Floristics and structure of the mossy cloud forest of Mt Gower summit, Lord Howe Island

REBECCA HARRIS[1]*, GERASIMOS CASSIS[1], TONY AULD[2] and IAN HUTTON[3]

The summit of Mt Gower, Lord Howe Island (31°33'S, 159°05'E), is a small area of 27 ha supporting mossy cloud forest. This study describes patterns in the floristic composition and structure of the vegetation of the summit, in relation to a range of environmental variables. A total of 42 vascular plant species was recorded, 86% of which are endemic to Lord Howe Island, and 17% of which are found only on the summit and upper slopes of Mt Gower and adjacent Mt Lidgbird. A complete species list for Mt Gower is presented, including species from the present survey and all previously recorded species. The composition of the vegetation differed in gullies and on ridges, reflecting differences in substrate rockiness and soil moisture, and was also influenced by the number of bird burrows and aspect. The summit of Mt Gower is of high conservation significance, due to the restricted distribution of the habitat type it represents, its relatively undisturbed state and high levels of endemism. Potential threats to the summit vegetation include the impacts of climate change, seed predation by introduced rats, and the introduction of weed species and exotic pathogens such as *Phytophthora cinnamomi*.

Key words: Lord Howe Island, Species distribution, Endemism, Conservation status, Climate change.

INTRODUCTION

LORD Howe Island is a small oceanic island approximately 500 km east of Australia and 1 350 km north-west of New Zealand (31°33'S, 159°05'E) (McDougall *et al.* 1981; Green 1994). It is approximately 11 km long, from 0.3 to 2.8 km wide, and covers an area of 1 455 ha (Pickard 1983a; Green 1994). In the south, the island rises steeply to two mountain peaks, Mt Gower (875 m) and Mt Lidgbird (777 m).

The island was discovered in 1788 and has been inhabited since 1834. It has a resident population of approximately 350 people and can accommodate 400 tourists at any one time (Lord Howe Island Board 2000). The age of the island, its recent occupation by humans, its protected status and its remote location have left Lord Howe Island one of the least modified of the few islands located around this latitude in the Pacific Ocean. Lord Howe Island, its surrounding islands and waters were declared a World Heritage Area in 1982. The island is managed by the Lord Howe Island Board, with the primary management emphasis directed at conservation of natural values.

The flora of Lord Howe Island is extremely rich and diverse, with an unusually high proportion of endemic species. Of the 241 native species of vascular plants, 105 (44%) are endemic to the island (Green 1994). This level of endemism is less than larger islands such as Hawaii (89%), New Zealand (82%), Fiji (61%) and New Caledonia (76%) (Lowry 1996), but significant given the small size of Lord Howe Island and higher than non-island regional floras in Australia (Keith *et al.* 1999). At least 16 of the endemic plant species have been considered rare, endangered or vulnerable, and many have extremely restricted ranges (Pickard 1983b). The high levels of endemism are believed to be a result of the island's long biological isolation, high altitudinal and climatic gradients, and high habitat diversity (Paramonov 1958; Recher and Ponder 1981). Many of the endemic species of plant are found in the mossy cloud forest on the summit of Mt Gower, and several are restricted to this habitat.

AIMS

Pickard (1983) recognized the vegetation on the summit of Mt Gower as distinct from the remaining Lord Howe vegetation, except for a small comparable patch on Mt Lidgbird. This study aims to describe patterns in the floristic composition and structure of the vegetation on the Mt Gower summit in relation to a range of environmental variables. We also assess the conservation significance of this vegetation type in terms of species composition, and potential threats.

METHODS

Study Area-Mt Gower summit

The 27 ha summit of Mt Gower is a south-north sloping plateau surrounded by sheer cliffs on all sides except to the north-east, where a narrow ridge links it with Mt Lidgbird. Several gullies with semi-permanent creeks cross the plateau, draining over the cliffs on the northern edge. The cloud forest is frequented by Providence Petrels *Pterodroma solandri*, which disturb the soil

[1]The Centre for Biodiversity and Conservation Research, The Australian Museum, 6 College St, Sydney, New South Wales, Australia 2010.
[2]Biodiversity Research Group, Dept. of Environment and Conservation (NSW), PO Box 1967, Hurstville, New South Wales, Australia 2220.
[3]PO Box 157, Lord Howe Island.
*Corresponding author. Present address: School of Geography and Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania, Australia 7001 (*Email: rmharris@utas.edu.au*)
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by creating burrows, and about 65 individuals of the endemic Lord Howe Island Woodhen *Tricholimnas sylvestris* (NSW NPWS 2002).

The vegetation of the summit of Mt Gower was classified by Pickard (1983a) as Gnarled Mossy Forest, a subformation of Evergreen Closed Forest. The dominant species are *Zygogynum howeanum* and *Dracophyllum fitzgeraldii*. All trees are low, ranging from about 2 to 5 m tall. Associated trees include *Cryptocarya gregsonii*, *Elaeocarpus costatus*, *Leptospermum polygalifolium* subsp. *howense*, *Negria rhabdothamnoides*, *Pittosporum erioloma*, *Symplocos candelabrum*, and the palms *Hedyscepe canterburyana* and *Lepidorrhachis mooreana*. Tree ferns (*Cyathea* spp.), large tussock sedges (*Machaerina insularis* and *Gahnia howeana*), ferns, mosses and lichens are common. This vegetation type also occurs on the summit of Mt Lidgbird above 750 m elevation, but is much more exposed and restricted in area (Pickard 1983a).

Climate

The climate of Lord Howe Island is humid-subtropical. It has a mean annual temperature of 19.2°C, ranging from 25°C to 17°C in Summer to 18°C–14°C in Winter (Clark and Pickard 1974). Average rainfall for the years 1888 to 1988 is 1 664 mm, with a maximum of 2 886 mm (1910) and a minimum of 998 mm (1888) (Mueller-Dombois and Fosberg 1998; Bureau of Meteorology records 2003).

Because of its high altitude, the summit of Mt Gower experiences a different climatic regime to the rest of the island, with extensive orographic cloud cover, lower temperature, modified wind patterns and a higher rainfall (possibly 15–20% more) (Green 1994). The continual cloud cover has the potential to influence the hydrological regime, radiation balance, physiological processes, soil properties and the ecology of the summit through its direct contact with the vegetation and the process of horizontal precipitation (Penafiel 1994; Pounds and Crump 1994; Pounds *et al.* 1999).

Geology and soils

Lord Howe Island is situated on the Lord Howe Island Rise, an undersea volcanic plateau that extends from New Zealand to the Chesterfield Reefs, midway between New Caledonia and the Queensland coast (McDougall *et al.* 1981). About 900 km to the north-east lies Norfolk Island on the Norfolk Ridge. Approximately 80% of the island is basaltic, the eroded remnant of a much larger shield volcano that was active over a relatively short period in the late Miocene (between 6.4 and 6.9 million years ago). Mt Gower is considered to represent an eroded caldera remnant (McDougall *et al.* 1981). The remainder of the island is calcarenite derived from coral sand, between 40 000 and 120 000 years old (Pickard 1983a; Green 1994).

There is very little information regarding the soils of Mt Gower other than the soil profile description given by Pickard (1983a). It showed an organic layer (mostly litter) of 7.5 cm depth, underlain by a plastic, clayey mineral soil to 15 cm. Between 15 cm and 17.5 cm there was a sharp gley horizon, below which the soil consisted of decayed, reddish rock with yellow mottling around hard "core stones" about 5 mm in diameter. The soil was slightly acidic (ranging from pH 5.5–6.5) and from 0–17.5 cm was very soft, with a high moisture content (Pickard 1983a).

Sites

We sampled 18 sites from 772–882 m in altitude, to provide a representative sample of the summit of Mt Gower (Fig. 1). Three sites were positioned on each of three separate gullies, and 3 on each of three separate ridges. The position of the sites within a gully or ridge was determined haphazardly, as it was influenced by accessibility. Sampling was carried out in November 2001. At each site several variables were measured: altitude, aspect, and slope, using a handheld GPS and clinometer.

At each site a 20 m × 20 m quadrat was marked out and five 1 m^2 sub-quadrats were established (one in the centre and one at each corner). A transect 20 m long × 2 m wide was also marked out from the centre of the quadrat in the direction of a random bearing.

The abundance of all plants in, or overhanging, the transect were recorded. The per cent cover of the dominant canopy trees was estimated from the centre point of each quadrat. Where there were more than 20 individuals of some fern species, the abundance of individuals was not counted, but recorded as 30. Abundance data are therefore underestimates for those sites with abundant ferns.

Habitat assessment

The following habitat variables were measured in each of the five sub-quadrats at each site:

a) per cent foliar cover of the tree canopy (>200 cm high);

b) per cent shrub canopy cover (20–200 cm high);

c) per cent ground herbs and grasses cover (0–20 cm high);

d) per cent leaf litter cover (all dead litter and debris up to 2 cm diameter);

e) substrate rockiness (4 categories, ranging from no rocks to very rocky);

f) debris and logs (3 categories, ranging from no logs or debris to very abundant);

g) soil moisture (4 categories, ranging from dry to waterlogged), and

h) the number of bird burrows.

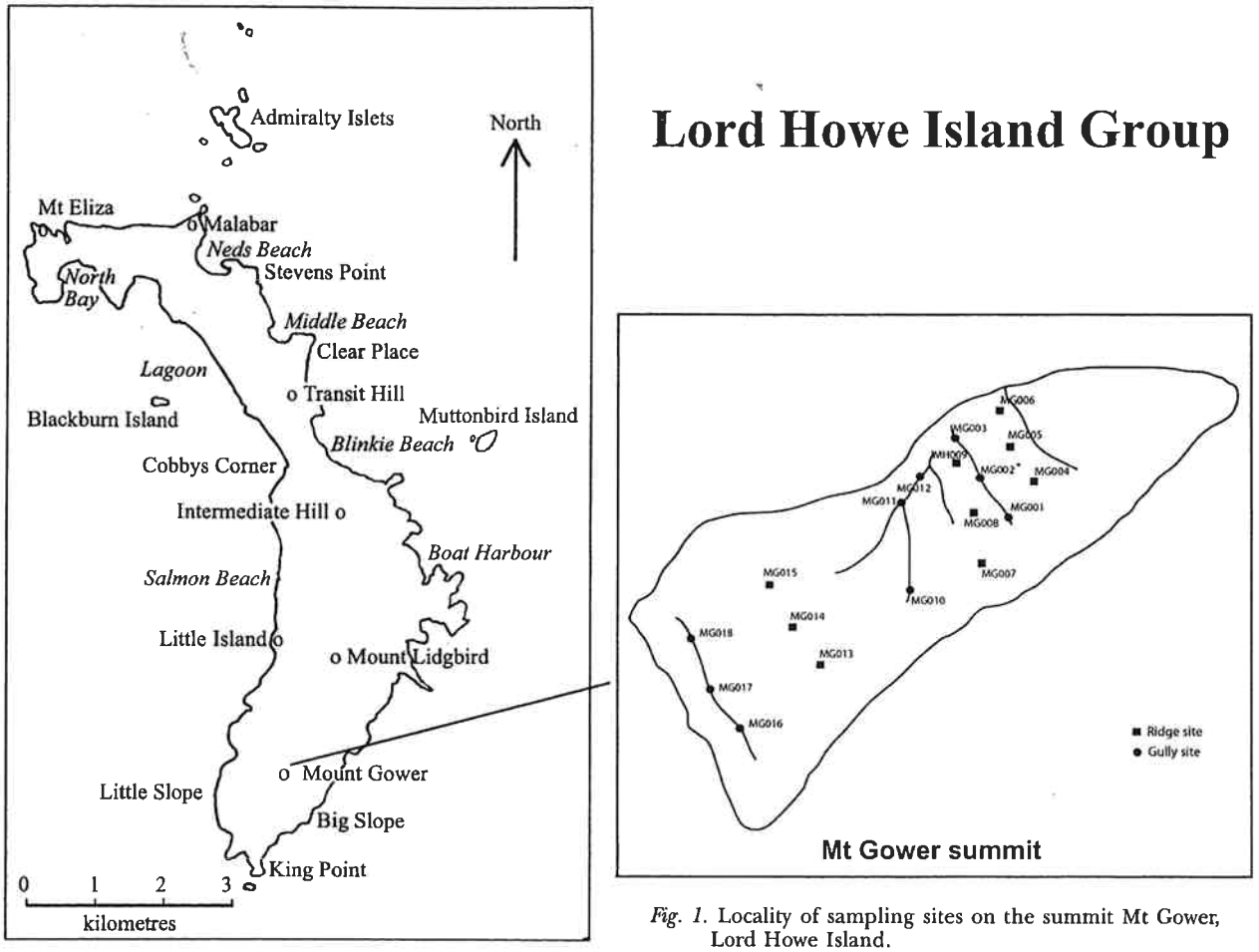

Fig. 1. Locality of sampling sites on the summit Mt Gower, Lord Howe Island.

DATA ANALYSIS

Species richness

Species richness was calculated from the number of plant species recorded along the transect and within the quadrat for each site. Differences in species richness between gully and ridge sites was examined using a nested Analysis of Variance (ANOVA), with position on a particular gully or ridge nested in habitat type (ridge or gully). There were 3 sites on each gully and ridge sampled. Homogeneity of variance was examined using Cochran's test (Underwood 1997) and no data transformations were applied.

Habitat structure

A comparison of sites on ridges and gullies was made. For each site, the mean ± se was calculated for the per cent cover of each vegetation level and leaf litter cover, with the standard error used as an indication of site patchiness. Totals of the categorical measures (rockiness, logs, soil moisture) across the 5 sub-quadrats were used. Pearson's Product-Moment Correlation Coefficient was used to investigate the relationship between the habitat variables and plant species richness at each site. Each habitat variable was compared across ridge and gully sites using ANOVA. Data exploration and analyses were performed using STATISTICA (StatSoft 1997).

Species composition

Canonical Correspondence Analysis (CCA) (ter Braak 1986) was used to determine how the vegetation responded to gradients in environmental variables and to investigate patterns evident among the sites based on species composition. Separate analyses were done on untransformed abundance data and cover of the dominant canopy species. The automatic forward selection procedure was used, in which the habitat variables are added to the model in the order that explains the greatest proportion of the variance. A Monte Carlo test (199 permutations) was used to test the significance of the influence of each variable. The program CANOCO Version 4 (ter Braak and Smilauer 1998) was used.

RESULTS

Species richness

A total of 42 plant species was identified on the 18 sites. Species richness ranged from a minimum of 10 to a maximum of 20, with a mean ± se of 14.6 ± 0.67. The highest species richness

was generally towards the northeastern part of the summit, and the lowest was found on sites on the exposed main ridge. The exception to this trend was two sites on the eastern side of the summit, which had similar richness values to the main ridge sites. Species richness did not differ significantly between gully and ridge sites ($F_{1,16} = 0.321$; $p = 0.58$), and there was no significant position effect ($F_{1,16} = 3.128$; $p = 0.06$).

Species composition

Thirty-six (86%) of the 42 species recorded in this survey were species endemic to Lord Howe Island. None were introduced. Eighteen of the species found were Pteridophyta (from 12 genera), 24 Magnoliophyta, including dicotyledons from 15 genera and monocotyledons from 5 genera (Table 1). An additional 15 species have been previously recorded from the summit but were not encountered in this survey. The conservation significance of these taxa is provided in Table 2 to allow consideration of the full list of the flora of Mt Gower summit.

Two fern species (*Asplenium milnei* and *Cephalomanes bauerianum*) and one flowering

Table 1. Conservation significance and biogeographical affinities of the vascular plant species recorded from Mt Gower summit (nomenclature according to Wilson 1994).

Family	Species	Biogeographical affinity (genus also present)*	Distribution of species	Conservation significance**
MAGNOLIOPHYTA				
Dicotyledonae:				
Asteraceae	*Olearia ballii*	NZ, Aust., PNG	Endemic, above 400 m, common on mountain summits	Locally common, Rare
	Olearia mooneyi	NZ, Aust., PNG	Endemic, common above 750 m	Locally common, Rare
Elaeocarpaceae	*Elaeocarpus costatus*	NC, NZ, Aust., from Madagascar and Mauritius to eastern Asia	Endemic, all altitudes in south of island	Rare
Epacridaceae	*Dracophyllum fitzgeraldii*	NC, NZ, Aust.	Endemic, on mountains from 120 m	Common, Not threatened
Gesneriaceae	*Negria rhabdothamnoides*	LHI	Endemic genus, common above 500 m, occasionally lower	Common, Not threatened
Lauraceae	*Cryptocarya gregsonii*	NC, Aust.	Endemic, locally abundant above 500 m in southern mountains	Uncommon, Not threatened
Meliaceae	*Dysoxylum pachyphyllum*	NC, NZ, Aust., SE Asia, Pacific Is.	Endemic, all altitudes	Not threatened
Myrsinaceae	*Rapanea myrtillina*	NC, Aust., NZ (*Myrsine*) (pantropical and subtropical)	Endemic, from 400 m to summits of southern mountains	Rare
Myrtaceae	*Leptospermum polygalifolium* ssp. *howense*	NC, NZ, Aust., Malesia	Endemic subspecies, mainly on mountain summits, rarely at lower altitudes	Not threatened
	Metrosideros nervulosa	NC, NZ, Bonin Is. to Philippines south through Melanesia to NZ and east to Hawaii	Endemic, from 400 m to summits of mountains, rarely at lower altitudes	Not threatened
	Metrosideros sclerocarpa	NC, NZ, Bonin Is. to Philippines south through Melanesia to NZ and east to Hawaii	Endemic, mainly below 300 m in southern mountains	Not threatened
Piperaceae	*Macropiper hooglandii*	NZ, Bonin Is. to the Solomon Is, the Marquesas and Rapa	Endemic, all altitudes	Locally common, Not threatened
Pittosporaceae	*Pittosporum erioloma*	NC, NZ, Aust., Africa, Asia, and the Pacific	Endemic, common from 450 m to mountain summits, occasionally at lower altitudes	Common, Not threatened
Rubiaceae	*Atractocarpus stipularis*	NC	Endemic, widespread at all altitudes	Not threatened
	Coprosma huttoniana	Borneo and Java across the Pacific to Hawaii and south to Aust. and NZ	Endemic, frequent in montane forests	Not threatened
	Coprosma putida	Borneo and Java across the Pacific to Hawaii and south to Aust. and NZ	Endemic, widespread at all altitudes	Common, Not threatened
Rutaceae	*Melicope contermina*	NC, NZ, Aust., tropical and subtropical	Endemic, mainly in Erskine Valley and mountain summits	Very uncommon, Rare
Symplocaceae	*Symplocos candelabrum*	NC, Aust., SE Asia, Melanesia	Endemic, from 400 m to summits of southern mountains	Locally common, Not threatened

Table 1 — *continued*

Family	Species	Biogeographical affinity (genus also present)*	Distribution of species	Conservation significance**
Winteraceae	*Zygogynum howeanum*	NC, Aust., Moluccas, PNG	Endemic, southern mountains at all altitudes	Not threatened
Monocotyledonae:				
Arecaceae	*Hedyscepe canterburyana*	LHI	Endemic genus, upper slopes and ridges of southern mountains from 400 m.	Not threatened
	Lepidorrhachis mooreana	LHI	Endemic genus, confined to mossy cloud forest above 750 m	Rare
Cyperaceae	*Gahnia howeana*	NC, NZ, Aust., China through Malesia to Aust. and Pacific	Endemic, on slopes and summits of southern mountains	Not threatened
	Machaerina insularis	NC, NZ, Aust.	Endemic, on slopes and summits of southern mountains	Rare, Not threatened
Orchidaceae	*Dendrobium moorei*	NC, NZ, Aust.	Endemic, frequent in northern forests from 400 m	Not threatened
PTERIDOPHYTA				
Aspleniaceae	*Asplenium milnei*	NC, NZ, Aust.	Endemic, common in lowland forest, occasionally to summits of southern mountains	Not threatened
	Asplenium pteridoides	NC, NZ, Aust.	Endemic, confined to southern mountains	Rare, locally abundant at 2 locations, 1 on each mountain at approx. 600 m
	Asplenium surrogatum	NC, NZ, Aust.	Endemic, mainly on summits of southern mountains	Uncommon, Not threatened
Athyriaceae	*Diplazium melanochlamys*	NC, NZ, Aust., tropical	Endemic, in southern forests	Not threatened
Blechnaceae	*Blechnum contiguum*	NC, NZ, Aust.	Confined to summits of southern mountains; also present on New Caledonia	Uncommon, Not threatened
	Blechnum fullagarii	NC, NZ, Aust.	Endemic, confined to cloud forest on southern mountains	Rare
	Blechnum howeanum	NC, NZ, Aust.	Endemic, southern mountains at all altitudes	Not threatened
Cyatheaceae	*Cyathea brevipinna*	NC, NZ, Aust.	Endemic, mainly on summits of southern mountains	Rare
	Cyathea howeana	NC, NZ, Aust.	Endemic, frequent on slopes and summits of southern mountains	Not threatened
	Cyathea macarthurii	NC, NZ, Aust.	Endemic, all altitudes	Common, Not threatened
Dennstaedtiaceae	*Histiopteris incisa*	NC, NZ, Aust.	Pantropical species, widespread all altitudes	Not threatened
Dryopteridaceae	*Lastreopsis nephrodioides*	NC, NZ, Aust.	Endemic, higher altitudes of southern forests	Not threatened
Grammitidiceae	*Grammitis* sp. (species *G. diminuta, G. nudicarpa* and *G. wattsii* not differentiated)	NC, NZ, Aust.	Endemic, all species mainly confined to mossy cloud forest on southern mountains, *G. diminuta* occasionally down to 200 m and *G. nudicarpa* occasionally to 500 m	Vulnerable
Hymenophyllaceae	*Cephalomanes bauerianum*	NC, Aust.	Southern mountains at all altitudes; also present on Norfolk Is.	Not threatened
	Hymenophyllum howense	NC, NZ, Aust.	Endemic, summits of southern mountains, rarely to 400 m	Rare
	Hymenophyllum moorei	NC, NZ, Aust.	Endemic, summits of southern mountains, rarely to 400 m	Rare
Polpodiaceae	*Phymatosorus scandens*	NC, NZ, Aust.	Mainly summits of southern mountains; also present in eastern Australia and New Zealand	Rare, Not threatened
Psilotaceae	*Tmesipteris truncata*	NC, NZ, Aust.	Above 500 m; also present in eastern Australia	Rare, Not threatened

*Aust. = Australia; NC = New Caledonia; NZ = New Zealand; LHI = genus endemic to LHI.
**based on Pickard (1983), Green (1994) and personal observation (TA, IH).

Table 2. Species recorded by previous workers as occurring on Mt Gower summit, but not found in this survey.

Family	Species	Biogeographical affinity (genus also found)*	Distribution	Conservation significance**
MAGNOLIOPHYTA				
Dicotyledonae:				
Apocynaceae	*Alyxia squamulosa*	NC, NZ, Aust, Pacific Is.	Endemic, mainly ridges off Mt Gower and Lidgbird 600 m to summits	Rare
Asclepidiaceae	*Marsdenia tubulosa*	NC, Aust.	Endemic. Only one collection from Mt Gower summit, in 1871	Possibly extinct
Asteraceae	*Lordhowea insularis*	LHI	Endemic, widespread and common above 600 m, occasionally lower	Not threatened
Grossulariaceae	*Corokia carpodetoides*	NZ, Aust., Chatham Is.	Endemic, locally common on summits of southern mountains, occasionally lower to 700 m	Rare, Not threatened
Iridaceae	*Dietes robinsoniana*	Southern Africa	Endemic, mainly southern mountains, all altitudes	Uncommon, Not threatened
Marattiaceae	*Marattia howeana*	NZ, Aust., Japan	Endemic, southern mountains	Very uncommon, Rare
Plantaginaceae	*Plantago hedleyi*	Aust.	Endemic, southern mountains from 400 m to summits	Rare
Santalaceae	*Exocarpos homalocladus*	NC, NZ, Aust., SE Asia, some Pacific Is., Hawaii	Endemic, uncommon at all altitudes	Uncommon, Not threatened
Smilacaceae	*Smilax australis*	NC, Aust. (worldwide)	All altitudes, common at low altitudes; also present in northern and eastern Australia	Not threatened
Solanaceae	*Solanum aviculare*	NC, NZ, Aust., S. America	Mainly above 600 m; also present in eastern Australia, New Caledonia, New Zealand, Solomon Is., Vanuatu and the Kermadecs	Rare
Urticaceae	*Elatostema grande*	NZ, Aust. (Old World Tropics)	Endemic, in southern forests above 300 m	Widespread, but not common. Possibly impacted by feral pigs
Monocotyledonae				
Cyperaceae	*Bulbostylis densa*	Tropics and subtropics	Only one collection, from Mt Gower summit (Pickard 1971)	Rare
Cyperaceae	*Uncinia debilior*	NZ, Aust, Sth America	Endemic, summits of southern mountains	Rare
Juncaceae	*Luzula longiflora*	Aust., Eurasia (cosmopolitan)	Endemic. Ledges on upper slopes of southern mountains	Rare
Orchidaceae	*Pterostylis obtusa*	NC, NZ, Aust., PNG	Rare on moist grassy ledges on summits of southern mountains; also present in eastern Australia	Rare, Vulnerable
PTERIDOPHYTA				
Aspleniaceae	*Asplenium goudeyi*	NC, NZ, Aust.	Endemic, widespread all altitudes	Uncommon, Not threatened
Blechnaceae	*Blechnum geniculatum*	NC, NZ, Aust. (southern hemisphere)	Endemic, confined to permanent waterfalls of southern mountains, mainly Mt Gower	Rare
Dryopteridaceae	*Polystichium whiteleggei*	NC, NZ, Aust. (cosmopolitan)	Endemic, locally common on slopes and summit edges of southern mountains	Uncommon, Not threatened
Gleicheniaceae	*Sticherus lobatus*	NC, NZ, Aust. (southern hemisphere)	Southern end of Mt Gower summit; also in northern and eastern Australia	Very uncommon, Rare; Believed to be a recent arrival by natural means and spreading on the summit
Lycopodiaceae	*Huperzia varia*	NZ, Aust. (cosmopolitan)	Upper slopes of Mt Gower; also present in southern Australia and New Zealand	Very uncommon, Rare (Pickard 1983 as *Lycopodium myrtifolium*)
Osmundaceae	*Leptopteris moorei*	NZ, Aust., PNG, Vanuatu, Fiji and Samoa	Endemic, confined to summit of Mt Gower	Rare, Threatened
Polypodiaceae	*Pyrrosia confluens*	Aust, NC, Norfolk Is., S-E Asia	Also present in eastern Australia, New Caledonia, and Norfolk Is.	Rare

*Aust. = Australia; NC = New Caledonia; NZ = New Zealand; LHI = genus endemic to LHI
**based on Pickard (1983), Green (1994) and personal observation (TA, IH).

plant (*Cryptocarya gregsonii*) were restricted to gully sites. Eight species were found only on ridge sites, four ferns (*Cyathea brevipinna, Cyathea howeana, Histiopteris incisa, Hymenophyllum moorei*) and four flowering plants (*Gahnia howeana* (referred to as *G. xanthocarpa* in Pickard 1983a and Rodd and Pickard 1983), *Machaerina insularis, Metrosideros sclerocarpa* (called *M. villosa* by Pickard 1983a and Rodd and Pickard 1983), and *Olearia ballii*). *Metrosideros sclerocarpa, Machaerina insularis* and *Cyathea howeana* were positively associated with bird burrows, while *Gahnia howeana, Olearia ballii, Asplenium milnei* and *Cephalomanes bauerianum* were found on sites with the fewest burrows.

Six species were recorded from only one site, including four flowering plants (*Gahnia howeana, Machaerina insularis, Olearia ballii* and *Rapanea myrtillina*) and two fern species (*Asplenium milnei* and *Cyathea howeana*). Sixteen species were found on five or fewer sites and 23 species were found on less than half the sites. The most widely distributed species were *Dracophyllum fitzgeraldii* (present on all sites), *Zygogynum howeanum* (recorded on all but one site), and *Blechnum contiguum* (recorded on 16 sites).

Habitat structure

Across all sites, tree cover (heights >200 cm) ranged from 26–80%; shrub cover (heights 20–200 cm) ranged from 6–44%; and cover of ground herbs and grasses (heights 0–20 cm) ranged from 0–48%.

The measured habitat variables on ridge and gully sites are summarized in Table 3. Gully sites had a significantly lower shrub cover ($F_{1,16} = 8.99$; $p = 0.009$) and a more patchy leaf litter cover ($F_{1,16} = 5.04$; $p = 0.039$) than ridge sites. The substrate of gully sites was also significantly rockier ($F_{1,16} = 20.06$; $p < 0.001$) and wetter ($F_{1,16} = 34.68$; $p < 0.001$) compared to ridge sites.

Correlations between habitat variables

Correlations between the measured habitat variables are shown in Table 4. Plant species richness showed a strong positive correlation with the number of bird burrows ($r = 0.743$, $p = 0.0001$) and was negatively correlated with leaf litter cover ($r = -0.540$, $p = 0.021$). No other variable was significantly correlated with species richness.

Per cent cover of canopy trees was negatively correlated with the cover of shrubs and ground herbs and positively correlated with bird burrows (Table 4). Soil moisture showed a significant positive correlation with the number of rocks and logs, and a negative relationship with shrub cover. The number of bird burrows was positively correlated with shrub cover and negatively correlated with leaf litter cover and altitude.

Table 3. Habitat measurements on Mt Gower sites.

Habitat measure	Overall mean ± se	Gully mean ± se	Ridge mean ± se
Per cent cover tree canopy (>200 cm high)	60.89 ± 3.72	59.33 ± 5.42	62.44 ± 5.36
Patchiness of tree cover	16.14 ± 1.81	13.95 ± 1.78	18.33 ± 3.11
Per cent cover shrub canopy (20–200 cm high)	20.61 ± 2.15	15.44 ± 1.78	25.78 ± 3.12
Patchiness of shrub cover	15.58 ± 1.55	13.54 ± 1.95	17.61 ± 2.31
Per cent cover of ground herbs and grasses (0–20 cm high)	9.34 ± 2.69	4.8 ± 1.78	13.89 ± 4.74
Patchiness of herbs and grasses	8.82 ± 1.85	6.17 ± 1.80	11.48 ± 3.09
Per cent leaf litter cover	60.06 ± 6.99	66.0 ± 6.32	54.11 ±12.60
Patchiness of leaf litter	14.31 ± 2.09	18.52 ± 2.30	10.10 ± 2.96
Substrate rockiness	4.89 ± 0.72	7.11 ± 0.68	2.67 ± 0.73
Debris and logs	7.67 ± 0.36	8.11 ± 0.51	7.22 ± 0.49
Soil moisture	6.61 ± 0.47	8.22 ± 0.55	5.0 ± 0.0
Bird burrows	4.89 ± 1.09	3.67 ± 1.22	6.11 ± 1.78

Table 4. Correlations between habitat variables and plant species richness.

	Altitude	% cover trees	% cover shrubs	% cover ground herbs	Litter cover	Logs	Soil moisture	Number of bird burrows	Substrate rockiness
Altitude		0.11	0.01	0.37	0.44	0.39	0.14	-0.49*	-0.31
% cover trees			-0.64**	-0.35	0.46	-0.29	0.04	-0.35	0.19
% cover shrubs				0.48*	-0.35	0.11	-0.48*	0.47*	-0.38
% cover ground herbs					-0.28	0.29	-0.25	0.26	-0.24
Litter cover						0.10	0.31	-0.76**	-0.12
Logs							0.47*	-0.11	0.28
Soil Moisture								-0.19	0.57*
Number of bird burrows									0.03
Plant species richness	-0.45	-0.31	0.24	0.26	-0.54*	0.09	0.07	0.74**	0.31

*Correlation significant at the 0.05 level.
**Correlation significant at the 0.01 level.

Environmental determinants of the summit vegetation

Abundance data

The results of the CCA of the abundance data are shown as a biplot in Figure 2. The arrows depict the relative influence of the habitat variables on the composition of the plant community, with the line length relative to the other variables, rather than an absolute degree of influence (ter Braak and Verdenschot 1995). Site position (gully or ridge) ($F = 2.96$, $P = 0.005$), the number of bird burrows ($F = 1.86$, $P = 0.015$), and aspect ($F = 1.82$, $P = 0.030$) had a statistically significant influence on the composition of the vegetation. The influence of substrate rockiness ($F = 1.57$, $P = 0.075$), altitude ($F = 1.15$, $P = 0.28$), slope ($F = 0.96$, $P = 0.410$), soil moisture ($F = 0.93$, $P = 0.54$) and logs ($F = 0.78$, $P = 0.66$) were not statistically significant. On the basis of species composition and abundance, gully and ridge sites are separated in the ordination. No other patterns in the distribution of sites on the summit are apparent.

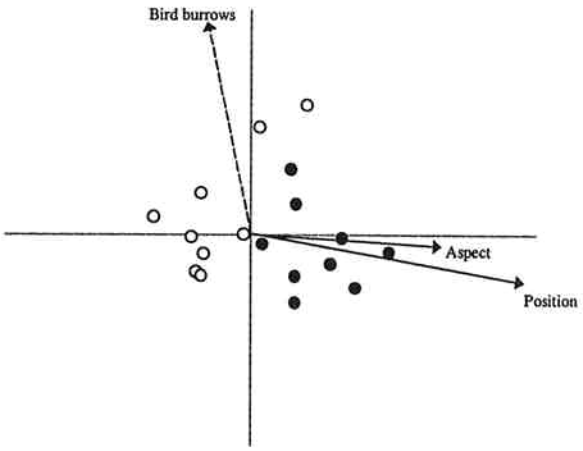

Fig. 2. CCA ordination of plant abundance. Solid lines represent variables with a statistically significant influence. Open and closed circles represent ridge and gully sites respectively.

Canopy cover

The CCA on the dominant canopy species (Fig. 3) shows the sites grouping on the basis of position. Position ($F = 2.24$, $P = 0.025$) and substrate rockiness ($F = 1.90$, $P = 0.07$) were the only measured habitat variables with a significant influence on the composition of the dominant canopy species. Gully and ridge sites are strongly separated in the ordination diagram, indicating that they have dissimilar canopy species compositions. Sites are also grouped into the different gullies and ridges. The most distinct ridge is the large, exposed ridge towards the middle of the summit, and the most western gully is the most dissimilar from the other gullies.

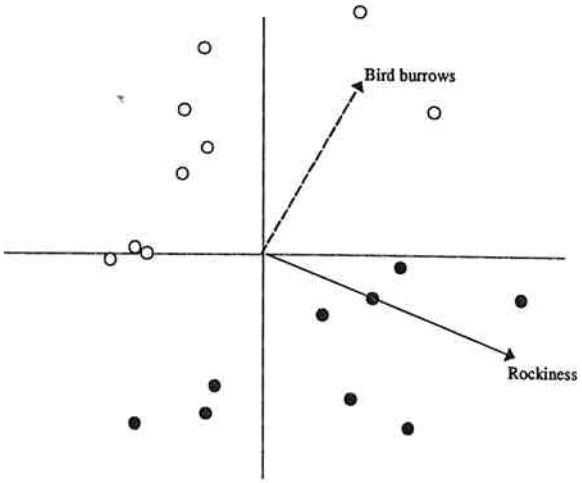

Fig. 3. CCA ordination of dominant canopy cover. Solid lines represent variables with a statistically significant influence. Open and closed circles represent ridge and gully sites respectively.

DISCUSSION

Of the 42 vascular plants recorded from the summit of Mt Gower, 36 (86%) are endemic. The relatively small area of the summit of Mt Gower therefore supports at least 34% of the endemic plants of Lord Howe Island. Several endemic species are mainly confined to the summit of Mt Gower and the smaller summit of Mt Lidgbird or upper slopes, including *Blechnum contiguum, Corokia carpodetoides, Cyathea brevipinna, Hymenophyllum howense, Hymenophyllum moorei, Leptopteris moorei* and *Olearia mooneyi*. These high levels of endemism on the summit area support the hypothesis that Lord Howe Island has been isolated for a long period of time and illustrate the conservation significance of the summit area. Other endemics mainly occur on the summit of Mt Gower, but do extend to lower altitudes as well (e.g., *Cyathea howeana, Grammitis diminuta, G. nudicarpa, G. wattsii, Lepidorrhachis mooreana, Leptospermum polygalifolium* ssp. *howense*), while a few non endemic species are confined to the summit of Mt Gower on Lord Howe Island (e.g., *Sticherus lobatus*).

The flora of the island shows affinities with Australia, New Caledonia and New Zealand. Fifty-four per cent of the island's genera are also found in Australia, 42% are also on New Caledonia and 31% are common to New Zealand. Although Lord Howe was never connected to a larger landmass, there is a chain of now-sunken volcanoes to the north and a parallel chain of sunken volcanoes in the Tasman Sea, between Lord Howe and Australia. Some of the flora could therefore have originated through island hopping during the ice ages, when the sea level was lowered by 100–200 m and these volcanoes were above sea level (Mueller-Dombois and Fosberg 1998). Compared

to the rest of Lord Howe Island, a slightly higher proportion of the genera found on Mt Gower summit show affinities with New Zealand, most likely in response to climatic constraints (Tables 1 and 2).

The current distribution and composition of the plants on the summit of Mt Gower is largely determined by variation in topography, substrate rockiness and aspect. These results support the pattern found by Pickard (1983a), who identified the importance of exposure on the vegetation of Lord Howe Island. Exposure on the summit of Mt Gower would be determined by the interaction between wind, the topography of the gullies and ridges, and aspect. Canopy trees were tallest in the gullies, and very low on the exposed, wind-swept ridges. The main ridge is the most exposed, wind-swept part of the summit, and the vegetation is extremely low and impenetrable. The composition of the vegetation in the gullies was different to that on the ridges, reflecting the rockier, wetter conditions in these areas.

Sites with the lowest cover of canopy trees generally had a higher cover of shrubs and ground herbs and more bird burrows (Table 3). The wettest sites were also the rockiest and had the most logs, but had the lowest shrub cover. The greatest number of bird burrows was found on sites with the highest shrub cover, the least leaf litter cover and at the lower altitudes. The distribution of species across the summit reflects the heterogeneous nature of the summit. More than 50% of the species recorded in this survey were found on less than half of the 18 sites, and 14% were found on only one site. This survey recorded 42 species of a total of 57 that have been previously recorded from the summit of Mt Gower. Several species such as the ferns *Sticherus lobatus*, *Marattia howeana*, *Blechnum geniculatum* and *Polystichium whiteleggei* have highly restricted distributions, and did not occur in our study plots. Others, including *Asplenium goudeyi*, *Corokia carpodetoides*, *Lordhowea insularis*, *Solanum aviculare* and *Smilax australis*, although not uncommon, were also not recorded in this survey.

The number of bird burrows was also found to be significantly correlated with both species richness and the composition of the summit vegetation. Bird burrows were concentrated towards the northeastern end of the summit, with fewer burrows towards the southwestern end. No bird burrows were found on the sites on the main, exposed ridge. More than 27 000 breeding pairs of Providence Petrel nest on Lord Howe Island between May and October, predominantly on the summits of Mt Gower and Mt Lidgbird (Fullager *et al.* 1974; Pickard 1983a; Marchant and Higgins 1990). These high densities cause elevated nutrient levels and disturbance of the soil and ground cover (Pickard 1983). Pickard (1983a) identified these as factors enhancing weed distribution on the summit of Mt Lidgbird and lowland areas of Lord Howe Island. While no introduced species were recorded in our survey plots, the areas of the summit most susceptible to weed invasion, such as around the temporary research igloo and the lookout where walkers on guided tours visit the summit, were not included in this survey. Exotic species have been recorded in these areas by Pickard (1984).

Conservation and management

The summit of Mt Gower has been carefully managed to maintain its high conservation significance, and it remains relatively undisturbed. Access to the summit is restricted to walking groups led by registered guides and walkers are discouraged from walking any distance from the lookout at the eastern end of Mt Gower. This minimizes the frequency of visitations and off-track disturbances.

Current listings of plant species under the NSW *Threatened Species Conservation Act 1995* or the *Environmental Protection and Biodiversity Act 1999* do not reflect the true conservation significance of the Mt Gower cloud forest vegetation. *Geniostoma huttonii* was listed in 2003 as endangered under the NSW *Threatened Species Conservation Act 1995*, but no other plant species have yet been listed as threatened at either the state or national levels. Two endemic species associated with a very restricted exposed habitat type on a south-west ridge near the summit are considered to be endangered (*Coprosma inpoinata* and *Xylosma parvifolium*). One species (*Sticherus lobatus*) is confined to a small area on the summit, and is of high conservation significance as the only location on Lord Howe Island of this coastal Australian species. The rare orchid *Pterostylis obtusa* and the fern *Leptopteris moorei* also have highly restricted distributions and may warrant listing as threatened. None of these species were encountered in this study.

The mossy cloud forest of Mt Gower and to a much lesser extent that on Mt Lidgbird is unique on Lord Howe Island (Pickard 1983a). It represents an important habitat type both for associations of vascular plants species as well as non vascular plants (Ramsey 1984) and invertebrates (G. Cassis 2003 pers. comm.). Consequently, the Mt Gower summit is of very high conservation significance. Applying a criteria-based scheme to assess threat status of ecological communities (EPBC Act guidelines), the ecological community on the summit of Mt Gower should be considered endangered (Environment Australia 2003). The geographic distribution is very restricted and the nature of

its distribution makes it likely that the action of a threatening process could cause it to be lost in the near future.

Threats to the summit vegetation and associated fauna are twofold. Cloud forests are extremely fragile ecosystems that play an important hydrological and ecological role (Hamilton *et al.* 1994). Globally, they are believed to be one of the most rapidly disappearing forest ecosystems due to the impacts of clearing, grazing, exotic plants, anthropogenic fire and climate change (Hamilton *et al.* 1994). The protection of Mt Gower in the Lord Howe Island Permanent Park Preserve should ensure that only climate change and possibly exotic plants may be major threats to the mossy cloud forest on Lord Howe Island. Future climate change is likely to have a great impact on the vegetation of Mt Gower over the next century, by altering the pattern and amount of rainfall, evapotranspiration and cloud cover (Poulsen and Niels 1997; Pounds *et al.* 1999; Still *et al.* 1999; McCarty 2001; Walther *et al.* 2002). Under current predictions, vegetation patterns are expected to shift upwards in elevation (Pounds *et al.* 1999; Hughes 2000; McCarty 2001; Walther *et al.* 2002; Parmesan and Yohe 2003; Root *et al.* 2003). The species predicted to be most vulnerable to climate change are those with small or isolated ranges and low genetic variation (Hughes and Westoby 1994). Many of the species on the summit of Mt Gower fall into these categories, and so are likely to be at risk of extinction. In particular, species confined to the cloud forest above 750 m on the summits of Mt Gower and Mt Lidgbird, such as *Lepidorrhachis mooreana, Olearia mooneyi* and *Blechnum fullagarii*, are particularly vulnerable to climate change.

In contrast, other threats have a more local basis. These include disturbance and seed predation caused by introduced rats, minimal disturbance by walkers, and the introduction of invasive weed species. Black Rats *Rattus rattus* are abundant in spite of a baiting regime carried out by the Lord Howe Island Board. Seed predation by rats on Mt Gower is thought to have limited recruitment of the palm species *Lepidorrhachis mooreana*, resulting in an uneven age class distribution (I. Hutton 2003 pers. observ.). Along the southern edge of the summit, which is regularly baited, however, seedling recruitment is extensive. Further work is needed to quantify the size distributions and assess the possible impacts of rats on these endemic palms. Improved conservation outcomes would be possible if rats were eradicated from the island, a possibility currently being considered by the Lord Howe Island Board (Saunders and Brown 2001). Currently, tourist impacts are likely to be minimal and while the number of tourists allowed on Lord Howe Island at any one time is limited, the impact from walkers should not substantially increase.

A major concern for the summit vegetation would be the introduction of a plant pathogen such at *Phytophthora cinnamomi* by walkers. The impact of this pathogen on the vegetation would depend on the susceptibility of the flora to the pathogen, combined with the climatic conditions on the summit. At present, this impact is unknown, although key structural components of the summit vegetation such as the epacrid *Drachophyllum fitzgeraldii* are at high risk given other studies on Epacridaceae in Australia (Keith 1998; Keith and Ilowski 1999). *Gahnia howeana,* which was found in one plot in this study, was previously included in *G. xanthocarpa*, a species that has been identified as susceptible to *P. cinnamomi* in New Zealand (McKenzie *et al.* 2002). Other species on the summit from genera that have been shown to be at risk to this pathogen elsewhere include: *Coprosma* (McKenzie *et al.* 2002), *Cryptocarya* (Brown 1998), *Leptospermum* (Weste 2003), *Metrosideros* (Kliejunas and Ko 1976), *Symplocos* (Brown 1998) and *Syzygium* (Brown 1998). The implementation of footwear sanitation protocols should be considered a priority in the management of Mt Gower.

Introduced weed species pose a potential threat to the integrity of the vegetation on the summit of Mount Gower. Approximately 218 species of introduced plant have become naturalized on Lord Howe Island (Green 1994), 18 of which have been declared noxious weeds by the Lord Howe Island Board. All of these weed species have originated in the central settlement area and are spreading out from the settlement area at different rates over time. *Psidium cattleianum* is heavily invading the foothills and lower north slopes of Mt Lidgbird, and is occasionally found at 600 m on both of the southern mountains. *Ageratina adenophora* occurs over relatively large areas in gullies exposed to high water flows on both Mt Gower and Mt Lidgbird to 450 m. In the longer term these and other noxious weed species have the potential to invade the summit of Mount Gower. The Lord Howe Island Board has in recent years developed a weed strategy for the Island and although some work has commenced, ongoing, long-term work is required to complete eradication of weeds.

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