these relicts have no recruitment prospects because of lack of an attendant nurse shrubland, and are progressively disappearing from the regional forest gene pool. At best, the components of seral scrub available for natural succession are depauperate, fire-filtered relicts of the original woody flora. Accordingly, the selection of species for restoration projects should not be limited to the local flora.

We recommend that the preliminary goal of woody vegetation restoration should be the establishment of a cover of fast-growing, drought-tolerant, ecological generalist species (after Pywell et al. 2003). Where sources of woody propagules are limited, the re-establishment of the woody vegetation matrix will entail the pragmatic selection and reintroduction of early- and mid-successional woody species that possess properties conducive to rebuilding a shrubland canopy. Experimentation is needed to develop intervention techniques to foster reconstitution of shrublands in seed-source-depauperate landscapes. Possible methods include: scarification of grass-dominated ground surfaces; herbicide suppression of sward grasses; direct broadcasting, sowing or drilling of seed; and laying brush. Restoration may also benefit from an improved understanding of the effects of seasonal weather variations on shrub establishment. For example, in Australia, studies have shown that conditions that are suitable for shrub and tree establishment in semi-arid environments occur episodically, and these may coincide with unusually wet spells (Clarke & Davison 2001; Clarke 2002).

Many threatened-plant habitats are nested within extensive hill-country ecosystems, and the return to woody vegetation may pose short- to medium-term risks to the threatened plants therein. Overall, the role of woody plants (mainly shrubs) in non-forest ecosystems with threatened plants is poorly understood. Some threatened plants may have expanded local ranges caused by deforestation; they will be repatriated to their original sites with a return of wood. Examples on stony alluvial terraces in which this could occur are several of the subshrub carmichaelias and some *Convolvulus* and *Leptinella* species.

Although we recommend a generic formula to reintroduce woody cover to many threatened plant ecosystems, ensuring the persistence of many threatened species will require ongoing, habitat-specific research, and deliberate, adaptive management experiments. Site-specific weed control to reduce competition from exotic grass swards is one component of this. As an example, experimental weed control is underway for *Pachycladon cheesemanii* [*Ischnocarpus exilis*] on limestone pedestals at Awahokomo, Waitaki Valley, with the removal of *Hieracium pilosella* and *Sedum acre*. We further suggest that supplementary plantings of rare species for reasons other than survival of the local gene pool be predicated on first rebuilding the more common, woody, structural components of seral scrub.

10.2 ROLE OF EXOTIC PLANTS IN DRYLAND RESTORATION

Passive or minimal intervention management for the long-term return of predominantly indigenous woody vegetation in dry eastern New Zealand ecosystems may hasten expansion of more grazing-intolerant introduced plants in some situations where seed sources are present (however, we note that active management strategies such as continued sheep grazing may not effectively curtail introduced plant spread). Exotic plants may have antagonistic, benign, complementary or positive roles in long-term succession towards predominantly indigenous woody vegetation, depending on the resource value in question (i.e. scenic, landscape, ecological (biodiversity), threatened species / habitat, ecosystem, ecosystem services such as water supply, scientific, and cultural and historic values). Conflicts will inevitably arise when the impacts of introduced plant species on resource mixes are considered. For example, research might show that briar (*Rosa rubiginosa*) is beneficial to soil moisture and nutrient budget ecosystem values, and that it facilitates indigenous woody colonisation by acting as a nurse plant, but is neutral to lizard habitat values, and antagonistic to scenic and landscape values. Exotic plants and their dryland impacts are a neglected research topic, so conservation attitudes will initially partly rely on intuitive judgement. Persistence alone is not a robust criterion to judge weediness; for example, although briar may persist for many decades, it may in the absence of indigenous shrubs it may impart benefits as already suggested.

To date, most weeds of the dryland zone to date are Northern Hemisphere grasses and forbs that possess a suite of vigorous and 'generalist' attributes that contrast with those of much of the native grass and forb flora. Short generation time, rapid growth, copious propagules, stoloniferous and rhizomatous spread, and wide ecological tolerances mean that some introduced species, such as sward grasses, may persist for substantial periods within reconstituted dry shrublands and low forest. Sward grasses are a prominent component of the most problematic of dryland ecosystems for restoration—short-tussock grassland. Because few seed sources for native shrubs survive in dry short tussock grassland, the focus of conservation effort has been on the maintenance of tussock grass and inter-tussock forb species. Grazing by farm stock has been recommended in the past to contain introduced species in short (i.e. silver) tussock grasslands on Banks Peninsula (Meurk et al. 1989). Meurk et al. (2002) have shown a differential impact of farm stock and rabbits on native and introduced plants in Mackenzie Basin short tussock grasslands, with stock exclusion leading to an increase in weed dominance in silver tussock grassland. However, as an induced vegetation state, short tussock grassland is inherently unstable and probably impossible to maintain in a constant demographic condition with or without sheep grazing (Rose et al. 2004). Conservation managers may have to tolerate some initial increase in sward grasses en route to restoring dominant woody native cover.

It is certain that the number and variety of woody weeds will increase in the future beyond iconic briar, gorse, broom and thyme. The weediness of exotic shrubs may also vary along precipitation, as well as intactness, gradients. There may well be an inverse relationship between precipitation and the persistence of woody weeds. In other words, woody weeds may be more persistent and more problematic in preventing the reconstitution of late-successional, indigenous shrubland or low forest in degraded, dry environments than in wetter ones.

We conclude that empirical studies are needed to underpin attitudes to weeds and weed management priorities in eastern New Zealand dryland environments. There is little research to inform DOC's weed policy for the high country, and from which to draw site-specific advice.

10.3 ROLE OF DISTURBANCE IN DRYLAND RESTORATION

Natural disturbances are essential processes in most ecosystems, and it has been demonstrated that their loss or disruption through anthropogenic intervention may threaten the persistence of certain species (e.g. Milton & Dean 2000). Concerns have been expressed that many of New Zealand's rare plants are disturbance dependent and are now threatened through human activities that stabilise soils and reduce erosion risk (Given 2001). However, we caution against this generalisation:

- There is a need to distinguish between types of disturbance. Those disturbances that alter the structure of populations, communities and ecosystems will have consequences for plants that are different from those of a process-perturbating nature such as herbivory (which have less influence on energy capture and nutrient cycling).

- Our appraisal of pre- and post-settlement landscape disturbance by type and across New Zealand dryland ecosystems shows that the periodicity and spatial extent of pre-settlement natural disturbance was generally low. Further, the periodicity and scale of many disturbances substantially exceeded that of the generation time of plants. In such cases, plants may occupy environments prone to occasional disturbances, but not rely upon disturbance for population persistence; when seed-derived regeneration opportunities are few, plants typically invest as much in asexual reproduction as in sexual reproduction. Therefore, the spatio-temporal pattern of disturbance needs to be considered in conjunction with life-history strategy in interpreting the role of disturbance in population rejuvenation or maintenance.
- Disturbance may replenish nutrients previously lost to an ecosystem through soil weathering. However, in dry environments, leaching may be negligible, and availability of soil nutrients is generally above average. For example, in dry eastern New Zealand, basicolous plants (plants showing a preference for base rich materials; Molloy 1994) often occur on substrates that are not calcium-rich limestone or marble. Nevertheless, substantial nutrient depletion would have accompanied deforestation and exploitative pastoralism.

10.4 PROTECTION AND RESTORATION OF DRYLAND ENVIRONMENTS

Little (1.9%) of the eastern New Zealand dryland zone is protected as public conservation land. The reallocation of land through tenure review of Crown pastoral leases provides an unprecedented opportunity to improve the representation of at least some dryland environments in lands managed by DOC. Approximately 30% of reviewable crown pastoral lease land lies within our dryland zone (accounting for c. 12.5% of the national 50 555 km^2 total) and therefore may potentially enter Tenure Review. In their analysis of LCDB1 indigenous vegetation cover classes across land tenure types, Walker, Lee et al. (2004c) showed that reviewable pastoral leases retained higher proportions of indigenous vegetation cover than freehold land. For example, the average percentage indigenous vegetation cover across the 38 Level IV environments of Environment N that occur within South Island high country is 42% of the c. 1400 km^2 on pastoral leases compared with 24% of the 2300 km^2 on freehold land. Therefore, it appears that indigenous biodiversity has been retained on pastoral leases to a greater extent than on land under freehold tenure; this may be due to effective restrictions on farming uses that disturb soil or vegetation under the Land Act (1948) and the subsequent CPLA (1998). The New Zealand Biodiversity Strategy (DOC & MfE 2000) includes the priority action 'Add to public conservation lands those habitats and ecosystems important for indigenous biodiversity that are not represented within the existing protected area network or that are at significant risk of irreversible loss or decline'. Remaining indigenous vegetation in dryland environments is a prime example of under-represented and threatened biodiversity, and is therefore a priority for addition to conservation lands through Tenure Review.

Tenure Review has contributed to protection of poorly represented dryland environments only marginally (Walker, Lee et al. 2004c). This is because low-altitude, dryland environments are generally highly valued for intensive land uses such as horticulture, viticulture, cropping, and subdivision; and the biodiversity of these zones has been highly modified and previously regarded as being of low priority for conservation. Because of the tension between economic use and protection, it remains to be seen whether the representation of dryland environments in public conservation lands will increase as a result of Tenure Review in the future.

The great majority (85% of the land area) of the dryland zone is under private tenure, and therefore policy formulation and advocacy for dryland ecosystem restoration should focus on private as well as Crown tenure. There has been a marked trend towards land use intensification in dry lowland environments in recent years, and a combination of clearance regulation and positive incentives for biodiversity protection (e.g. rates or taxation relief) is urgently needed to avoid further biodiversity loss (Lee & Walker 2004). Increasing biomass in a post-fire and grazing management regime may lead to public concern over a perceived increase in fire risk and weed spread. Our judgement, however, is that biodiversity accruals from woody successions, albeit with an introduced element, may offset and outweigh increased fire risk.

10.5 FURTHER DRYLAND RESEARCH

The large body of grassland research in eastern South Island has favoured snow tussocks (*Chionochloa rigida*) in the wetter mid- and upper montane zone, while the dryland zone has received relatively little attention. Apart from inventory (e.g. Norton & Lord 1992; Meurk 1995) and palynology (Clark et al. 1996; McGlone & Moar 1998), ecological research is mainly limited to saline soils and their communities, and the dynamics of short tussock grasslands. Only recently have any studies expressly focussed on the woody component of these environments (e.g. Walker, Lee et al. 2004a, b). Bellingham (1998) studied the facilitation of establishment of one shrub by another, and another study has shown that shrub seed size, season of germination, and between-year variation in summer rainfall could all be important in shrub recruitment in burnt browntop (*Agrostis capillaris*) grassland (Sessions & Kelly 2000). Studies of hard tussock and silver tussock grassland in dry environments point to their current instability under both pastoral and conservation management (e.g. Rose et al. 1995; Meurk et al. 2002).

Semi-arid woodland ecosystems in other countries may be relevant reference points for understanding and predicting future dryland vegetation dynamics in New Zealand. What lessons have been learned elsewhere that we may apply to the New Zealand situation? For instance, experiments in Australia in tree and shrub establishment in temperate grassy woodlands demonstrate that seedling establishment is an extremely rare event, and is episodic and probably disturbance-induced (Clarke 2002). Further, Ryel et al. (2003) have shown that rainwater recharging of soil water deficits at depths of over 0.1 m in semi-arid environments of Utah, USA, is almost entirely via the roots of woody plants.

Other influences are more subtle, but no less influential and pervasive—dramatic invasion of the Northern Hemisphere's C_4 grasslands by woody C_3 plants is accompanying the historical increase in atmospheric CO_2 (Johnson et al. 1993; Bond & Midgley 2001).

Although this review has focused on vegetation, there is an accumulating body of research on the invertebrates and lizards of seral tussockland and scrub, both on common and threatened animals. Rather than recommend an ad hoc list of priority research topics in this report, we suggest that a strategic review of dryland research needs is timely. However, while there is still room to improve understanding of pre-settlement ecosystems, we suggest that future research should be focused on reversing the decline of dryland biodiversity, specifically facilitating the restoration of structurally complex indigenous species dominated woody communities to support secure populations of threatened dryland biota. We see potential for substantial benefits from integrating animal, plant, and ecosystem process research in the future.

10.6 GENERAL CONCLUSIONS AND RECOMMENDATIONS

Our review asks what we mean by disturbance, and what role it should play in setting restoration goals for dryland New Zealand. We conclude that there is a distinction between:

- Frequently disturbed coastal, riverine and cliff environments, where flooding and sedimentation, storm-water erosion, and wind and salt are dominant and constant influences, and
- Comparatively stable, inland, stony terrace, hill-country and wetland environments, where physical disturbance was of such low frequency and magnitude as to be unimportant in provisioning the landscape with a perpetual local mosaic of secondary vegetation.

We found no evidence that fire created networks of secondary vegetation that provided fire-dependent successional plants with constant habitat within dryland environments. It appears that bird herbivory was the dominant mechanical regulator of vegetation composition and structure. The palaeoecological evidence for Late Holocene dryland New Zealand is for dominant shrubland and low forest, replete with a rich herbaceous flora moderated by bird disturbance within the understorey. Grasslands were likely a feature throughout the Holocene about braided riverbeds and primary terraces that were frequently disturbed by flooding and sedimentation, on localised high-stress sites and ecosystems (e.g. dry ridges, shallow soil lenses, ephemeral wetlands, saline patches) and patchily present on leached, acidic, montane peneplains of east Otago. Above the treeline, *Chionochloa* grassland was less important than today, even with its recent contraction from exploitative pastoralism

Our environmental classification distinguishes between genuine dryland environments determined by moisture and frost stress, and tussock-dominated, equably moist, more-upland environments. The 2.5 million hectares of pastoral leasehold land forms the bulk of the high country, but there is not much overlap between our mapped dryland environment and pastoral leases or the high country. The imperatives for protection and restoration of this highly modified, uncharismatic, under-researched, yet ecologically distinct environment are best enunciated in the New Zealand Biodiversity Strategy. Accordingly, we offer representativeness arguments for an increased protected area status. To meet this deficit, private conservation initiatives will perhaps be more important than those of the Crown because that is the balance of land tenure.

Today, relatively homogeneous secondary vegetation tends to mask the landform-determined heterogeneity of the potential vegetation of this eastern South Island environment in pre-settlement times. Mapped environmental patterns do not indicate ecosystem diversity at small scales, and national vegetation reconstructions do not well reflect the potential ecosystem richness of this zone.

Our pre-settlement reconstructions argue for woody-vegetation restoration goals for most dryland environments. Intuitively, there appear to be many biotic and ecosystem process benefits. In general, herbivore- and fire-free management tactics will foster this state, although a rather slow emergence of shrubs and trees is likely in more seed-depauperate and grass-vigorous environments. Dryland restoration goals are best met with a minimalist management paradigm that resembles or mimics that of the natural, low-disturbance, pre-settlement semi-arid environment. Exotic herbs, grasses and shrubs will inevitably be prominent components of woody successions, and a challenge for dryland conservation managers, not least in deriving conservation attitudes. The ecological roles of individual exotic species may be at once antagonistic, benign, complementary or positive depending on the mix of resource values in question.

Approximately 25% of New Zealand's c. 1000 threatened and data-deficient plants occur in dryland, eastern New Zealand. We suggest restoration of matrix shrubland or low forest is critical for more resilient habitats and ecosystems. However, individual restoration formulae will still be necessary because of the range and complexity of threats across the different ecosystems. We recommend a strategic review to identify priorities for basic and applied dryland research, highlighting an urgent need for an applied research focus on reversing the decline of dryland biodiversity.

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13. Glossary

Edaphic: 1. of or relating to the soil. 2. Resulting from or influenced by soil rather than climate.

Edaphically dry: dry soil conditions.

Mesic: habitat that has moderate amounts of moisture—neither decidedly wet or decidedly dry—yet well-drained.

More mesic: habitat tending to wet, yet still well-drained.

Matrix shrubland: extensive shrubland surrounding and enveloping isolated pockets of alternative vegetation.

Mesic matrix ecosystems: moist ecosystems surrounding isolated pockets of alternative ecosystems.

Appendix 1

CLASSIFICATION FEATURES OF DRYLAND ENVIRONMENTS, INCLUDING THOSE RELEVANT TO *Muehlenbeckia astonii*

Tables A1.1 and A1.2 on pages 108–109

TABLE A1.1. FACTORS USED TO CLASSIFY DRYLAND ENVIRONMENTS, AND TO DEFINE THE POTENTIAL ENVIRONMENTAL ENVELOPE OF *Muehlenbeckia astonii*.

FACTOR	ABBREVIATION IN TABLE A1.2	USED IN DRYLAND CLASSIFICATION?
GENERAL		
Slope (25 m from digital elevation model in LENZ*)(°)	Slope	Yes
GEOLOGY		
Category of top rock layer (NZLRI†)		
Alluvium and till	Al	Yes
Calcareous younger sedimentary (Limestone)	Cs	Yes
Gneiss	Gn	Grouped
Loess	Lo	Yes
Older sedimentary (Greywacke, Argillite, Conglomerate)	Os	Yes
Peat	Pt	Grouped
Schist	Sc	Yes
Volcanic: rhyolite	Vb	Grouped
Volcanic: basalt	Vr	Grouped
Volcanic: ultrabasic	Vb	Grouped
Younger sedimentary, non-calcareous	Ys	Yes
Towns etc.	Town	Grouped
SOIL SUBSTRATE (LENZ†)		
Acid-soluble phosphate (mg/100 g)	acidp	Grouped
Age (1 = young, 2 = old)	age	Yes
Calcium (mg/100 g)	calcium	Grouped
Chemical limitations to growth (1 = low, 3 = high)	chemlims	Yes
Drainage (1 = very poor, 5 = good)	drain	Yes
Induration (1 = non-indurated, 5 = very strongly indurated)	Ind	Grouped
Particle size (mm)	psize	Grouped
CLIMATE (LENZ†, ASSOCIATED ENVIRONMENTAL SURFACES‡)		
Moisture availability		
October vapour pressure deficit (kPa)	octvpd	Yes
Annual Penman water deficit (mm)	pendef	Yes
Rainfall: potential evapotranspiration ratio	r2pet	Yes
Rainfall variability	rnvar	Yes
Frost		
Date of first air frost (numbered days)	firstafrost	Yes
Date of first ground frost (numbered days)	firstgfr	
Ground-frost-free days	gfrostfree	
Degrees July air frost (°C)	julafrosy	
Degrees July ground frost (°C)	julgfrost	Yes
Date of last air frost (numbered days)	lastafrost	
Date of last ground frost (numbered days)	lastgfrost	
Solar radiation		
December solar radiation ($MJ/m^2/day$)	decsolrad	Yes
June solar radiation ($MJ/m^2/day$)	junesolrad	Yes
Mean annual solar radiation ($MJ/m^2/day$)	meansolrad	
Temperature		
Average warmest month temperature (°C)	avtwarm	
Growing degree days (°C)	gdd	
Mean annual soil temperature (°C)	massoil	
Mean annual temperature (°C)	mat	Yes
Mean minimum temperature of the coldest month (°C)	tmin	
Mean annual extreme minimum temperature (°C)	anntmin	
VEGETATION		
Potential vegetation§		

* Leathwick et al. 2003

† New Zealand Land Resource Inventory; Landcare Research, unpublished data

‡ J.R. Leathwick, unpubl. data

§ Leathwick et al. 2004

TABLE A1.2. AVERAGE ENVIRONMENTAL CHARACTERISTICS OF THE EIGHT EASTERN NEW ZEALAND DRYLAND TYPES (A TO H).
Key to abbreviations and units in Appendix 1, Table A1.1.

			GEOLOGY (% AREA)												SOIL (AVERAGE VALUE ACROSS AREA)						
	ELEVATION	SLOPE	AL	CS	GN	LO	TOWN	OS	PT	SC	VB	VR	VU	YS	ACIDP	AGE	CA	CHEMLIMS	DRAIN	IND	PSIZE
A	46	2	4	0	0	1	0	0	0	0	0	0	0	0	2.1	1.5	2.2	1.1	3.4	1.7	1.3
B	176	8	3	1	0	2	0	5	0	0	0	0	0	14	2.3	1.9	2.2	1.0	3.8	3.5	4.6
C	59	2	14	0	0	2	0	0	0	0	0	0	0	0	2.4	1.4	1.9	1.2	3.1	1.6	1.4
D	104	3	13	0	0	8	1	0	0	0	0	0	0	3	3.7	1.6	2.1	1.0	3.5	3.0	2.4
E	420	15	11	5	0	1	0	32	0	0	1	0	1	4	3.0	2.0	1.6	1.0	4.8	3.7	4.1
F	138	3	31	0	0	17	1	0	0	0	0	0	0	1	3.4	1.8	2.0	1.0	3.8	2.7	1.9
G	419	3	19	0	0	2	0	0	0	1	0	0	0	1	3.5	1.4	1.9	1.0	3.9	2.4	2.5
H	485	12	5	0	0	6	0	10	0	33	0	0	0	1	3.0	2.0	1.7	1.0	4.5	3.6	3.6

	MOISTURE AVAILABILITY				FROST							SOLAR RADIATION					TEMPERATURE			
	OCT-VPD	PEN-DEF	R2-PET	RN-VAR	FIRST A-FROST	FIRST G-FROST	G-FROST FREE	JUL A-FROST	JUL DG FROST	LAST A-FROST	LAST G-FROST	DEC SOL-RAD	JUNE SOL-RAD	MEAN SOL-RAD	AVT WARM	GDD	MAS	MAT SOIL	TMIN	ANN TMIN
A	52	430	140	219	129	110	180	4.1	9.8	229	295	2386	620	148	18.6	3210	14.9	13.8	4.1	-2.0
B	46	392	149	205	114	95	144	5.2	11.3	237	316	2356	581	145	17.3	2737	13.6	12.5	3.0	-2.5
C	42	385	145	181	119	89	134	7.3	12.8	258	320	2332	548	143	17.1	2692	13.4	12.4	2.9	-3.0
D	56	704	89	203	120	80	119	8.4	14.5	263	326	2391	562	148	16.9	2618	12.9	12.2	2.4	-2.9
E	52	491	130	204	93	41	59	10.8	17.4	285	347	2377	546	146	15.4	1996	11.1	10.4	0.5	-4.8
F	46	477	104	216	105	63	87	12.1	18.9	281	341	2267	495	137	16.1	2193	11.7	11.0	0.7	-4.7
G	45	496	103	186	79	17	21	20.7	24.0	327	360	2282	480	137	15.1	1745	10.2	9.4	-1.7	-7.9
H	41	410	122	187	78	22	29	19.2	22.8	330	358	2267	474	136	14.6	1622	9.8	9.0	-2.0	-7.5

Appendix 2

BIBLIOGRAPHY OF THE HISTORY OF NATURAL FIRE IN EASTERN SOUTH ISLAND

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Appendix 3

DATA USED TO COMPILE FIGURE 8 IN THE TEXT

LOCATION	GRID REFERENCE	FIRE DATES FROM CHARCOAL (y BP)	FIRE INTERVAL(y)	REFERENCE
Duncan Stream, Mackenzie Basin	H38 755 764	7996, 5068, 4825, 2929	1928; 243; 1896	McGlone & Moar 1998
Quagmire Tarn, Arrowsmith Range	J35 576 633	3800*; 3500; 2600	300; 900	Burrows & Russell 1990
Glendhu, Waipori River, east Otago	H44 580 810	3 c. 4000–3650†; c. 1100*	2725 (one fire interval between mid point of three fires at 4000–3650 and one at c. 1100)	McGlone & Wilmshurst 1999
Manorburn, Central Otago		7670 ± 70; 5660 ± 130; 2110 ± 90;1470 ± 110	2010; 3550; 640	Basher et al., unpubl. data
Ashburton River, Canterbury		4500 ± 70; 2140 ± 70	2360	Basher et al., unpubl. data
Porters Pass, Canterbury		8900 ± 110; 6900 ± 90	2000	Basher et al., unpubl. data
Site 1, Twizel River, Canterbury		8000 ± 90; 5170 ± 90; 5070 ± 130;4830 ± 80; 2930 ± 80	1900; 2140 (middle date taken as mid point of three over-lapping dates)	Basher et al., unpubl. data
Site 2, Twizel River, Canterbury		6810 ± 90; 5220 ± 90; 3790 ± 80; 2930 ± 80	1590; 1430; 860	Basher et al., unpubl. data
Broadfields, Christchurch	M36 659 364	6504 ± 94;1860 ± 96	4644	Molloy 1995

* Charcoal layers not radiocarbon dated; age estimates from peat bog or lake sediment stratigraphy.

† Treated as one event because of possibility of continuing inflow of surface charcoal to peat bog from surrounding catchment slopes.

Appendix 4

RARE PLANTS (BY PLANT TYPE): ECOSYSTEMS (E, IN 18 CATEGORIES), THREAT CATEGORIES AND QUALIFIERS, AND HABITAT NOTES

1 = dry, alluvial terrace, fan, and outwash basin floor (originally diverse shrubland with grass and forb patches)
2 = dry hill-country (originally conifer-hardwood or *Nothofagus* forest with patches of shrubland and grassland)
3 = wet / dry frosty hollow on alluvial floodplains and terraces (meanders and ox-bows producing light gaps and margins to forest)
4 = cliff and talus
5 = braided riverbed
6 = inland saline ecosystem
7 = hydothermal
8 = littoral zone of ephemeral wetland
9 = mire
10 = swamp
11 = aquatic macrophyte
12 = flush / seepage
13 = river and stream bank
14 = coastal cliff, talus, and terraced headland
15 = sand and gravel beach
16 = coastal dune hollow and sand plain
17 = coastal dune
18 = estuary and lagoon

TAXON	E	THREAT*	QUAL.[†]	NOTES
Fern				
Anogramma leptophylla	2, 4	5 Gradual decline	TO, EF	Dry rocks or banks
Botrychium australe	2	6 Sparse	DP, SO	Open sites in dry lowland forest
Pleurosorus rutifolius Fée	4	6 Sparse	SO	Cliffs
Psilopsid, lycopod, or quillwort				
Tmesipteris aff. *tannensis* (CHR 496779; Banks Peninsula)	2	1 Nationally critical	DP, OL	Lowland forest
Non-composite dicotyledonous herb				
*Acaena buchananii (*Hookf.)	6, 14	5 Gradual decline		Stony terraces and inland saline ecosystem
Aciphylla subflabellata (W.R.B.Oliv.)	1, 2	6 Sparse	DP	Dry shrubland and tussockland
Anisotome lyallii Hook.f.	14	7 Range restricted		Coastal cliffs
Atriplex billardierei	15	7 Range restricted	CD, TO, HI	Beach sands
Atriplex buchananii	6, 14	6 Sparse		Coastal rock outcrops and inland saline ecosystem
Atriplex cinerea	15	Coloniser	SO, OL	Coastal strands
Cardamine (a) (CHR 312947; 'tarn')	8	2 Nationally endangered	DP, EF	Ephemeral wetland
Cardamine (c) (CHR 500569; Awahokomo)	4	1 Nationally critical	EF, OL	Limestone pedestals
Ceratocephala pungens	1, 2	1 Nationally critical	HI, EF	Desert pavements
Chenopodium detestans	8	8 Data deficient	TO	Turfs of ephemeral wetlands
Chenopodium pusillum	1	8 Data deficient		Dry stony terraces
Colobanthus (a) (CHR 515133; Pareora River)	4			Dryland lowland cliffs; synonym of *C. brevisepalus*
Colobanthus brevisepalus Kirk	1	8 Data deficient		Stony terraces

TAXON	E	THREAT*	QUAL.†	NOTES
Colobanthus 'Tengawai'	4			Dryland lowland cliffs; synonym of *C. brevisepalus*
Crassula colorata var. *acuminata* (Reader) Toelken	1	Vagrant		Stony terraces, Marlborough
Crassula multicaulis (Petrie) A.P.Druce et Given	1	6 Sparse	EF	Lake and tarn margins, damp hollows in riverbeds and tussockland
Crassula peduncularis (Smith) F.Meigen	8, 13	2 Nationally endangered	SO, EF	Lake margins and stream banks
Daucus glochidiatus (Labill.) Fisch., Mey. Et Lallemant	1, 2	4 Serious decline	DP, SO	Open places in lowland alluvial plains
Epilobium brevipes Hook.f.	4	7 Range restricted		Cliffs
Epilobium chionanthum Hausskn.	9, 10	5 Gradual decline	DP	Swamps and bogs
Epilobium pictum Petrie	2	8 Data deficient		Dry forest
Eryngium vesiculosum	14	5 Gradual decline	SO?	Coastal turfs
Euphorbia glauca G.Forst.	14, 15	4 Serious decline	EF	Coast
Galium aff. *perpusillum* (CHR 476063 Kaitorete)	1, 16	8 Data deficient		Kaitorete sand plains and dry intermontane alluvial terraces
Galium trilobum Colenso	3	8 Data deficient		Dry forest margins
Non-composite dicotyledonous herb				
Gentianella aff. *astonii* (b) (CHR 529111; Pareora River)	4	1 Nationally critical	OL	Limestone cliffs
Gentianella aff. *astonii* (c) (CHR 519113; Awahokomo)	4	7 Range restricted	EF, OL	Limestone pedestals
Gentianella aff. *astonii* (d) (CHR 529114; Ward)	4	7 Range restricted	ST	Cliff and talus
Gentianella aff. *astonii* (e) (CHR 542276; Manahune)	4	1 Nationally critical	OL	Cliff and talus
Gentianella astonii	4	7 Range restricted	ST	Limestone ridges and cliffs
Geranium (a) (CHR 518296; Pareora River)	4	7 Range restricted	OL	Lowland limestone cliff
Geum divergens Cheeseman	4	7 Range restricted		Rocky places, Clarence Valley
Gingidia aff. *montana* (a) (CHR; North Otago)	4	7 Range restricted	DP	Limestone cliffs
Gingidia baxterae	4	7 Range restricted	DP	Limestone cliffs
Gingidia enysii	4	7 Range restricted	DP	Limestone outcrops
Gratiola nana Benth.	3, 8	5 Gradual decline	SO	Wet depressions or turf margins of lakes and kettles
Gunnera arenaria	16	5 Gradual decline		Damp sand flats
Hydrocotyle pterocarpa F.Muell.	3, 10	Not threatened		Lowland wet margins and swamp ground
Hypericum aff. *japonicum* (b) (CHR ; 'tarn')	8	6 Sparse	DP	Tarn margin
Ischnocarpus exilis Heenan	4	1 Nationally critical	CD, HI, OL	Limestone pedestals
Ischnocarpus novae-zelandiae (Hook.f.) O.E.Schulz	4	5 Gradual decline	DP	Cliffs
Lepidium desvauxii	14, 15	8 Data deficient	SO	Coastal rocks and sand
Lepidium kirkii Petrie	6	2 Nationally endangered	CD, HI, EF	Inland saline ecosystem
Lepidium oleraceum G.Forst. s.s.	14	2 Nationally endangered	CD, HI, EF	Coastal cliffs and talus
Lepidium sisymbrioides subsp. *kawarau* (Petrie) Thell.	4	2 Nationally endangered	CD, HI	Cliffs and talus
Lepidium sisymbrioides subsp. *matau* (Petrie) Thell.	1	1 Nationally critical	CD, HI, EF	Stony terraces
Lepidium sisymbrioides Hook. f. subsp. *sisymbrioides*	1	5 Gradual decline	CD	Stony terraces
Lepidium tenuicaule Kirk	14	5 Gradual decline		Coastal gravel pavements
Limosella curdieana F.Muell.	8	Vagrant	SO	Ephemeral wetland
Mazus arenarius Heenan, P.N.Johnson, et C.J.Webb	16	5 Gradual decline		Sand plain

Appendix 4 contd.

TAXON	E	THREAT*	QUAL.†	NOTES
Mazus novaezeelandiae subsp. *impolitus* Heenan f. *impolitus*	1,3	4 Serious decline	CD, HI	Wet riparian sites in dry east
Mimulus repens	18	6 Sparse	DP, SO	Coastal damp sands and marshes
Montigena novae-zelandiae (Hook.f.) Heenan	1, 2, 4	5 Gradual decline	DP, RF?	Rock talus
Myosotis australis var. *lytteltonensis* Laing et A.Wall	14	1 Nationally critical	CD, HI, EF	Coastal cliffs
Myosotis colensoi (Kirk) Macbride	4	2 Nationally endangered	CD, EF	Limestone talus
Myosotis laingii Cheeseman	4	8 Data deficient		Possibly dry montane rock outcrops
Myosurus minimus subsp. *novae-zelandiae* (W.R.B.Oliv.) Garn.-Jones	6, 8	2 Nationally endangered	HI, EF	Ephemeral wetlands surrounded by dry scrub and forest
Myosotis pygmaea var. *glauca* G.Simpson et J.S.Thomson	1, 4	2 Nationally endangered	CD, EF	Stony terraces
Myosotis pygmaea var.*minuiti-flora* G. Simpson et J. S.Thomson	1, 8	3 Nationally vulnerable	EF	Turf margins of tarns and lakes
Myosotis pygmaea Colenso var. *pygmaea*	16	4 Serious decline	DP	Coastal dune hollows
Myosotis traversii var. *cinera-scens* (Petrie) L.B.Moore	4	Extinct	DP	Castlehill Basin limestone talus
Myosotis uniflora Hook.f.	1	8 Data deficient		Stony terraces
Myriophyllum robustum Hook.f.	9, 18	5 Gradual decline		Peaty ponds, lagoons and lake margins
Neopaxia erythrophylla Heenan	4	6 Sparse	DP	Scree
Neopaxia lineariifolia Heenan	8, 12	8 Data deficient		Turf margins of tarns, seepages, streams, and lakes
Oreomyrrhis (CHR 364086; 'minute flower')	14	6 Sparse		Coastal turfs
Oxalis aff. *rubens* (CHR; 'scree')	4	6 Sparse		Voucher pending
Poranthera microphylla Brong.	2	7 Range restricted	SO	Dry forest
Ranunculus aff. *royi* (CHR 513327; Waihao)	4	1 Nationally critical	HI, OL	Lowland limestone cliffs
Ranunculus aff. *stylosus* (CHR 515131; Manahune)	4	2 Nationally endangered	HI, OL	Cliff and talus
Ranunculus recens Kirk var. *recens*	14			Coastal turfs
Rorippa divaricata (Hook.f.) Garn.-Jones et Jonsell	3, 8, 18	2 Nationally endangered	CD, EF	Shores of ponds, lakes, rivers, and estuaries
Rumex neglectus Kirk	5, 8, 13	7 Range restricted	HI	Coastal gravels, turfs, banks
Sebaea ovata (Labill.) R.Br.	16	1 Nationally critical	CD, SO, HI, EF	Coastal ephemeral wetlands
Sicyos aff. *australis* (AK 252822; New Zealand)	14	4 Serious decline	HI	Coastal talus and boulderfield
Stackhousia minima Hook.f.	8	Not threatened	DP, HI	Turf margins of tarns, kettles, and lakes
Stellaria elatinoides Hook.f.	1, 2	Extinct		Dry scrub or forest
Tetragonia tetragonioides (Pallas) Kuntze	1, 2, 14	6 Sparse	EF	Coastal unconsolidated sites and dry shrubland
Urtica aspera Petrie	4	6 Sparse	DP	Rock talus
Wahlenbergia akaroa J.A.Petterson	14	7 Range restricted		Banks Peninsula coastal cliffs
Composite dicotyledonous herb				
Brachyscome (a) (WELT 10278; Ward)	1	2 Nationally endangered		Dry scrub
Brachyscome (b) (CHR 518295; Pareora River)	4	Not Threatened		Lowland limestone cliff, Not considered distinct taxon (de Lange et al. 1999)
Brachyscome pinnata	1	1 Nationally critical	CD, HI, OL	Canterbury Plains alluvial floodplains
Celmisia hookeri Cockayne	14	6 Sparse		Coastal pavements
Celmisia lindsayi Hook.f.	14	7 Range restricted		Coastal pavements
Centipeda aotearoana N.G.Walsh	8	8 Data deficient		Ephemeral wetlands
Centipeda minima subsp. *minima*	8, 13	1 Nationally critical	SO, EF	Wet or dry margins of lakes, ponds, and streams

TAXON	E	THREAT*	QUAL.†	NOTES
Craspedia (a) (CHR 511522; Clutha River)	1	1 Nationally critical	HI, OL	Stony terraces
Craspedia (c) (CHR 529115; Kaitorete)	16	7 Range restricted	CD, HI, OL	sand plain, Kaitorete Spit
Craspedia (j) (CHR 516302; Lake Heron)	8	1 Nationally critical	HI, OL	Lake margin, intermontane kettle lakes
Euchiton ensifer (D.G.Drury) Holub	1, 8	6 Sparse	DP	Ephemeral wetlands, damp hollows in alluvial terraces
Ewartiothamnus sinclairii (Hook. f.) Anderb.	4	7 Range restricted		River gorges
Gnaphalium luteoalbum var. *compactum* Kirk	1	6 Sparse	DP, EF	Ablation pavements and ephemeral wetlands
Lagenifera montana	3, 13	8 Data deficient		Lowland swamps, wet scrub or sedge swards by lakes and lagoons
Leptinella (a) (CHR 515297; Clutha River)	1	1 Nationally critical		Stony terraces in inland basins
Leptinella filiformis (Hook.f.) D.G.Lloyd et C.J.Webb	1	1 Nationally critical	EW, CD, HI	Dry alluvial floodplains
Composite dicotyledonous herb				
Leptinella intermedia (D.G.Lloyd) D.G.Lloyd et C.J.Webb (CANU 17225)	1	8 Data deficient		Dry scrub
Leptinella minor	2, 13, 16	7 Range restricted		Margins of swamps, streamsides, and sandy tidal flats
Leptinella nana (D.G.Lloyd) D.G.Lloyd et C.J.Webb	1, 2, 4	2 Nationally endangered	CD, EF	Dry forest
Leptinella serrulata D.G.Lloyd et C.J.Webb	1	5 Gradual decline		Margins of rivers
Raoulia (a) (CHR 79537; 'K')	1	8 Data deficient		Waimakariri River bed
Raoulia aff. *hookeri* (AK 239529; 'coast')	15	5 Gradual decline		Coastal gravels and cliffs
Raoulia beauverdii	1	6 Sparse		Stony terraces
Raoulia monroi	1	5 Gradual decline	EF	Stony terraces
Raoulia parkii	1	5 Gradual decline	EF	Dry stony terraces
Senecio dunedinensis Belcher	4	6 Sparse	EF	Talus
Senecio glaucophyllus ssp. *basinudus*	14	7 Range restricted		Coastal cliffs
Senecio hauwai Sykes	14	7 Range restricted	ST	Coastal mudstone cliffs, Marfells to Cape Campbell
Senecio scaberulus (Hook.f.) D.G.Drury	14	2 Nationally endangered	HI, EF	Coastal shrublands and forest margins
Senecio sterquilinus	2	7 Range restricted		On malodorous friable soil around petrel burrows
Sonchus kirkii Hamlin	14, 16	5 Gradual decline	HI	Wet coastal cliffs and sand habitats
Vittadinia australis	1,5	8 Data deficient		Dry scrub
Dicotyledonous tree or shrub				
Carmichaelia astonii G. Simpson	4	7 Range restricted		Limestone cliffs
Carmichaelia carmichaeliae (Hook. f) Heena	4	3 Nationally vulnerable		River gorges
Carmichaelia compacta	4	7 Range restricted		River gorges
Carmichaelia crassicaule	1, 2	5 Gradual decline	RF	Scrub
Carmichaelia curta	4	2 Nationally endangered	HI	Rock outcrops of dry intermontane basins
Carmichaelia hollowayi	4	1 Nationally critical	CD, RF	Limestone outcrops of Waitaki Valley
Carmichaelia juncea	5	2 Nationally endangered	HI, EF	Heads of dry riverbeds
Carmichaelia muritai	14	1 Nationally critical	CD	Coastal cliffs
Carmichaelia stevensonii	4	5 Gradual decline		River gorges
Carmichaelia torulosa	4, 13	7 Range restricted	ST, RF	Streamsides and scrub, north Canterbury
Carmichaelia vexillata	1, 2	5 Gradual decline	RF	Arid terraces and spurs

TAXON	E	THREAT*	QUAL.†	NOTES
Coprosma intertexta G.Simpson	1, 2	6 Sparse		Scrub
Coprosma obconica subsp. *obconica*	2, 3	5 Gradual decline	RF	Dry podocarp–broadleaved forest
Coprosma pedicellata	3	5 Gradual decline		Wet depression in alluvial floodplains forest
Corallospartium crassicaule var. *racemosum* (CHR 141532)	1, 2	8 Data deficient		Dry scrub
Dracophyllum uniflorum var. *frondosum* G.Simpson	4	5 Gradual decline	DP	Limestone cliffs
Hebe amplexicaulis f. *amplexicaulis*	1, 4	7 Range restricted		Inland South Canterbury on low altitude to montane rock outcrops, cliffs, gorge
Hebe amplexicaulis f. *hirta* Garn.-Jones et Molloy	4	7 Range restricted		Hairy morph within *H. amplexicaulis* population
Hebe aff. *pimeleioides* (CHR 173403; Mackenzie Basin)	1	5 Gradual decline	CD	Dry outwash plains of intermontane basin
Dicotyledonous tree or shrub				
Hebe armstrongii (J.B.Armstr.) Cockayne et Allan	1	2 Nationally endangered	CD, HI	Montane frosty kettleholed valley floors
Hebe cupressoides Hook.f.	4	3 Nationally vulnerable	CD, HI	Dry scrub
Hebe pareora Garn.-Jones et Molloy	4	7 Range restricted		Hunter Hills, rock outcrops and gorge walls
Hebe pimeleoides var. *glauco-caerula* (J.B.Armstr.) Cockayne et Allan (CHR 462377)	1	Not threatened		Stony terraces
Hebe pimeleoides var. *rupestris*	4	5 Gradual decline	CD	Dry scrub
Hebe rupicola	4	7 Range restricted		Cliffs
Hebe strictissima	4	7 Range restricted		Banks Peninsula rock outcrops and bluffs and scrub
Helichrysum dimorphum Cockayne	1, 2	2 Nationally endangered	CD, HI, RF	Dry scrub, Waimakariri Basin
Heliohebe lavaudiana	4	4 Serious decline	CD	Banks Peninsula rock outcrops
Helichrysum plumeum Allan	4	7 Range restricted		Kirkleston Mountains, rock outcrops
Heliohebe raoulii subsp. *maccaskillii* (Allan) Garn.-Jones	4	2 Nationally endangered		Limestone escarpments, North Canterbury
Helichrysum selago var. *tumidum* Cheeseman	14	7 Range restricted		Coastal cliffs
Ileostylus micranthus (Hook.f.) Tiegh.	1, 2	Not threatened	CD, RC, TO	Wide range of hosts in dry scrub
Korthalsella salicornioides (A.Cunn.) Tiegh.	1, 2	6 Sparse	EF	Kanuka of dry scrub-forest is main host
Kunzea aff. *ericoides* (b) (AK; 'sand')	16	5 Gradual decline		Coastal sand plain
Melicytus aff. *alpinus* (c) (CHR 541568; Otago)	1	8 Data deficient		Dry scrub
Melicytus aff. *alpinus* (d) (CHR 541567; 'dark')	4	8 Data deficient		Dry scrub
Melicytus aff. *alpinus* (e) (CHR 541566; Waipapa)	1, 2	5 Gradual decline		Dry scrub
Melicytus aff. *alpinus* (f) (CHR 530143; Brockie)	4	8 Data deficient	OL	Dry scrub
Melicytus aff. *alpinus* (i) (CHR 541569; 'Blondin')	2	7 Range restricted		Dry scrub and forest
Melicytus aff. *crassifolius* (CHR 279358; 'cliff')	14	7 Range restricted		Coastal cliff
Melicytus crassifolius s.s.	14,16	6 Sparse	DP	Coastal rocks and sand
Melicytus flexuosus Molloy et A.P.Druce	3	5 Gradual decline	RF	Margins of podocarp-broadleaved forest
Muehlenbeckia astonii Petrie	1, 2, 14	3 Nationally vulnerable	CD, RF	Dry scrub
Olearia bullata	1, 12	6 Sparse	RF	Wet seepages in dry scrub

TAXON	E	THREAT*	QUAL.†	NOTES
Olearia fimbriata Heads	2, 4	4 Serious decline		River gorges in dry scrub
Olearia fragrantissima Petrie	2	6 Sparse		Dry forest
Olearia hectorii Hook.f.	3	3 Nationally vulnerable	CD, RF	Openings in dry forest
Olearia lineata (Kirk) Cockayne	1, 2	6 Sparse	RF	Dry scrub
Pachystegia aff. *insignis* (CHR; Lowry)	4	8 Data deficient		Marlborough river gorges
Pachystegia minor (Cheeseman) Molloy	4	8 Data deficient		River gorge
Pachystegia rufa Molloy	4	7 Range restricted	CD, ST	River gorge
Pimelea aff. *arenaria* (AK 216133; Southern New Zealand)	16	4 Serious decline	DP, RF	Coastal sand plain
Pimelea aff. *prostrata* (CHR 257898; Kaitorete)	16	8 Data deficient	OL	Sand plain, Kaitorete Spit
Pimelea lyallii	14, 15	5 Gradual decline		Coastal cliff and sand
Pimelea 'Pisa' (CHR)	4	7 Range restricted		Dry scrub
Pimelea suteri	1	7 Range restricted		Dry scrub
Pimelea tomentosa (J.R.Forst. et G.Forst.) Druce s.s.	4, 14	4 Serious decline	EF	Coastal cliff
Pseudopanax ferox Kirk	2	6 Sparse	CD, RF	Dry forest
Solanum aviculare f. *latifolium*	2, 14	6 Sparse		Coastal scrub and forest
Sophora molloyi Heenan et de Lange	14	7 Range restricted		Coastal cliffs
Teucridium parvifolium Hook.f.	2	5 Gradual decline	CD	Dry scrub and forest
Tupeia antarctica (G.Forst.) Cham. et Schlecht.	2	5 Gradual decline	CD, HI	Dry forest hosts
Dicotyledonous liane				
Brachyglottis sciadophila (Raoul) B.Nord.	2	5 Gradual decline		Dry forest
Carmichaelia appressa G.Simpson	16	7 Range restricted	OL	Sand plain, Kaitorete Spit
Carmichaelia kirkii	1, 2	2 Nationally endangered	DP	Scrub
Clematis marata J.B.Armstr.	1, 2	6 Sparse	DP	Scrub
Convolvulus fracto-saxosa	1	6 Sparse		Arid terraces
Convolvulus verecundus subsp. *verecundus*	1	6 Sparse		Stony terraces
Fuchsia procumbens R.Cunn. ex A.Cunn.	3	6 Sparse		Dryland forest margins
Muehlenbeckia ephedroides Hook.f.	1, 15	6 Sparse		Stony terraces and cliffs
Rubus aff. *schmidelioides* (AK ; 'strawberry')	1 ,2	7 Range restricted		Dry scrub and forest
Grass				
Achnatherum petriei	4	7 Range restricted	CD	Rock outcrops of dry intermontane basins
Agrostis imbecilla	1, 8	6 Sparse		Ephemeral wetlands in stony terraces
Amphibromus fluitans	8	2 Nationally endangered	EF	Lowland ephemeral wetlands
Anemanthele lessoniana	2	6 Sparse	DP	Bony ground in dry lowland forest
Australopyrum calcis subsp. *calcis*	4	2 Nationally endangered	CD, ST, OL	Limestone cliff; Leatham Valley, Marlborough
Australopyrum calcis subsp. *optatum*	4	3 Nationally vulnerable	CD	Lowland limestone cliffs
Austrofestuca littoralis	15	5 Gradual decline	CD, SO, HI	Coastal sands and gravels
Chionochloa beddiei	14	7 Range restricted		Coastal cliffs
Dichelachne lautumia Edgar et Connor	14	7 Range restricted	ST	Limestone cliff
Elymus apricus	1, 2	7 Range restricted		Dry scrub
Elymus aff. *solandri* (a) (AK 222754; 'channel')	4	8 Data deficient		Cliffs

TAXON	E	THREAT*	QUAL.†	NOTES
Elymus aff. *solandri* (b) (CHR 279228 ; South Marlborough)	4	8 Data deficient		Cliff and talus
Elymus falcis Connor	1, 2, 4	7 Range restricted		Riverbeds, rock outcrops and dry scrub of inland basins
Elymus sacandros	14	7 Range restricted		Coastal limestone cliffs
Elymus tenuis	1	8 Data deficient		Dry scrub
Festuca actae	14	7 Range restricted		Banks Peninsula rock outcrops and bluffs
Festuca aff. *novae-zelandiae* (CHR 252541; Awahokomo)	4	1 Nationally critical	CD, EF, OL	Limestone pedestals
Koeleria aff. *novozelandica* (AK 252546; Awahokomo)	4	1 Nationally critical	CD, OL	Limestone pedestals
Lachnagrostis littoralis ssp. *Salaria* Edgar	18	7 Range restricted		Salt meadow and inland salt lake
Lachnagrostis tenuis	14, 18	7 Range restricted		Salt marsh and coastal cliff
Poa acicularifolia ssp. *acicularifolia*	4	7 Range restricted		Limestone cliff
Poa spania Edgar et Molloy	4	1 Nationally critical	CD, OL	Limestone pedestals
Puccinellia raroflorens Edgar	6	1 Nationally critical	CD, DP	Inland saline ecosystem
Puccinellia walkeri ssp. *walkeri*	14	7 Range restricted	OL	Coastal rock outcrops and inland saline ecosystem
Rytidosperma merum Connor et Edgar	1, 2	6 Sparse	DP	Dry scrub and grassland
Simplicia laxa Kirk	4	2 Nationally endangered	CD, HI	Cliffs, inland
Trisetum aff. *lepidum* (CHR 251835; Awahokomo)	4	1 Nationally critical	CD, EF	Limestone pedestals
Sedge				
Carex albula Allan	1	7 Range restricted		Stony terraces
Carex berggrenii Petrie	8	6 Sparse		Margins of waterbodies
Carex carsei Petrie	9	8 Data deficient		Lowland bogs
Carex cirrhosa Bergg.	8, 13	5 Gradual decline	DP, HI	Margins of lakes and ponds and in river beds, 600–1000 m a.s.l.
Carex decurtata Cheeseman	1	7 Range restricted		Dry scrub
Carex inopinata	2, 4	2 Nationally endangered	CD	Dry scrub and forest
Carex *kaloides* Petrie	1, 13	6 Sparse		Levees
Carex litorosa Bailey	18	4 Serious decline	DP, HI	Brackish marshes
Carex muelleri Petrie	1	6 Sparse		Arid terraces
Carex raoulii Boott	14	8 Data deficient		Coastal scrub and forest
Carex tenuiculmis (Petrie) Heenan et de Lange	9, 10	6 Sparse		Swamps, damp grassland and scrub
Carex uncifolia	1,8	7 Range restricted		Damp channels in outwash terraces and fans
Desmoschoenus spiralis (A.Rich) Hook.f.	17	5 Gradual decline	CD, EF	Coastal dunes
Eleocharis neozelandica	8, 16	5 Gradual decline	EF	Ephemeral wetlands in dune hollows
Isolepis basilaris Hook.f.	8	4 Serious decline	EF	Ephemeral wetlands; margins of lakes, tarns, lagoons, rivers
Isolepis fluitans (L.) R.Br.	8, 10	5 Gradual decline	SO	Swampy ground and lake edges to 750 m a.s.l., Lake Tekapo
Uncinia elegans (Kūk.) Hamlin	4	6 Sparse		Basin floor scrub
Uncinia strictissima (Kūk.) Petrie	1, 2, 12	2 Nationally endangered	DP, HI	Dry scrub and forest
Rush or allied plant				
Centrolepis strigosa (R.Br.) Roem. et Schult.	16	6 Sparse	SO, EF	Moist sand flats
Juncus holoschoenus R.Br. var. *holoschoenus*	8	2 Nationally endangered	DP, SO	Ephemeral wetlands about Christchurch
Luzula celata Edgar	1, 5, 15	4 Serious decline		Stony dry terraces and dune hollowsTaxon

TAXON	E	THREAT*	QUAL.†	NOTES
Luzula traversii var. *tenuis*	4	7 Range restricted	DP	Cliffs in Cromwell Gorge
Orchid				
Pterostylis micromega Hook.f.	9	1 Nationally critical	CD, HI, EF	Swamp
Pterostylis tanypoda D.L.Jones, Molloy et M.A.Clem	1, 2	6 Sparse	EF	Tussock grassland
Pterostylis tristis Colenso	1	6 Sparse	EF	Gravel terraces
Other monocotyledonous herb				
Hypoxis aff. *hookeri* (CHR 486447; New Zealand)	1, 2	8 Data deficient	SO	Dry weedy places in eastern districts
Iphigenia novae-zelandiae (Hook.f.) Baker	8	5 Gradual decline	DP, HI	Turfs of lakes and kettles
Libertia peregrinans Cockayne et Allan	1, 2, 4	5 Gradual decline	HI	Dry scrub
Other monocotyledonous herb				
Triglochin palustris L.	9, 12	2 Nationally endangered	SO	Peat bogs
Monocotyledonous tree or shrub				
Cordyline australis	2, 10	Not threatened	CD	Dry forest

* Molloy et al. (2002)

† Qualifier categories from Molloy et al. (2002) defined below:

Qualifier	Stands for	Definition
EW	Extinct in the wild	Exists only in cultivation or in captivity
CD	Conservation dependent	Likely to move to a higher threat category if current management ceases
DP	Data Poor	Confidence in the listing is low due to the poor data available for assessment
RC	Recovering	Total population showing a sustained recovery
ST	Stable	Total population stable
SO	Secure Overseas	Secure in other parts of its natural range outside New Zealand
TO	Threatened Overseas	Threatened in those parts of its natural range outside New Zealand
HI	Human Induced	Present distriution is a result of direct or indirect human activity
RF	Recruitment Failure	Current populations may appear stable but the age structure is such that catastrophic declines are likely in the future
EF	Extreme Fluctuations	Extreme unnatural population fluctuations, or natural fluctuations overlaying human-induced declines, that increase the threat of extinction
OL	One Location	Found at one location (geographically or ecologically distinct area) in which a single event (e.g. a predator irruption) could soon affect all individuals of the taxon

Appendix 5

AVERAGE ENVIRONMENTAL FACTOR VALUES IN FOUR COMMUNITIES (A–D) CONTAINING *Muehlenbeckia astonii*

FACTORS DERIVED FROM DIGITAL INFORMATION (I.E. DEM, LENZ AND ASSOCIATED ENVIRONMENTAL SURFACES)	A	B	C	D
General				
Predominant aspect converted to degrees north (max 180°)	92	86	42	106
Predominant aspect converted to degrees east (max 180°)	102	74	54	66
Elevation (m)	102	62	41	232
Slope (°)	5	8	14	12
Substrate				
Particle size (1 = clay, 5 = massive)	3.3	2.8	2.3	3.6
Induration (1 = non-indurated, 5 = very strongly)	3.7	3.4	2.0	3.8
Drainage (1 = poor, 5 = good)	4.0	4.8	4.2	4.5
Chemical limitations to growth (1= low, 3 = high)	1.0	1.0	0.9	1.0
Calcium (1 = low, 5 = high)	2.1	1.9	1.6	1.5
Age (1 = old, 3 = young)	1.9	1.6	1.3	1.9
Acid-soluble phosphate (mg/100g)	3.3	3.1	1.4	3.1
Frost				
Date of last ground frost (days numbered)	307	289	246	335
Degrees July ground frost (°C)	12	9	4	16
Ground-frost-free days	157	190	270	106
Date of first ground frost (days numbered)	99	115	151	76
Degrees July air frost (°C)	7	4	1	11
Air-frost-free days	157	190	270	106
Date of first air frost (days numbered)	130	65	24	108
Date of last air frost (days numbered)	258	143	37	296
Solar radiation				
June solar radiation (MJ/m^2/day)	563	538	540	540
December solar radiation (MJ/m^2/day)	2369	2331	2326	2365
Mean annual solar radiation (MJ/m^2/day)	147	143	142	144
Temperature				
Mean minimum temperature of the coldest month (°C)	25	36	57	7
Mean annual extreme minimum temperature (°C)	–22	–15	3	–43
Mean annual soil temperature (°C)	130	130	135	120
Mean annual temperature (°C)	122	123	130	112
Average warmest month temperature (°C)	168	168	171	162
Growing degree days (°C)	2612	2643	2908	2232
Moisture				
Rainfall variability (mm)	201	202	188	209
October vapour pressure deficit (kPa)	49	44	39	54
Annual Penman water deficit (mm)	682	508	326	682
Rainfall: potential evapotranspiration ratio	76	107	142	84

FACTORS DERIVED FROM DIGITAL INFORMATION (I.E. DEM, LENZ AND ASSOCIATED ENVIRONMENTAL SURFACES)	A	B	C	D
Factors derived from information collected on site				
Bedrock on surface (% of sites)	29	13	64	38
Rock on surface (% of sites)	29	40	82	100
Cover broken rock (% cover)	11	7	17	24
Size of loose rock (cm)	8	36	17	20
Degrees north (°)	127	81	58	61
Degrees east (°)	68	97	64	31
Slope (°)	17	24	29	17
Physiography category 1 (% of sites)	14	6		
Physiography category 4 (% of sites)			17	
Physiography category 5 (% of sites)	43	65	42	25
Physiography category 6 (% of sites)	43	24	42	75
Physiography category 7 (% of sites)		6		