Assessment of the weed control programme on Raoul Island, Kermadec Group

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Carol J. West
Department of Conservation
P O Box 743
Invercargill

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Abstract

The weed eradication programme on Raoul Island has been running for 20 years and has been regularly reviewed during that time. The number of hours expended on weed eradication has varied from year to year, as circumstances dictated. Over the years the focus has shifted from heavy reliance on the use of chemicals (and fire) to control dense infestations of species to the current situation where most time is spent searching for individual plants (or groups) of the target species and physical destruction of those. The exotic plant species have been listed in different categories for action, and in this assessment the categories have been reduced to three only. Category A species are to be eradicated and are subdivided into two groups in which the reason for eradication is different. Categories B and C comprise the rest of the exotic flora and are currently not targetted for eradication, although some have been in the past, and some may be in the future. The latter category contains introduced species which have historic significance and the former contains the balance of the flora. Active control of a few of these species is recommended. Thirteen species are listed and discussed in Category A(i), four in A(ii), seven in B and eight in C. The remainder of species in categories B and C are listed in Appendices 2 and 3, with brief notes. For each of the species in the body of the text, their history on the Island, ecology, control methods and future work requirements are described. Documentation of these details enables a clear understanding of how much progress has been made already, what the characteristics of the different species are, how much more there is to do, and how that will be achieved, given current knowledge and technology.

Although only one species can be clearly identified as having been eradicated in 20 years of operation, the level of reduction of category A species in that time is substantial. Every dead plant is one less contributing to future generations. Many of the species have a persistent seed bank and this inevitably prolongs the eradication programme for an unknown period of time. At this stage of the programme, any individual which contributes seed to the seed bank pushes the conclusion of the programme further into the future. Thus, the primary goal of the programme is to prevent this happening, by finding and destroying all individuals before they set seed.

1. Introduction

The presence of exotic species on Raoul Island has been the subject of interest or concern for many decades now. Perhaps the first comment on the intrusion of exotic plants into the natural communities of Raoul Island was made by Guthrie-Smith (1936) who stated ". . . lovely as is the island in its half tropical luxuriance, its charm nevertheless is deprecated to the naturalist by the presence of goats and pigs and by the settlement at different periods of several different families, each of whom has dragged in its wake unwanted weeds; it grated on our feelings to note, for instance, the ngaio woods at Western Bay [Denham Bay] carpeted with our garden ageratum . . ."

When Sorensen was stationed on the Island for seven months in 1944 he investigated natural history and, although his focus was on animal species, he devoted time to collecting all exotic plant species he could find, as well as any weedy native species that he observed: "General work during the month included the collecting of samples of the introduced weeds appearing on the island . . . The collection of introduced and native weeds is now complete unless further spring plants appear." Sorensen (1944). This collection of exotic plants by Sorensen was undertaken at the request of A. J. Healy, Botany Division, DSIR (W. R. Sykes, pers. comm.).

The first modern, comprehensive evaluation of the flora and vegetation of Raoul Island was undertaken in 1966–67 when Bill Sykes from Botany Division, DSIR, spent three months on the Island as part of the Ornithological Society of New Zealand (OSNZ) expedition. Since that time Bill has been the major advisor to the relevant management authority for Raoul on which plant species should be targetted for eradication. Regular visits to the Island enabled him to assess the progress of eradication programmes and to update the priority lists for eradication efforts.

Following Bill's retirement in 1992, the Department still required advice on the effectiveness and direction of control operations and, as the incumbent weed scientist for Science and Research Division, I was asked to undertake the work. In 1993, I spent ten weeks on Raoul, from May to August, becoming familiar with the flora and vegetation, and investigating the ecology and control of all targetted weed species as well as checking for any recent introductions to the Island. A further visit of eight days was made in October 1994 and this enabled valuable observations during a different growing season.

In this report I give a brief introduction to Raoul Island, then I outline the history of weed eradication operations on Raoul Island and suggest a revised framework for managing the exotic component of the flora. Within this framework I present information on each of the currently or previously targetted species: its history on the Island, ecology, control methods and effectiveness to date, and control operations required in future. The rest of the introduced plant species are listed in two appendices. Thus, the entire exotic flora is considered in this report. Finally, I discuss general points which have a bearing on understanding the ecology of weed species on Raoul Island and the progress of the plant eradication operations on the Island thus far.

2. Raoul Island

Raoul Island is the northernmost and largest island of the Kermadec Group which lies within the central Polynesian biogeographic region (Udvardy 1975). Raoul is located at 29° 15' S and 177° 55' W. The Island is an active volcano 2943 ha in extent and rising to a maximum height of 512 m above sea level. It is roughly triangular in shape, with a central crater and ridges >300 m high running south (Mahoe Ridge) and west (Hutchisons Ridge) of the crater rim (Figure 1). The crater contains Blue Lake — a large, cool lake with a boggy margin; Green Lake — a smaller, heavily mineralised, warmer lake with thermally active ground at the western end; and Tui Lake — a tiny, mustard-coloured body of water surrounded by tree ferns and pohutukawa forest. The crater rim is steep on its internal faces and there are few points of access, but the floor of the crater is gently undulating. Denham Bay, on the south-west side of the Island, is a 3 km long arching sandy beach with the pohutukawa forest on the flat backed by high cliffs. In the centre of this flat is a large raupo-fringed freshwater swamp. A group of eight small islets is clustered 3–7 km off the north-eastern coast of Raoul. Of significance in this report are the two closest islets — North and South Meyer (Figure 1) — because some of the principal weeds on Raoul are also dispersed to these islets.

All of the islands are young (Quaternary) volcanoes arising from the Kermadec Ridge. Rock types documented from Raoul Island and its outliers include basalt and basaltic andesite, palagonite tuff, and dacite pumice (Lloyd and Nathan 1981). The soils of Raoul Island are highly fertile as a result of the composition of the volcanic material from which they are derived and the climatic regime in which they have developed. The older soils are yellow-brown loams and the remainder are recent soils derived from volcanic ash, with alluvial and colluvial derivatives (Wright and Metson 1959).

Raoul generally lies south of the subtropical convergence and has a warm temperate climate. The mean annual temperature is 19°C with a 3°C difference for mean annual daily maximum and minimum. In winter, 1993, temperatures ranged from 8–23°C. Humidity is generally high (>80%), and annual rainfall averages 1538 mm and is well distributed throughout the year, although October and November have lower rainfall (New Zealand Meteorological Service 1983). In winter west–south-west winds prevail whereas in summer winds blow from the east–north-east. Tropical cyclones are characteristic during the summer months, and have a strong modifying effect on the forests of Raoul Island (Sykes 1977a).

The dominant vegetation on Raoul is *Metrosideros kermadecensis* (Kermadec pohutukawa) forest. Above 300 m is "wet forest" where the principal understorey species is *Ascarina lucida* var. *lanceolata* (Kermadec hutu), in association with *Rhopalostylis baueri* var. *cheesemanii* (Kermadec nikau), *Homalanthus polyandrus* and *Pseudopanax kermadecensis* (Kermadec five-finger). The wet forest lies within the cloud zone and collects moisture from the mist. Below 300 m is "dry forest" and the understorey is principally *Myrsine kermadecensis* (Kermadec mapou), *Coprosma acutifolia* and *Macropiper excelsum* subsp. *psittacorum* (kawakawa).

FIGURE 1 RAOUL ISLAND AND THE OUTLYING GROUP OF SMALL ISLANDS TO THE NORTH-EAST SHOWING PLACES MENTIONED IN THE TEXT AND ALL EXISTING TRACKS.

Coastal fringes of the forest typically comprise *Myoporum kermadecense* (Kermadec ngaio), *Cyperus ustulatus* and *Isolepis nodosa*. The forest gradually increases in height with distance from the shore. Grasslands dominated by buffalo grass, *Stenotaphrum secundatum*, are common on the previously inhabited Northern Terraces (Figure 2) and the coastal fringe of Denham Bay. But further from previous occupation sites, the grasslands tend to be dominated by the endemic grass, *Imperata cheesemanii* and, west of Ravine 8 (Figure 2), the tropical native grass *Cenchrus calyculatus* which has spiny fruits and was dubbed velcro grass by the 1993–94 team. Much of the grassland on the Northern Terraces is composed of introduced species but native grasses are a major component of vegetation on the steep faces of Hutchison's Bluff (Figure 1) and on slips in Denham Bay and other steep sites in coastal places.

There are approximately 300 species of vascular plants recorded from Raoul Island, but almost two-thirds are introduced species, and of those the greatest representation is from grasses. Very few of the introduced species have a major effect on the native vegetation, but some are being eradicated. Others are widespread and dense in places but do not displace forest so there is no need to control them. In time they will be overtopped and eliminated or greatly reduced in extent by the forest.

Raoul Island has considerable natural and historic values. Archaeological evidence indicates that Maori used Raoul as a stopping-over place on their voyages between Aotearoa — New Zealand — and the Pacific (Johnson 1991). Some of that evidence is provided by plant species discussed in this report. Several of the plants brought to Raoul by early European settlers are also of historic significance, and these are discussed as well. There are 23 species of vascular plants endemic to the Kermadecs, and most of these are on Raoul Island. Also, Raoul once was home to the greatest concentration of seabirds ever known from New Zealand but the depredations of cats, Norway rats and kiore have reduced the avifauna to a very low level. Most of the time the forest is silent. Thus, the benefits to be gained from restoration of Raoul by removal of the major plant and animal threats are enormous.

Already goats have been eradicated and this has resulted in greatly increased abundance of most of the endemic plant species. Eradication of the major weed species, as outlined in this report, will enable effective functioning of the forest ecosystem. Finally, eradication of cats and rats will allow seabirds and others, such as the red-crowned parakeet, to return to Raoul from the nearby Meyer Islets. What a wonderful place it will be!

FIGURE 2 DETAIL OF THE NORTH COAST OF RAOUL ISLAND AND THE AREA AROUND THE MET. STATION, SHOWING PLACES MENTIONED IN THE TEXT AND EXISTING ROADS AND TRACKS.

3. History of weed eradication operations

Weed control operations on Raoul Island commenced in 1972 (Devine 1977). The decision to ultimately eradicate certain introduced plants was taken as a result of recommendations of both the 1966–67 OSNZ party and a small group of officials from the Department of Lands and Survey and New Zealand Forest Service — a party from both departments had visited the Island in 1970 to investigate the impact of exotic plants and animals (McMillan 1971). At the outset the introduced vascular plants on Raoul Island were grouped into seven categories:

A Species which so threaten (whether actually or potentially) the preservation of the natural state that their extermination is a desirable and feasible goal.

B Species which so threaten the preservation of the natural state that their extermination is desirable, but is not feasible at the present time.

C Species which need monitoring so that if they appear likely to become aggressive they can be quickly eliminated.

D Species which are known to be vigorous and sometimes aggressive elsewhere but not requiring immediate control.

E Species which may be a potential threat in one habitat and not in another and requiring selective control.

F Species of historical and allied significance which may be protected.

G Specimens of plants in the reserve producing fruit for human consumption which may be protected.

There were six species listed in category A:
Caesalpinia decapetala — Mysore thorn
Psidium cattleianum — purple guava
Psidium guajava — yellow guava
Olea europaea subsp. *cuspidata* — African olive
Furcraea foetida — Mauritius hemp
Hibiscus tiliaceus — shore hibiscus.

It is not known which species were listed in the other categories for Devine's paper (1977) deals only with the category A species.

The plant control programme for Raoul was revised in 1982 (Anon. 1982b) and the number of categories was reduced from seven to five and the definitions were revised. The first two categories remained the same but the next three (C–E) became category C and the last two categories were merged into category D. Category E was a new category. Introduced plants were classified according to their degree of threat to the natural environment (including potential) and those in category A were listed in order of priority for extermination. Eradication was the aim of categories A and E, control for category C, interim protection for category D and no action for category B. The category definitions in 1982 were:

A Weeds" where threat is reversible and covered by current programme for extermination.

B Weeds" where plant invasion is irreversible; no control provided for in current programme.

C Adventives which are a potential threat and are included in the current programme for surveillance and/or limited control.

D Persistent relics of cultivation either of historical significance, a landscape feature or providing edible fruit which may be protected.

E New or recent arrivals which can be exterminated by a short-term operation initiated under the programme before they become naturalised.

The number of species in category A was increased to ten, two species were identified in category B, seven species in category C, an unspecified number of species in category D and three species in category E.

Species in category A were:
Caesalpinia decapetala — Mysore thorn
Senna septemtrionalis — Brazilian buttercup
Psidium cattleianum — purple guava
Psidium guajava — yellow guava
Olea europaea subsp. *cuspidata* — African olive
Passiflora edulis — black passionfruit
Furcraea foetida — Mauritius hemp
Anredera cordifolia — Madeira vine
Foeniculum vulgare — fennel
Hibiscus tiliaceus — shore hibiscus.

Species in category B were:
Alocasia brisbanensis — aroid lily
Stenotaphrum secundatum — buffalo grass.

Species in category C were:
Aleurites moluccana — candlenut (no control)
Populus nigra — Lombardy poplar
Araucaria heterophylla — Norfolk pine (control of seedlings only)
Ricinus communis — castor oil plant
Gomphocarpus fruticosus — swan plant
Phormium tenax — New Zealand flax (no control)
Brachiaria mutica — Para grass.

Species included in category D were:
Cordyline fruticosa — ti
Colocasia esculenta — taro
Prunus persica — peach
and others.

Species in category E were:
Vicia sativa — vetch
Trifolium campestre — hop trefoil
Senecio jacobaea — ragwort.

From 1983–85 the only changes made to the lists were the addition of recently reported species to category E. For example, pampas grass was added in 1984.

In the draft Kermadec Islands management plan of 1986, the same five categories were employed as in 1982 (Sherley 1986). The species listed in Categories A and B were the same. Only Lombardy poplar and seedlings of Norfolk pine were listed in category C. In category D species were not listed but ti, candlenut and adults of Norfolk pine were given as examples. Category E contained the three species listed in 1982 as well as pampas grass.

In 1992, the weed eradication programme was again revised (Anon. 1992) and the number of categories was further reduced, from five to four. The first four categories were essentially the same but the fifth had been dropped. Thus, the categories as they stood in 1992 were:

A Species which so threaten (whether actually or potentially) the preservation of the natural state that their extermination is a desirable and feasible goal.

B Species which so threaten the preservation of the natural state that their extermination is desirable, but is not feasible at the present time.

C Adventives resulting from accidental or deliberate introduction which are a potential threat and are included in the current programme for surveillance.

D Persistent relics of cultivation either of historic significance, a landscape feature or providing edible fruit which may be protected.

The number of species listed in category A was increased to 13 and *Hibiscus tiliaceus* was reclassified from category A to C (Anon. 1992). Two species were listed in category B, nine named species and all other farm weeds in category C, and two named species and all other historical plants introduced for cultivations in category D.

The species listed in category A were:
Caesalpinia decapetala — Mysore thorn
Psidium cattleianum — purple guava
Psidium guajava — yellow guava
Olea europaea subsp. *cuspidata* — African olive
Furcraea foetida — Mauritius hemp
Senna septemtrionalis — Brazilian buttercup
Passiflora edulis — black passionfruit
Anredera cordifolia — Madeira vine
Cortaderia selloana — pampas grass
Araucaria heterophylla — Norfolk pine (seedlings only)
Cirsium vulgare — Scotch thistle
Foeniculum vulgare — fennel
Senecio jacobaea — ragwort.

In category B were:
Alocasia brisbanensis — aroid lily
Stenotaphrum secundatum — buffalo grass.

In category C were:
Ricinus communis — castor oil plant
Tropaeolum majus — garden nasturtium
Trifolium campestre — hop trefoil
Populus nigra — Lombardy poplar
Brugmansia suaveolens — night bells

Brachiaria mutica — Para grass
Hibiscus tiliaceus — shore hibiscus, fou
Gomphocarpus fruticosus — swan plant
Vicia sativa — vetch.

In category D were:
Cordyline fruticosa — ti
Prunus persica — peach.

During the earlier part of the period that the Department of Lands and Survey undertook weed eradication (1972–1981) a small team of people (usually three) worked on the Island for periods of up to six months (Griffiths 1980; Hancox 1982). From the 1981–82 season through to 1987–88 at least one person from that department or the Department of Conservation (1987–88) was stationed on the Island for a year, in association with the staff of the Meteorological Station. Usually more weed control people were sent up from Lands and Survey for a few months to assist the permanent staff member (Sherley 1986). It was during these early days of the eradication programme that the big knockdown spraying regimes for category A species were undertaken. The work was difficult because water sometimes had to be carried considerable distances and there were large areas, particularly of Mysore thorn, to be sprayed. The hot, humid climate made working conditions unpleasant.

In 1989 the Meteorological Service withdrew from the Island as most of their weather data could be collected by an automatic weather station. At this point the Department of Conservation took over management of the facilities on the Island, and the area which had been excluded from the Nature Reserve, as the Meteorological Station and farm, was added to the Nature Reserve. Teams of four people (usually) were stationed on the Island for one-year terms from 1989–90 to the present day. Their primary focus was weed eradication, although the skills of the personnel selected also had to focus on the need to maintain accommodation, communications and facilities on the Island, as well as provide additional weather data on contract to the Met Service.

A chronological list of those staff who have been primarily responsible for weed eradication on Raoul Island is given in Appendix 1.

4. Revised classification for weeds

The entire exotic flora is considered in this report to provide a baseline of what species are present in 1993–94, their general abundance (differences from those noted by Sykes (1977a) are given) and the level of threat posed to the indigenous vegetation. Also, the flora is divided between those which were introduced deliberately for food or decoration and may have historical significance and those which were of accidental or deliberate genesis and are not seen to have any historical significance. Species designated for eradication (category A) may have historical significance but their threat to conservation of the natural state of the Island far outweighs their value as a historical resource.

All of the species previously listed in control programmes are discussed in detail (as outlined in the introduction) and a few species requiring more attention are added to these detailed descriptions. The remainder of the flora is appended in two categories, as indicated above (Appendix 2, 3).

It is apparent that some of the species listed in each category in 1992 do not fit the definitions given for them and that some species should be placed in another category. In addition, the 1992 category B is redundant, for two reasons. Firstly, the two species listed do not pose the threat that was first envisaged, partly because of changes resulting from the eradication of goats. Secondly, we are most unlikely to be in the situation where eradication of these species is feasible. Thus, a revised classification of three categories is suggested:

A Species which so threaten (whether actually or potentially) the preservation of the natural state that their eradication is essential, and recently introduced species which pose a lesser threat whose eradication is achievable.

B Adventives resulting from accidental or deliberate introduction which have no historic significance and which pose a minimal or no threat to the forest ecosystem of Raoul Island.

C Persistent relics of cultivation of historic significance or providing edible fruit which may be protected.

Category A contains all species which must be eradicated, however, this category is subdivided into two sections:

Category A(i) Species which are known to have the potential to significantly alter the structure and composition of the native vegetation of Raoul Island in the long term.

Category A(ii) Species which are unlikely to have long term significant impact on the structure and composition of the native vegetation of Raoul Island but which are of sufficiently low abundance to be eradicated.

Categories B and C comprise all other species, some of which may have to have some degree of control exercised over them. It is important to distinguish

between those species which may have historical significance (category C) and those which do not (category B), given that the Department is charged with protecting resources of historic as well as natural significance. It is possible also, that some of the old cultivars present on the Island (e.g., of grapes, peaches or citrus) could have horticultural value and should be retained on the Island until more is known about them (this is the subject of a separate, rather long term, investigation that I am carrying out). Those species which should be controlled in some locations or should be observed for information on rate of spread or ability to set seed are discussed in detail for both categories. In some cases species listed in category B would have been listed in category A but the opportunity to eradicate them has been missed.

Species discussed in detail within all three categories are:

Category A(i)

Caesalpinia decapetala — Mysore thorn

Senna septemtrionalis — Brazilian buttercup

Passiflora edulis — black passionfruit

Anredera cordifolia — Madeira vine

Psidium cattleianum — purple guava

Psidium guajava — yellow guava

Olea europaea subsp. *cuspidata* — African olive

Cortaderia selloana — pampas grass

Araucaria heterophylla — Norfolk pine
(plants of nonhistoric significance only)

Furcraea foetida — Mauritius hemp

Ricinus communis — castor oil plant

Phyllostachys aurea — walking stick bamboo

Brachiaria mutica — Para grass.

Category A(ii)

Foeniculum vulgare — fennel

Gomphocarpus fruticosus — swan plant

Populus nigra — Lombardy poplar

Senecio jacobaea — ragwort.

Category B:

Alocasia brisbanensis — aroid lily

Stenotaphrum secundatum — buffalo grass

Cirsium vulgare — Scotch thistle

Bryophyllum pinnatum — air plant

Tropaeolum majus — garden nasturtium

Trifolium campestre — hop trefoil

Vicia sativa — vetch.

Category C:

Cordyline fruticosa — ti

Aleurites moluccana — candlenut

Hibiscus tiliaceus — shore hibiscus, fou

Brugmansia suaveolens — night bells

Araucaria heterophylla — Norfolk pine (adults of historic significance only)

Prunus persica — peach

Vitis vinifera — grape

Phoenix dactylifera — date.

The remainder of the exotic species are assigned to either category B or C and are listed at the end of this report (as Appendices 2 and 3, respectively) with brief notes on current distribution and date of first record, if known.

4.1 MODUS OPERANDI

Eradication takes priority over control. Within category A species are listed in order of the perceived threat posed to native vegetation. All will have an impact, but some will spread more quickly than others whereas some will be more difficult to control than others, and the priority order suggested takes into account both of these factors. Within category B species are listed in order of perceived threat and the desirability of control at some locations. The listing in category C is in order of historical value for all species which have ever been listed specifically in an earlier control programme or which may be regarded as weedy to some extent. Thus, when detailing specific work programmes the order of species listings should be taken into account.

5. Category A weeds

SPECIES WHICH SO THREATEN (WHETHER ACTUALLY OR POTENTIALLY) THE PRESERVATION OF THE NATURAL STATE THAT THEIR ERADICATION IS ESSENTIAL, AND RECENTLY INTRODUCED SPECIES WHICH POSE A LESSER THREAT WHOSE ERADICATION IS ACHIEVABLE.

Category A(i) ***Species which are known to have the potential to significantly alter the structure and composition of the native vegetation of Raoul Island in the long term.***

5.1 *Caesalpinia decapetala* — MYSORE THORN

5.1.1 History

Sykes (1977a) states that the first reference to this species on Raoul comes from Carver's (1889–93) plan of Bell's garden in Denham Bay in 1891, where he included an "acacia" forming part of the boundary. Neither Cheeseman (1888) nor Oliver (1910) recorded Mysore thorn as a naturalised plant and presumably, at that stage, it was still fulfilling its primary function as goat-proof fencing for the plantations (Sykes 1977a). The Bell family had lived on the north side of the Island probably since early 1880 (Johnson 1991) but continued to farm at Denham Bay for as long as they could. Thus, some form of fencing to exclude goats and sheep from plantations would have been necessary.

In 1937 Davison (1938) noted that "acacia" had been introduced to Raoul by settlers. In maps appended to the report of the Aeradio Committee (of which Davison was part) the acacia is marked to the north-west of the swamp in Denham Bay, in the area initially occupied by the American settler Halstead (Johnson 1992). Aerial photographs of Raoul Island taken on 29 January 1943 show clearly a large, almost continuous infestation of Mysore thorn extending back towards the cliffs at the north-western edge of Denham Bay swamp. At this date, the extent of the infestation is calculated as being 4 ha. In 1944, Sorensen (1944) observed that dense clumps of a thorny acacia which extended over many square chains of the Denham Bay flat near the swamp and back at the foot of the cliffs, were up to 20 ft high in places and had "choked out quite an area of native plants and two large orange trees". He noted that it was flowering profusely (in August) and was extending its range, and he regarded it as harmful to native vegetation. Sorensen also reports from Davison (who was on the Island again in 1944) that the Mysore thorn had vastly increased since 1938.

Davison (1938) knew about the Mysore thorn, but did not regard it as a serious threat to the native vegetation of the Island, as he states in his report: "Apart from the arum [*Alocasia brisbanensis*] and cherry pie [*Ageratum*

houstonianum] and a creeping plant like a cucumber but with a bunch of seed head covered with hairy spines [*Sicyos australis* — a native species], the Island is remarkably free from weeds of a harmful nature, and special efforts should be made to keep it so, and care should be taken that undesirable plants are not introduced with the packing straws, etc., of imported stores." Obviously, Davison and Sorensen discussed the Mysore thorn in Denham Bay when they were both on the Island in 1944 (Sorensen 1944), but it was not until 1967 after the OSNZ party had visited Raoul that concern was expressed to the Department of Lands and Survey of the threat the Mysore thorn posed to indigenous vegetation of the Island. Bill Sykes, botanist on the expedition, recommended eradication (Merton 1969).

Aerial photographs of Raoul Island taken on 26 November 1964 unfortunately do not cover Denham Bay. Sykes (1977a) records that in 1966 and 1967 Mysore thorn was growing over considerable areas of Denham Bay and that the stems climbed to nearly 20 m. In his view, the Mysore thorn seemed to threaten the indigenous vegetation of Raoul more than any other introduced plant. In 1972, Mysore thorn was estimated to cover 16 ha in Denham Bay, and by 1974, the area covered was more accurately estimated to be 22 ha (Devine 1977). Control of Mysore thorn in Denham Bay commenced in 1974 with aerial application of Tordon 2G but the area covered was less than that originally intended because of hopper failure during the operation. When Atkinson visited Raoul in 1975 he also estimated the area of serious infestation to be 22 ha, based on measurements from aerial photographs taken on 29 July 1975. A smaller infestation of 1.1 ha was noted south of the Denham Bay swamp and other smaller clumps were seen (Atkinson 1975). Thus, one year after the control operation commenced there was no obvious reduction in the area occupied by Mysore thorn. The effect of the first application of Tordon was to kill about 90% of an infestation but some stems survived and seedlings germinated through the area, although not abundantly (Atkinson 1975). In 1975 Tordon was again applied aerially by helicopter to the worst areas of Mysore thorn infestation in Denham Bay (Atkinson 1975).

The extent of mature vines was reduced rapidly by the use of chemicals and burning, and during the 1980s Sykes (1980, 1984, 1990), on his regular visits to Raoul, saw only seedlings on the flat in Denham Bay. In 1980, he strongly recommended that burning of the fern-covered clearings be continued, to hasten the decline of the Mysore thorn seed bank. Hancox (1982) worked on Raoul in 1981 and stated that much of the original infestation was under control and in future more time would be spent "pushing through the undergrowth to look for the individual plants". When Sykes visited in 1984 he formed the same opinion, stating that blanket spraying and burning of areas was no longer required and that control would consist of hand pulling of seedlings and spot control of larger vines (Sykes 1984). Bracefield (1987) removed 2146 vines from Denham Bay and blanket sprayed one area. Gardner (1988) killed a total of 5468 plants. Aerial photographs taken on 2 March 1992 show no trace of Mysore thorn in Denham Bay. Although Mysore thorn was present at this date, it was limited to single, small plants which are not detectable on aerial photographs. Several seeding vines were killed in 1993 (pers. obs.) and in 1994 two seeding plants, several flowering plants and hundreds of seedlings were removed from Denham Bay (Fastier 1994). There have been no more seeding

adult plants found since then although more seedlings and non-flowering vines up to 6 m long have been removed (Uren 1994).

The Mysore thorn growing on the cliffs behind the bay has been difficult to gain access to, but careful climbing and abseiling to each plant have enabled effective control. The cliffs have been a focus of Mysore thorn eradication since 1974, including aerial operations, and Sykes (1980, 1984, 1990) has consistently reminded weed workers of the need to destroy these plants. Today the cliffs remain the most difficult point of control and three sites containing flowering vines were observed by Uren (1995b). These are targetted for control.

An infestation of Mysore thorn has been known of towards the head of Ravine 8 (see Figure 2) since before 1972 (Devine 1977). In 1972 this infestation was estimated to cover c. 1000 m^2. From 1972–73 the Mysore thorn at this site was used in trials to evaluate the effectiveness of Tordon 2 G granules. In 1975, after widespread use of this herbicide on the Ravine 8 infestation, only two vines and 39 small seedlings remained alive; the seedlings were pulled out (Atkinson 1975). In 1976, seven vines were recorded at this site (Trotter 1976). Ombler (1977) reports that in 1977 there was an area of dense Mysore thorn regeneration at the lower end of the plot and 50 seedlings were scattered over most of the original plot area. The seedlings were pulled by hand and the dense patch sprayed with Tordon 520. In 1978, 21 seedlings were removed (Dale (1979) and in 1979 13 seedlings were pulled out (Adlam 1979). No plants were found in 1982 whereas in the previous year two plants were noted growing from old rootstock (Selby 1982a). Sykes (1984) found one large plant in this site which had not been checked for over a year. In 1990 only two plants were present and these were both killed (Clapham 1991a). The site has been checked regularly since then and no further plants have been found.

5.1.2 Ecology

Mysore thorn is a scrambling spinous vine with narrow pinnate leaves, in the legume family (Fabaceae). This vine will grow at least as tall as the vegetation which supports it and when growing on Kermadec pohutukawa, therefore, it will grow up to 20 m tall (Sykes 1977a). The species is light-demanding and germinates only in high light environments, such as canopy gaps dominated by ferns (*Histiopteris incisa* and *Hypolepis dicksonioides*) or open areas on the cliffs behind Denham Bay. Occasionally plants will germinate in areas dominated by ladder ferns (*Nephrolepis* cf. *cordifolia* and *N. hirsutula*) beneath a light and sparse canopy, and they will be straggly until they reach the canopy. Once in the light they will grow prolifically and quickly spread across the canopy. In 1982, Selby (1982b) reported for the first time that Mysore thorn does flower within its first year. Within seven months plants had germinated, grown up to 2 m in length and were flowering. He noted, also, that this vine will flower when beneath a fern canopy.

Growth of plants is rapid. Rees (1982) monitored the growth rate of nine seedlings from a range of situations in Denham Bay (Table 1). He found that plants seemed to grow slowly up to 800 mm tall and then grew rapidly. The initially slow growth rate was assumed to be a result of competition with ferns, aroid lily and nightshade (*Solanum americanum*). Sykes (1990) warned that Mysore thorn could flower and form fruit in well under two years in good

conditions and noted that nine-month-old plants were flowering. Samson (1993a) observed that seedlings could grow up to 2 m in a few weeks and could be setting seed when only 4–6 months old. Young plants are cryptic. Frequently they germinate among water fern (*H. incisa*) and the shape and colour of the water fern and the Mysore thorn are so similar that many young plants remain undetected. Even when growing up a trunk on the edge of a light gap, young plants can be missed easily. However, as soon as the plants commence flowering the bright yellow flowers are very visible (Figure 3), and the plants are easily detected from any distance. Plants usually flower from June through to November. The length of time from flowering to seed set is not known but seed pods are persistent and can be found year round on adult plants.

Seed pods contain 7–10 small, brownish seeds which have very hard seed coats. The seeds can remain dormant in the soil for a number of years (a characteristic of many legumes) and usually germinate when they are exposed to light. Thus, soil disturbance in areas previously occupied by Mysore thorn is likely to result in exposure of seeds followed by seedling germination. Ombler (1977) reported that hundreds of Mysore thorn seedlings had sprouted in slips

TABLE 1 GROWTH DETAILS OF NINE MYSORE THORN SEEDLINGS AT DENHAM BAY (REES 1982).

	PLANT NUMBER (HEIGHT IN mm)								
DATE	1	2	3	4	5	6	7	8	9
5/12/81	40	–	40	–	50	–	50		30
3/1/82	200	–	90	280	170	–	110	100	80
9/2/82	310	400	200	410	270	170	180	170	160
3/3/82	450	420	340	540	490	305	440	200	320
2/4/82	450	450	340	720	800	460	500	200	360
4/5/82	450	510	350	1000	900	640	500	210	500
1/6/82	530	580	420	1000	1060	830	690	350	590

Details of plants

Plant 1: burnt area among nightshade.
Plant 2: first plant in burnt area died, another selected just outside burnt area.
Plant 3: burnt area among nightshade, nearly died in January.
Plant 4: bush edge under tree canopy among aroid lily and ferns.
Plant 5: among old vines on top of large rock with very little soil.
Plant 6: old slip near a large rock, among old vines and aroid lily.
Plant 7: among old vines and aroid lily just under tree canopy.
Plant 8: on track under bush canopy.
Plant 9: burnt area among young nightshade and fern.

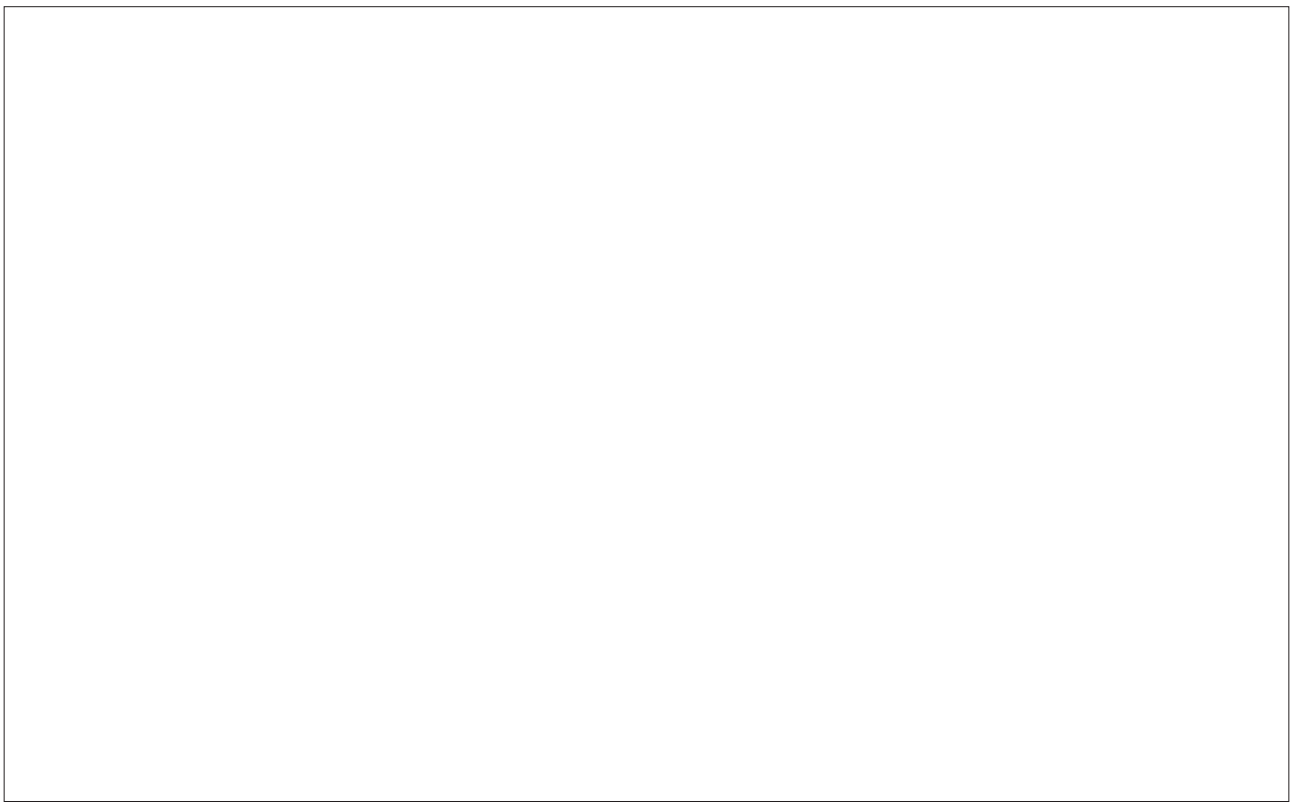


Figure 3 Mysore thorn flowering in a ferny clearing in Denham Bay, August 1990 (Photo: W.R. Sykes).

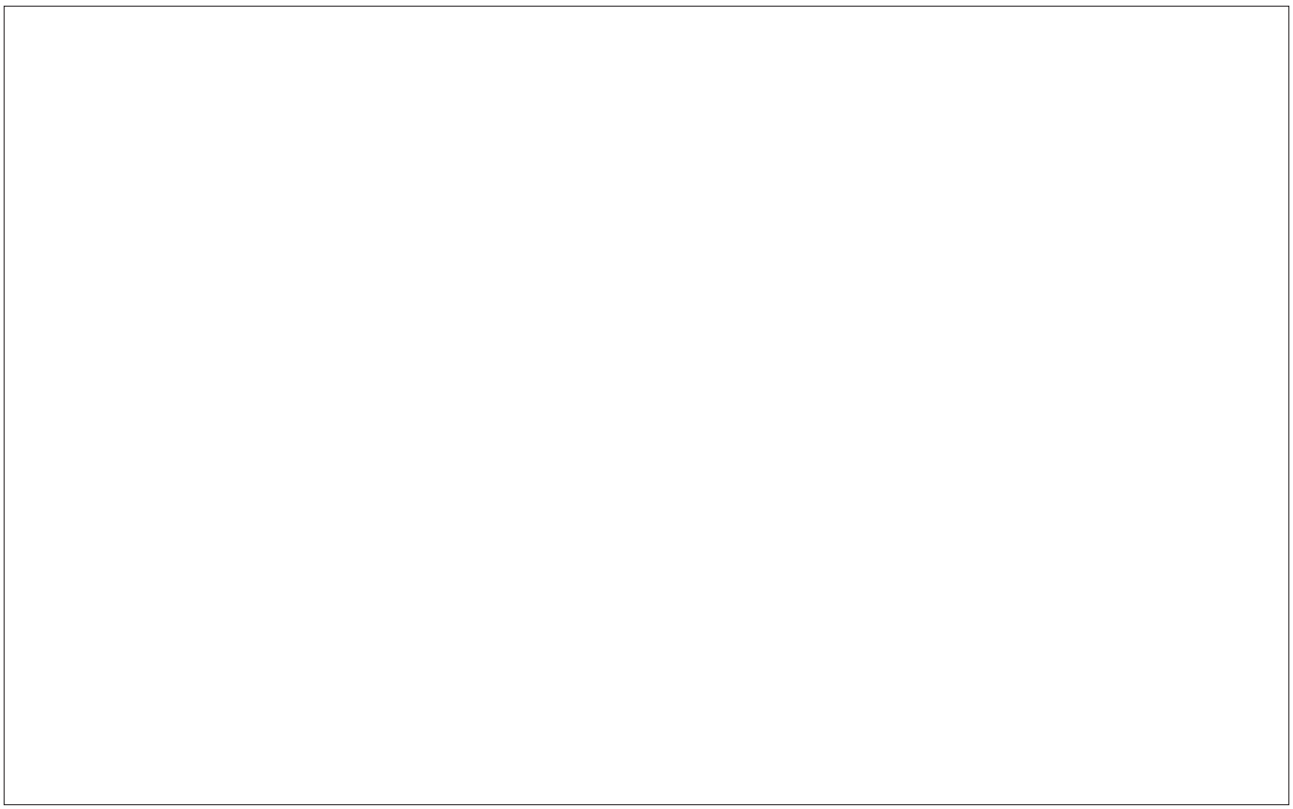


Figure 4 Knapsack spraying of Mysore thorn in Denham Bay, 1976 (Photo: J. Trotter).

along the base of the cliffs which were caused by earthquakes in 1976. Mysore thorn seeds are not normally dispersed far from the parent plant. Champness (1975) noticed that the pods open facing upwards and the seeds lie in the open pod until disturbed by wind or rain. Thus, seeds are likely to be dispersed only a few metres away and, in general, seedlings are most likely to appear where adult plants have been. Occasionally, however, longer distance dispersal can occur. The small infestation in Ravine 8 that was discovered in the early 1970s may have resulted from seed dispersed by humans or by wind. Although wind dispersal sounds unlikely, it is possible. Ravine 8 is due north of the largest area of Mysore thorn in Denham Bay and during periods of strong winds, the ravine acts as a wind funnel. Atkinson (1975) suggested that a whole seed pod could have been carried to this site in an exceptional gale.

Essentially, the pattern of spread of Mysore thorn is predictable. Seeds are not dispersed far from parent plants and will germinate in high light environments. Seeds may persist in the soil for many years so areas where plants have grown need to be checked regularly for years to come. The only practicable point in the life cycle to exert control is before seed set. The aim is to halt any further additions of seed to the seed bank, thereby reducing the length of time that surveillance and control needs to be implemented. Mysore thorn can be searched for and found at any time of year but is easiest to spot when it is flowering. Therefore, control work must be carried out consistently over the flowering period (June to November) to catch plants while they are flowering but before they set seed.

5.1.3 Control methods

In the past, several control methods were used: aerial and ground-based application of herbicides, and burning. The earliest trials (1972–74) established that Tordon 2G granules could kill large, cut vines (Devine 1977). At the start of the control operation in Denham Bay, the initial knockdown was achieved by aerial application of Tordon 2G granules from a helicopter in a pattern which would open up the Mysore thorn canopy sufficiently to allow ground operations to be carried out in subsequent years. In 1975 all of the the Mysore thorn visible from the air was treated in six hours of flying time and this resulted in an estimated kill rate of >70% (Champness 1975).

The ground-based operations relied on a water pipeline system which was reticulated through the worst infested areas. Spray operators attached a motorised knapsack unit to the pipeline to spray Mysore thorn with Tordon 520 'Brushkiller' (Figure 4). The densest infestations were controlled in this way until at least 1986. By this time the pipeline was breaking down and knapsack spraying was continued for the worst infestations, without the use of the pipeline. Saltwater was often used instead of freshwater (e.g., Ombler 1977). Isolated plants and small seedlings were hand-pulled (Bracefield 1987). In 1991–92, plants were hand-pulled, if small enough, or cut and treated with Tordon 2G granules (Clark 1992).

Burning was also used in clearings dominated by Mysore thorn, as recommended by Sykes (1980). A trial in 1980 established that Mysore thorn could be killed by burning, and the other advantage was that baring the soil to that degree would enhance germination of Mysore thorn seeds, thereby

exhausting the seed bank more quickly (Sykes 1980). In 1982, five Mysore thorn plots were successfully burnt in Denham Bay. A further plot was not burnt because of lack of water (Selby 1982c). Since 1982 fire has not been used as a control method, possibly because most of the regeneration was of native species and young Mysore thorn could be more easily removed as individuals.

Currently Mysore thorn control is achieved by systematically searching the Denham Bay flats and cliffs and hand pulling all plants. Pulled plants are hung up in nearby vegetation to desiccate. Those plants which are too big to pull out are cut and Tordon 2G granules are scattered at the base of the plant. If any plants have set seed, as much seed as possible is collected, then taken back to the Hostel and destroyed.

5.1.4 Future work

The current method of Mysore thorn control should be continued for an unspecified number of years into the future. The unknown factor is the length of time that seeds can remain viable in the soil. Slips can occur at any time on the cliffs at Denham Bay — prompted by earthquakes or heavy rain (both of which are common phenomena) — and any freshly bared soil could contain viable Mysore thorn seeds. Ground can also be bared on the flats, through the uprooting of trees during cyclones, or through flooding. In 1993 several seeding vines were destroyed but they had already dispersed fresh seed. Even if no more Mysore thorn plants set seed on the Island from 1993, it could still be ten years (but most likely more) before viability of seeds in the seed bank is reduced to zero. The Ravine 8 site should be checked annually. Constant surveillance and immediate control are the keys to Mysore thorn eradication.

5.2 *Senna septemtrionalis* — BRAZILIAN BUTTERCUP

Previously *Cassia floribunda*

5.2.1 History

Brazilian buttercup was presumably introduced to Raoul Island as an ornamental shrub because that is the normal purpose for introduction of this species to other countries (Sykes 1977a). Because the species was not recorded as a cultivated or naturalised plant by Cheeseman (1888) or Oliver (1910), it is assumed that it was introduced this century. Sorensen (1944) did not record this species among his naturalised plant collections. By 1967 Brazilian buttercup was naturalised in the forest from the Hostel eastwards for c. 2.5 km (Figure 5), in gullies from Low Flat to Ravine 8, in the old Denham Bay plantations, near Boat Cove and at Blue Lake (Sykes 1977b).

Brazilian buttercup was also present on North and South Meyer (Taylor 1974, Sykes 1977a). Sykes (1984) later recorded this species as widespread and common on the middle and upper western faces of South Meyer and present, but less dense and more localised, on the western side of North Meyer. In c. 1985, Chandler (n.d.) commented on the contrasting growth form of the Brazilian buttercup on the Meyers and on Raoul. On the Meyers, the plants were

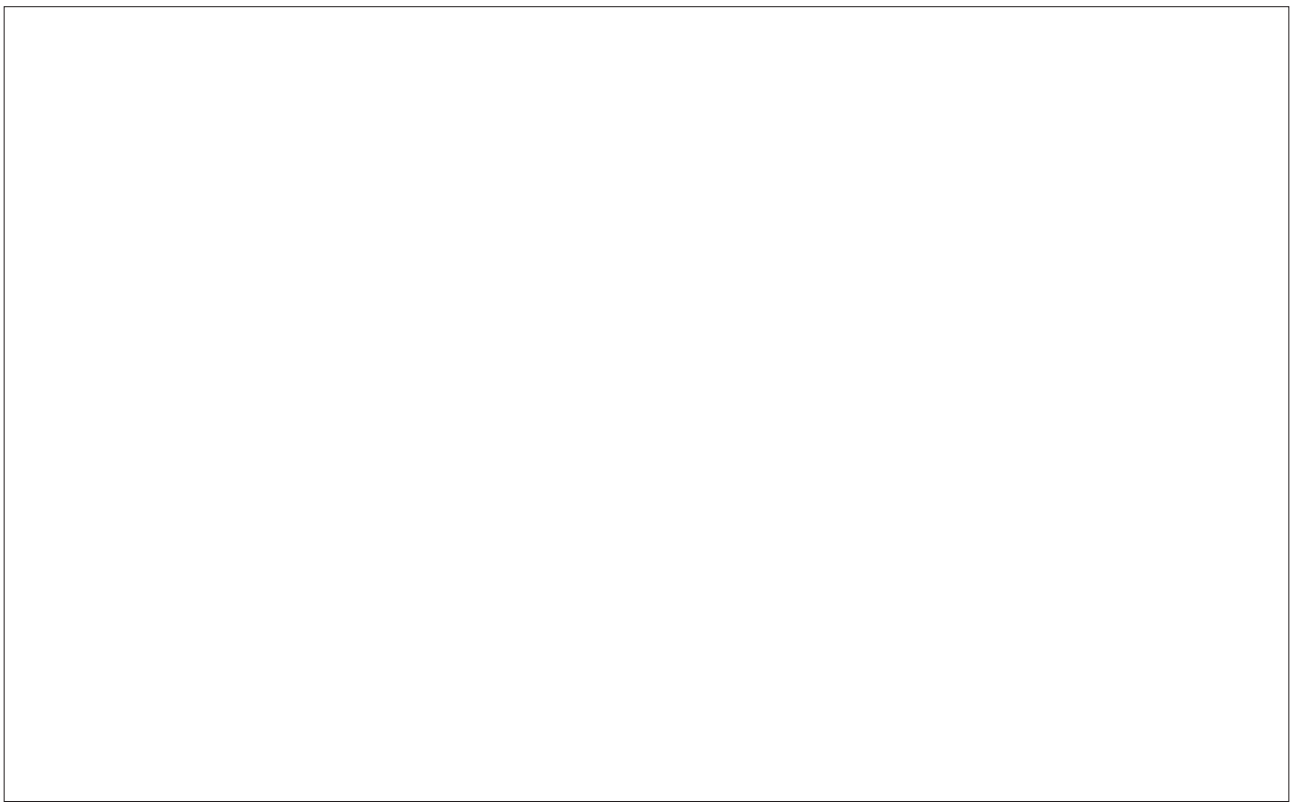


Figure 5 Brazilian buttercup lining the road behind Low Flat, 1966 (Photo: W.R. Sykes).

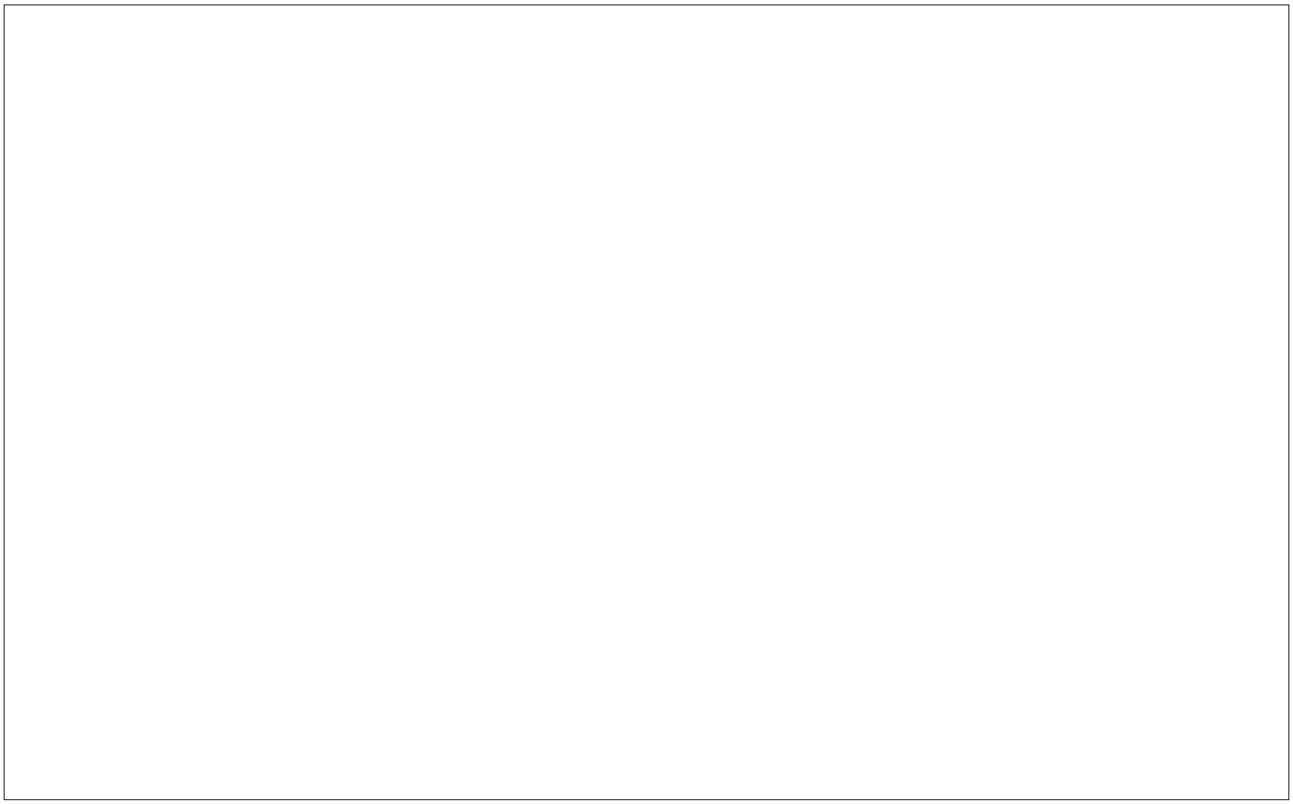


Figure 6 A dense mass of Brazilian buttercup sedlings being hand pulled by some of the volunteers in August 1993.

shorter and stubby with a thick stem and seedlings were few. In 1990, Sykes noticed that the Brazilian buttercup shrubs on North Meyer were under stress and had fewer leaves than the plants on Raoul. He also observed a general lack of Brazilian buttercup seedlings on North Meyer, in contrast to Raoul where seedlings were more abundant. However, Clapham (1991a) observed that the bushes on the Meyers, although smaller than those on Raoul, had seeded prolifically, and he collected five large freezer bags full of seeds from five small to medium sized bushes on North Meyer. Fastier (1994) and his team removed hundreds of mature Brazilian buttercup trees from the western slope of North Meyer and the north-western slope of South Meyer.

The original listing of category A species did not include Brazilian buttercup (Devine 1977) and eradication was not begun until 1978 after initial poisoning trials which commenced in 1975 (Anon. 1982a). Champness (1975) warned that this species was spreading rapidly and that germination success was very high. After control commenced, Sykes (1980) noted the obvious decline of the species around Low Flat, the Orchard, Denham Bay and the crater, as a result of spraying. However, Selby (1980) observed an increase in the number of young seedlings and suggested that this could be related to the low goat numbers. He thought that Brazilian buttercup seedlings would have been eaten by goats. In 1984, one small bush was found on the ridge between Mahoe and Darcy Point (Sykes 1984). This plant was removed, but could have resulted in a considerable increase in the range of Brazilian buttercup on the Island if it had seeded. Bracefield (1987) killed 64,365 plants and sprayed four areas, mainly on Low Flat and between Bell's Ravine and Ravine 6. Gardner (1988) killed 16,920 seedlings, from a wide range of sites. In a sweep of the Orchard from Denham Bay track to the edge of Bell's Ravine in October 1990, 436 Brazilian buttercup plants were removed (Crawley 1990). Very few of the plants seen by Sykes in 1990 were mature and those with pods were depodded and the seeds destroyed.

In January 1993, 12 mature trees and >1700 seedlings were killed around Blue Lake and several large trees and >6000 seedlings were removed from the bluffs and ravines above the airstrip (Samson 1993b). During the 1993–4 season, mature, seeding plants, some of which were estimated to be up to 10 years old, were located (or historic plots relocated) from near Western Spring as far east as Rayner Point spur on the north side of the island, around Blue Lake and extending 100 m up the lower slopes of Moumoukai, on the lower slopes of Mt Campbell and around Green Lake — especially the eastern side. Seedlings were recorded from Tui Lake and the vicinity of the swamp in Denham Bay (Fastier 1994). Several areas which required grid searching were indicated by Fastier (1994) and Uren (1995a) reported that 90 mature seeding plants, >1600 adolescents and >99,000 seedlings of Brazilian buttercup were killed from the crater area alone. In all cases seed pods were removed from mature plants and burnt at the Hostel, and the vegetation in the area of each infestation was cleared to provide more light and hasten the germination of Brazilian buttercup seeds. This latter strategy was suggested by Bill Sykes during his visit to the Island in 1994 (Sykes 1994).

Currently the species is scattered along the Northern Terraces from Western Spring in the west to Rayner Point in the east. In the crater it is scattered around all lakes but commonest around Blue Lake, and seedlings are occasionally

found at the northern end of Denham Bay. Thus, the species has extended its range since the late 1960s (Sykes 1977a). Mature seeding plants are still present and adding to the seed bank but are much less abundant than when the eradication programme commenced (Sykes 1994).

5.2.2 Ecology

Brazilian buttercup is a shrub, up to 4 m tall, with pinnate leaves and is in the same family as Mysore thorn (Fabaceae). The flowers are bright golden yellow and flowering is from November through to May (Rees 1982). Small green seeds (about the same size and shape as mung bean seeds) average 30 per pod (Champness 1975). Pods are clumped on the branches and seed production is prolific, e.g., Uren (1994) records that 2.5 kg of seed was taken from 11 mature flowering plants.

Like Mysore thorn, Brazilian buttercup is light-demanding and grows in light gaps in the forest or at the forest edge. When a mature bush is killed, hundreds of seedlings germinate in the space that the parent occupied (Crawley 1991b) (Figure 6). The greater part of this flush of germination is related to increased light levels once the parent canopy is removed. However, it is possible that the parent plant may also leach chemicals into the soil which inhibit seed germination.

The plants grow rapidly, and it is likely that plants in the forest which are two years old could flower and set seed (Sykes 1990). Flowering of plants is related to the amount of light received and can be a function of plant size. Plants do not flower in their first year, but those in high light environments could flower in the following year. In canopy gaps in the forest, plants are usually 2 m tall before they flower and set seed (Figure 7). As Uren (1995a) has observed "the life span of the Brazilian buttercup seems to be a short but fertile one".

Most seed is dispersed only a short distance from the parent plant, by the explosive opening of the seed pod. However, some seeds are carried long distances, e.g., the isolated young plant on Mahoe ridge and the infestations on the Meyers. Sykes (1977a, 1984) has suggested that birds are responsible for the long-range dispersal which has happened. Human visits to the Meyers are very infrequent, and Brazilian buttercup was already established there by the time of the Ornithological Society Expedition in 1966–7 which is when the islands had their most intensive period of human use. Birds could have dispersed the seeds in mud attached to their feet or feathers, or possibly as ingested seed. The seed is not likely to be eaten by the major seed dispersing birds though, because it is dry and not attractive to the disperser. It is possible that seed destroyers, such as kakariki which live on the Meyers but are recorded visiting Raoul (Veitch 1994), could disperse intact seeds. However, humans as a dispersal agent of Brazilian buttercup cannot be ruled out.

Because of the normal mode of dispersal, by explosion of the pod, spread of Brazilian buttercup is predictable. The extension of its range, since first recorded by Sykes (1977a) is a result of normal incremental spread. The seeds will persist in the soil for a number of years (a characteristic of many legumes). Therefore, any light gaps formed in previously infested sites are likely to have abundant germination of Brazilian buttercup. Numbers of seed buried in the soil are likely to be greater downhill of infestations, and will decrease with increasing distance from infestations.

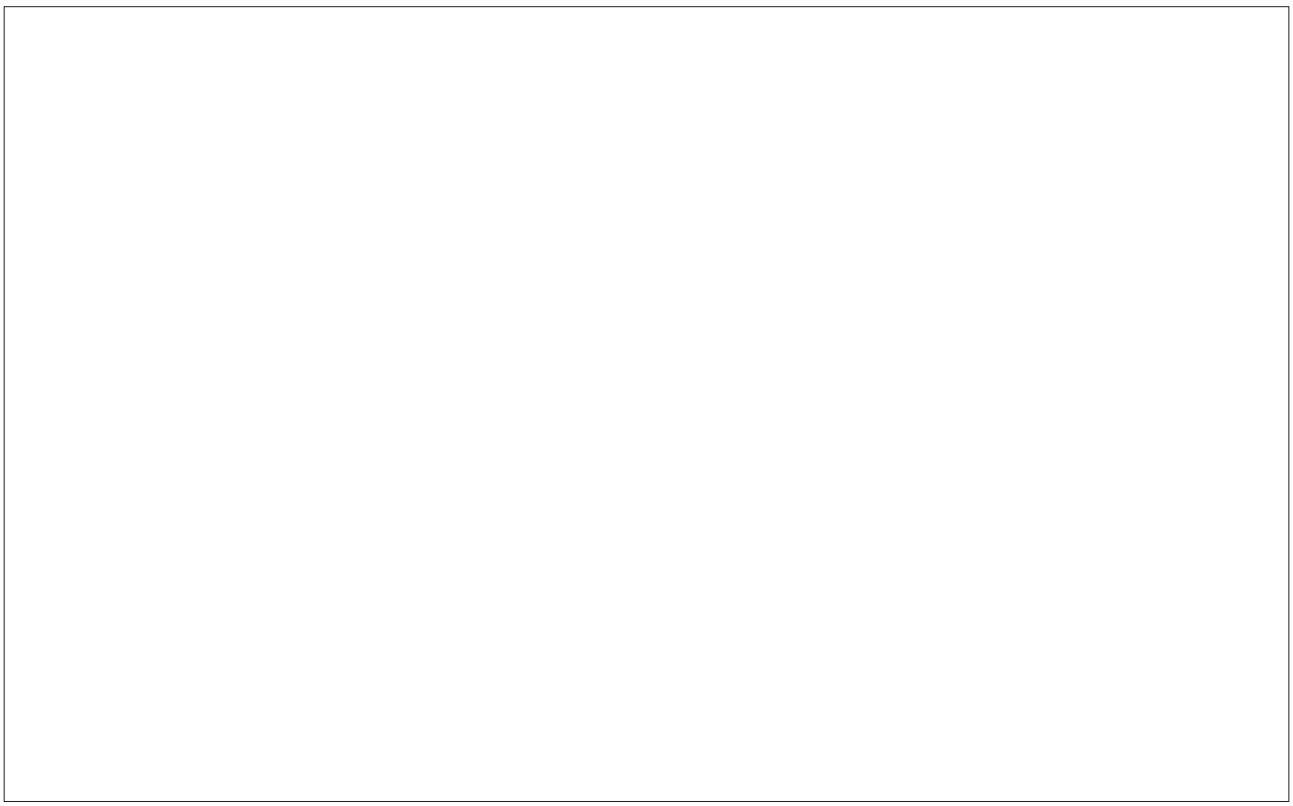


Figure 7 Young Brazilian buttercup shrubs in a forest light gap which have flowered and set seed for the first time, August 1993.

As with Mysore thorn, the practicable point of control is before the plants set seed for the first time. Plants are more easily seen when in flower. Where seedlings have come up densely where the parent plant was, the seedlings can be left to self-thin and pulled before they flower. As suggested by Sykes (1994) and implemented by Simon Uren and his team, clearance of the understorey vegetation where mature seeding plants have been killed should hasten the germination of seeds and theoretically reduce the number of seeds remaining dormant in the soil.

5.2.3 Control methods

Brazilian buttercup is very susceptible to the Tordon group of sprays (Sykes 1980) and Crawley (1991b) established that Escort effectively killed Brazilian buttercup trees. In 1991–92, seedlings were hand-pulled and the larger plants were cut and the stumps sprayed with Escort from 500 ml bottles (Clark 1992).

Currently, large plants are poisoned with Tordon 2G granules and adolescent and seedling plants are hand-pulled. Seed pods are removed from all fruiting trees and burnt back at the Hostel. Understorey vegetation is cleared in the vicinity of mature plants once they have been removed to encourage germination of seed in the soil.

5.2.4 Future work

The location of all known sites of Brazilian buttercup should be checked annually for regeneration from seed. Areas in the vicinity of each infestation should be grid-searched and more remote locations should be scanned at every opportunity. Part of the problem with the current abundance of Brazilian buttercup is that previously treated sites have not been visited for several years

and mature plants are now present on those sites. Incremental spread from the original sites has also resulted.

On the Meyer Islands a check should be made for flowering plants annually but (apart from flowering plants) destruction of plants should be undertaken every second year in order to minimise the damage to the fragile, burrow-ridden soils. The best time of year for control is late August–early September to avoid disturbing the majority of nesting or fledgling birds.

Because Brazilian buttercup has occasionally been dispersed long distances, e.g., Mahoe ridge, and many parts of the island are difficult of access and infrequently visited, it is suggested that helicopter surveillance during the flowering season of Brazilian buttercup could be a cost-effective method of determining the extent of this species. Further west towards Hutchisons Bluff, further east from Rayner Point and along both sides of Mahoe ridge are places which should be searched by helicopter. Surveillance by boat is another method which teams often try but this is weather dependent and only part of the coast and bluffs are visible.

5.3 *Passiflora edulis* — BLACK PASSIONFRUIT

5.3.1 History

This common edible fruit has probably been on Raoul since the days of occupation by the Bells. Black passionfruit was first recorded for Raoul Island by Sorensen (1944) and was well established by the time of his visit. Most of the original dispersal of naturalised plants was probably accidental by humans (Sykes 1977a), as black passionfruit seems to have spread out from foci where most human activity has been, e.g., Low Flat, Boat Cove and the crater. Some deliberate planting of passionfruit may have been undertaken by coast watchers. Grapes were planted near the observation hut on Trig V (Expedition Hill) and it is likely that the passionfruit observed at this location by Sykes (1977a) resulted from similar earlier plantings. One large vine was removed from among Mysore thorn in Denham Bay (Trotter 1976).

Both Selby (1980) and Sykes (1980) state that black passionfruit had spread considerably in the last decade and recommended that it be transferred from a category C weed to a category A weed. Ombler (1977) had also made this recommendation. Many plants had been destroyed in the Low Flat and Orchard areas by weed teams but there were still a number of mature vines and seedlings present. The species was subsequently transferred to category A and concerted efforts at control were commenced in 1980 (Anon. 1982a).

By 1984, when Sykes visited the Island again he observed a considerable amount of this vine especially in the area from Low Flat to Bell's Ravine. He also noted outliers near Fishing Rock road and at Blue Lake (Sykes 1984). Bracefield (1987) killed 7069 black passionfruit vines, from Boat Cove to Ravine 6 but mostly from Low Flat and Gardner (1988) killed 26,647 passionfruit, mainly from Low Flat. On his next visit, Sykes (1990) saw few black passionfruit plants but most were large. The distribution was similar to that known from past

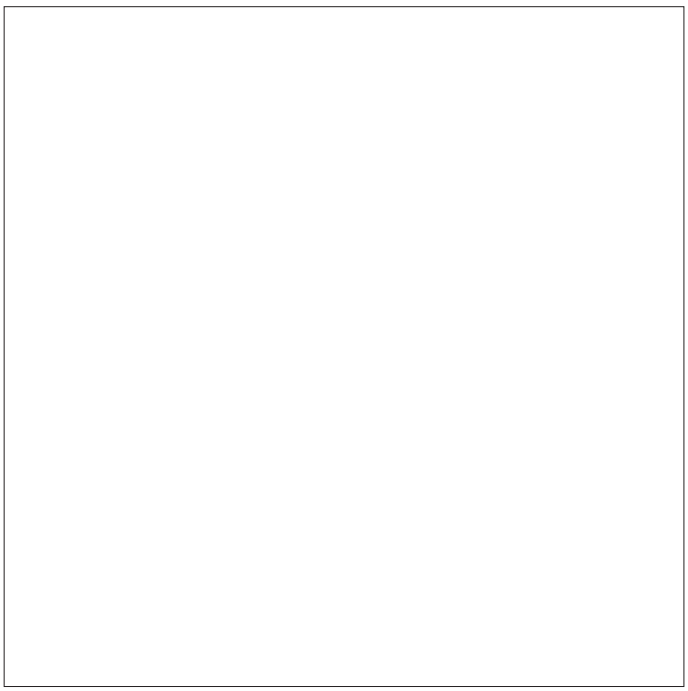


Figure 8 Black passionfruit flowers and foliage, 1944 (Photo: J.H. Sorensen).

years, but the density was much lower, and the plant he had previously seen at Trig V was gone. This plant had been destroyed in 1975 by Champness, much to the distress of the Meteorological Service staff on the Island at the time. Clapham (1991a) found plants up to 160 m altitude on Mt Campbell and recorded the spread of black passionfruit further west to Ravine 6. By 1994, passionfruit had moved further east and was above and below the road from Fishing Rock to Rayner Point and was also near Boat Cove Hut (Fastier 1994).

5.3.2 Ecology

Black passionfruit is a vigorous vine in the passionfruit family (Passifloraceae) which climbs with the aid of tendrils. The leaves are glossy and divided into three lobes. An important point to note is that the first 6–8 leaves of seedlings are undivided. Like Mysore thorn this vine climbs to the top of the trees which support it, and smothers them. The species is light-demanding and vines which germinate in a light gap send out several stems from ground level and these climb up stems when they encounter them. The flowers are produced singly and are large and showy (Figure 8). Flowering is from July to March. Fruits are dark purple when ripe and contain numerous black seeds which are surrounded by sweet pulp. The seeds are mature enough to germinate before the fruits turn purple (Sykes 1990). Fruiting is from January to April.

Fruits are eaten by rats (Norway and kiore) and birds (e.g., tui). Rats tend to destroy most of the seeds eaten whereas the birds disperse the seeds because they swallow the seeds whole with the pulp.

Vines are fast growing and are capable of flowering and fruiting within three years. Seedlings germinate in light gaps and light flecks and can be found scattered through the forest. Seedlings will often be found in tight clumps because they have germinated from a single bird dropping or the occasional whole fallen fruit which has not been eaten by rats. The pattern of spread of black passionfruit is not as predictable as the two legumes already mentioned, although to date, it appears to have steadily spread from the main focal point at Low Flat. New infestations could appear at locations remote from the current distribution, as a result of bird movements. For example, Mahoe ridge could be affected.

5.3.3 Control methods

Plants were hand-pulled or cut, but herbicides were not required for control (Clark 1992). Currently, mature vines are cut and the roots either pulled out or treated with Tordon 2G granules. Seedlings and young vines are pulled up and left to desiccate.

5.3.4 Future work

All sites from which passionfruit has been recorded should be checked annually. The range of this species overlaps considerably with that of Brazilian buttercup, so the two species can be checked and searched for in tandem.

Aerial reconnaissance, as recommended for Brazilian buttercup, will be useful to determine the extent of this species. It has tended to spread from foci of human activity, but because of its fruiting habit, seeds are likely to be spread to remote sites. Mature vines should be easy to spot from the air because of the large glossy yellow-green leaves which will be in the pohutukawa canopy.

5.4 *Anredera cordifolia* — MADEIRA VINE

5.4.1 History

Sykes (1977a) suggests that Madeira vine has recently become established on Raoul and notes that in 1967 it was growing in a ravine near the Meteorological Station — near a rubbish dump and further down near the beach. Champness recorded two plants in 1975 — one in Bell's Ravine and one near the Norfolk Pines at Denham Bay, and observed that both plants had run very wild. Time did not permit the removal of the Denham Bay plant — and there has been no record of it subsequently (it is likely that the Denham Bay plant was misidentified because it was never recorded there by anyone else). In 1976 Sykes (1977b) noted that the population in Bell's Ravine was decimated by floods which washed the plants out to sea and in the same year he reported Madeira vine from the open slopes immediately east of Fishing Rock where ten years earlier it was not observed to be present. From this time this vine was recognised as a potentially serious threat to vegetation on Raoul and attempts were made to control it with herbicides. In 1980, Sykes (1980) observed that there had been little spread of this species since 1978 and in 1984 he affirmed that there had been little change in the status of this species in the past decade as it was still present in both sites (Sykes 1984). This plant was added to the category A list in 1985 and the search for a herbicide which would kill it continued (Anon. 1985). Presumably, the persistent efforts to control this species had kept it more or less in the same places. Sykes (1990) recorded no significant change since 1984. Clark (1992) noted the presence of both infestations but Samson (1993a) did not find Madeira vine in Bell's Ravine. However, Fastier (1994) did locate Madeira vine there. Thus, the species still persists at both locations and has been reported as spreading further west from the Fishing Rock site (E.K. Cameron, pers. comm., Uren 1994) .

5.4.2 Ecology

This plant is a soft-leaved vine, in the family Basellaceae, whose leaves become more succulent when exposed to salt spray. Madeira vine has racemes of small white flowers on Raoul (from January to March) but has not been observed to set fruit. However, it is a threat because it disperses vegetatively by knobbly tubers (Figure 9) which are produced frequently in the leaf axils along the stems. The tubers are easily dislodged and roll down slopes. It is also possible

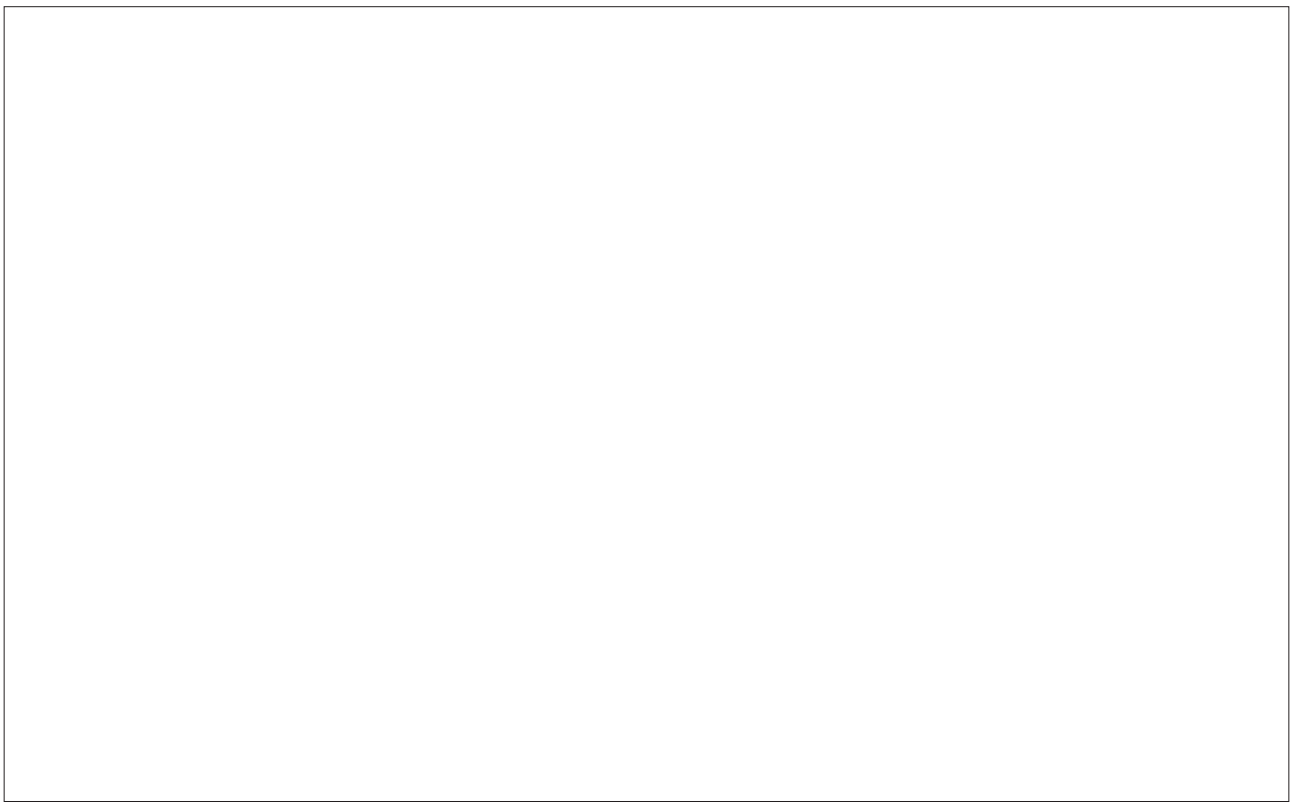


Figure 9 Madeira vine at Fishing Rock with large numbers of knobbly tubers and semi-succulent leaves, June 1993.

that they could be dispersed around the coast by sea, and establish new colonies if washed above the strand line. This is apparently the normal method of dispersal for this plant elsewhere in the Pacific (Sykes 1977b).

Like the other vines mentioned, Madeira vine is light demanding. At Fishing Rock it grows on a north-facing scree slope and is colonising the forest edge above the scree. Madeira vine is very tolerant of salt spray and grows in coastal locations in Rarotonga (Sykes 1977b). Although spread of the vine at the known locations will be predictable, tubers dispersing around the coast could result in infestations at a host of locations on Raoul, and the plant could also spread to the Meyers.

Whereas the leaves of Madeira vine are soft and susceptible to herbicides, the tubers are resistant. Regrowth of plants consistently occurs from tubers. Thus, the plant is very difficult to eradicate.

5.4.3 Control methods

Selby (1982d) and Sykes (1984) commented on the extreme resistance to herbicides that this species shows and suggested that physical destruction of the plants and tubers might be the only method of control. Ombler (1977) trialled Gramoxone paraquat, Tordon 520 Brushkiller and Tordon 2G granules on the Fishing Rock population and these appeared to kill all leaf and stem growth, but not the tubers. Tordon 50D was trialled by Dale (1979). Adlam (1979) treated one area at Fishing Rock with sulphuric acid and undiluted Weedazol TL and trialled Actazine 80 and Simazol 4A but none of these treatments were successful. A further trial with caustic soda apparently caused the breakdown of tubers into a jelly-like substance (Adlam 1979). It was suggested that Roundup (1%) and Weedazol (2%) be trialled for their

effectiveness at controlling Madeira vine (Anon. 1985). Gardner (1988) sprayed 50 m^2 at Bell's Ravine, although it is not stated which herbicide was used.

In 1991, Clapham used Escort on the infestation at Bell's Ravine, and part of the Fishing Rock infestation. He found that Escort didn't kill the tubers and suggested that the best way of limiting the spread of this plant would probably be to spray the fringes and remove the tubers by hand (Clapham, 1991b). Crawley (1991a) reported that Ammate XL killed only small patches of Madeira vine. Clark (1992) found that the plant at Bell's Ravine could be controlled by sheer persistence but at Fishing Rock the site is large and very steep and much more difficult to control. He could find no practical way to kill the tubers. Samson (1993a) sprayed the Madeira vine at Fishing Rock with Escort and Landmark and neither herbicide was effective. Fastier (1994) trialled the following herbicides on 2 x 2 m plots of the vine at Fishing Rock: Ammate, Roundup, Velpar, Escort, 2, 4 D, and Tordon D5 and 2G granules. All poisons seemed to be ineffective. Whereas some of the vines wilted the tubers were not affected by any of the herbicides used.

Many different herbicides have been trialled in an effort to kill Madeira vine. However, the resistance of the tubers leads to continued growth. The leaves and stems of the parent plant are killed but new growth sprouts from the tubers.

Manual removal of tubers from the site appears to be the only option for eradication. Tubers should be collected into sacks and then burnt or covered in thick black polythene to enhance rotting. Tubers which are jammed in rock crevices could be damaged with crowbars and have herbicide applied. Alternatively, they could be marked and any new foliage repeatedly removed, either manually or with herbicide, until the reserves of the tuber are used up.

Thus, a suggested procedure for eradication is:

1. Rig up security lines at the Fishing Rock site.
2. Spray the infestations at Fishing Rock and Bell's Ravine with Escort or Roundup to knock down the foliage and stems.
3. Remove all accessible tubers by hand, gathering them into sacks and taking them back to the Hostel for destruction in the fire pit.
4. Mark the locations of all tubers lodged in rock crevices or buried too deeply to remove safely and persistently spray or remove by hand all regrowth which sprouts from the tubers. Eventually, the reserves in the tubers should be exhausted if the regrowth is removed before it has translocated food to the tubers.
5. Record the success (or otherwise) of this method to enable a change of approach if this is not working.

5.4.4 Future work

It is imperative, given the difficulty of killing this species, that the relatively small infestations currently on Raoul be eradicated. Since the tubers are resistant to herbicide, it is highly likely that they are resistant to salt water also. Therefore, it is only a matter of time before the tubers which roll down the scree slope at Fishing Rock fall into the sea and are dispersed around the coast.

This may be the mechanism by which the Fishing Rock infestation established because this plant was known only from Bell's Ravine in 1967.

Manual eradication of this species has been suggested as the only effective method since 1984. The seriousness of the threat that this species poses should not be underestimated and physical removal of the tubers must be commenced immediately. While the method suggested might seem daunting and tedious, it is an untried option and should be attempted now before the scale of the problem becomes larger and eradication becomes even more difficult.

5.5 *Psidium cattleianum* — PURPLE GUAVA

Previously *Psidium littorale*

5.5.1 History

Cheeseman (unpub.) records purple guava as a crop grown by Bell in 1887. In 1944, Sorensen noted several trees of what he tentatively called red guava in Denham Bay and stated that there was no sign of fruit on them. However, since he photographed purple guava from the northern side of the Island, but called it yellow guava, it is possible that his record of purple guava from Denham Bay is incorrect. Sykes (1977a) did not record purple guava from Denham Bay, so it seems likely that it was never grown there, although Sykes (1990) mentions a report of it from the south-east end of Denham Bay.

The main localities for purple guava are Low Flat through to the Orchard behind the Meteorological Station (Sykes 1977a) and further west to the ridges above the Woolshed, the crater near Blue Lake and Tui Lake and near the Fishing Rock road junction (Fastier 1994).

Purple guava has never been recorded naturalising in large numbers on Raoul, although it has spread into the crater in the last 20 years. Given its invasive behaviour on other Pacific Islands, it is prudent to eradicate this species before it does disrupt the forest ecosystem on Raoul. Eradication of purple guava began in 1973 and by 1980, as a result of the work done, Sykes (1980) could not find the species growing on Raoul in November 1980. However, he advised vigilance with regard to this species. When Sykes next visited Raoul, in October 1984, he found quite a few plants, some of which were too large to pull out. Also a single flowering tree was found in the Dry Crater by Tui Lake, a considerable distance from previously known sites (Sykes 1984). Bracefield (1987) killed 99 "guava", species not specified, mainly from near the Woolshed. Gardner (1988) killed 302 purple guava, mainly from the Orchard. In October 1990, 82 plants were killed in the area between Denham Bay track and Bell's Ravine (Crawley 1990). In 1990, plants were found in the Orchard and by Boat Cove Road (Sykes 1990). Clapham (1991a) killed 15 purple guava in the Dry Crater and 172 "guava" less than 1 m tall, most probably this species as it is the more common. In 1994 purple guava was found along the lower northern slopes of the Island from Bell's Ravine to the crater rim near the Fishing Rock road junction and was common in the Tui Lake/Dry Crater area and on the southern side of Blue Lake. All plants were destroyed (Fastier 1994).

More mature plants and saplings were killed on the southern side of Blue Lake in early 1995 (Uren 1995a) and only occasional plants were noted and removed from the northern side of Raoul.

5.5.2 Ecology

Purple guava is a small tree, reaching 6 m, in the myrtle family (Myrtaceae). The leaves are small (c. 5 x 3 cm) and glossy and the trunk is smooth with pale brown to reddish bark. The easiest way to find purple guava in the forest is to look for the trunk, as none of the native species look like this. Trees flower from June to March and fruit from late summer into autumn. The fruits are usually purple (occasionally yellow) and c. 2 cm diameter (Figure 10 and 11). The numerous small seeds are dispersed by birds which eat the fruit. Probably rats also eat the fruit but destroy most of the seeds. Because purple guava seeds are bird dispersed the pattern of spread is not predictable and it could establish in remote parts of the Island. Longevity of purple guava seeds in the soil is not known but may be several years as the seed coat is very hard. Cut stumps will regenerate vigorously from basal buds (Sykes 1990).

This guava is another light-demanding species and is most commonly found near the forest edge, e.g., the edge of Blue Lake, in the vicinity of the Orchard on the Northern Terraces, or in light gaps in the forest, e.g., in the crater.

5.5.3 Control methods

From 1973–75 trials using Tordon 2G and diesel painted on cut or ring-barked stems were not effective as treated plants recovered by suckering. Escort was trialled for its effectiveness in killing purple guava (Crawley 1990). This species was sparse in 1991–92, and treated by cutting, peeling back the bark and spraying with Escort (Clark 1992).

Any plants located should be hand-pulled, if possible. Pulled up plants should be broken and hung up to desiccate. If the plant is too large the stem should be frilled and Escort or Ammate applied to the cambial region.

5.5.4 Future work

Plots of known occurrence of purple guava should be checked annually for seedlings, and all areas of forest should be scanned for the distinctive trunks of larger individuals. Because this species can be bird dispersed all relatively open areas of forest are susceptible to invasion.

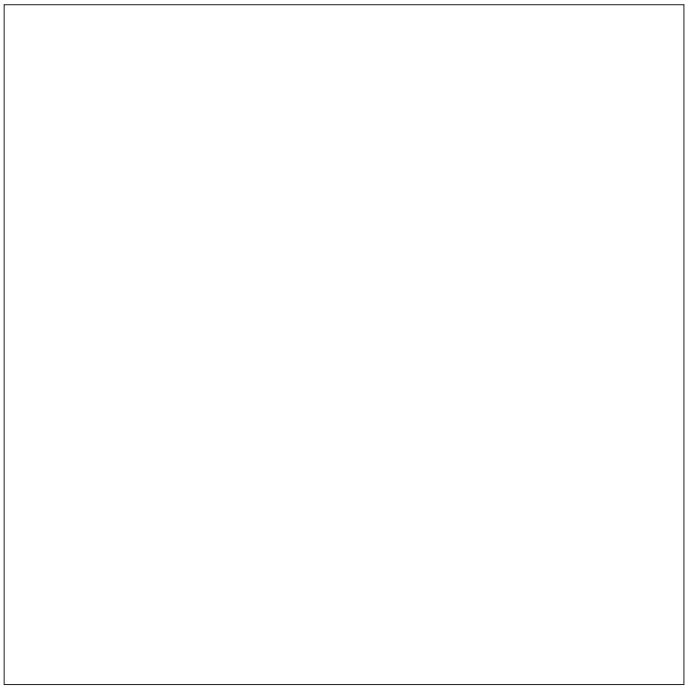


Figure 10 Purple guava with a flower and young fruit, 1944 (Photo: J.H. Sorensen).

5.6 *Psidium guajava* — YELLOW GUAVA

5.6.1 History

Yellow guava was introduced to Raoul as a fruit tree by the settlers of last century (Smith 1887, Cheeseman unpub.). It was not recorded as a naturalised plant until 1964 (Sykes 1965) when it was noted forming large suckering thickets on the northern side of the Island, in the crater and at Denham Bay. As with purple guava, yellow guava has not been noted in large numbers on Raoul Island. However, because this species is invasive in other Pacific Islands, eradication is desirable before the species does become a problem. Eradication commenced in 1972 and by 1980 there were still plants present above the Woolshed (Sykes 1980). In 1984 further plants were seen including one near Blue Lake which had been cut and poisoned but had resprouted (Sykes 1984). Gardner (1988) killed 92 yellow guava, mostly west of Bell's Ravine, and two from Denham Bay. Four plants growing between Denham Bay track and Bell's Ravine were killed in October 1990 (Crawley 1990). Sykes (1990) noted the persistence of this species in sites from which it had been known for many years, e.g., Denham Bay, Fishing Rock turn-off, by the road near the Woolshed, and near Blue Lake. In 1994, yellow guava was found in, and removed from, only two locations: the Orchard and the western shoreline of Blue Lake (Fastier 1994). One mature, fruiting plant has been removed from near Blue Lake since then (Uren 1995a).

5.6.2 Ecology

Yellow guava is a small tree, growing to c. 3 m, in the myrtle family (Myrtaceae). The leaves are large (up to 14 x 7 cm) and have strong venation.Young leaves are densely hairy. The bark is smooth, like that of purple guava. Flowering is from July to March and fruiting from summer to autumn. The fruit are up to 4 cm diameter and yellow-skinned and the many hard seeds are dispersed by birds. Rats will also eat the fruit but will destroy many of the seeds. This species persists by sprouting from basal and lateral buds when the main stem is cut, and spreads by suckering (Sykes 1990).

Dispersal of yellow guava cannot be predicted because it is bird dispersed. It has had a relatively wide distribution in the past: Denham Bay, the Northern Terraces, Low Flat and the crater. However, like purple guava, this species is light demanding so will be found in light gaps or at the forest edge.

Figure 11 Unripe fruit on purple guava, 1944 (Photo: J.H. Sorensen).

5.6.3 *Control methods*

From 1973–75 trials using Tordon 2G and diesel painted on cut or ring-barked stems were not effective as treated plants recovered by suckering. Sykes (1980) recommended the use of a tractor to pull out plants on the slopes above the Woolshed, given their resistance to sprays and their ability to resprout once cut.

Any plants located should be hand-pulled, if possible. Pulled up plants should be broken and hung up to desiccate. If the plant is too large the stem(s) should be frilled and Escort or Ammate applied to the cambial region.

5.6.4 *Future work*

Plots of known occurrence of yellow guava should be checked annually and all areas of forest should be scanned for the distinctive trunks of larger individuals. Because this species can be bird dispersed all relatively open areas of forest are susceptible to invasion.

5.7 *Olea europaea* subsp. *cuspidata* — AFRICAN OLIVE

Previously *Olea europaea* subsp. *africana*

5.7.1 *History*

This species would have been introduced to Raoul for its fruit, but possibly only this century since it was not noted by Cheeseman (1888, unpub.) or Oliver (1910). There is a note in Oliver's notebook (c. 1908) which is attributable to S. Percy Smith: "Olives also would flourish there". It is possible, then, that members of the Kermadec Islands Fruit and Produce Association syndicate took olive plants to the Island, following Smith's suggestion. Sykes (1977a) records African olive as being abundantly naturalised in 1967 on the Terraces, from the Meteorological Station to around Bell's Ravine. African olive was particularly concentrated in the Orchard covering practically the entire bush fringe from the implement shed back toward the main orange grove and past the Kalona Plot. It was mostly in semi-grassed areas but there were many trees on the bush ridges leading up to the cliff base (Anon. 1982a).

Eradication of African olive commenced in 1973 when a number of the larger trees (one 12 x 12 m) were cut down (Anon. 1982a). Considerable effort was put into locating and killing this species, including assistance from some Meteorological Service staff (Trotter 1976), and by 1980 it was mainly confined to a small area of the Orchard near the Kalona Plot and to the slopes above the Woolshed (Sykes 1980) although, during 1980, 700 trees were removed from the Orchard (Selby 1980). The species was still present in low numbers at the same sites in 1984, although some plants were nearly mature (Sykes 1984). Bracefield (1987) killed 38 olives: three were large trees and most were from the Orchard. Gardner (1988) killed 106, mainly from the Orchard. In 1990, Sykes observed one adult and one seedling in the Orchard close by the Hostel. Clapham (1991a) killed 86 African olive seedlings, mainly <1 m tall. Although,

with the control measures undertaken to date, African olive is infrequent, occasional large, fruiting trees are found (Fastier 1994, Uren 1995a). Currently the species is dispersed along the northern side of the Island from near the Woolshed to the Orchard area near the Hostel, and is occasional on the shore of Blue Lake and lower slopes of Mt Campbell. It has been found up near the transition zone of dry and wet forest (Uren 1995b). Thus, it has expanded its range since 1967.

5.7.2 Ecology

African olive is a tree, up to c. 12 m tall, in the olive family (Oleaceae). The leaves are green above and slightly grey below. Abundant small flowers are produced from July to March and the fruits are present from summer to autumn. Fruits are small (c. 8 mm diameter) and black, when ripe, and are eaten by birds. Rats may also eat and destroy seeds. Because this species is bird dispersed, it is likely to appear in locations remote from the original trees. However, like most other category A species it is also light demanding so will be found in light gaps or at the forest edge. This species suckers freely from cut stumps.

5.7.3 Control methods

From 1973–75 mature trees were cut and poisoned with Tordon 2G or 520 and diesel. This method was reasonably successful, although Dale (1979) noted regrowth and resistance to sprays used. Cutting stems without herbicide application resulted in regeneration of stumps by suckering. Seedlings of African olive were hand pulled. Sykes (1980) records the resistance of this species to herbicides and notes its ability to resprout from cut stumps. Selby (1980) noted that 12 different poisons were tried on this species but, apart from Tordon 520, none seemed to work. He wrenched all trees and burnt them. In this way, over 700 trees were killed in one year in the Orchard alone. Crawley (1990) noted that Escort was trialled for its effectiveness at killing African olive.

Any plants located should be hand-pulled, if possible. Pulled up plants should be broken and hung up to desiccate. If the plant is too large the stem(s) should be frilled and Escort or Ammate applied to the cambial region.

5.7.4 Future work

Plots of known occurrence of African olive should be checked annually and all areas of forest should be scanned for this species. Because this species can be bird dispersed all relatively open areas of forest are susceptible to invasion. Aerial reconnaissance by helicopter should also be used to check the distribution of African olive. The height that mature trees can reach plus the form of the tree canopy may enable mature specimens to be seen from the air.

5.8 *Cortaderia selloana* — PAMPAS GRASS

5.8.1 History

Pampas grass is one of the most recent plant introductions to Raoul Island and was first recorded on a retaining wall built near the flying fox at Fishing Rock in 1976. It appears that the final step of building an effective retaining wall was to sow some plant cover and pampas grass, a species not present on Raoul, was used. The pampas, and its assumed method of introduction was recorded by Sykes (1984), who removed the plants promptly. One of the plants had flowered earlier in the year. In 1990, Sykes inspected the retaining wall and found five or six plants, one of which had flowered. All of these plants were destroyed. Three plants were removed from the site in 1991 (Clapham 1991a). During my visit in 1993 a single juvenile plant which was growing on the retaining wall was pulled out.

The ease with which this plant was introduced to the Island illustrates the need for vigilance over movement of materials to Raoul.

5.8.2 Ecology

Pampas grass is a tall, tussock-forming species in the grass family (Poaceae) and the leaves have sharp, cutting edges. The flowers are borne in dense plumes on stalks up to 2 m tall and later develop into numerous wind-dispersed seeds. Pampas grass is a coloniser of open ground, and on islands such as Little Barrier has colonised open coastal sites. On Raoul, there are many open coastal faces and ridges which could be invaded by pampas. Since pampas grows taller and more densely than the species which currently colonise such sites it would be a very strong competitor and would dominate the sites, effectively halting forest regeneration.

5.8.3 Control methods

Hand-pull any seedlings which appear.

5.8.4 Future work

The last plant at the site was removed in 1993. The retaining wall and environs of the top winch shed at Fishing Rock should be checked annually until at least 2003 to ensure that any further plants which might germinate from seed stored in the soil are removed. Seed longevity of pampas is not known.

Figure 12 View west along Low Flat beach towards the Norfolk pines, 1944. At the extreme left on the skyline Norfolk pines naturalised in the forest are visible (Photo: J.H. Sorensen).

5.9 *Araucaria heterophylla* — NORFOLK PINE

(Plants of nonhistoric significance only)

5.9.1 History

Norfolk pines were planted on the Northern Terraces of Raoul by Thomas Bell towards the end of last century (Sykes 1977a). According to Venables (1937), in December 1936, one Norfolk pine 100 ft high and 5 ft in girth was chopped down to make a boat to sail to the southern Kermadec Islands, but the boat was too heavy. Some of the trees still present by the Woolshed are original Bell plantings but most of the group of 48 trees are the progeny of those trees. Champness (1975) noted 50 large trees at this site in 1975 and cited an unpublished report of J.E. Anderson from 1937 in which 23 trees of 70–103 feet tall (20–30 m) and 3–4 feet diameter (90–120 cm) were recorded at this site. During the past fifty years or more, Norfolk pines have naturalised into the forest, on bluffs above the terraces, as recorded by Sorensen (1944) (Figure 12). Periodically these trees in the forest are cut down. Currently there are a small number of trees emergent from the bluffs (Figure 13). All of the trees growing near the Woolshed have been measured, and on the basis of their diameter at breast height (d.b.h.), 12 trees have been identified as most likely to be from Bell's original planting. Most of these trees grow in a straight line from the road towards the coast but three of them are immediately west of this line with one near the Woolshed on the edge of Bell's Ravine (Figure 14). (It is possible that these three trees are not original plantings but have large diameters because they have grown in more open conditions away from the planted line.) The rest are derived from these original trees. Appendix 4 gives the d.b.h. for all trees measured in 1993; a total of 48 trees.

Figure 13 The same view in November 1994 showing the main group of Norfolk pines (see map in Figure 14) and outliers naturalised in the forest further inland.

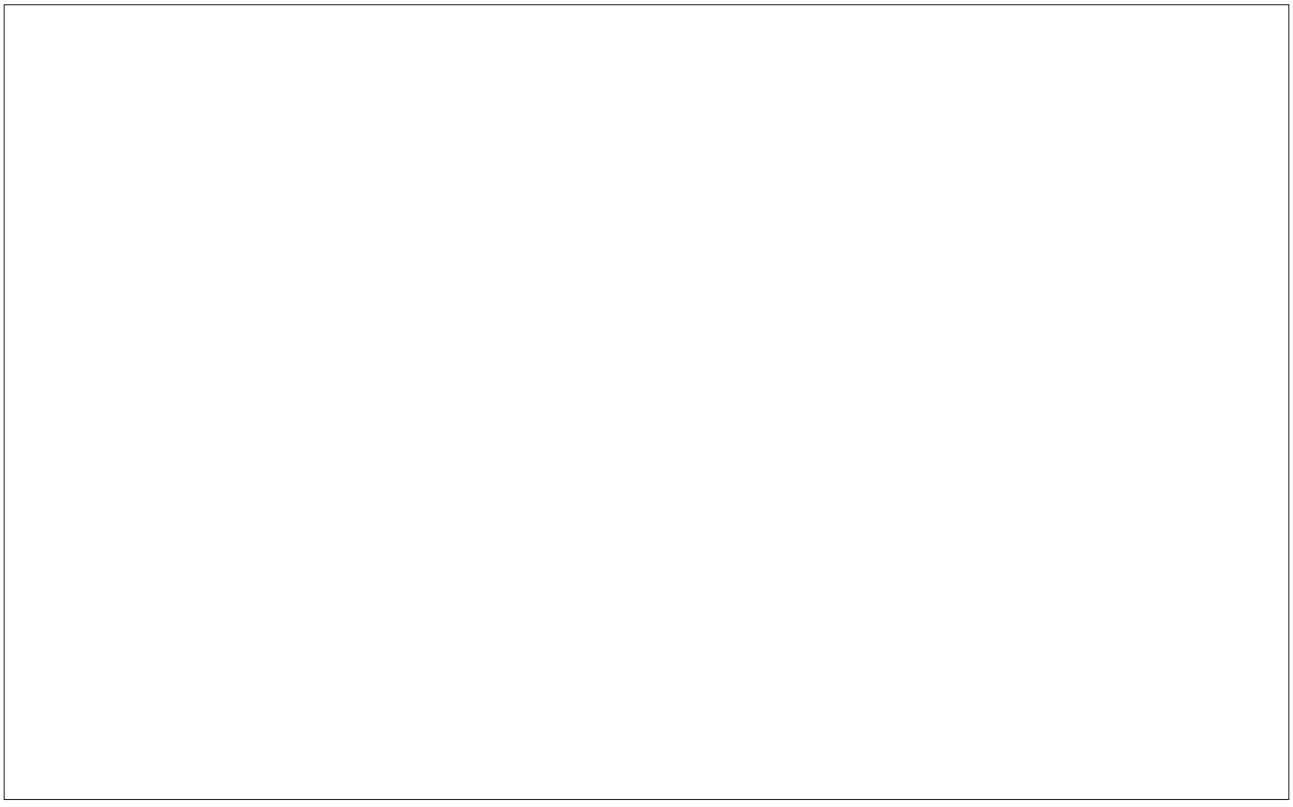


FIGURE 14 APPROXIMATE LOCATION OF THE 48 NORFOLK PINES NEAR THE WOOLSHED, 1993. TREES WHICH ARE ASSUMED TO BE ORIGINAL PLANTINGS HAVE THEIR DIAMETER ALONGSIDE. ISOLATED SMALLER DIAMETER TREES ARE INDIVIDUALLY SHOWN, AND THE MAIN STAND IS INDICATED BY THE BLOCK, SOUTH OF THE ROAD AND WEST OF A LARGE *Nerium oleander* BUSH. (Sketch-map not drawn to scale.)

A group of 4 trees at the south end of Denham Bay was established this century. They were assumed to have been planted by the Bells (Champness 1975). A photograph of the south end of Denham Bay taken by Oliver in 1908 shows no trace of Norfolk pines (Figure 15), but by 1944, when Sorensen was on the Island, they were obvious (Figure 16). Although instructed to remove these trees in 1976, the weed team left them because of concern for their possible historic value (Trotter 1976). Today they are still a prominent feature of the landscape (Figure 17).

Since the commencement of the weed eradication programme, thousands of Norfolk pine seedlings have been pulled out. Taylor (1974) removed one 8 ft tall tree from the track to Denham Bay near the top of the ridge. In 1975, 1023 seedlings and 5 young trees were killed in Denham Bay (Champness 1975). Bracefield (1987) removed six plants from Denham Bay. Gardner (1988) killed 130 plants in Denham Bay. Six plants were removed near Bell's Ravine in October 1990 (Crawley 1990). In March 1991, 2500 seedlings were pulled out in Denham Bay (Crawley 1991b) and a further 4000 were removed the following month (Crawley 1991c).

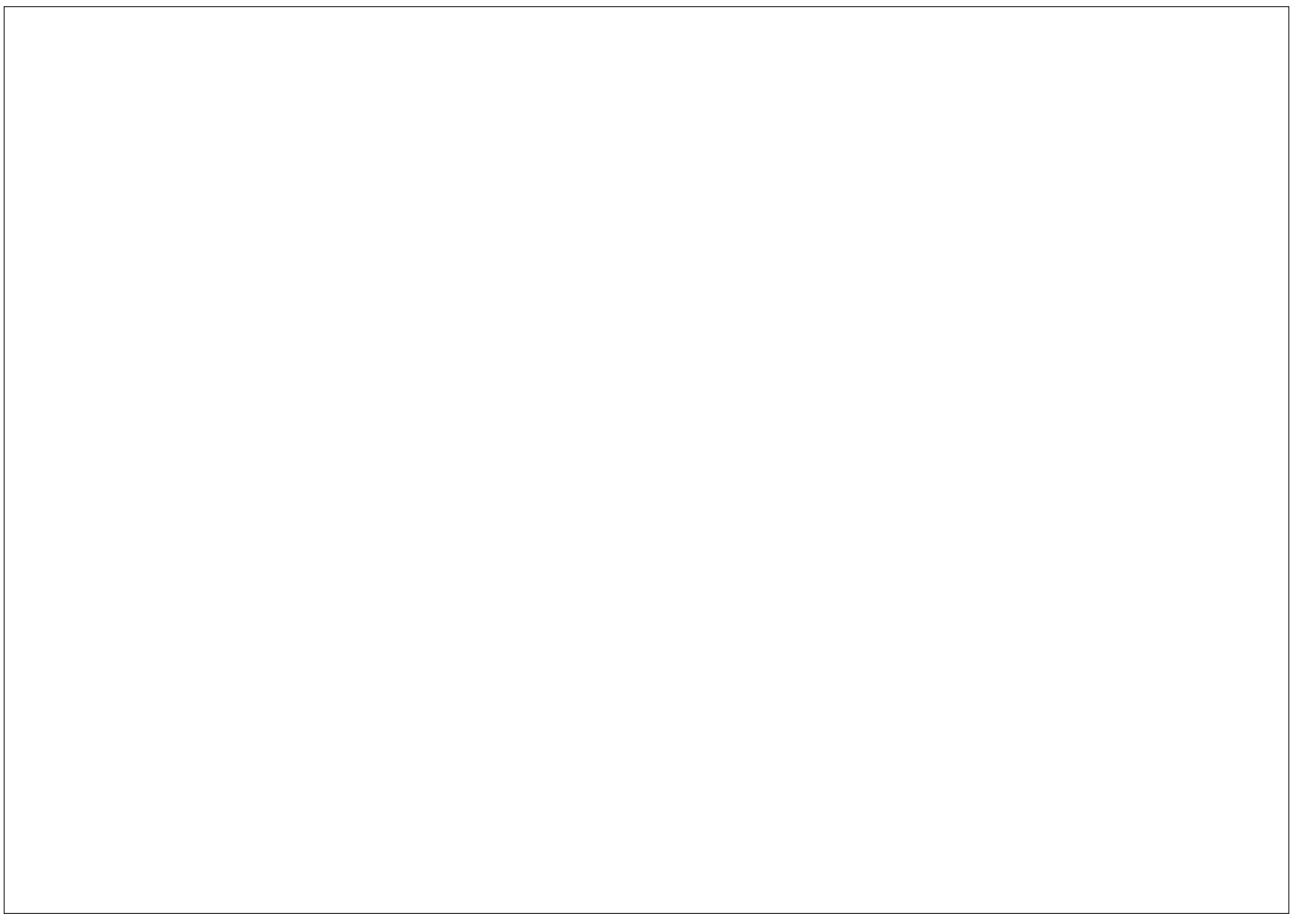


Figure 15 View south along Denham Bay, 1908, with no sign of Norfolk pines (Photo: W.R.B. Oliver. Reproduced with permission from the Kermadec Expedition Album, Alexander Turnbull Library. Ref, no. C21461).

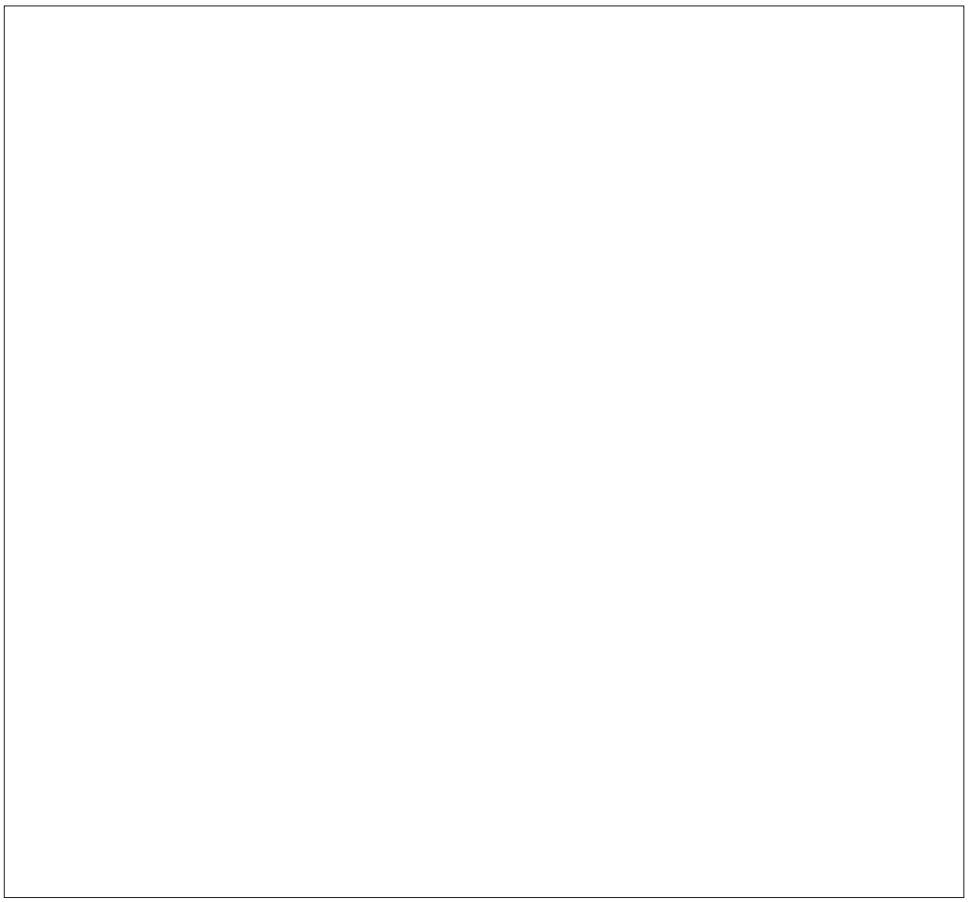


Figure 16 View onto the south end of Denham Bay with a group of young Norfolk pines visible on the edge of the beach, 1944 (Photo: J.H. Sorensen).

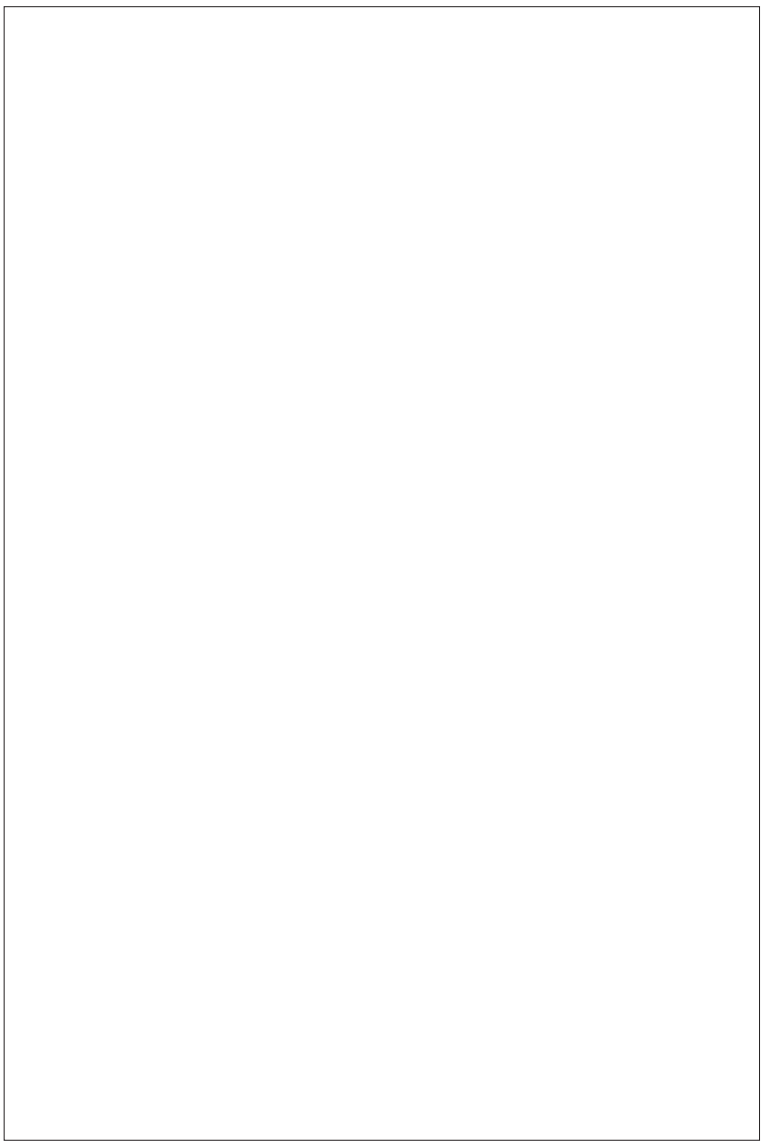


Figure 17 The Denham Bay Norfolk pines in October 1994. The wreck of the *Kinei Maru* which ran aground in 1986 lies in the surf zone.

5.9.2 Ecology

Norfolk pine is a tall, pyramidal tree up to 45 m tall, in the same family as kauri (Araucariaceae). The leaves are short, densely packed and scale-like. Male and female cones are probably produced on the same tree although there are records of male and female cones being borne on separate trees. (In Auckland, Norfolk pine certainly has cones of both sexes produced on the same tree — E.K. Cameron, pers. comm.) The large female cones shatter on impact with the ground, scattering the seeds, or they disintegrate in the crown and the winged seeds are blown on the wind.

The species is light-demanding and the many seedlings which germinate beneath the parent trees usually do not persist. Establishment is successful where seeds have been blown onto bluffs and open ridges. Norfolk pine represents a threat to the forest on Raoul Island for two main reasons. Firstly, this species grows much taller than Kermadec pohutukawa (see Figures 12 and 13) and therefore will occupy space previously used by pohutukawa, thereby substantially altering the forest structure. Secondly, gymno–sperms (such as Norfolk pine) create much more acidic soils in their vicinity and are likely to restrict the sites in which the native forest species can establish. However, Wright & Metson (1959) did not note any marked difference in the appearance of the soil profile beneath the Norfolk pines on the sand dunes in Denham Bay. The pines would have been present at this site for <50 years when these observations were made.

Norfolk Island, where this species originates, is at the same latitude as Raoul, but further west. There is no doubt that Norfolk pines could come to occupy all available habitat on Raoul Island if left untreated because of the similarity of climate on both islands.

5.9.3 Control methods

Hand pull seedlings and chainsaw trees. Herbicide is not necessary as the cut stumps do not resprout, and the seedlings are easily pulled up.

5.9.4 Future work

Check for and remove seedlings in the vicinity of the parent trees on the Northern Terraces. Cut down all trees which are not the original Bell plantings, i.e., all trees <140 cm d.b.h. near the Woolshed, on the ridge above Bell's Ravine, and at Denham Bay.

Monitor the original trees on the Northern Terraces and record whether male and female cones are produced on the same trees. If some trees are unisexual these could be used as a basis for vegetative propagation and the continuation of this historically significant species on the Island. Male cones are probably visible in spring and the trees bearing male cones should be marked at that time. Later, female cones which are borne higher on the trees will become visible and trees bearing those should be marked.

5.10 *Furcraea foetida* — MAURITIUS HEMP

5.10.1 History

Thomas Bell probably introduced Mauritius hemp to Raoul as a substitute for sisal (Sykes 1977a). The species was first recorded as naturalised, in Denham Bay, by Sorensen (1944) who estimated that there were several hundred plants, big and small, in one patch. He described this plant as thriving and spreading and noted that some tall, dry spikes showed where it had recently flowered, although when he inspected the plants in August there was no sign of developing flower spikes. Davison, from the Aeradio Committee, had obviously seen Mauritius hemp in 1938 since he told Sorensen (1944) that the species had vastly increased since 1938. Sorensen's view was that this aloe or century plant, as he called it, was harmful to native vegetation. Sykes (1977a) recorded Mauritius hemp from the Dry Crater beside Tui Lake in 1967 and noted that in Denham Bay it grew in several dense stands towards the seaward edge of the forest. In 1975, one plant on the north side of the Island near the start of the Denham Bay track was removed (Anon. 1976).

Before eradication commenced in 1974 the clump in the Dry Crater was 30–40 m across (Devine 1977). There were two sites in Denham Bay: one area extended westward from the swamp under the pohutukawa fringe for 300–400 m in clumps of varying size, and the other area was on the bush fringe east of the swamp and consisted of 2–3 large plants (Anon 1982a). In 1980 Sykes (1980) noted that this species had almost been eradicated. By 1982 only 11 plants were found in Denham Bay (Selby 1982a) and in 1984 a few young plants were found in Denham Bay but none were seen in the Dry Crater (Sykes 1984). Again, in 1990, a few young plants were seen in Denham Bay (Sykes 1990). Clapham (1991a) removed 12 plants from the Dry Crater. The plants ranged from 20 cm to 2.5 m tall but were not flowering. By 1993 Mauritius hemp appeared to have been eradicated. However, in 1994, two plants were found in Denham Bay and several plants were found growing epiphytically on pohutukawa in the Dry Crater. All plants were removed and one was planted in the garden at the Hostel for identification purposes (C. R. Veitch pers. comm.). Later in 1994 one epiphytic plant was removed from pohutukawa in Denham Bay (Uren 1994).

5.10.2 Ecology

Mauritius hemp is a perennial monocotyledon with fleshy leaves up to 3 m tall, in the agave family (Agavaceae). The leaves may or may not be spiny. Flower spikes to c. 12 m tall are produced from the centre of each plant. Fruit have not been recorded from the plants on Raoul (Sykes 1980), but on the flower spikes numerous small bulbils (vegetative dispersal units) are produced. The bulbils drop off and roll away or land on pohutukawa branches and sprout. Flowering has been recorded in October.

The conditions required for best growth of Mauritius hemp are not known. In the locations in which it was growing on Raoul there was moderate shading beneath pohutukawa forest. Aside from the spread of the plant through bulbils, the plants themselves also spread from the base. So, once established at a site, the area occupied increases through growth of the individual plants. Dense stands can be built up, and these impede regeneration of the native forest species.

Dispersal of this plant is predictable because it only spreads vegetatively. Unlike Madeira vine, it does not grow close enough to the sea for sea dispersal around the coast to be a threat.

5.10.3 Control methods

Many herbicides were trialled and were not effective, or were suggested for trial, e.g., Tordon 520 and 2G, Weedazol TL, Phytazol A, Roundup, but hand removal of the plants was determined to be the best method (Champness 1976).

Plants are pulled or grubbed out then covered with black polythene or some opaque material (Sykes 1984) which excludes light and hastens breakdown of the plant tissue. In 1978, for example, approximately 4000 small to medium-sized plants from one of the two Denham Bay sites were picked and wrapped in polythene (Dale 1979). In 1979, Adlam enclosed bulbils in four gallon tins.

5.10.4 Future work

The two known sites for Mauritius hemp — Denham Bay and the Dry Crater — should be checked annually for plants. Epiphytic bulbils will be difficult to spot, but plants growing from these should be seen well before they get to flowering size.

5.11 *Ricinus communis* — CASTOR OIL PLANT

5.11.1 History

Oliver (1910) recorded castor oil plant as a naturalised species in 1908. As Sykes (1977a) points out, the species must have been introduced early in the settlement phase because Morton (1964) refers to the Bells collecting Jew's ear fungi from the branches of castor oil plant. Jew's ear fungi grow on dead wood normally, so the trees must have been a reasonable size or age to have begun dying back. Sorensen (1944) photographed castor oil plants at Bell's Flat, near the present-day Woolshed.

Sykes (1977a) noted castor oil plant from four localities along the northern side of Raoul, from west of the Woolshed to near the Fishing Rock road junction. Apart from small stands of this species being formed at each location, he felt that the species probably had not increased its range since first reported by Oliver. In October 1990, 63 plants were destroyed in the Orchard area between Denham Bay track and Bell's Ravine (Crawley 1990). Clapham (1991a) reported that the area covered by castor oil trees was being reduced. In 1993, castor oil plant was noted from the Northern Terraces and at Low Flat. However, in 1995 a large stand of mature castor oil plants was discovered c. 100 m west of Ravine 8 (Uren 1995a). All plants were removed and the site was marked.

5.11.2 Ecology

Castor oil plant is a small, spreading tree up to 4 m tall, from the euphorbia family (Euphorbiaceae). The leaves are large, soft and deeply lobed (20–40 cm diam.). The flowers are clustered in heads and the softly spiny capsules contain rectangular seeds up to 15 mm long. Champness (1975) notes "The seeds are poisonous and a violent purgative, not to be eaten under any circumstances". Flowering and fruiting times are not known.

The species is light demanding and currently grows at the edge of the forest behind the Hostel or in light gaps. It is not clear why castor oil plant has not spread more widely on Raoul. It grows best in the same situations that the other category A plants enjoy. It may not be a strong competitor for resources or it may be limited by predation on seeds by rats (with cast-iron constitutions!). Some species may take a very long time to establish before they become aggressively invasive and it is possible that castor oil plant may be one of these. In terms of its growth habit and requirements, castor oil plant could disrupt forest regeneration in the same way as Brazilian buttercup or the guava species. Therefore, it would be prudent to eradicate castor oil plant while it is in low numbers instead of waiting to see if it does spread.

5.11.3 Control methods

Pull out young plants. Cut down large plants and poison bases with Tordon 2G granules.

5.11.4 Future work

Castor oil plant should be eradicated now, while still in low numbers. The methods used above would be appropriate. Treatment sites should be checked annually for at least 10 years to remove any seedlings which might germinate.

5.12 *Phyllostachys aurea* — WALKING STICK BAMBOO

Previously *Phyllostachus viridis*

5.12.1 History

Bamboo was most likely introduced to the Island in association with the Meteorological Station, in the late 1940s-early 1950s. Early photographs of the Meteorological Station garden, on the area in front of the Hostel, which I have seen, show what appear to be small diameter clumps of bamboo to the west of the garden, more or less in the location that the bamboo is in now. The bamboo grows on a pohutukawa-dominated hillock immediately to the north-west of the Hostel and is spreading out across the lawn. There are a few clumps in the lawn which are now mown around. The bamboo is also spreading back into the forest.

5.12.2 Ecology

Bamboo is is a densely growing perennial grass (family Poaceae) which, in this species, attains a height of 3 m. When bamboos flower they die and regenerate again from seed. However, flowering only occurs very infrequently (often at 50–100 year intervals), and walking stick bamboo has never been reported flowering in New Zealand. Thus, the bamboo should persist and slowly expand if not controlled.

Spread of bamboo is achieved by buds sprouting from underground running rhizomes. The growth of bamboo is so dense that it halts regeneration of forest species. Thus, in time, with the death of the forest canopy it will come to dominate any site at which it grows.

5.12.3 Control methods

The only control used on this species to date has been mowing of the shoots which constantly spring up in the lawn.

A suggested method for control is to cut all existing bamboo poles and spray the young spikes which will arise with 2% Roundup. Alternatively, use Galant at a rate of 300 ml/10 *l* water/100 ml crop oil. Spraying fully grown bamboo will be difficult and is likely to cause more harm to non-target species. Regrowth up to 1 m tall is easier to target and will hopefully be large enough to translocate sufficient herbicide to the root system and kill the plant. The cut bamboo can be used about the station.

5.12.4 Future work

Begin the task of removing the bamboo thicket. It would be best to control the whole thicket at once rather than trialling cutting and spraying regrowth in one part of the the thicket. The reason for this is that parts of the thicket which are remote from the spraying site will be connected by rhizomes and will support subsequent regrowth.

5.13 *Brachiaria mutica* — PARA GRASS

5.13.1 History

Para grass was first recorded in a shallow gully near Bell's Ravine by Sykes (1977a) in 1966–67. Since then, the species has not spread from its original location in the abandoned Orchard above the Woolshed. The size of the infestation has increased, however. In 1967 Para grass occupied a space just a few metres in circumference, but by 1974 it occupied 0.5–1 acre (Taylor 1974) and by 1994 it had grown to cover nearly a hectare (Sykes and West in press). Ombler (1977) noted that Para grass excluded all others and suggested that treatment be instigated. To date the species has flowered sparingly on Raoul (Sykes and West in press) but it does appear to be an aggressive competitor through vegetative spread.

Presumably introduction of Para grass to Raoul was associated with the Meteorological station farm, either accidentally or deliberately, given its rate of expansion, although Sykes (1975) suggests the species results from the Bell era. This species is used as a forage grass in the tropical parts of Australia (Skerman and Riveros 1990).

5.13.2 Ecology

Para grass is a stoloniferous perennial species (family Poaceae) which grows up to 2 m tall. Leaf blades are long, hairy and up to 16 mm wide. Most growth occurs in the summer months. Vegetative spread is via long stolons and bending branches, both of which root at the nodes. Lateral spread of 5 m per season has been recorded elsewhere (Skerman and Riveros 1990). Spread of the species by seed is unlikely as flowering is uncommon and sparse. The climate on Raoul is probably too cool for seed set, and marginal for flower initiation (Skerman and Riveros 1990).

Para grass prefers swampy places and stream banks for maximum growth (Skerman and Riveros 1990). Therefore, on Raoul it is unlikely to spread much beyond the gully it currently occupies. However, because it tolerates partial shade it is likely to persist, even under a tree or shrub canopy, for many years. This species has spread aggressively within this gully on Raoul and Taylor (1974) observed it smothering shrubs and buffalo grass.

5.13.3 Control methods

Chemical control of this dense sward, using Roundup or Galant would be most effective.

5.13.4 Future work

Spray the infestation with 2% Roundup or Galant and replant the site with seedlings of native tree species raised on the island. Monitor the site and remove any regrowth.

Category A(ii) Species which are unlikely to have long term significant impact on the structure and composition of the native vegetation of Raoul Island but which are of sufficiently low abundance to be eradicated.

5.14 *Foeniculum vulgare* — FENNEL

5.14.1 History

In 1969 Sykes (1977a) first recorded this species growing near the swimming pool in the paddock by the Meteorological Station Hostel. All of the plants seen were destroyed. Since that time, fennel plants have grown periodically on the same site. Taylor (1974), Trotter (Trotter 1976, Sykes 1977b) and Ombler (1977) all observed and removed a few plants from this site. In 1975, Champness did not find fennel near the swimming pool but did remove one large plant from behind the generator shed (the first time fennel was noted in this location and possibly a misidentification). When Sykes visited Raoul in November 1980 there was no sign of this species (Sykes 1980) but when he next visited in October 1984 a mature plant with an old flower stalk and a few seedlings were seen near the swimming pool and destroyed. In 1990–91 and 1993, fennel was not seen (Sykes 1990, Clapham 1991a, pers. obs.) but in 1994 three plants were detected and destroyed (Veitch 1994, Uren 1995a). Fennel was presumably an accidental introduction to the Island (Sykes 1977a).

5.14.2 Ecology

Fennel is a perennial herbaceous plant, from the carrot family (Apiaceae), which dies back to a stout rootstock after flowering. The plants usually reach 2 m height. Numerous seeds are produced from the yellow-flowered heads and these seeds are wind dispersed a short distance or attach to animals and are dispersed in that way. Plants flower from November through to May.

Fennel is a characteristic plant of open spaces and will grow on coastal slopes and on slips in the forest. Once established, dense infestations usually result, and this impedes regeneration of the native vegetation. This species is certainly persistent. Small numbers have been recorded and removed periodically but it still persists more than 25 years after being first reported. In 1982 fennel was regarded as exterminated but annual surveillance was recommended at least until the end of 1983 (Anon. 1982b)!

5.14.3 Control methods

Grub out plants and burn or desiccate. As much of the taproot should be removed as possible as fennel can resprout from root fragments.

5.14.4 Future work

The site where fennel has been recorded should be checked annually and any new plants grubbed out.

5.15 *Gomphocarpus fruticosus* — SWAN PLANT

Previously *Asclepias fruticosus*

5.15.1 History

This species was first collected on Raoul by Sorensen (1944). In 1966–67, Sykes recorded swan plant from rough pasture near the Meteorological Station. Champness (1975) commented that it was near the Meteorological Station and had spread along the road to Fishing Rock. He noted swan plant's apparent ability to compete with buffalo grass, and suggested its behaviour be watched. Ombler (1977) noted this plant was common and suggested it could become a problem in the future. Thirteen plants were pulled out by Adlam (1979). Clapham (1991a) observed 4–5 plants from the same locality. In 1993, the species was still recorded from this area and from near the Hostel. Successive weed teams have removed plants from this site but there are always a small number present each year.

5.15.2 Ecology

Swan plant is bushy shrub up to 2 m tall which has milky sap and belongs to the milkweed family (Asclepiadaceae). Leaves are linear, c. 10 x 1 cm. The smallish flowers (c. 15 mm diam) are clustered in small groups. The swan-shaped fruits are green (ripening to brown) and inflated, c. 4–6 cm long. Numerous, small, silkily hairy seeds are clustered in the fruit and are wind dispersed when the fruit wall ruptures upon drying.

It is worth eradicating this species which is currently in very low numbers because it is a relatively tall and densely growing shrub which thrives in high light environments. It is also a wind-dispersed species, and if left uncontrolled could disperse to more remote locations on the island. It is, therefore, a species which could interfere with recolonisation of open areas by forest.

5.15.3 Control methods

All plants found have been hand pulled (e.g., Ombler 1977, Adlam 1979) and this method should be used in future.

5.15.4 Future work

Check the area where the plant has been recorded in the past, at least twice each year. Hand pull each plant and hang up to desiccate. Remove any fruit present, even green pods, and destroy by burning.

5.16 *Populus nigra* — LOMBARDY POPLAR

5.16.1 History

Sykes records this species as a relatively recent introduction to the Island. In 1966–69 there was a line of trees which had been planted around a reservoir on the Terraces and a few presumably wild trees above Low Flat on an open bank. Champness (1975) noted that all of the poplars on Raoul appeared to be attacked by poplar rust, and only the basal suckers had any leaves. Stems were

still green but branches bore only small leaf buds. He recommended removal of this species. In 1993 there was just one tree present, on the western edge of Bell's Ravine at the road side.

5.16.2 Ecology

Lombardy poplar is a tall, narrow tree up to 20 m tall, from the willow family (Salicaceae). Only male clones are present in New Zealand and the species spreads occasionally by suckering or by detached branches and twigs taking root. Lombardy poplars grow better in cool climates and are unlikely to thrive on Raoul.

5.16.3 Control methods

Poison standing stems with Roundup and fell with a chainsaw once dead.

5.16.4 Future work

Remove the one remaining tree.

5.17 *Senecio jacobaea* — RAGWORT

5.17.1 History

Sykes (1980) found a single plant of ragwort near Mahoe Hut in November 1980. The plant had not yet flowered and it was pulled out. It appears that ragwort seed had come in on building materials used to build the hut (Sykes 1990). Sykes (1984) reported that ragwort has not reappeared. Clapham (1991a) did not find ragwort in 1990–91. The Mahoe Hut site has been checked regularly since 1980 and no further ragwort plants have been seen.

5.17.2 Ecology

Ragwort is a biennial or perennial daisy up to 1 m tall, from the daisy family (Asteraceae). In the first year of growth a basal rosette is produced and in the second year yellow flowers are produced at the top of the flowering stem which grows from the centre of the rosette. Numerous small seeds with a fluffy pappus are produced and dispersed widely by the wind. Plants flower from November through to July, but on Raoul could flower at any time of year.

Like Scotch thistle, ragwort is a plant of open ground and light gaps. It will grow on coastal slopes and along tracks, wherever there is sufficient bare ground for the seeds to germinate and establish.

5.17.3 Control methods

The single plant was pulled out by hand. Should any others be found, hand removal should be sufficient.

5.17.4 Future work

The Mahoe Hut site should be checked annually for any further germination of ragwort.

6. Category B weeds

ADVENTIVES RESULTING FROM ACCIDENTAL OR DELIBERATE INTRODUCTION WHICH HAVE NO HISTORIC SIGNIFICANCE AND WHICH POSE A MINIMAL OR NO THREAT TO THE FOREST ECOSYSTEM OF RAOUL ISLAND.

6.1 *Alocasia brisbanensis* — AROID LILY

Previously *Alocasia macrorrhizos*

6.1.1 History

In 1887 aroid lily was noted by Cheeseman as a plant cultivated by the Bells. He recorded it as "kapi (or large *Arum*) edible root". At this time then, aroid lily was not obviously naturalised, since Cheeseman did list naturalised plants that he saw at the time. Smith (1887) also records "kapi (a New Guinea plant with an edible root 2 ft long. . .)". Kape is the name widely used in Polynesia for *Alocasia macrorrhizos* (Massal and Barrau 1956). In 1908, Oliver (1910) did not record the aroid lily as being naturalised. By 1937, aroid lily was reported as "now one of the worst weeds" by Anderson (1938), although Davison recalled that the species was not common in the remoter southern parts of the Island (Sykes 1977a). Davison, himself, (1938) did regard the aroid lily (which he called arum) as a harmful weed. In 1944, Sorensen observed that the "introduced arum lily has a tremendous hold and especially in the gullies". Sykes (1977a) recorded aroid lily as dominant in much of the herbaceous layer in nearly all areas of the Island in 1966–67. Thus, since the early part of this century, aroid lily has spread throughout Raoul Island, and it is without doubt the most widespread naturalised plant on the Island. Aroid lily has also spread to the nearby Meyer Islets and was recorded in small patches from both North and South Meyer in 1967 (Anon. 1982a). In 1990, Sykes observed two small groups of this plant on North Meyer. All plants were pulled up and hung in tree forks to desiccate (Sykes 1990).

The spread of this plant on Raoul was assisted by the goats which were abundant on the Island but were eradicated in 1984. The effect of the goats was to eat all palatable species out of the understorey and to climb into the pohutukawa trees to eat foliage of that species and any others that they could reach. Thus, they created an unnaturally light canopy cover and often an almost bare ground layer. Aroid lily, which was unpalatable to goats (Sykes 1969, 1977a; Parkes 1984), was able to spread throughout both the dry and the wet forest as it grows best in relatively high light levels.

Eradication of the goats on Raoul has had a major impact on the aroid lily. In most parts of the forest, especially the wet forest, the understorey is dense with regeneration of native trees and ferns. Also, the pohutukawa canopy has

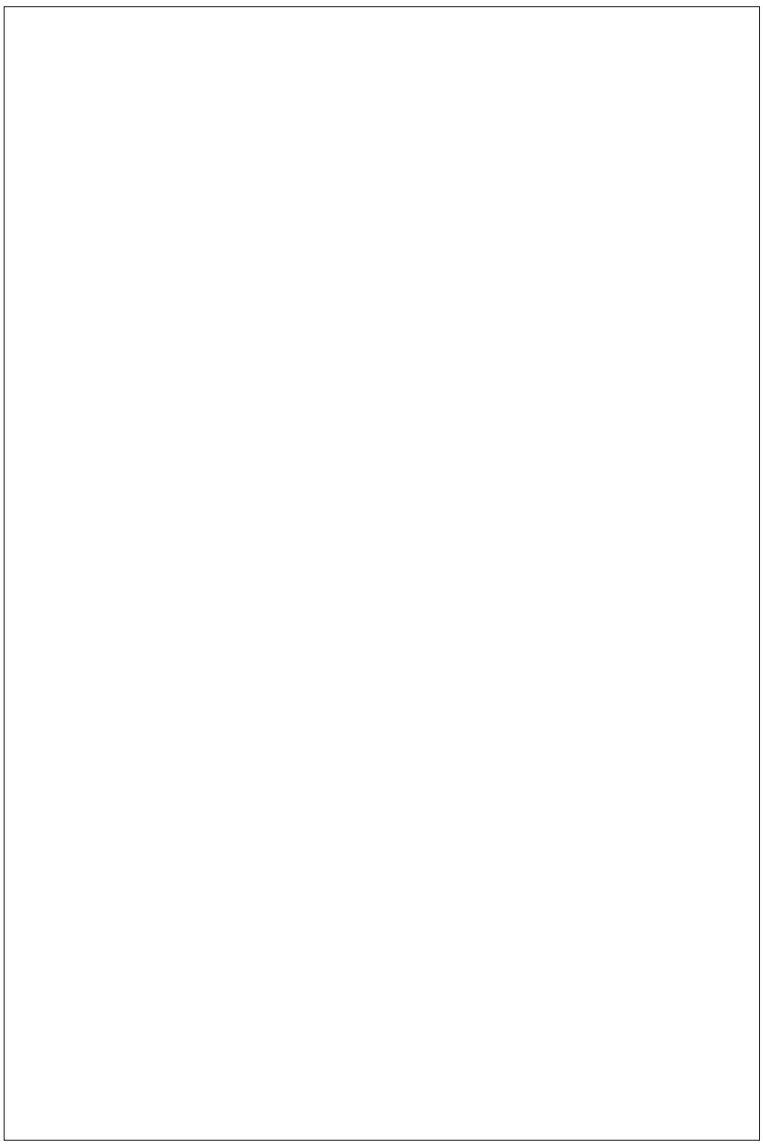


Figure 18 Aroid lily flower and foliage, October 1994.

recovered to produce much more dense shade. The aroids in the forest persist as large rhizomes (up to 60 x 10 cm) with one or two stunted leaves protruding from the end. It is a matter of time before the starch reserves of the rhizomes are exhausted and the plants under the forest die out.

6.1.2 Ecology

Aroid lily is a large rhizomatous perennial in the arum family (Araceae). The rhizome usually grows along the soil surface and can be over 50 cm long. In well-grown plants 4–5 sagittate leaves arise from the end of the rhizome on stems up to 2 m tall. The leaves, which are large (75 x 50 cm), die back from the tips during spring and during this phase the leaf stalks are mucilaginous. Flowers are produced freely on plants in full sun. The flowers are typical of the arum family with numerous small creamy yellow flowers crowded on a stalk which is surrounded by a pale green sheath, or spadix (Figure 18). The flowers are fragrant, with a perfume similar to violets. Flowering is from August through to April. Fruit are small (1 cm diameter), red and fleshy and are clustered on the flower stalk. The rhizome, if damaged, will sprout from lateral buds, but the terminal bud is dominant.

The foliage of aroid lily contains abundant calcium oxalate crystals which are very irritating to skin tissue and eyes. Workers on Raoul have been affected when sap has splashed in their eyes while cutting the aroid back during track maintenance (e.g., Champness 1975, Bracefield 1987). Rashes can develop where sensitive skin contacts aroid foliage when moving through dense stands (e.g., Hancox 1982). In general, care should be taken when this species is encountered.

Aroid lily is light demanding and grows best in canopy gaps, at the forest edge and in the grassland. In the canopy gaps on ridges and in Denham Bay, the extent to which aroid lily can invade is clearly seen. Dense stands up to 2 m tall, or more, are formed. The usual height for the aroid is c. 1 m. Areas up to 0.5 ha or more may be covered in aroid, e.g., south end of Denham Bay (Figure 19). However, most infestations today are no more than 10 x 10 m. Aroid lily also grows in the grassland fringes around the Island but it cannot compete with the dense growth of buffalo grass, and is most usually confined to the damper hollows.

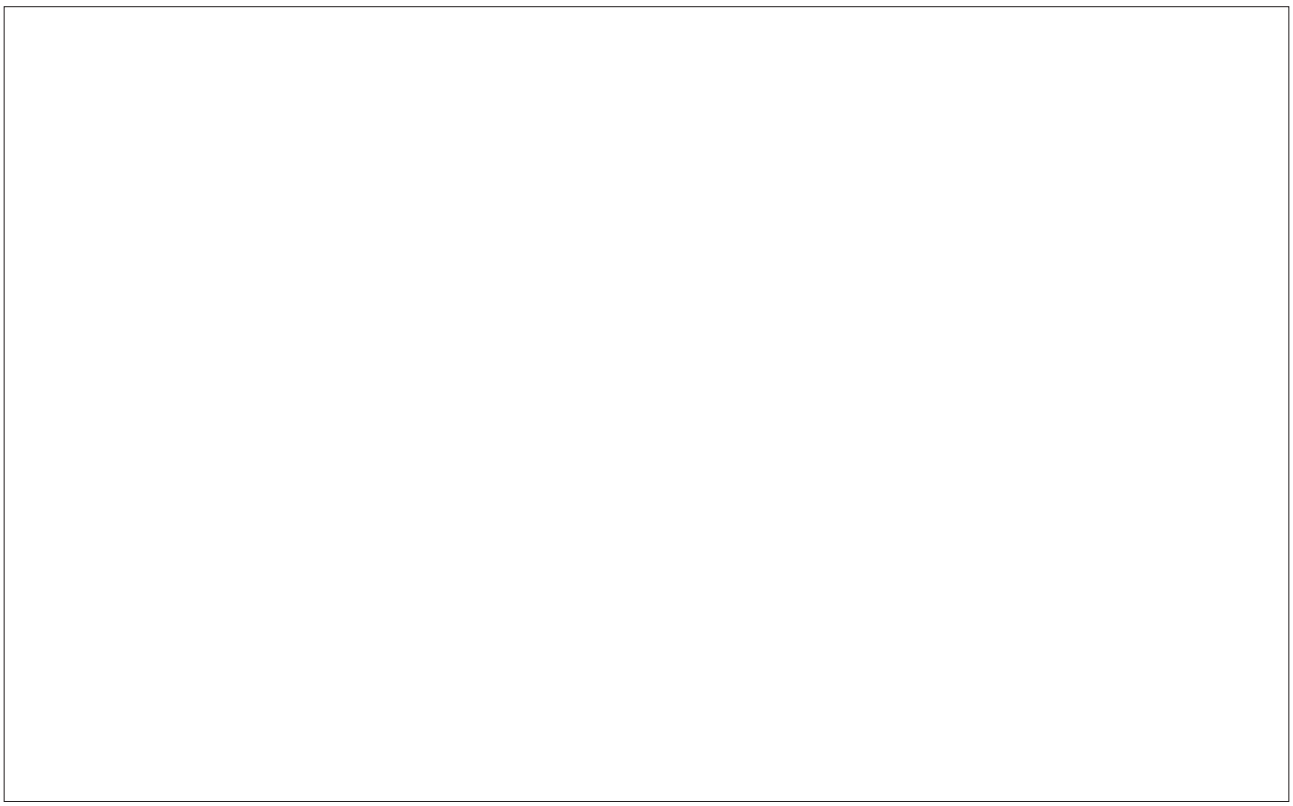


Figure 19 Aroid lily growing in a light gap at the south end of Denham Bay. Black, vertical, slim stems in the photo are grape vines, October 1994.

Widespread distribution throughout Raoul and onto the Meyer Islets has probably resulted from birds dispersing the seeds. Vegetative reproduction will occur from fragments of the rhizomes rolling down hills. The goats probably caused a fair amount of rhizome damage when moving through the forest and they could have enhanced the rate of spread in this way. Because aroid lily is bird-dispersed its spread is unpredictable but since it covers virtually all of Raoul Island and is also on the Meyers, the only places it can infest now are the other small islets adjacent to the Meyers. The seed probably does not persist long in the soil, unlike Mysore thorn and others, so aroid lily will not colonise disturbed areas rapidly because the seed will have to be dispersed into the area. If rhizomes are already present, then they could grow rapidly in high-light conditions created following tree falls, slips, etc.

Now that the goats have been eradicated from Raoul, aroid lily does not pose the threat that it did when the forest was so grossly modified by browsing. The natural light levels beneath the forest canopy are too low for this species. As the forest canopy gradually closes in on clearings, the aroid lily will be further reduced and will be restricted to the forest edge, e.g., around the lakes, road edges, etc.

6.1.3 Control methods

It was observed during early control operations on other species that Tordon 2G was ineffective at poisoning aroid lily.

6.1.4 Future work

Hand-pull small seedlings in high light areas if away from any infestation.

6.2 *Stenotaphrum secundatum* — BUFFALO GRASS

6.2.1 History

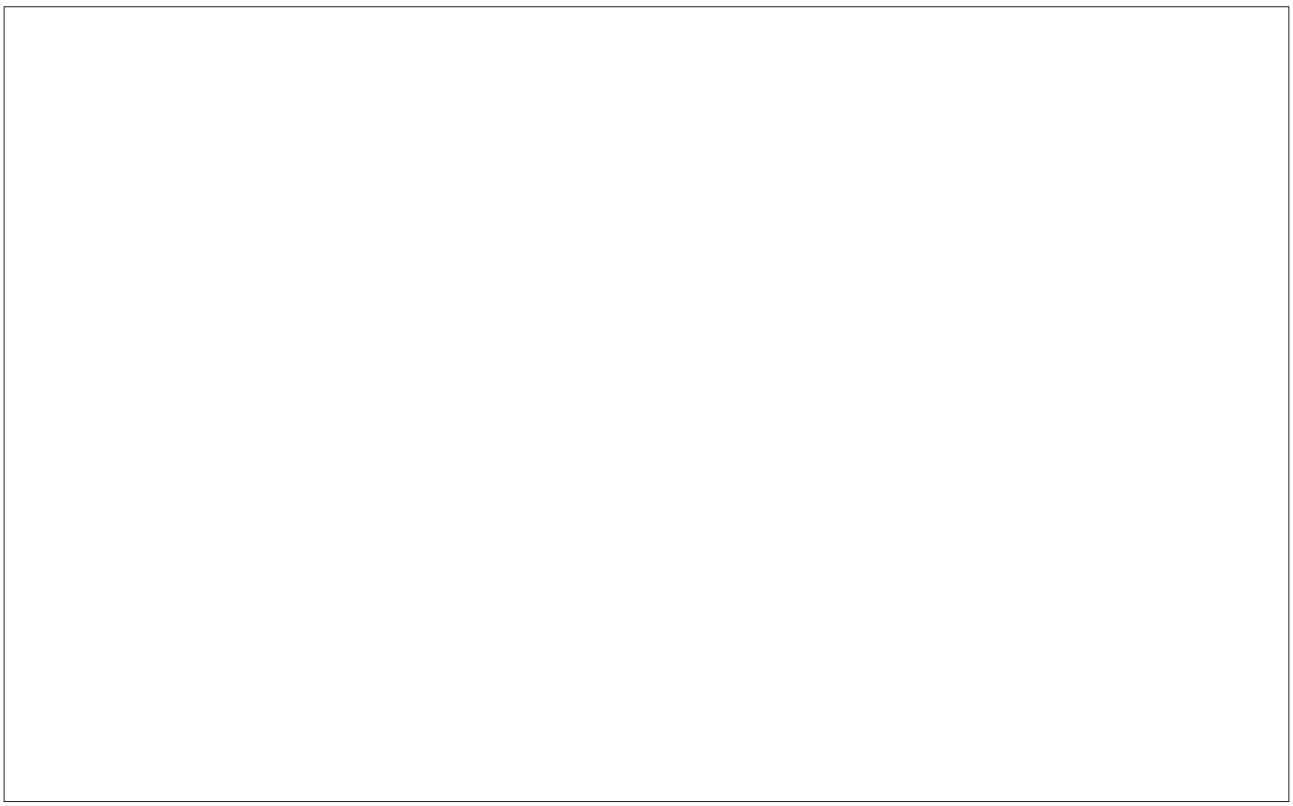
Oliver (1910) recorded "buffalo grass meadow" communities on the Northern Terraces (Figure 20), the north rim of the crater and in one area on the east side of the Island. He noted the species had been on Raoul Island for 20 years (Oliver 1910, p. 148). Cheeseman (1888), twenty years earlier, makes no mention of this species. Presumably, the species was introduced by Bell who tried to establish pasture for sheep both in Denham Bay and on the Northern Terraces (Morton 1964). Pasture species such as *Poa pratensis* probably did not do well in the warm climate of Raoul and species of more tropical origin may well have been sought as fodder. (Smith, 1887, reports that Bell planted 15 acres of *P. pratensis* and that it was growing well. However, the species has not persisted on Raoul.)

Sykes (1977a) documented buffalo grass from the same areas as Oliver but also noted large stands above Wilson and Lava Points and small areas above Coral Bay, Darcy Point, Boat Cove and in Denham Bay, indicating that the species has spread considerably since the days of settlement.

6.2.2 Ecology

Buffalo grass is a stoloniferous perennial grass (family Poaceae) which grows in dense and deep swards in the open. It is very tolerant of salt spray and does well by the coast. On ridges and slopes, this grass is up to 50 cm tall, but in hollows can be up to 1 m tall. The species flowers and sets seed freely on Raoul. Seeds are mostly dispersed over short distances by wind and over longer distances in mud attached to footwear or the fur and feathers of animals. Occasionally young plants are found along tracks through the forest, even in the wet forest.

Figure 20 Dense buffalo grass on the northern terraces, 1908. (Reproduced with permission from the W.B. Oliver Kermadec Expedition Album, Alexander Turnbull Library. Ref. no. C21463)



Stands of buffalo grass are exceedingly dense and usually exclude all other species. However, there are a few areas where other species have been able to establish into the sward. Near the Meteorological Station, in 1990, there was a fire which burnt a number of pohutukawa trees and some buffalo grass. In this area today are seedling pohutukawa which were able to establish at the same time as the buffalo grass was recovering from the fire. On slopes above the Woolshed large numbers of karaka seedlings are establishing in buffalo grass near adult karakas. Karaka seeds are the largest of any fruit produced on Raoul, and there are sufficient starch reserves in the seeds to enable seedlings to germinate and establish in the dense buffalo grass swards. In general, the commonest species seen amongst buffalo grass is the endemic grass *Imperata cheesemanii*.

Buffalo grass is light-demanding and will gradually be reduced in extent as the forest expands. Oliver (1910) noted this species was being killed by the shadow of Kermadec pohutukawa trees.

The leaves of buffalo grass, although appearing to be blunt, have a strong tip which can irritate skin when wading through dense swards. Some people are more sensitive than others.

6.2.3 Future work

Hand pull seedlings where seen away from the major buffalo grass swards.

6.3 *Cirsium vulgare* — SCOTCH THISTLE

6.3.1 History

This plant arrived on Raoul Island between 1967 and 1976 when it was first recorded by Sykes (1977a). Scotch thistle is a common contaminant in grass seed, hay, etc., and was introduced to Raoul in connection with the farming activity associated with the Meteorological Station.

Initially Scotch thistle was confined to the farm paddocks west of the Hostel but spread to the airstrip further west. In 1978, Sykes commented that he was disappointed to see so many seeding thistles in the old farm pastures. Five plants were found in Denham Bay in 1982 and pulled out before they seeded (Selby 1982a). Selby (1982a) recommended that Scotch thistle be put on the category A list to increase the amount of effort put in to its control. By 1984, this plant had extended its range to just beyond Ravine 8 (Sykes 1984). In 1990, Sykes felt that there were fewer Scotch thistles than on his previous trip. He also recorded this species on North Meyer for the first time (Sykes 1990). Scotch thistle is now widely dispersed along the Northern Terraces west of the airstrip towards and above Western Spring. Crawley (1990) noted that Scotch thistle was the main species to colonise much of the ground disturbed by archaeological diggings west of the Woolshed in 1990. Dispersal is predominantly west of the initial infestation.

6.3.2 Ecology

Scotch thistle is a prickly, biennial, herbaceous daisy (family Asteraceae) up to 100 cm tall. A rosette of leaves is formed in the first year of growth and in the

second, a flower-bearing stem is formed. The purple flowers are clustered at the end of the stem and the numerous, wind-dispersed seeds (fairies) are blown from the heads. Flowering and seeding probably takes place in most months (Sykes 1984).

This species requires relatively open conditions for germination and establishment and will not invade dense grass swards. However, it will spring up at track edges, on slips and barer ridges. It will also germinate in light gaps in the forest. On the New Zealand mainland Scotch thistle is one of the few biennial exotics which disperses a long way into the forest. The species is not a problem in forest as it does not disrupt regeneration and usually grows sparsely only in the lightest places. On open grassy slopes, it could be common but would seldom grow densely.

When this species was first observed on the Island, all plants were destroyed, but one or two had ripe seed (Sykes 1977b). Because control pressure was not consistently applied to this species, it has since expanded to the point where eradication is no longer feasible. On Raoul, given that forest is the natural cover for the entire Island, Scotch thistle is not a serious problem. It will in no way interfere with the regeneration to forest of the areas which are currently grass- or fern-covered. On the Meyers, this species could interfere with nesting seabirds.

6.3.3 Control methods

To date plants have been grubbed out at the rosette stage or at flowering. Crawley (1990) reported that the thistles near the Woolshed were sprayed.

6.3.4 Future work

Scotch thistle has spread too widely now for eradication to be feasible as the effort now required far outweighs the benefits to the natural forest cover. Plants should be grubbed out if remote from the main infestations. The Meyers should be checked regularly and plants destroyed only if scarce. If abundant, do not grub them out but chop them down, as more plants could germinate in disturbed ground.

6.4 *Bryophyllum pinnatum* — AIR PLANT

6.4.1 History

Sorensen (1944) was the first to describe this plant from Raoul. He did not know its name but dubbed it the "lantern flower plant", and stated that it was a small plant reaching 2 ft 6 in. high and carrying numbers of small greenish purple "lanterns". At that time this species was plentiful and covered about an acre near the swamp in Denham Bay. Sykes (1977a) recorded air plant from the same location as well as a small area in the dune slack a short distance from the main site. Now the site in the dune slack has expanded considerably and densely growing air plant is the dominant species (Sykes & West in press). See plate 12G of Webb *et al.* (1988) for an illustration of this population. The original population by the swamp has also expanded. The increase in area occupied has been slow but steady, and is continuing.

6.4.2 *Ecology*

Air plant is a succulent member of the crassula family (Crassulaceae) which grows up to 70 cm tall. The leaves are hairless and toothed with a dark margin. In high light the uppermost leaves on the stem often turn red, as do the "lanterns" which are the inflated calyx surrounding the flower and later the fruit. Any seed which is formed is unlikely to be fertile (Webb *et al.* 1988). Flower buds were recorded on plants near the swamp in August but flowering is generally from November to May (Webb *et al.* 1988).

Population expansion is by lateral vegetative spread. New populations could establish by carriage of vegetative material to other suitable sites. The common name of air plant relates to the ability of this species to grow in dry, almost soilless habitats — sites which are marginal for many other species. Air plant is unlikely to spread outside of Denham Bay but there is still plenty of available habitat within the bay. Although this species is light-demanding it does grow in shade beneath the canopy, but the stands are less dense (Sykes 1994).

6.4.3 *Control methods*

Control of this species is not advocated at this stage (other species have much higher priority) but chemical control would be the only practicable method given the density of stems. Application of 2% Roundup is suggested in the first instance.

6.4.4 *Future work*

Mark the leading edges of the two infestations with pegs, and record the locations of any other infestations. Record the movement of the leading edges relative to the pegs annually.

6.5 *Tropaeolum majus* — GARDEN NASTURTIUM

6.5.1 *History*

This species was not recorded by Cheeseman (1887), Oliver (1910), or Sorensen (1944), and was presumably introduced as a garden plant some time during this century (Sykes 1977a). It is mainly distributed along the north side of the Island, in sites disturbed by humans, e.g., Northern Terraces, the Orchard, Low Flat, Fishing Rock Road, and Moumoukai summit clearing. The species has not spread in extent since 1967.

6.5.2 *Ecology*

Garden nasturtium is a scrambling, aromatic, herbaceous annual or short-lived perennial with rather succulent stems, from the family Tropaeolaceae.The leaves are nearly circular and c. 20 cm diam. Flowers are in red or orange tones. On Raoul, the species flowers almost continuously. Fruit are dry, segmented into three and contain one seed per segment.

Once established at a site, the species grows amongst other vegetation (Figure 21) and has not been observed outcompeting any other species. On

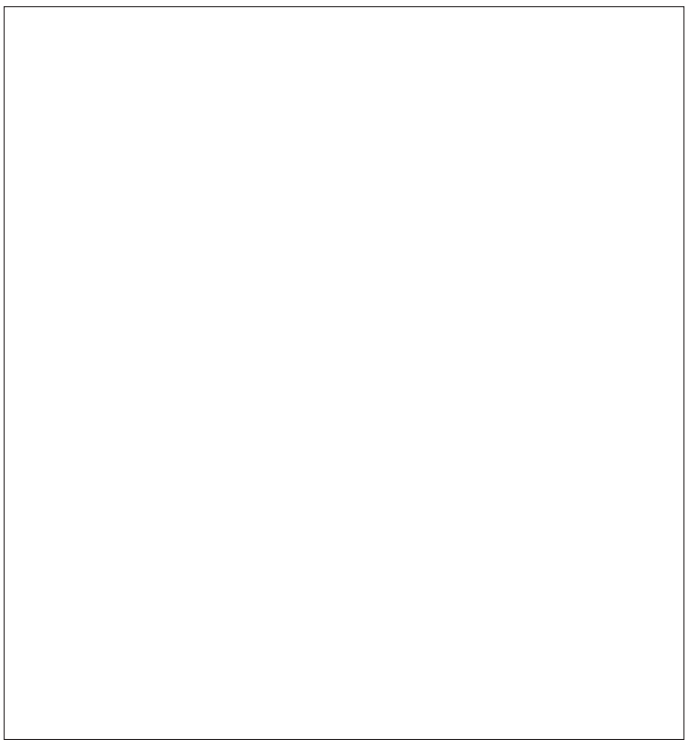


Figure 21 Garden nasturtium growing among *Cyperus ustulatus*, *Nephrolepis* aff. *cordifolia* and aroid lily on Moumoukai, October 1994.

Raoul, the species does not seem to climb up adjacent vegetation, as it often does on the mainland. Seeds are not dispersed very far as they simply drop off the plant.

6.5.3 Control methods

The plants on Moumoukai were sprayed with Roundup in September 1988 (DoC file 21-220).

6.5.4 Future work

There is no need to eradicate this species for ecological reasons because it is non-invasive, unlike some other members of the genus, e.g., *Tropaeolum speciosum*. The infestation on the summit of Moumoukai could be removed for aesthetic reasons, but it is a low priority.

6.6 *Trifolium campestre* — HOP TREFOIL

6.1.1 History

This species was first collected in 1980 from near the generator shed (Sykes 1984) and still grows in the vicinity although it is uncommon.

6.6.2 Ecology

Hop trefoil is an annual legume (family Fabaceae) with leaflets c. 4–15 mm long. The yellow flowers are clustered, 20–40 per head. Seed pods are c. 2 mm long and usually contain one seed c. 1 mm diam. Plants flower from November through to May. Like other herbaceous legumes, hop trefoil is light-demanding and grows in open sites. It is not a threat to forest regeneration and it is, therefore, not worth the effort to eradicate it.

6.6.3 Future work

No action required.

6.7 *Vicia sativa* — VETCH

6.7.1 History

This species was first collected in 1980 and recorded by Sykes (1984) from the immediate vicinity of Boat Cove Hut. Although all plants seen in 1980 were pulled out, they must have seeded because the species persists today (Sykes & West in press). In 1994, vetch was seen only on this area, growing at the turn-around area at the end of the road. Some, but not all, plants were pulled out.

6.7.2 Ecology

Vetch is an annual, scrambling leguminous herb (family Fabaceae) with pinnate leaves and grasping, branched tendrils. Leaflets are 5–40 mm long. The rosy purple flowers and seed pods were present in October. Seed pods are black and up to 60 mm long, containing 5–12 seeds. Seeds are dispersed by explosion of the seed pod, and unless carried in mud on vehicle tyres or footwear, expansion of the area occupied will be gradual.

The species is not a threat to forest regeneration, and in open habitats is not invasive, but grows amongst other vegetation.

6.7.3 Future work

Hand pull from the vicinity of Boat Cove Hut if the opportunity arises. Remove any plants remote from the current infestation site.

7. Category C weeds

PERSISTENT RELICS OF CULTIVATION OF HISTORIC SIGNIFICANCE OR PROVIDING EDIBLE FRUIT WHICH MAY BE PROTECTED.

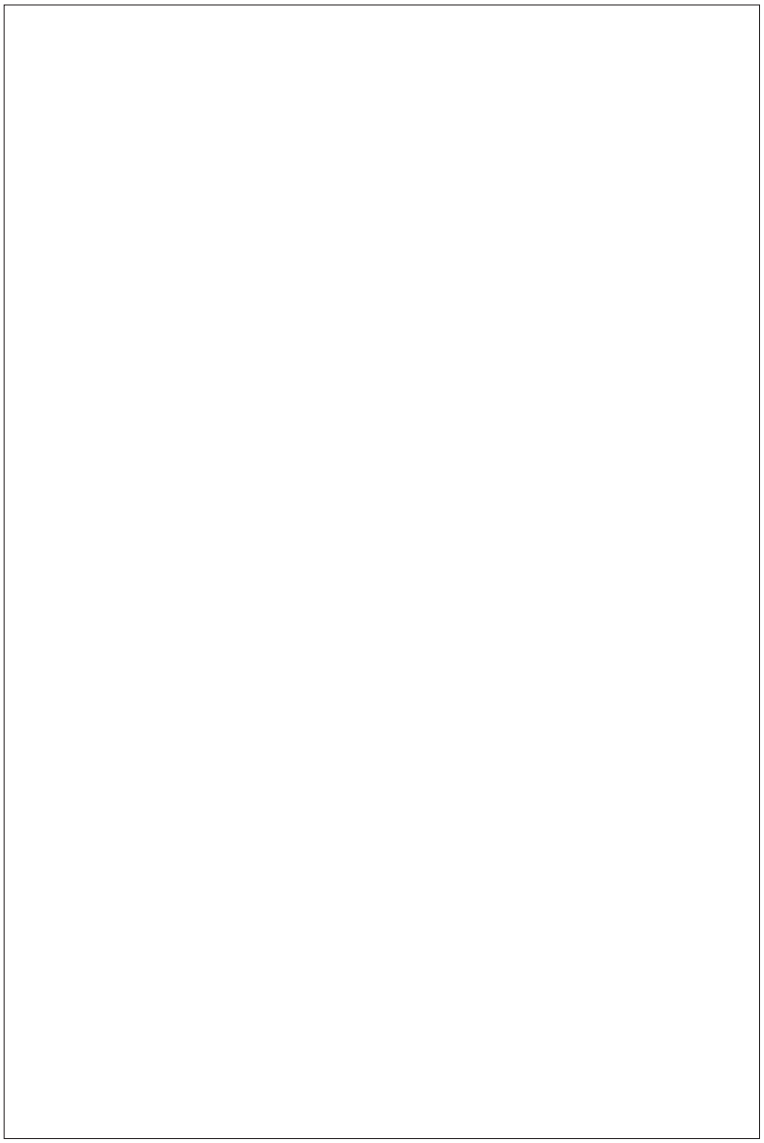
7.1 *Cordyline fruticosa* — TI

Previously *Cordyline terminalis*

7.1.1 History

It is most likely that this plant was brought to Raoul by Polynesian travellers (Sykes 1977a). Ti grows where there have been Polynesian or European settlements on Raoul, e.g., Low Flat, the Terraces, Denham Bay and Coral Bay. Since the departure of settlers, the range of this species has decreased, as the cultivation clearings have regenerated to forest. Davison (1938) stated that ti was not present in quantity and Sorensen (1944) recorded it from Coral Bay and from near the swamp in Denham Bay. In Denham Bay, Sorensen thought the ti was increasing. Today, ti is not uncommon, but is localised.

Figure 22 A small ti plant flowering by the road edge near Low Flat, August 1993.



7.1.2 Ecology

Ti is a small, perennial, monocotyledonous shrub up to 3 m tall in the cabbage tree family (Asphodelaceae). The stems are slender and broad linear leaves are borne at the end of each stem (Figure 22). Leaves are up to 90 cm long and 15 cm wide. New stems sprout from the base of old ones, and cut stems will regrow from lateral buds. Clusters of mauve flowers are produced during winter and spring on Raoul. The species virtually never produces fruit on Raoul, although immature fruit were observed on one plant once (Sykes 1977a) and in 1978 six plants were observed fruiting (Dale 1979). Ripe fruit are red (Healy and Edgar 1980).

The species has declined on Raoul because it is light demanding and the old

cultivation sites are growing over. Today ti persists in light gaps on the Northern Terraces, at Low Flat and in Denham Bay and Coral Bay as well as growing along the road edge.

Dispersal of the species by seed is very unlikely given the lack of seed production on Raoul. Sykes (1977a), however, suggests that the plants on top of South Meyer probably resulted from bird dispersed seed. It is possible too, that people could have taken ti to the Meyers. For example, Hovell (1890) writes that he "crossed over to Meyer Islet . . . and . . . entered into occupation of it planting bananas, melons, pumpkins, etc. . . ." Maybe ti was among the crops planted on the Meyers by early settlers such as Hovell. The most usual method of spread of ti is by vegetative fragments. This is particularly noticeable along the road edge where passing vehicles may break and carry stems before dropping them further down the road. These soon root and sprout new shoots.

Ti is fire tolerant, as exemplified by the fire near the Meteorological Station in 1990. Less than three years after the fire ti in the burnt area were sprouting from the base.

7.1.3 Future work

Leave alone.

7.2 *Aleurites moluccana* — CANDLENUT

7.2.1 History

Recorded by Cheeseman (1888) from the north and east side of the Island — not very common. Also by Oliver (1908) from Low Flat and Coral Bay and as recently planted at Denham Bay and on the Terraces. Both Cheeseman (1888) and Sykes (1977a) reason that candlenuts were introduced to Raoul by Polynesians. The main stand of candlenuts is at Coral Bay, a site used by Maori, but never disrupted by European settlement. Morton (1964) described the finding of candlenut fruit by the Bell girls. This was a great discovery for the Bell family, and it seems clear that they were not responsible for introducing the species to the Island. Elsewhere today, candlenut trees persist in the sites listed by Oliver (1908).

7.2.2 Ecology

Candlenut trees grow up to 15 m tall with trunks up to 80 cm d.b.h. and are in the euphorbia family (Euphorbiaceae). The leaves are relatively large (c. 10 x 8 cm) and are deltoid in shape. Flowers are insignificant and the time of flowering is not known. The fruit are large (c. 2 x 2 cm) and stone-like with a pronounced beak at one end. Cracking open the hard, stony fruit reveals a soft, oil-rich seed. This was threaded on string and lit to provide a light source by the Bells (Morton 1964). Fruiting times are not known, but fruit can be found at all times of year beneath the trees in Denham Bay and at Low Flat. Abundant seedling regeneration was noted beneath ring-barked trees in Denham Bay (Ombler 1977).

7.2.3 *Control methods*

Hand pull seedlings. In 1993 three seedlings were removed from beneath a candlenut on Low Flat.

7.2.4 *Future work*

Remove seedlings from beneath adult trees. The species will not disperse far because of the large size of the seed, especially given that most trees or groves are on flat land.

7.3 *Hibiscus tiliaceus* — SHORE HIBISCUS, FOU

7.3.1 *History*

Sykes (1977a) notes that Carver (1889–1893) sketched shore hibiscus or fou, as "bau shrub" in Bell's garden in Denham Bay in 1891 and Morton (1964) noted that this plant was used by the Bells for fibre. However, Sorensen (1944) was the first to positively record this species from Raoul Island. In the days of settlement this plant was cultivated for its fibre and was apparently, at that stage, not naturalised (Sykes 1977a). Presumably Bell took plants across to Low Flat from Denham Bay when he moved to the northern side of the Island.

In Denham Bay, Sorensen (1944) noted that there were several large patches of fou which had been planted and were growing well. He observed plenty of buds on the plants, but no open flowers, in August. Sykes (1977a) recorded shore hibiscus from Denham Bay and Low Flat. Currently, there are two extensive areas of this plant in Denham Bay, one by the hut (Figure 23) and the other further south and closer to the cliffs. In 1975 each of these patches was

Figure 23 The patch of fou, shore hibiscus, by Denham Bay hut shows up clearly with its yellow-green foliage, August 1993.

estimated to be 4000 m² in extent (Devine 1975). At Low Flat shore hibiscus is extensive in the south-western corner of the flat.

In 1993 one small plant was found growing above the strand line at Coral Bay and the same plant was first seen in 1991 (Clapham 1991b). This plant may have established from seed as shore hibiscus is a common strand plant in the Pacific (Merrill 1940). What is uncertain, though, is where the seed originated from. Seedlings have only occasionally been recorded under the large stands on Raoul Island (Clapham 1991b), and seed set has not been observed. It is possible that the Coral Bay plant germinated from seed dispersed from elsewhere in the Pacific. Alternatively, the plant at Coral Bay could have established from a stem fragment washed around the coast from Denham Bay or Low Flat. However, given that all known stands are some distance from the sea, this explanation is less likely.

At the start of the weed eradication programme, shore hibiscus was listed as a category A plant (Devine 1977). In 1980, Sykes noted that the plants at Low Flat and Denham Bay had not increased much and because they were only slightly increasing through vegetative layering should be accorded low priority in the eradication programme.

7.3.2 Ecology

Shore hibiscus is a sprawling shrub up to 4 m tall belonging to the mallow family (Malvaceae). Leaves are densely hairy below and velvety to touch, almost circular and c. 10–30 cm diam. Yellow flowers with dark purple centres are c. 30–70 mm long. Flowers are produced from November to December. Fruit have not been recorded on Raoul.

On Raoul, shore hibiscus grows as pure stands covering areas up to 50 x 50 m in old plantation sites. The dense stands expand gradually through layering of branches and they virtually exclude all other species. Thus, this species is an effective competitor and is impeding regeneration of native species, as well as restricting the growth of other adventive species, such as aroid lily. However, it does not grow under the forest canopy as it is a light-demanding species. The one plant at Coral Bay is in full light at the strand line. Shore hibiscus could spread further into the clearings it occupies but will not spread into forest. Thus it poses a lesser threat than those vines which invade the forest canopy, or those trees and shrubs which grow within small light gaps in the forest.

7.3.3 Control methods

Various chemicals, including Tordon 2G and 520, have been used on the plant at Denham Bay without much success (Sykes 1980). In 1975 some stems were ring-barked and painted with a 50:50 mixture of Tordon 520 and diesel (Champness 1975) and this appeared to be successful (Anon. 1976). Selby (1980) commented that poisons have no effect on this species and suggested that the only feasible method of eradication was cutting and burning. Clapham (1991b) planned to cut the single plant at Coral Bay and spray the stump with Escort. If he did, the plant was resistant.

7.3.4 *Future work*

Detailed observation of the existing clumps of shore hibiscus to discover if viable seed is set would help to unravel the history of this species on Raoul. The clump by Denham Bay hut should be checked monthly from November through to April to record flowering and fruit set.

7.4 *Brugmansia suaveolens* — NIGHT BELLS

Previously *Datura suaveolens*

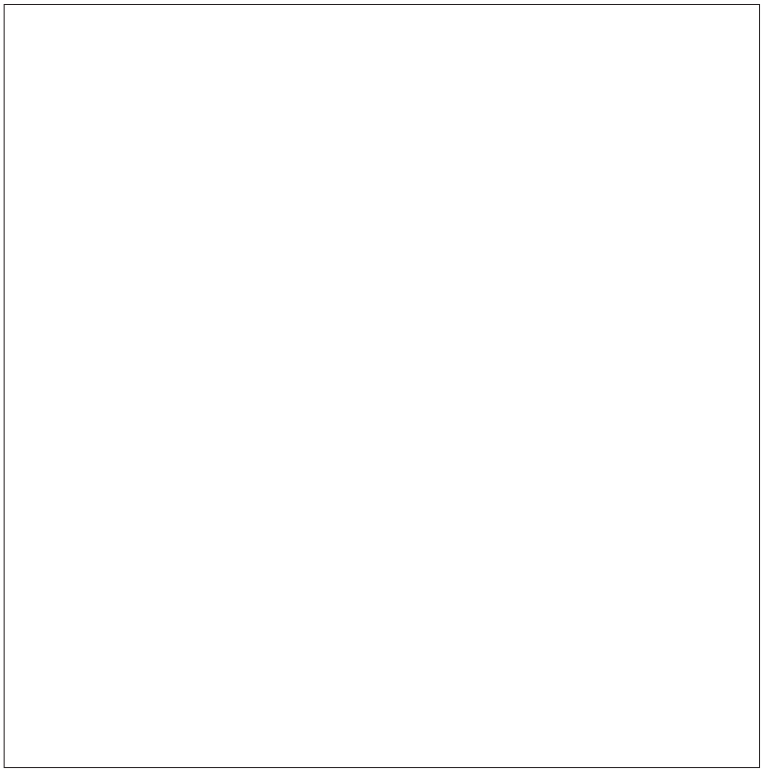
7.4.1 *History*

Although not recorded by Cheeseman (1888) or Oliver (1910), this species was presumably introduced by Thomas Bell as a garden plant (Sykes 1977a), as Nightbell Gully is referred to by Morton (1964). Sorensen (1944) photographed "trumpet plant" which is this species (Figure 24). Sykes (1977a) recorded night bells only from the mouth of Nightbell Gully, in 1966–67. In 1993, however, the species was seen near the road at Bell's Ravine and scattered along the forest edge and in the open in the central part of the Orchard, immediately east of Nightbell Gully. Sykes (pers. comm.) recalls that night bells was present in the Orchard in 1966–67 although that location was not recorded in his Flora.

7.4.2 *Ecology*

Night bells is a softly woody perennial shrub up to 3 m tall and is in the nightshade family (Solanaceae). The leaves are large (25 x 12 cm) and papery. During most of the year, large, white, trumpet-shaped flowers are produced. The flowers are sweetly scented at night. Fruit production has not been noted.

Figure 24 Nightbells in a sea of *Ageratum houstonianum*, 1944 (Photo: J.H. Sorensen).



This species is light demanding and currently grows in the open or at the forest edge. It is apparent that this species might be spreading. Sykes (1977a) has never recorded fruit from the plants on Raoul. Fruit production may not have been observed, or it is possible that the species could be spread by vegetative fragments from machinery. The grass in the orchards has in the past been periodically cut and it is likely that bits of the night bells have been caught up in the mower blade or tractor wheels and dropped off along the road or farm tracks.

7.4.3 *Control methods*

Grub out plants and hang in nearby trees to desiccate.

7.4.4 *Future work*

Observe those plants at Bell's Ravine, every two weeks for a year to see whether fruit are set.

7.5 *Araucaria heterophylla* — NORFOLK PINE

(Adults of historic significance only)

Control of this species is described in section 5.9.3. Only the 12 trees assumed to have been those originally planted by Thomas Bell are to be left standing. All progeny, including the trees at Denham Bay are to be destroyed, given the potential this species has to invade and alter the structure of the forest on Raoul Island, albeit slowly. The trees planted by Bell are in poorer condition than their nearby offspring, and most suffer from central stem rot. As they die out, no replacements should be allowed to grow. However, if there are unisexual trees present, these could be cloned as suggested in section 5.9.4, and used to perpetuate the specimens of historic significance on the island.

7.6 *Prunus persica* — PEACH

7.6.1 *History*

Peaches were introduced to Raoul by the earliest settlers (Haigh 1968) and were noted both by Smith (1887) and Cheeseman (1887 unpub.). According to Venables (1937), Bell cultivated three varieties of peach. Sorensen (1944) photographed peach blossoms. Sykes (1977a) records that both clingstone and freestone varieties are present in old plantations on the Terraces and at Denham Bay. In 1993 peaches were recorded from Denham Bay, the Terraces, Low Flat, in groups along the Boat Cove Road and near Boat Cove Hut. Peaches were naturalising freely, especially in the vicinity of Boat Cove Hut. At Low Flat, what is probably a recent dwarf cultivar grows on the edge of the bracken at the eastern end of the flat.

7.6.2 *Ecology*

Peach trees (family Rosaceae) are deciduous on Raoul and grow up to 4 m tall. Pale pink flowers are present through winter and spring and green fruit are evident from late winter (Figure 25). Sykes (1977a) records that "fruits are generally small and tend to rot as they ripen, apparently because of disease and high humidity".

People have assisted the spread of peaches around Raoul Island by carrying fruit and throwing away the stones. The clumps of peach trees have arisen from one or a few trees establishing at a site and seedlings establishing as the progeny of those trees. All of the infestations are in areas frequently accessed by people, e.g., along Boat Cove Road. The species is light-demanding, so persists in old cultivation sites and establishes in clearings or along the road edge.

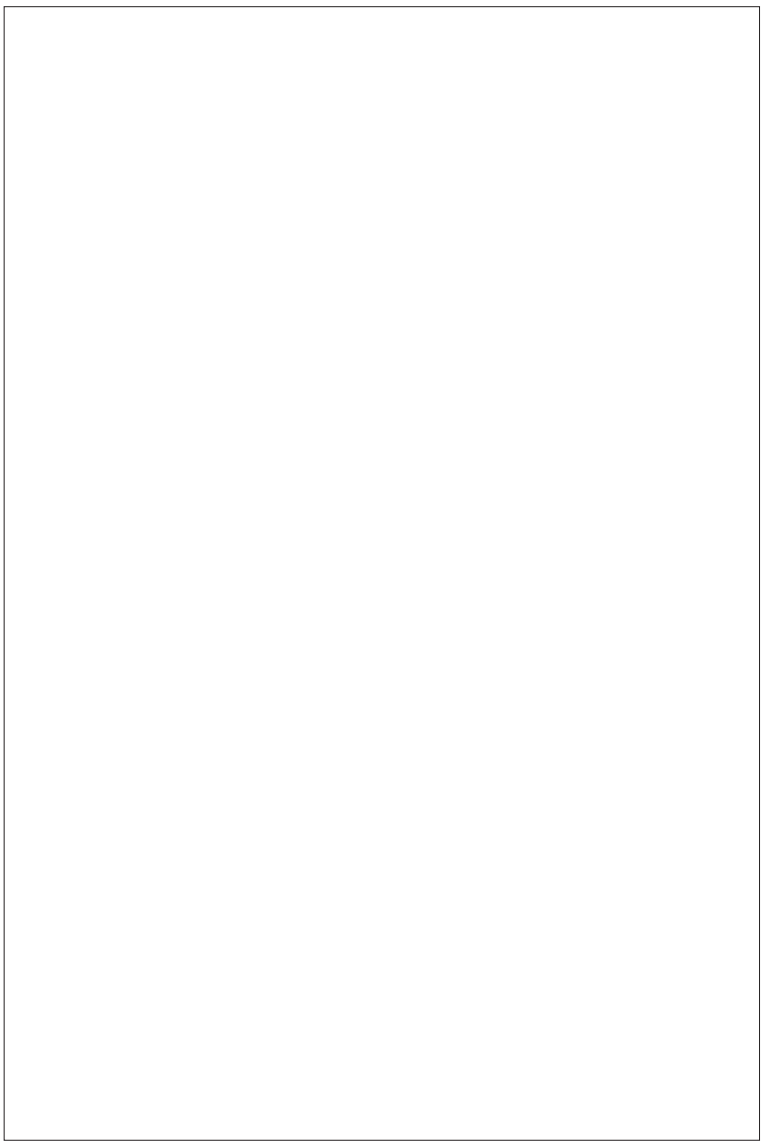


Figure 25 Young peach fruits on trees at Low Flat, October 1994.

Peach stones were not common in 1993, and rat chewed stones were not observed. It is possible, though that rats could cache peach stones, but they would most likely be put in places which are too dark for germination or seedling establishment.

7.6.3 Control methods

Cut and paint stumps with Tordon. Cut stumps may sucker if not adequately poisoned.

7.6.4 Future work

The peaches on Raoul probably do not have much horticultural value as they are prone to fruit rot. They do have historical significance, but the only trees which are likely to be original plantings are those at the northern end of the swamp in Denham Bay and those immediately west of Bell's Ravine, in the vicinity of the date palms. All other peach trees should be removed.

7.7 *Vitis vinifera* — GRAPE

7.7.1 History

Grapes are one of the earliest recorded exotic fruit crops from Raoul Island. In 1836–37 the earliest settlers on the Island, the Reeds and Bakers, sold grapes to passing whalers (Haigh 1968). In 1887 Cheeseman (unpub.) and Smith (1887) noted grapes as being used by the Bells. Large (1888) quotes Thomas Bell as saying that grapes do not succeed well on Raoul Island "from some cause or other". Grape vines were established in association with various settlements on Raoul. During the Coastwatch years of World War II a vine was grown outside the Coastwatchers Hut on Trig V (Expedition Hill) and this was still growing rampantly in 1966–67 (Sykes 1977a). Attempts have been made to destroy the vine on Trig V and it may now be absent from this location. Elsewhere grapes are still known from three sites in Denham Bay — at the northern end of the swamp, by the hut, and near the grove of cherimoya behind the Norfolk pines. A large vine occupies most of a clearing of low-growing shrubs and ferns on the western side of the vehicle track to Low Flat beach. Grapes are also recorded from the Orchard and from an old orchard area west of Bell's Ravine.

7.7.2 Ecology

Grape vines (family Vitaceae) are deciduous woody climbers with coarsely toothed leaves to c. 18 cm diam. Forked tendrils enable the vines to climb high into the canopy of surrounding trees (see Figure 19). The small, green, fragrant flowers are clustered in long clumps and are present from October through to December. Two types of fruit have been recorded on Raoul. Most have small black fruit (Sykes 1977a) but others have green fruit (S. Uren pers. comm.).

Grape vines have a similar effect on the forest canopy as Mysore thorn and black passionfruit but, because they are deciduous and native trees and shrubs of Raoul can grow all year, do not have as much impact. However, the weight of grape foliage and stems built up over the years is sufficient to smother all but pohutukawa.

Various workers on Raoul have reported seedling grape vines, but none of these records have been substantiated. Instead these reports relate to lateral branches formed from prostate stems buried in the soil or covered with dense grass or deep litter. New shoots of grape are very soft and can easily be mistaken for seedlings.

7.7.3 Control methods

Trace back stems, many of which will have rooted in contact with the ground, and pull out. Scatter Tordon 2G granules in areas where stems can't be pulled up.

7.7.4 Future work

Only the plants in the Orchard and on Trig V (if still present) should be eradicated. For the plants at Low Flat, at Denham Bay and west of Bell's Ravine, cut down the stems to keep the foliage out of the tree canopy but do not eliminate from each site. These plants are likely to be the oldest and may be of horticultural significance. Live material has been taken for propagation in New Zealand to identify the types of grape present. Thus, the plants on Raoul should not be eradicated until the results of these investigations are known.

7.8 *Phoenix dactylifera* — DATE

7.8.1 History

Date palms have been on Raoul at least since the time of the Bells as a sketch by Carver of "Bells kitchen garden" on the Northern Terraces in 1892 clearly shows date palms as well as Norfolk pines (Johnson 1991). Dates are still present in the vicinity of the Bell settlement at this site and are most likely to be the ones illustrated by Carver. A taller growing clump of dates grows near Denham Bay hut, and is presumed to be older than those on the Northern Terraces. There is a large clump of date palms behind the foxway winch shed at Fishing Rock and small plants lacking trunks and with fronds up to 2 m long are scattered along the crater rim adjacent to Boat Cove Road.

7.8.2 Ecology

Date palms (family Arecaceae) are slow-growing trees which, on Raoul, have attained a height of 12 m. Fronds on mature trees are up to 4 m long. Small plants are produced by suckering at the base of the trunks but the species has not spread by this method. Large clumps of small flowers are produced below the fronds on large trees. Flowering was recorded in August 1993 and many flies were attracted to the flowers. Fruit production has never been recorded on Raoul and Sykes (1977a) suggests that fruiting is unlikely because of the humid oceanic climate. The young plants along the crater rim are suckers planted many years ago which are growing slowly (Sykes pers. comm.).

7.8.3 Control methods

Control of dates has never been undertaken on Raoul. In the first instance, removal of young plants could be attempted by digging them out.

7.8.4 Future work

The dates at Denham Bay and on the Northern Terraces west of Bell's Ravine should be left alone. They are of historic significance as they are relics of European settlement in the 19th century. These dates should also be observed to discover whether fruit are produced on Raoul. Monthly observations of the trees from August onwards should suffice.

8. Discussion

The first botanists to visit Raoul — Cheeseman in 1887 and Oliver in 1908 — recorded all naturalised exotic species present then. Only one of the species listed in Category A (castor oil plant) was naturalised then, and was noted by Oliver (1910). Both guava species were listed by Cheeseman (unpub.) as crops grown by the Bells but none of the other species were recorded, although some are surmised to have been cultivated then. All of the earliest botanical observers on Raoul, from Cheeseman through to Sorensen, saw weeds of cultivation as the most prolific introduced plants. Oliver recorded two "introduced formations" on Raoul: the "*Ageratum* meadow" which occupied all clearings in Denham Bay; and the "buffalo grass meadow" which extended from the northern terraces to Low Flat and the crater rim nearby, as well as in one place on the east coast. These are weeds of cultivated and open ground and do not pose a long-term threat to forest cover, although the dense buffalo grass swards greatly slow down the rate of forest recolonisation. *Ageratum houstonianum* is still common today as a weed in open, disturbed ground. Guthrie-Smith (1936) mentioned both of these species, too, in relation to the Meyer Islets which he stated were fortunate ". . . in being waterless, therefore not fouled with humanity and therefore goatless, pigless and innocent of such iniquities as ageratum and buffalo grass." Unfortunately, these islets are not so weed-free today.

It was only when the settlements in Denham Bay and on the northern side of the Island were abandoned that the species which were to pose a threat to the forest on Raoul became apparent as they were no longer kept in check by harvesting and cultivation. The first warning bells were sounded in 1944 by Sorensen when he saw the impact of Mysore thorn in Denham Bay but other, more widespread species attracted more attention, e.g., *A. houstonianum*, *Sicyos australis* and aroid lily. At this stage there was no weed control undertaken but caution was exercised with regard to importation of plants to the Island. By then, though, most of the species listed in Category A were already present on the Island and were beginning to spread. More than 20 years later when Sykes first visited Denham Bay, Mysore thorn was even more firmly entrenched. At this point eradication of this species was recommended. Other species were also recommended for eradication because, even though they were not particularly widespread and were having less obvious impact on the forest, experience on other Pacific islands had shown the enormous impact these species could have, in time, e.g., African olive and purple and yellow guava.

Weed eradication has been a goal of operations on Raoul Island for the past 20 years. In that time, only one species, ragwort, can be clearly identified as having been eradicated. Ragwort was recorded as a single plant and was killed before it flowered. Other species which have not spread beyond their known, limited ranges have been able to persist because of seeds in the seed bank or vegetative propagules. Examples are pampas grass, Mauritius hemp, fennel and swan plant. For the species which had much greater initial abundances, great progress has been made on eradication of most. Reduction in the extent of

Mysore thorn provides the clearest example of progress towards eradication of one of the worst weeds on the Island. Instead of solid curtains of this vine climbing up and killing pohutukawa a walk through Denham Bay reveals nothing of the existence of this species, and it is only by searching diligently through the clearings, on the cliffs, and beside the stems of trees and shrubs that young Mysore thorn plants are found. Species such as Brazilian buttercup have extended their range during the period of the eradication programme, but the numbers of mature seeding plants have been reduced substantially.

One of the difficulties of the weed eradication programme is continuity of effort. When teams are present on the Island for one-year periods and there is limited time during the changeover period for exchange of information and familiarisation by the new team, some time can be lost or information not fully appreciated while the new team is learning about the eradication programme and the Island. Record-keeping in relation to site details for specific weed species continues to improve and this, combined with the commitment of staff to follow up on all records, should reduce the incidence of previously treated sites becoming reinfested with target species. Thus, situations such as currently experienced with Brazilian buttercup should not recur.

Some workers have commented on the apparently poor job done by previous weed teams or individuals. In most cases, though, this perception relates more to the fast growth rates of the weed species on Raoul than a lack of effort by staff. Growth rates on Raoul are much faster than in most places on the New Zealand mainland, which is the experience base of most staff on the Island. As indicated earlier in this report several species of both shrubs and vines can be of sufficient size to flower and set seed within two years. One of the reasons for providing a history of each target weed was to indicate the level of control which has been exerted over the years.

There has been a change in the type of effort required for each species as the eradication programme has progressed. In the initial stage of eradication the greatest effort is expended on destruction of the existing, usually dense populations of the target species. However, within a relatively short time (and with the current exception of Madeira vine) the initial populations are reduced substantially. The effort then switches to most time being spent searching for individuals or small groups of the target species. Once found, destruction is usually quick and easy. Most of the category A(i) species fall into this latter stage. Effective searching and documentation of sites are the most critical factors in this phase of weed eradication as the aim is to stop any further seeding of plants and therefore the earlier termination of the weed eradication programme.

Several of the weed species are much easier to find when they are flowering (e.g., Mysore thorn, Brazilian buttercup). Others are easier to see as adults as their stems look quite different from the native species in the forest (e.g., purple and yellow guava) but some others are easier to find as juveniles because their foliage is a different colour or form from most native species yet the adult trunks blend in with the trunks of native species (e.g., African olive). There is usually some characteristic of the target species which enables it to be distinguished from the surrounding vegetation.

Grid searching is the most effective way of finding target species, and the distance between search lines must be varied according to the density of the

vegetation. In forest with a slight understorey 10 m spacing would be sufficient but in dense areas, 5 m spacing would be more appropriate. On subsequent searches of each site, the search pattern must be changed, e.g., rotated by 90° each time to avoid familiarity of approach and improve the chances of finding target species.

On Raoul, the invasive weeds all have greatest impact on the dry forest and most are not known to grow above 300 m altitude. It is possible that the wet forest is less vulnerable to invasion because the understorey and canopy are generally more dense. Also, for species with seeds dispersed by explosion of the pods (e.g., Brazilian buttercup) or by vegetative propagules (e.g., Mauritius hemp) dispersal uphill takes much longer than dispersal downhill, and the initial sites of establishment of all of the target species was in the inhabited lowlands. However, recent teams have recorded greater altitudinal ranges for species such as black passionfruit, African olive and Brazilian buttercup (Fastier 1994, Uren 1995b).

The majority of the weeds targetted for eradication on Raoul are of tropical as opposed to temperate origin and this reflects the warm climate on Raoul. The native vegetation of the Island grows much more rapidly than the temperate species introduced there, but the introduced subtropical species can grow just as fast as the native vegetation and infiltrate or dominate the native communities. Although the climate is not warm enough for sexual reproduction of some of the subtropical target species (e.g., Madeira vine, Para grass), vegetative reproduction is sufficiently aggressive to warrant their eradication.

Most of the species targetted for eradication are light-demanding. They were initially established in plantations or gardens and have been able to spread into the forest by taking advantage of light gaps which are continually formed on Raoul. There are four main ways in which light gaps are created on the Island: tree falls during cyclones; slips caused by earthquakes; slips caused by flash floods (e.g., the downpour which caused the Bells to finally desert Raoul — Bell 1911); and destruction of vegetation by volcanic eruptions (see Sykes 1977a). Given the dynamic nature of the Island there will always be light gaps forming and being recolonised. Some of the native species regenerate best in light gaps too (e.g., *Homalanthus polyandrus*) but can be outcompeted by adventive species.

New slip sites should be checked for weed species, especially where they are near known previous infestation sites as seeds may have been buried in the soil for many years. As soon as dormant seed is exposed to higher light levels it will germinate and the high light environment of slips will favour the growth of light-demanding weed species. Similarly, light gaps formed after cyclones should also be checked, especially along the northern side of the Island, in the crater and in Denham Bay. Eruptions are far less frequent (fortunately) and are also less likely to promote weed growth as the most effective coloniser of ground bared by eruptions appears to be Kermadec pohutukawa. However, many of the target weed species are capable of invading the pohutukawa forest once it has re-established.

Germination of seed from the seed bank can be speeded up by increasing the light levels reaching the ground in areas where parent plants have been removed. In the early 1980s controlled burns in Denham Bay were used to accelerate germination of Mysore thorn seeds buried in the the soil but shaded by a fern canopy. Sykes (1980) suggested this strategy and Selby (1982b)

reported that it was working well. In 1994, Sykes (1994) recommended removing surrounding ground-cover vegetation from sites where parent plants of Brazilian buttercup had seeded recently. This would achieve the same effect and, because only a small area is cleared, would not greatly enhance the potential for erosion.

Weed species which are not so light-demanding and grow densely beneath the pohutukawa canopy pose a significant threat even though they may be limited to vegetative spread (e.g., Para grass, bamboo). In this situation the forest canopy remains only for the life of the existing trees. Once they fall or die, the weeds will persist at the site as they are usually tolerant of high light conditions. It should be noted, however, that Kermadec pohutukawa is virtually indestructible (except by volcanic eruptions and smothering vines) and continues to grow once felled by cyclones or slips. Regeneration by seed, of course, is impeded by dense ground cover.

Invasive weeds generally affect native vegetation in one of two ways: the most obvious impact is by those species which smother the canopy, eventually killing the host trees and then the subcanopy and ground cover layers as the canopy trees disintegrate; less obvious impact comes from those species which grow densely in the subcanopy or as ground cover and inhibit forest regeneration. As mentioned in the paragraph above, the effect of these species is not noticed for much longer, until the canopy begins to disintegrate naturally. All of the shrub and tree species targetted for eradication on Raoul will inhibit forest regeneration by occupying sites which would otherwise be inhabited by native species. They will not generally occupy all sites and most native species would be able to regenerate but to a lesser extent. Over time, the forest would change from one dominated by native species to one dominated by exotics, and the rarer elements of the native flora (including a number of endemic species) would be lost first.

Vines are the greatest canopy killers (although parasitic plants such as mistletoes can be just as effective) and several species are targetted in the weed eradication programme for Raoul (e.g., Mysore thorn, black passionfruit, Madeira vine). The native flora of Raoul lacks woody vine species, and has, therefore, evolved in their absence. This could have resulted in a flora which is less able to grow in the presence of vines and is subsequently more susceptible to their effects. *Sicyos australis* is the only native tree-climbing vine on Raoul, but it is non-woody and short-lived and has no lasting effect on the forest edge shrubs that it scrambles over.

Not only are the weeds targetted for eradication subdivided into vines and others but they can also be subdivided into those that affect forest vegetation versus coastal communities. Most of the category A species threaten the forest but a few (e.g., pampas grass, fennel) pose a greater threat to coastal shrublands and herb communities. In forest they are readily overtopped and die slowly through lack of light but in the lower growing, more open coastal communities they are aggressive competitors. Pampas also springs up readily on slip sites and in large light gaps and, being wind-dispersed, the seeds are readily transported to remote locations. Madeira vine poses a threat to coastal communities and also threatens forest.

A further subdivision of target weeds relates to their mode of dispersal: predictable vs unpredictable. Fortunately, many of the species are usually dispersed only short distances by explosion of seed pods (e.g., Mysore thorn, Brazilian buttercup), by wind dispersal of seeds (e.g., Norfolk pine) or by gravitational dispersal of vegetative propagules (e.g., Mauritius hemp, Madeira vine). Thus, they spread incrementally from existing infestations and their pattern of spread is generally predictable. For those species relying on gravity and pod explosion most dispersal will be downhill of existing infestations whereas lateral and uphill dispersal will be less significant. Most spread of wind-dispersed species is in the direction of the prevailing wind.

Species with fleshy fruits tend to be dispersed by birds. Either the fruit containing the seed is taken whole by the bird (e.g., African olive) or the seeds are picked out of the fruit (e.g., black passionfruit, yellow guava). Generally, birds disperse seeds in an unpredictable fashion as they move from the weed species they are feeding on to a roosting or perching site. Despite black passionfruit being bird-dispersed, it has tended to spread incrementally from foci associated with human activity. However, it and all other bird-dispersed species could potentially appear in any suitable habitat around the island.

Whether the dispersal pattern of species is predictable or unpredictable, effective invasion by these species relies on seeds being able to germinate in the sites to which they are dispersed. In many instances conditions are not right for seed germination, but most of the target weed species on Raoul have seeds which can lie dormant in the soil for many years, as part of the seed bank. When conditions improve (usually high light associated with soil movement or tree fall) the seeds germinate and a new weed infestation arises.

Also, species which are generally dispersed in a predictable fashion occasionally do turn up in unexpected places. Two examples from Raoul illustrate this point. Firstly, species which are primarily terrestrial can also grow epiphytically, e.g., Mauritius hemp. It is not inconceivable that other target species could establish epiphytically and this possibility should be borne in mind when grid-searching. Secondly, chance dispersal by seeds being transported in mud adhering to birds' feet or feathers, or in the clothing or on boots of people is probably responsible for most of the remote dispersal of some species. Brazilian buttercup has been on the Meyer Islets for many years and its method of introduction is not known but is not likely to have been deliberate. Aroid lily is also present on the Meyers and will have been taken across by birds. With regular movement of birds between Raoul and the Meyers seeds of fleshy fruited species in particular will be moved between the two places. It is, therefore, important that eradication efforts on Raoul continue to include the Meyers so that these two islands do not act as a source of weed re-infestation to Raoul. The Meyers themselves are a very valuable part of the nature reserve and should have the weeds eradicated as a priority for their own sake anyway.

Longer distance dispersal of Madeira vine becomes more likely the longer the infestations remain untreated as the number and size of the tubers builds up. Inevitably, tubers will fall into the sea and be dispersed around the coast of Raoul, or to the Meyers, and have the potential to start new infestations. I cannot stress strongly enough the urgency with which this plant must be dealt with. Any species which is as difficult to eradicate as this one is in its current,

limited locations, is going to be orders of magnitude more difficult to deal with once it has dispersed to many, more remote locations.

In order to enable areas remote from currently known infestations of the target weed species to be checked, it is suggested that helicopter surveillance be used at least every two years. Areas which should be checked are the Mahoe ridge down to sea level on both sides, the eastern side of the Island from Rayner Point around to Boat Cove and both sides of Hutchisons Ridge from Denham Bay and Western Spring westwards. This request was made by Fastier (1994) also, and while helicopter surveillance might be difficult to organise, it will be essential to the success of the weed eradication programme. Species which could profitably be searched for by helicopter are Mysore thorn and Brazilian buttercup (when they are flowering), black passionfruit, Madeira vine and African olive. The flowering times of Mysore thorn and Brazilian buttercup barely overlap (in November) so it may be necessary to do separate runs for these species. Brazilian buttercup, however, is higher priority given its greater abundance and current range.

The species currently targetted for eradication are those which are causing significant threats to the native vegetation of Raoul Island in the presence of two species of rat: kiore (*Rattus exulans*) and Norway rat (*R. norvegicus*). However, it is expected that some species might become significant weeds once rats are eradicated (eradication of rats and cats is currently programmed for 1998). Species such as macadamia, puriri, papaya and possibly grapes, dates and some citrus could increase in abundance in the absence of rats. There are two reasons why some of these introduced species might increase in abundance and range. Firstly, rats eat large amounts of seed, e.g., all nuts produced by the macadamias on Raoul are eaten by rats — the ground beneath the trees is littered with opened shells. When kiore were eradicated from Tiritiri Matangi Island in the Hauraki Gulf, puriri seedlings grew under the one tree in the main bush area for the first time in recorded history (pers. obs.). Secondly, eradication of rats and cats will allow bird populations to increase. Some of these bird species will be effective seed dispersers. As bird numbers increase, so too will dispersals, and some of the currently restricted exotic species could increase substantially, to the detriment of the native forests of Raoul. It would be prudent to remove species such as macadamia and puriri before the rat eradication commences. However, reclassification of these species is more appropriate closer to the time of the rat eradication programme. Closer observation of some species may be required also.

In summary, considerable progress has been made towards eradication of all weeds which significantly threaten the natural plant communities of Raoul Island (and the Meyer Islets). This assessment serves to illustrate the progress which has been made and also gives an indication of the work which has yet to be done. The length of the eradication programme increases with every individual weed that disperses viable seeds or vegetative propagules. Thus, searching for and destroying all individuals before they can reproduce is the target. Bearing in mind the unknown seed longevity of all target species and given the tenacity of even the most restricted category A weeds, it is probably realistic to predict that the weed eradication programme on Raoul Island will run for a further 20 years.

9. Recommendations

9.1 ***That the three categories encompassing the entire introduced flora be adopted.***

9.2 ***That the assignation of species in each category be accepted.***

9.3 ***That the lists of species in each category be revised regularly, as more is known about the species themselves, and that a revision be undertaken before the rat eradication operation.***

9.4 ***That the actions suggested for each of the species be undertaken.***

9.5 ***That particular effort be put into hand removal of Madeira vine at Fishing Rock and in Bell's Ravine.***

9.6 ***That monitoring of seed formation be undertaken for shore hibiscus, night bells, and date.***

9.7 ***That the rate of spread of air plant be monitored.***

9.8 ***That every effort be made to undertake aerial surveillance of remote parts of Raoul Island as soon as possible, and regularly thereafter as long as weed eradication remains a goal of management on the Island.***

9.9 ***That weed eradication on the Meyer Islets proceeds in tandem with that on Raoul.***

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11. References

Adlam, J.P. 1979. Raoul Island Expedition 1979 final report. Unpublished report to Department of Lands and Survey, Wellington, file no. 22/1517/1.

Anderson, J.E. 1938. Kermadec Islands. Report of Aeradio Committee (unpublished). Department of Internal Affairs. 25 p.

Anon. 1976. Raoul Island: statement of programme to eradicate exotic plants. Department of Lands and Survey, Wellington, file no. 22/1517.

Anon. 1982a. Interim management guidelines — Kermadec Islands Nature Reserve (April 1982 revision). Department of Lands and Survey, Wellington.

Anon. 1982b. Raoul Island Nature Reserve: plant control programme (May 1982 revision). Department of Lands and Survey, Wellington, file no. RES 1/5/3/9.

Anon. 1985. Kermadec (Raoul Island) Nature Reserve plant control programme (May 1985 revision). Unpublished report to Department of Lands and Survey, Wellington, file no. RES 1/5/3/9.

Anon. 1992. Raoul Island habitat management. Unpublished report, Auckland Conservancy, file no. DOC 212-20.

Atkinson, I.A.E. 1975. Report on visit to Raoul Island, July 24–25, 1975. Unpublished report to Outlying Islands Advisory Committee, Department of Lands and Survey, Wellington.

Bell, R.S. 1911. Diary of Raoul Sunday Bell on Raoul (Sunday) Island 1908–1911. Presented to the Alexander Turnbull Library 1958 by Mrs W.R.B. Oliver.

Bracefield, M. 1987. Raoul Island 1886/87. Unpublished report to Department of Conservation, Auckland Conservancy, file no. DOC 212-20. 9 p.

Carver, R.W. 1889–1893. Sketches and other papers relating to the Kermadecs. Misc. mss. W 17 (unpublished). Alexander Turnbull Island, Wellington.

Champness, G.R. 1975. Raoul Island Expedition 1975. Department of Lands and Survey, Wellington, file no. 22/1517/1

Champness, G.R. 1976. Extermination of introduced plants on Raoul Island. Department of Lands and Survey, Wellington, letter dated 26 March 1967 on file no. 22/1517/1

Cheeseman, T.F. 1887 (unpublished). Notebook. Auckland Institute and Museum.

Cheeseman, T.F. 1888. On the flora of the Kermadec Islands; with notes on the fauna. *Transactions and Proceedings of the New Zealand Institute* 20: 151–181.

Chandler P. (n.d.) Buttercup (*Cassia floribunda*). File note. Department of Lands and Survey, Wellington. File no. RES 1/5/3/9.

Clapham, M. 1991a. Letter on file to Bill Sykes dated 3/3/91. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Clapham, M. 1991b. Letter on file to Bill Sykes dated 17/6/91. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Clark, A. 1992. Situation report on file. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Crawley, R. 1990. October 1990 monthly report. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Crawley, R. 1991a. January 1991 monthly report. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Crawley, R. 1991b. March 1991 monthly report. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Crawley, R. 1991c. April 1991 monthly report. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Dale, P. 1979. Raoul Island 1978/1979. Unpublished report to Department of Lands and Survey, Wellington, file no. 22/1517/1.

Davison, E.B. 1938. Kermadec Islands. Report of Aeradio Committee, Appendix C (unpublished). Department of Internal Affairs. 14 p.

Devine, W. T. 1975. Report for Outlying Islands Reserves Committee: treatment of introduced plants, Raoul Island (other than Mysore). Department of Lands and Survey, Wellington, file no. 22/1517.

Devine, W.T. 1977. A programme to exterminate introduced plants on Raoul Island. *Biological Conservation* 11: 193–207.

Fastier A. 1994. End of season weed report. Unpublished report to Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Gardner, S. 1988. Raoul Island 1987/88. Unpublished report to Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Griffiths, A. 1980. Report on file. Department of Lands and Survey, Wellington, file no. 22/1517.

Guthrie-Smith, H. 1936. Sorrows and joys of a New Zealand naturalist. A. H. & A. W. Reed, Dunedin. 252 p.

Haigh, J.B. 1968. Raoul (Sunday) Island, Kermadec Group: a brief history. *Whakatane Historical Review* 16: 66–80.

Hancox, D. 1982. Dreamland. *Mt Aspiring National Park News*, No.2. March 1982.

Healy, A.J.; Edgar, E. 1980. Flora of New Zealand. Vol. III. Government Printer, Wellington.

Hovell, H.K. 1890. Letter on file. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Johnson, L. 1991. A history and archaeological survey of Raoul Island, Kermadec Islands. *Auckland Conservancy Technical Report Series No. 2*. 71 p.

Large J.T. 1888. Notes of a trip to the Kermadec Islands. *Wairoa Guardian*, c. 17–27 August 1888.

Lloyd, E.F.; Nathan, S. 1981. Geology and tephrochronology of Raoul Island, Kermadec Group, New Zealand. *New Zealand Geological Survey Bulletin 95*. DSIR, Wellington.

Massal, E. and Barrau, J. 1956. Food plants of the South Sea Islands. *South Pacific Commission Technical Paper No. 94*. 51 p.

McMillan, G. 1971. Kermadec Islands — inspection November/December 1970. Department of Lands and Survey, Wellington, file no. 22/1317.

Merrill. E.D. 1940. Man's influence on the vegetation of Polynesia, with special reference to introduced species. *Chronica Botanica* 10: 334–345.

Merton, D.V. 1969. The Ornithological Society of New Zealand Kermadec Islands expedition. Department of Internal Affairs unpublished report. 36 p.

Morton, E. K. 1964. Crusoes of Sunday Island. A. H. & A. W. Reed, Wellington. 354 p.

New Zealand Meteorological Service 1983. Summaries of climatological observations to 1980. *New Zealand Meteorological Service Miscellaneous Publication 177*: 170.

Oliver, W.R.B. c. 1908. Notes from the literature relating to the Kermadec Islands. Turnbull Library, Wellington.

Oliver, W.R.B. 1910. The vegetation of the Kermadec Islands. *Transactions and Proceedings of the New Zealand Institute* 42: 118–175.

Ombler J. 1977. Report of 1977 expedition to Raoul Island. Department of Lands and Survey, Wellington, file no. 22/1517/1.

Parkes, J.P. 1984. Feral goats on Raoul Island. II. Diet and notes on the flora. *New Zealand Journal of Ecology* 7: 95–101.

Rees, D. 1982. General report — Raoul Island. Unpublished report, Department of Lands and Survey, Wellington, file no. 1/5/3/6/2.

Samson, B. 1993a. Raoul Island Weed Control Programme. Department of Conservation, Auckland Conservancy unpublished report, file no. DOC 212-20.

Samson, B. 1993b. January 1993 monthly report. Department of Conservation, Auckland Conservancy, file no. DOC 212-20.

Selby, R.M. 1980. Raoul Island Expedition 1980. Unpublished report, Department of Lands and Survey file RES 1/5/3/9, Wellington.

Selby, R.M. 1982a. Raoul Island expedition 1982. Mysore thorn: overall results from last years treatment. Letter on file, Department of Lands and Survey file 1/5/2/11, Wellington.

Selby, R. M. 1982b. Raoul Island Expedition 1981. Unpublished report, Department of Lands and Survey file RES 1/5/3/9, Wellington.

Selby, R.M. 1982c. Annual report for 1982 expedition to Raoul Island. Unpublished report, Department of Lands and Survey file RES 1/5/3/9, Wellington.

Selby, R.M. 1982d. Letter to W. Devine re Raoul Island Nature Reserve: plant control programme. May 1982 revision. 8 June 1982. Department of Lands and Survey file RES 1/5/3/9, Wellington.

Sherley, G.H. 1986. Kermadec Islands Management Plan — public draft. Department of Lands and Survey, Wellington.

Skerman, P.J. and Riveros, F. 1990. Tropical Grasses. *FAO Plant Production and Protection Series no. 23*. Food and Agriculture Organisation of the United Nations, Rome.

Smith, S.P. 1887. The Kermadec Islands; their capabilities and extent. Government Printer, Wellington. 29 p.

Sorensen, J.H. 1944. Raoul Island Diary: 26/4/44–20/11/44 (unpublished, lodged at DoC S&R library, Wellington).

Sykes, W.R. 1965. Notes on the 1964 eruption and the vegetation of Raoul Island. *Proceedings of the New Zealand Ecological Society* 12: 20–23.

Sykes, W.R. 1969. The effect of goats on the vegetation of the Kermadec Islands. *Proceedings of the New Zealand Ecological Society* 16: 13–16.

Sykes, W.R. 1975. Introduced plants in the Kermadec Islands. Unpublished report to Department of Lands and Survey, Wellington, file no. 22/1517/1.

Sykes, W.R. 1977a. Kermadec Islands flora: an annotated checklist. *DSIR Bulletin 219*. Government Printer, Wellington. 216 p.

Sykes, W.R. 1977b. Raoul Island vegetation survey: 26 November–7 December 1976. Unpublished report to Department of Lands and Survey, Wellington, file no. 22/1517/1.

Sykes, W.R. 1978. Kermadec Islands — 8/2/1978–15/2/1978. Unpublished report to Department of Lands and Survey, Wellington. 5 p.

Sykes, W.R. 1980. Kermadec Expedition — November 1980. Unpublished report to Department of Lands and Survey, Wellington. 6 p.

Sykes, W.R. 1984. Kermadec Islands Expedition — October 1984. Unpublished report to Department of Lands and Survey, Wellington. 16 p.

Sykes, W.R. 1990. Kermadec Islands Expedition — August 1990. Unpublished report to Department of Conservation, Wellington. 12 p.

Sykes, W.R. 1994. Introduced plants on Raoul. Unpublished report to Department of Conservation, Auckland.

Sykes, W.R.; West, C.J. (in press) New records and other information on the vascular flora of the Kermadec Islands. *New Zealand Journal of Botany*.

Taylor, A. 1974. Report of 1974 expedition to Raoul Island. Department of Lands and Survey, Wellington, file no. 22/1517/1.

Trotter, J.G. 1976. Raoul Island management expedition 1976. Unpublished report to Department of Lands and Survey, Wellington, file no. 22/1517/1.

Udvardy, M.D.F. 1975. A classification of the biogeographical provinces of the world. *IUCN Occasional Paper No.18*. IUCN, Morges, Switzerland.

Uren, S. 1994. Raoul Island first quarter report. Unpublished report to Department of Conservation, Auckland. File no. DOC 212-20.

Uren, S. 1995a. Raoul Island second quarter report. Unpublished report to Department of Conservation, Auckland. File no. DOC 212-20.

Uren, S. 1995b. Raoul Island third quarter report. Unpublished report to Department of Conservation, Auckland. File no. DOC 212-20.

Veitch, C.R. 1994. Raoul Island May to August 1994: a Report to the Regional Conservator, Auckland Conservancy, following a visit to Raoul Island. Unpublished report. Department of Conservation, Auckland Conservancy.

Venables, A.M. (Ed.) 1937. The Kermadec Group: the unvarnished truth about Sunday Island — 'A land of dreams'. Walsh Printing Company, Auckland.

Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988. Flora of New Zealand. Vol. IV. Naturalised pteridophytes, gymnosperms, angiosperms. Botany Division, DSIR, Christchurch.

Wright, A.C.S.; Metson, A.J. 1959. Soils of Raoul (Sunday) Island, Kermadec Group. *N.Z. Department of Scientific and Industrial Research Soil Bureau Bulletin 10*: 1–49.

Appendix 1

RAOUL WEED PEOPLE

1972	Len McConnell
1973	Chris Smuts-Kennedy
1974	Arthur Taylor
1975	Graham Champness, Sonny Biddle
1976	John Trotter, Ian Thorne, Rob Selby
1977	John Ombler, Kim Morrison, Dick Kennett, John Gardiner, Bob Selby
1978	Paul Dale, Darryl Morrow, Chris Garton
1979	Ben Adlam, Gilly Adam, Tony Woods
1980–81	Bob Selby, Dave Hancock, Pat Riddett
1981–82	Dave Rees, Bob Selby, Dicey Davidson
1982–83	Dick Cropp, Alf Blundell
1983–84	Darryl Morrow, Rob Wall, Paul Chandler
1984–85	Mark Davies, Jon Maxwell, Paul Chandler, Paul McGahan
1985–86	Mike Fowler, Paul Chandler, Alan Johnston
1986–87	Mark Bracefield
1987–88	Simon Gardner, Lance Cane
1988–89	no staff
1989–90	Simon Gardner
1990–91	Martin Clapham
1991–92	Ant Clark
1992–93	Barry Samson
1993–94	Al Fastier, Grant Harper, Dave Moulder, Len Webb
1994–95	Simon Uren, Blair Ewington, Sean Husheer
1995–96	Jenny Steven, Georgie Hedley, Keith Springer, Gary Lewis

Appendix 2

NOTES ON DISTRIBUTION, PHENOLOGY, AND DATES OF FIRST KNOWN RECORDS OR COLLECTIONS OF PLANTS OF NO KNOWN HISTORIC SIGNIFICANCE

Category B

Adventives resulting from accidental or deliberate introduction which have no historic significance and which pose a minimal or no threat to the forest ecosystem of Raoul Island. First records are derived from the literature or from herbarium collections.

GYMNOSPERMS
PINACEAE
Pinus radiata
Date of introduction not known. When observed in 1970s appeared unthrifty. All trees were felled in 1978 but one was left in the orchard. Not seen recently and is probably no longer present. Cultivated relic.

ANGIOSPERMS
DICOTYLEDONS
APIACEAE
Apium graveolens — wild celery
Recorded by Cheeseman 1887 and not reported since then.

Ciclospermum leptophyllum — slender celery
First recorded by Sorensen 1944. Widespread in open places along the Terraces, e.g., airstrip, road side. Also on the dune crest at Denham Bay.

Daucus carota ssp. *sativus* — carrot
Recorded by Cheeseman 1887. Probably extinct as an adventive — Sykes.

Pastinaca sativa — wild parsnip
Probably died out as an adventive — Sykes.

APOCYNACEAE
Catharanthus roseus
First recorded by Oliver 1908.
Denham Bay — DB8 and scattered towards the coast. One outlier clump in the dune slack just north of the Norfolks.

ASTERACEAE
Achillea millefolium — yarrow
Only reported in 1944, by Sorensen.

Arctotheca calendula — Cape weed
Collected in 1972, only, by Veitch and reported by Sykes 1977.

Aster subulatus — sea aster
First collected by Cooper 1956. Widespread, e.g., Denham Bay, Western Spring, but often not abundant. Dense stands at the south-eastern corner of Blue Lake on

damp ground and in the dune slack at Denham Bay. Plants vary considerably in size. Some at Denham Bay flowering and fruiting in July.

Bidens pilosa — cobblers' pegs
Collected by McGillivray 1854. Recorded by Cheeseman 1887 as plentiful in open and rocky places. Widespread in open areas in dry and wet sites at all altitudes, e.g., Western Spring, Rayner Pt, Boat Cove, north end of Denham Bay. Some plants flowering in winter. Plenty of ripe fruit by the end of October.

Carduus tenuiflorus — winged thistle
First collected by Sorensen 1944. Last seen 1974 near the Met station.

Conyza bonariensis — wavy-leaved fleabane
Recorded by Cheeseman 1887 and Oliver 1908.
Juvenile plants seen in scattered locations on the Terraces.

Crepis capillaris — hawksbeard
Only reported in 1944, by Sorensen, and once in 1969.

Galinsoga quadriradiata — galinsoga
First collected by Sykes 1966–67. Common in cultivated ground around the Hostel, and on freshly bared earth at the airstrip.

Gnaphalium subfalcatulum
First collected by Cooper 1956.

Gnaphalium pensylvanicum
First collected by Sorensen 1944. Now growing in mown grass behind the Met. Station.

Hypochoeris glabra — smooth catsear
Only reported by Sykes in 1964 from Green Lake shore, one day before the eruption.

Hypochoeris radicata — catsear
Recorded by Cheeseman 1887 and Oliver 1908.

Lapsana communis — nipplewort
First collected by Sykes 1966–67. Currently along mown tracks on Low Flat and at edge of paddocks at back of Farm Terrace.

Leontodon taraxacoides — hawkbit
First collected by Sykes 1964. Common at Denham Bay in the first dune slack and along the dune crest.

Senecio vulgaris — groundsel
Recorded by Cheeseman 1887 and Oliver 1908.
Two small seedlings may have been seen on steep descent into Denham Bay in 1993.

Sigesbeckia orientalis
Recorded by Cheeseman 1887 as common in open, sunny places in bush.
Not seen, although looked for at Coral Bay and on North Meyer.

Sonchus oleraceus — sow thistle
Recorded by Cheeseman 1887 (as *S. oleraceus* var. *asper*) as common on cliffs and by Oliver 1908.

In coastal areas on cliffs, on the airstrip, and in other open sites, e.g., by the *Hebe* on Hutchisons ridge. Common along the Denham Bay dune crest and in the dune slack. Leaves thicker and more sharply pointed near the coast.

Tagetes erecta — African marigold
First collected by Sykes 1966–67 and not seen since.

Taraxacum officinale — dandelion
First recorded by Oliver 1908.
Scattered around Met. Station, at the top of Ravine 8 track and Denham Bay track. A few plants flowering in July, more in August.

BORAGINACEAE
Cynoglossum amabile
First collected by Sorensen 1944. Known from Boat Cove Road just past the Rayner Point turnoff, but not seen recently — presumed died out.

BRASSICACEAE
Capsella bursa-pastoris — shepherd's purse
Recorded by Cheeseman 1887. Not reported since the 1960s.

Coronopus didymus — twin cress
Recorded by Cheeseman 1887 and Oliver 1908.
Abundant in coastal areas on cliffs. Also abundant around the Hostel and on disturbed soil, e.g., new airstrip. Common in other open, waste places. Also on North Meyer.

Lepidium hyssopifolium
Recorded by Oliver 1908.

Lobularia maritima — alyssum
Recorded by Cheeseman 1887 and not reported wild since then.

Raphanus sativus — radish
First collected by Sykes 1966–67. Died out.

Rapistrum rugosum — turnip weed
Only reported in the 1966–67 by Sykes.

Sisymbrium officinale — hedge mustard
Recorded by Oliver 1908 (as *Brassica adpressa*).
A group of plants grows on the Low Flat track with *Lapsana communis*. Also beside Blue Lake.

CARYOPHYLLACEAE
Cerastium fontanum ssp. *vulgare* — mouse-ear chickweed
Recorded by Cheeseman 1887 (as *C. vulgatum*). Recorded by Oliver 1908 (as *C. viscosum*).
Along mown tracks from Low Flat to the airstrip and around the Met. Station.

Cerastium glomeratum — annual mouse-ear chickweed
First collected by Sorensen 1944.

Dianthus barbatus — Sweet William
First collected by Sykes 1966–67.
Died out — from seed deliberately scattered in crater.

Dianthus caryophyllus — carnation
First collected by Sykes 1966–67.
Died out — from seed deliberately scattered in crater.

Polycarpon tetraphyllum — allseed
First recorded by Oliver 1908.
Very common around the coast on cliffs.

Silene gallica — catchfly
First recorded by Oliver 1908.

Spergula arvensis — spurrey
Only reported by Sorensen in 1944.

Stellaria media — chickweed
Recorded by Cheeseman 1887 and Oliver 1908.
Common on cultivated ground around Hostel and in waste places further afield.

CHENOPODIACEAE
Chenopodium album — fathen
Only reported in 1944, by Sorensen.

CONVOLVULACEAE
Calystegia sepium — pink bindweed
Recorded by Cheeseman 1887 as rare.

Ipomoea alba — moon flower
Growing on fern and grass outside Denham Bay Hut and near the *Tibouchina*.

EUPHORBIACEAE
Euphorbia hirta — asthma plant
Recorded by Oliver 1908.
Grows on heated ground in the Green Crater.

Euphorbia peplus — milkweed
Recorded by Cheeseman 1887 and Oliver 1908.
Common along mown tracks and road edges on the northern side of the island, at Denham Bay, and also along Blue Lake track.

FABACEAE
Lotus pedunculatus — lotus
First collected by Sykes 1967. Probably has died out — Sykes.

Lotus suaveolens — hairy birdsfoot trefoil
First collected by Sorensesn 1944. Noted growing in two places on the track from Fleetwood Bluff to Low Flat.

Medicago arabica — spotted bur medick
First collected by Sykes 1967. Not common.

Medicago lupulina — black medick
First collected by Sykes 1967. One plant seen near woolshed, by Chas Parker's grave.

Medicago nigra — bur medick
Recorded by Oliver 1908 (as *M. denticulata*).
Growing along road edge near Met. Station. More plants apparent in August, scattered along road edge. On track to Fishing Rock.

Medicago sativa — lucerne
First recorded by Sykes 1978. Near the hostel and on the Terraces.

Phaseolus lunatus — sieva bean
First collected by Cooper 1955. Presumed died out.

Trifolium dubium — suckling clover
Recorded by Oliver 1908 (as *T. procumbens*).
Common on Fishing Rock track.

Trifolium pratense — red clover
Recorded by Cheeseman 1887 and Oliver 1908.
Seen in the orchard. Flowering in October.

Trifolium repens — white clover
Recorded by Cheeseman 1887.
Common on mown and grazed areas on the Terraces and in the lawn around the hostel. Flowering in October and visited constantly by bees.

Trifolium subterraneum — subclover
No CHR record of collection. Probably has died out — Sykes.

FUMARIACEAE
Fumaria muralis — scrambling fumitory
Recorded by Cheeseman 1887 and Oliver 1908.
On cultivated ground around the Hostel and around the Met Station. Flowering in July. Abundant in coastal petrel burrow areas on the western side of North Meyer.

GERANIACEAE
Geranium dissectum — cut-leaved cranesbill
Recorded only by Cheeseman 1887 and then not common.

Geranium molle — dove's foot cranesbill
Recorded by Cheeseman 1887 and Oliver 1908 but not reported since then.

LAMIACEAE
Lamium purpureum — red dead nettle
First recorded by Sorensen 1944. Common in cultivated ground around the Hostel.

Stachys arvensis — staggerweed
First collected by Sorensen 1944 and has been recoded from near the hostel since then.

LINACEAE
Linum trigynum — yellow flax
First collected by Sykes 1966–67 and noted as common on the old landslips at the western end of Denham Bay.

MALVACEAE
Hibiscus rosa-sinensis — hibiscus
First collected by Sykes 1967 from the hostel garden. Several plants of the orange flowered form grow around the Hostel. There is also a plant with entirely red petals at the bus stop (behind the Hostel), favoured by tui in the early morning. Cultivated.

Malva parviflora — small-flowered mallow
First collected by Sorensen 1944 and noted by Sykes as near the hostel in 1966–67. In October 1994 not seen on Raoul but abundant on North Meyer on soft petrel-burrowed earth.

Modiola caroliniana — creeping mallow
First collected by Sorensen 1944. Noted in the back cow paddock on the Terraces. Also on the Ravine 8 track near the turn off to Western Spring. Scattered in open areas on the northern side of Raoul.

Sida rhombifolia — paddy lucerne
Reported by Oliver 1908.
Distributed along roads and tracks, e.g., Low Flat, Rayner Pt, Boat Cove Rd, Denham Bay. Some of the biggest plants are beneath the *Brugmansia suaveolens* in Bell's Ravine. Seedlings common in August.

OROBANCHACEAE
Orobanche minor — broomrape
First collected by Sorensen 1944. One plant seen in 1994, growing with *Trifolium repens* and *Anthoxanthum odoratum* in mown grass in front of the Met. Station.

OXALIDACEAE
Oxalis thompsoniae
Recorded by Cheeseman 1887 as common.
Common in open places where there is little other vegetation, e.g., bush edge, base of cliffs. Generally in dryish sites. Also on coastal cliffs in loose soil, e.g., Rayner Pt. Beginning to flower in late July.

Oxalis latifolia — fishtail oxalis
Fist collected by Sykes 1966–67. Common around the Hostel, Met Station area and Low Flat on mown tracks. Some plants flowering in July.

PASSIFLORACEAE
Passiflora mollissima — banana passionfruit
Only known from one leaf collected by Sorensen in 1944.

PLANTAGINACEAE
Plantago lanceolata — narrow-leaved plantain
Recorded by Cheeseman 1887 and Oliver 1908.
Common on mown tracks and other open vegetation of short stature. Also on coastal cliffs in loose soil, e.g., Rayner Pt, and dunes, e.g., Denham Bay. Some plants are more hairy than others.

Plantago major — broad-leaved plantain
Recorded by Cheeseman 1887 and Oliver 1908.
Common on the new airstrip and occurs on edges of mown tracks. Also growing in boggy ground on the southern edge of Blue Lake. Some plants are very large — leaves >10 cm broad — and flowering stems to 60 cm tall.

POLYGONACEAE
Polygonum aviculare — wireweed
Only reported in 1944 by Sorenson.

Rumex acetosella — sheep's sorrel
Recorded by Oliver 1908 and last reported in 1944 by Sorensen.

Rumex brownii — hooked dock
Recorded by Cheeseman 1887 (as *R. flexuosus*).
Growing at the airfield and scattered around the Hostel and Met. Station. Also seen in open areas in wet forest.

Rumex obtusifolius — broad-leaved dock
Recorded by Cheeseman 1887 and Oliver 1908.

PORTULACAECEAE
Portulaca oleracea — purslane
First recorded by Sorensen 1944. Noted at Fishing Rock and the Green Lake crater. Also at Rayner Pt on coastal rocks. Also on North Meyer.

PRIMULACEAE
Anagallis arvensis ssp. *arvensis* var. *arvensis* — scarlet pimpernel
First collected by Sykes 1966–67. Common on coastal talus. Noted on the north coast and at Boat Cove. Also abundant on the dune crest at Denham Bay near the Norfolk pines.

PROTEACEAE
Hakea salicifolia — willow-leaved hakea
First collected by Cooper 1956 and has since died out — Sykes.

RUBIACEAE
Sherardia arvensis — field madder
First collected by Sykes 1966.

SCROPHULARIACEAE
Verbascum thapsus — woolly mullein
Not reported since 1944 by Sorensen.

Veronica arvensis — field speedwell
Recorded by Cheeseman 1887 and Oliver 1908.
Growing in lawn near Met Station, and in race beside cow paddocks.

Veronica persica — scrambling speedwell
Recorded by Oliver 1908 (as *V. agrestis*).

SOLANACEAE
Datura stramonium — thornapple
Recorded by Oliver 1908 and not seen since 1966.

Lycopersicon esculentum — tomato
First recorded by Sykes 1967. Widely naturalised beneath coastal cliffs, e.g., Lava Point — roosting starlings? Noted on the foreshore at Coral/Turtle Bay.

Nicotiana tabacum — tobacco
Recorded by Cheeseman 1887 and Oliver 1908.

Physalis peruviana — cape gooseberry
Recorded by Cheeseman 1887 and Oliver 1908.
Scattered along the northern terraces and along the northern edge of Blue Lake. Large, spreading bushes in flower and fruit in winter 1993.

VERBENACEAE
Verbena bonariensis — purple-top

First collected by Sorensen 1944. A common weed of open areas and one of the few that can grow in the dense buffalo grass swards. Widespread around farm and airstrip.

MONOCOTYLEDONS

CYPERACEAE

Kyllinga brevifolia

First recorded by Oliver 1908. Grows on warmed ground at western end of Green Lake. Has a dense green head.

Kyllinga nemoralis

First recorded by Sykes 1966–67. Noted near flax at Denham Bay.

Cyperus rotundus — nut grass

First recorded by Cooper 1956. This is the small, broad-leaved species with brown, open heads and of short stature, <15 cm tall. Grows densely at the airstrip.

Pycreus polystachyos

First collected by West 1993. This is a new record for Raoul Island and is the tall, thin species found often in buffalo grass. Widespread along northern terraces, esp. among buffalo grass. Also at Denham Bay and along the swamp edge at Blue Lake.

IRIDACEAE

Gladiolus x *hortulanus* — florist's gladiolus

First collected by Sykes 1966–67. This species has red and yellow flowers. There is a clump near the Hostel. At Denham Bay, an extensive clump grows south of the Norfolk pines and the coconut. There is also a clump near the poison shed north of the lagoon. Both were in active new growth, with healthy-looking corms in winter 1993. Also a clump by the gate to the woolshed. Most colonies flowering in October 1994.

Gladiolus cv.

Clumps grow on either side of the Met Station and these have cream flowers with purple stamens and pink markings on the lower petals, or pink flowers.

JUNCACEAE

Juncus flavidus

First collected by Sykes 1967. Has died out from Low Flat — Sykes.

POACEAE

Anthoxanthum odoratum — sweet vernal

Recorded by Oliver 1908.

Noted in mown areas around the Met Station and at Low Flat. Also at the northern end of Denham Bay.

Avena sativa — oat

Only reported in 1944 by Sorensen.

Axonopus affinis

First collected by Sykes 1964. Grows in Green Lake crater on open ground. Slender stems.

Bothriochloa bladhii

First collected by Sykes 1966–67. Has died out from Low Flat — Sykes.

Briza minor — small shivery grass
Recorded by Oliver 1908.
Scattered along tracks and road edges on northern side of the island.

Bromus diandrus
Only reported in 1944 by Sorensen.

Bromus hordeaceus
First collected by Sykes 1966–67 in mainly coastal sites.

Bromus willdenowii — prairie grass
Recorded by Oliver 1908.
Scattered along road edges. Also in the dune slack at Denham Bay and on North Meyer.

Calamagrostis epigeios
Only reported in 1944 by Sorensen.

Chloris gayana — Rhodes grass
First collected by Cooper 1956. Grows in tall grass at the end of the older airstrip. Also at edge of mown tracks near the Met. Station.

Cynodon dactylon — Indian doab
Recorded by Cheeseman 1887 and Oliver 1908.
Growing near Met. Station and at Denham Bay — long runners, prostrate.

Dactylis glomerata — cocksfoot
Recorded by Cheeseman 1887 and Oliver 1908.

Digitaria ciliaris
Recorded by Cheeseman 1887 (as *Panicum sanguinale*).

Digitaria sanguinalis — crab grass
First collected in 1994 from Hostel steps.

Digitaria setigera
Recorded by Cheeseman 1887 (as *Panicum* sp.).
Growing with other grasses at road edge in dry pohutukawa forest.

Echinochloa utilis
Only reported in 1944 by Sorensen.

Eleusine indica
Recorded by Cheeseman 1887.
Noted in the middle of Boat Cove Road in dry forest before Rayner Point.

Holcus lanatus — Yorkshire fog
Recorded by Oliver 1908.
Very rare — Sykes.

Hordeum murinum subsp. *leporinum*
First collected by Sorensen 1944. Very rare — Sykes.

Lolium perenne — perennial ryegrass
Recorded by Cheeseman 1887 and Oliver 1908.

Oplismenus hirtellus subsp. *hirtellus*
Recorded by Cheeseman 1887 (as *O. compositus*).

Common in dry forest, usually at lower altitudes than *O. imbecillus*. Often grows alongside this other species.

Oplismenus hirtellus subsp. *imbecillus*
Collected by McGillivray 1854 and recorded by Hooker 1856 (as *O. aemulus*). Recorded by Cheeseman 1887 (as *O. setarius*).
Often carpets the forest floor in dry forest, more widespread than the former species, and often at higher altitude.

Paspalum conjugatum — T grass
First collected by Sykes 1966–67. This is the very widespread, yellow-green grass with the bifurcate inflorescence (hence the name T grass) which grows extensively around Blue Lake, and is common along tracks, especially in open areas.

Paspalum dilatatum — paspalum
Recorded by Oliver 1908.
Grows in the dune slack near Denham's grave at Denham Bay. Also grows around the Hostel and Low Flat with buffalo grass and *Digitaria*.

Paspalum distichum — Mercer grass
Recorded by Sykes 1984 from a collection on the farm in 1978.

Paspalum urvillei — Vasey grass
Recorded by Sykes 1978 although first collected in by Cooper in 1956. Scattered along the road from Ravine 8 to Boat Cove Hut.

Phalaris minor
Only reported in 1944 by Sorensen.

Poa annua
Recorded by Cheeseman 1887 and Oliver 1908.
Some plants flowering on rock outcrops at the northern end of Denham Bay. Suddenly became apparent and increased in prominence in August as befits this late winter to spring annual.

Poa pratensis
Recorded by Cheeseman 1887 and last reported by Oliver in 1908.

Polypogon fugax
Recorded by Oliver 1908.

Sacciolepis indica
First collected by Sykes 1966–67.

Setaria pumila subsp. *pallidifusca* — millet
First collected by A.C.S. Wright 1949.
Common around the hostel, cow paddocks and along the road towards the airstrip.

Sporobolus indicus var. *capensis* — ratstail
Recorded by Oliver 1908.
Common along roads and in recently mown or open areas, e.g., airstrip, Turtle Bay.

Vulpia bromoides
Recorded by Oliver 1908.

Vulpia myuros
Recorded by Oliver 1908.

Vulpia myuros var. *megalura*
First collected by Sykes 1966–67. Abundant in Green Lake crater in open areas.

Appendix 3

NOTES ON DISTRIBUTION, PHENOLOGY, AND DATES OF FIRST KNOWN RECORDS OR COLLECTIONS OF PLANTS OF HISTORIC SIGNIFICANCE

Category C

Persistent relics of cultivation of historic significance or providing edible fruit which may be protected. First records are derived from the literature or from herbarium collections.

DICOTYLEDONS

ANACARDIACEAE

Mangifera indica — mango

First collected by West 1993. One large tree near the Kalona Plot felled when hit by a falling pohutukawa during Cyclone Sarah — still alive though. Cultivated relic.

ANNONACEAE

Annona cherimola — cherimoya, custard apple

Noted by Cheeseman 1887 (notebook).

A group of 5 trees, one of which has smaller leaves than the others, grows east of the Norfolk pines at Denham Bay. Appeared to have slight–moderate salt spray damage. Cultivated relic.

ARALIACEAE

Polyscias guilfoylei

First collected by Sykes 1974. A clump of 6 slender stems from a prostrate stem beneath pohutukawa and near an avocado grows just off the main road on the Terraces. There are two more trees further under the pohutukawa. Leaves are pinnate. Cultivated relic.

APOCYNACEAE

Nerium oleander — oleander

First collected by Sykes 1966–67. Persists around Bell's house site near the woolshed and planted around Hostel. Cultivated relic.

ASTERACEAE

Ageratum houstonianum — ageratum

Recorded by Cheeseman 1887 as abundant especially in abandoned cultivations. Recorded by Oliver 1908.

Very common in open places throughout the island in both wet and dry forest. In the clearing around Hutchisons Hut, Mahoe Hut, around the edge of Blue Lake, Rayner Pt, on rock outcrops at the northern end of Denham Bay. On bluffs above the Terraces. One isolated plant on Pukekohu was pulled out on 28/7/93.

Colonies beginning to flower abundantly from early July. Abundant on North Meyer on open slopes on western side.

CARICACEAE

Carica pubescens — mountain pawpaw

First recorded by Sorensen 1944. One mountain pawpaw found adjacent to a grove of peach trees in the central part of the orchard. Cultivated relic.

Carica papaya — pawpaw

No specimen in CHR. Several clumps of trees around the Hostel. Seedlings develop from fallen fruit. Some stems produced tightly bunched fruit, the others have fruit on a peduncle c. 50 cm long. Cultivated.

CONVOLVULACEAE

Ipomoea batatas — kumara

Noted by Cheeseman 1887 (notebook).

Not seen. Recorded and collected by Wynne Spring-Rice in 1990 from near Boat Cove Hut. She says it is "Owairaka Pink".

EUPHORBIACEAE

Acalphya wilkesiana

First recorded by Sykes 1966–67. Some plants persist by the Hostel but most are being overtaken by bamboo. One plant noted at the forest edge in the orchard. Cultivated relic.

FABACEAE

Sophora microphylla — kowhai

First recorded by Harper 1994. One fallen tree grows near the Braithwaite tanks. Cultivated.

Grant Harper has grown a plant from seed washed up on the beach. Potted up by glasshouse.

LAURACEAE

Cinnamomum camphora — camphor tree

First recorded by Bacon 1926–27. Tree died — Sykes.

Persea americana — avocado

First recorded by Sykes 1966–67. One small tree just off the main road near the Met. Station. One very large tree in the Kalona plot (damaged by pohutukawa which fell during Cyclone Sarah, but still alive) and on the other side of the track, one tall seedling. Leaves wind-damaged. Young plants in hostel gardens. Cultivated.

MELASTOMATACEAE

Tibouchina urvilleana

First recorded by Sorensen 1944. Covers a large area north-west of the dates by Denham Bay hut. Flowering in the fern clearing in early August.

MORACEAE

Ficus carica — fig

First recorded by Morton 1964. Four trees in a clump at Denham Bay by the poison shed at the northern end of the lagoon. One tree near the lime behind the Met. Station. One noted amongst grapevines at the head of Low Flat beach road. Not seen at Rayner Point. Entirely leafless in July.

Ficus macrophylla — Moreton Bay fig

First collected by Cooper 1956. One large tree with numerous prop roots grows back from the road behind the Met Station.

Morus alba — mulberry
First recorded by Oliver 1908. A large thicket grows directly behind the implement shed. Fruit ripening in August (1993) and being eaten by birds. Many ripe fruit in October 1994.

MYRTACEAE
Eucalyptus globulus
First collected by Sykes 1966–67. May no longer exist.

Eucalyptus maculata
First collected by Sykes 1966–67. Large tree with fallen trunks grows by the Hut at Denham Bay.

Syncarpia glomulifera — turpentine tree
First collected by Sorensen 1944. Large fallen trunk with numerous upright leaders seen flowering and fruiting on 4/8/93. Grows beside the eucalypt. New foliage very hairy.

PROTEACEAE
Macadamia tetraphylla — macadamia
First collected by Sykes 1974. A group grows at the back of the Terraces, past the burning pit. Some of these, including the largest, fell during Cyclone Sarah — still alive. All nuts seen were eaten by rats. A single tree grows near the small avocado just off the main road near the Met. Station.

ROSACEAE
Eriobotrya japonica — loquat
Plant died recently — Sykes.

RUBIACEAE
Coffea arabica — coffee
First recorded by Davison 1938 and collected by Sorensen 1944. Cheeseman 1887 in his notebook records: "a rubiaceous plant, evidently an outcast from some garden , was also not uncommon" in Denham Bay.

RUTACEAE
Citrus aurantifolia — lime
Noted by Cheeseman 1887 (notebook).
One layered tree grows on the Terraces at the side of a track south of the Met. Station. At Denham Bay, a group north of the hut were flowering and fruiting in July/August. One further clump grows north of Route 77 near an old hearth and with *Cordyline fruticosa*. This was also flowering and fruiting. Cultivated relic.

Citrus limon — lemon
Noted by Cheeseman 1887 (notebook).
Trees by the Hostel. Cultivated.

Citrus medica — citron
Noted by Cheeseman 1887 (notebook).
One tree seen on Low Flat. Fruit on it in winter. A group grows near the turpentine tree at Denham Bay. The fruit of these are more knobbly and orange than those at Low Flat. Also, the aroma of the fruit is less lemony — more soapy — the pith is not so thick, and it has seeds. Cultivated relic.

Citrus paradisi — grapefruit, shaddock
Noted by Cheeseman 1887 (notebook).
At least one tree on the Terraces, fruiting at this time of year. One tree grows at Denham Bay about halfway between Denham Bay Hut and the Norfolks and c. 30 m back from the forest edge. The fruits of this tree are very large with thick pith. Cultivated relic.

Citrus reticulata — mandarin
First collected by Sykes 1984. One small tree on the Terraces with small, firm-skinned flesh on the fruit. Cultivated relic.
First collected by West 1994. One large tree just east of Ravine 8 and south of the road with large, loose-skinned fruit. This was almost defoliated by salt spray in a storm in winter 1993. By October 1994, the tree had recovered by producing epicormic shoots. One ripe fruit present in the middle of the tree then.

Citrus sinensis — orange
Noted by Cheeseman 1887 (notebook).
Many trees on the Terraces and two tall trees on Low Flat. A small group of trees at Denham Bay near the hut. A windfallen tree in this group has upright growth with fierce spines. Two further trees grow near the poison shed at the north end of Denham Bay lagoon. One tree below Devastation Ridge plot (c. 18 cm d.b.h.) in forested gully near edge of Blue Lake. One tree opposite storage shed on Fishing Rock road and 2–3 trees on the ski slope (near the sign) and one on Judith above the road (not seen by me — Len Webb).

VERBENACEAE
Vitex lucens — puriri
First collected by Davison 1937. One tree grows in forest just behind the Braithwaite tanks. The diameter at breast height of this tree was 43.0 cm on 12/7/93. Two more trees grow near this large one. A small, multi-stemmed tree is c. 5 m north-west of this one and the other was not seen by me. According to Wynne Spring-Rice's records, there are possibly two more trees on the terraces, inland from the airstrip. Cultivated relic.

MONOCOTYLEDONS
ARACEAE
Colocasia esculenta — taro
Noted by Cheeseman 1887 (notebook).
Seen at Lava Point spring from the sea.

Xanthosoma sagittifolium — taro tarua
First collected by Sykes in 1967 beside the road near Low Flat turn-off. Also grows down Low Flat gully nearby.

ARECACEAE
Cocos nucifera — coconut
One plant 4–5 m tall grows just south of the Norfolk pines at Denham Bay. It has a trunk 1–1.5 m tall and c. 25 cm d.b.h. In October 1994 this tree looked rather storm-ravaged. There is also a plant at the Kalona plot which has a trunk c. 1.5 m tall. This tree managed to escape the falling pohutukawa from Cyclone Sarah. Cultivated relic.

CANNACEAE

Canna indica — Indian shot

No specimen in CHR. Grows in Denham Bay on or near the site of the old Bell homestead. Until recently was covered by Mysore thorn. In June 1993 one plant in flower was seen in the vicinity of the poison shed at the northern end of the lagoon, by John Dodgson.

MUSACEAE

Musa sp. — banana

Noted by Cheeseman 1887 (notebook).

Growing around the Hostel and in Bell's Ravine. A planting at Mahoe Hut does not appear to have survived although plants apparently bore fruit up there. Cultivated relic.

PHORMIACEAE

Phormium tenax — NZ flax, harakeke

First recorded by Sorensen 1944. A planted semicircular line of harakeke is just back from the beach at the southern end of Denham Bay and is visible from the beach behind *Coprosma petiolata* and ngaio. The plants are tall and straight with no sign of flower stalks, old or new, either in 1993 or 1994.

Appendix 4

DIAMETER AT BREAST HEIGHT AND CONDITION OF THE 48 NORFOLK PINES IN THE VICINITY OF THE WOOLSHED IN 1993.

Original trees

D.B.H.	CONDITION
188.0	heartrot, low branching
184.0	heartrot
174.5	heartrot
169.0	heartrot
166.0	heartrot
164.0	heartrot
161.0	heartrot
160.0	heartrot
156.5	heartrot
155.0	heartrot, wire
151.0	heartrot
147.5	heartrot, wire

Progeny

D.B.H.	CONDITION
124.5	sound
122.5	sound, low branching
110.0	sound, low branching
105.0	sound, low branching
98.0	sound, low branching
98.0	sound
94.0	sound
92.5	sound
89.0	sound
86.0	sound
83.0	sound
82.5	sound
82.0	sound
82.0	sound
79.5	sound
79.0	sound
78.5	sound
76.0	sound
74.5	sound
72.0	sound
71.0	sound
69.5	sound
65.0	sound

D.B.H.	CONDITION
64.0	sound
60.0	sound
56.0	standing dead
50.0	sound
50.0	sound
44.0	standing dead
43.5	sound
41.0	sound
35.5	sound
35.0	sound
33.5	sound
29.0	sound
21.0	sound