Eradication of alien plants on Raoul Island, Kermadec Islands, New Zealand

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Abstract In order to protect the endemic ecosystem of Raoul Island (2943 ha), a programme to eradicate alien plants commenced in 1972. Almost 30 years on it is possible that seven species have been eradicated, none of which was widespread but some of which were difficult to control. There are another 22 species on the eradication list, most of which are barely present. Seven species represent the greatest threat at present and also are the most difficult to control. These are *Senna septemtrionalis*, *Caesalpinia decapetala*, *Anredera cordifolia*, *Psidium cattleianum*, *P. guajava, Olea europaea* subsp. *cuspidata,* and *Passiflora edulis*. Difficulties of the programme include the rugged terrain, resistance of some species to herbicide, cryptic species, and long-lived seedbank of some species. Each year an area equivalent to one quarter of Raoul Island is grid-searched twice; this is the area where alien plants are known to be present. The remainder of the island is checked during the recreational time of staff and volunteers and occasionally by air. The alien plant eradication programme has been successful to date but still has many years to run. Changes in abundance or distribution of some alien plant species are expected as a result of the planned rat eradication in 2002 and, in anticipation of the changes, a number of species have been eradicated. Maintaining search efficiency and staff morale at low alien plant densities and determining the end point of the programme will be a challenge.

Keywords Conservation; endemic species; rat eradication; grid searching.

INTRODUCTION

Raoul Island is the northernmost (29° 15’ S, 177° 55’ W) and largest island of the Kermadec Group which lies within the central Polynesian biogeographic region (Udvardy 1975). The bulk of the island was first formally protected as a Fauna and Flora Reserve, along with the rest of the Kermadec Group, in 1934 (Devine 1977). It is currently designated as a Nature Reserve and is surrounded by a marine reserve. Since 1987 the New Zealand Department of Conservation has been responsible for management of Raoul Island and maintains a small permanent staff there, who undertake alien plant control, weather and seismological recordings and general maintenance of facilities.

Raoul is an active volcano 2943 ha in extent and rising to 516 m above sea level. There is a central crater containing three small lakes (Fig. 1) which is encircled by the crater rim, rising from 40 to 516 m. The last eruption, in 1964, resulted in the formation of a new, small crater within this central crater. From the crater rim, ridges >300 m a.s.l. run south (Mahoe Ridge) and west (Hutchison Ridge). On

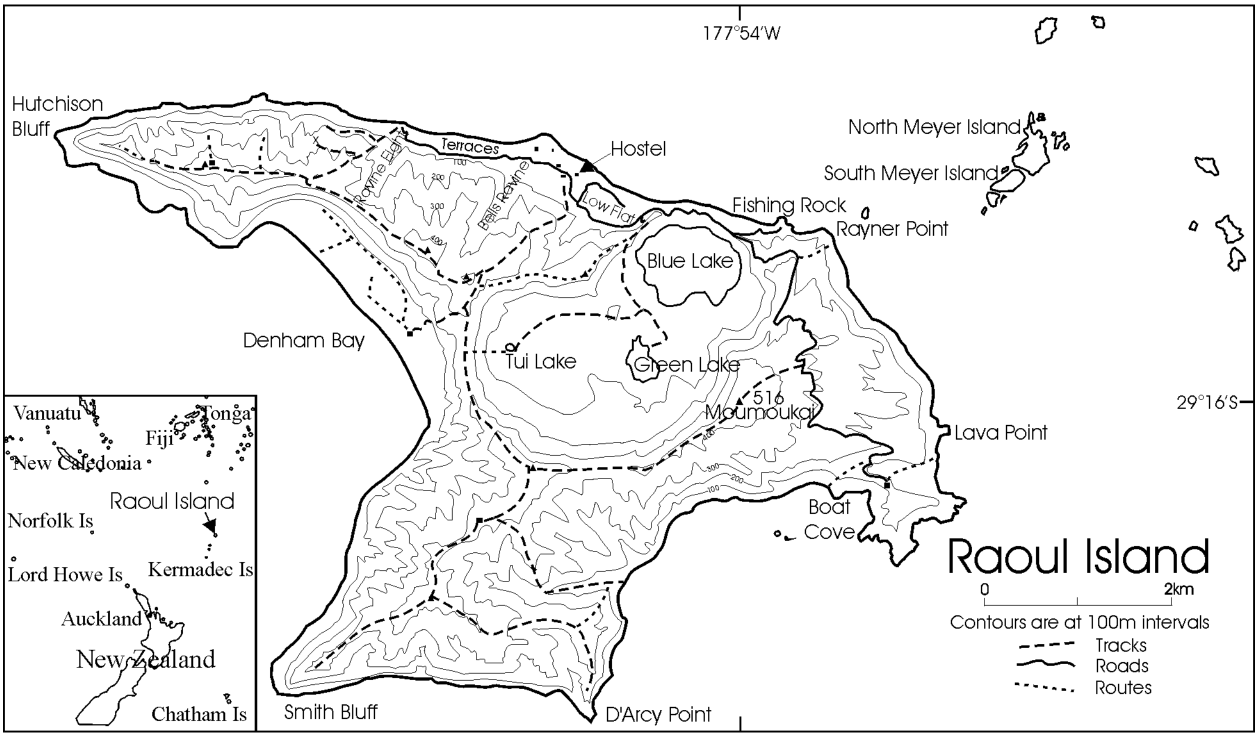

Fig. 1 Map showing features of Raoul Island mentioned in the text.

Pages 365-373 In Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

the north side of Hutchison Ridge deep ravines with no permanent running water reaching the sea. During periods of heavy rain, however, the ravines become torrents. Permanent seepages occur at just three points on the island and there is a swamp at Denham Bay. The terrain is steep and much of the coast is cliff-bound. The climate is warm temperate: average annual rainfall is 1538 mm, evenly spread throughout the year; mean annual temperature is 19°C; humidity is generally >80% (New Zealand Meteorological Service 1983). Tropical cyclones may occur during the summer and have a strong modifying effect on the forests of Raoul Island (Sykes 1977).

Forest dominated by *Metrosideros kermadecensis* is the main vegetation on Raoul Island. Above 300 m altitude is "wet forest" where the principal understorey species is *Ascarina lucida* var. *lanceolata* in association with *Rhopalostylis baueri* var. *cheesemanii*, *Homalanthus polyandrus*, and *Pseudopanax kermadecensis*. The wet forest lies within the cloud zone and collects moisture from the mist. At lower altitudes is the "dry forest" where the understorey is principally *Myrsine kermadecensis*, *Coprosma acutifolia* and *Macropiper excelsum* var. *psittacorum*. There is a narrow coastal zone where *Myoporum kermadecense*, *Cyperus ustulatus*, and *Isolepis nodosa* are common.

Catastrophic natural disturbances have occurred frequently during the history of Raoul Island. Volcanic eruptions have caused the total destruction of vegetation within parts of the crater and defoliation of plants elsewhere (Sykes 1977; Lloyd and Nathan 1981). Earthquakes are common and may cause slips and vegetation loss. Cyclones frequently topple trees. In some seasons two or three cyclones may strike whereas in other seasons there are none. Flash flooding also can destroy vegetation and cause massive slips on the steep slopes (Bell 1911).

Humans have visited and occupied Raoul Island for brief periods since c. 960 A.D. (Anderson 1980). Evidence to support periodic occupation by Polynesians since this date includes the discovery of many adzes, some prehistoric settlement sites which include obsidian flakes from New Zealand and the presence of *Rattus exulans* and Pacific plants such as *Aleurites moluccana* and *Cordyline fruticosa* (Sykes 1977; Johnson 1991).

The European discoverer of Raoul Island was Captain Sever on the *Lady Penrhyn* in 1788. During the early part of the 19th century Raoul Island was used as a source of water and wood by whalers exploiting the lucrative "French Rock Ground" for sperm and southern right whales (Sykes 1977; Johnson 1991). European settlement of the Island began in 1836 with James Reed and his family plus others. Goats (*Capra hircus*) and pigs (*Sus scrofa*) had already been introduced and established on Raoul by 1836 (Straubel 1954), presumably by whalers. Cats (*Felis catus*) were possibly introduced by whalers also (Gabites 1993). From 1836 until 1870 other family groups settled on the island, mainly to provide supplies to the whalers (Johnson 1991). From 1878–1914 Thomas Bell and his family were resident, and from 1889–1892, a New Zealand Government Settlement Scheme resulted in four families and eight individuals arriving on Raoul to establish gardens for the provision of fruit and produce to the New Zealand mainland (Johnson 1991).

From 1914–1935 Raoul Island was generally uninhabited apart from a brief five month period in 1926–1927 when Alf Bacon and two others arrived to grow crops (Venables 1937). The wreck of the *Columbia River* in 1921 near Boat Cove is assumed to be the source of the *Rattus norvegicus* which abound on Raoul Island (Merton 1968). In 1935 Bacon returned to the island and a further group, including Venables, settled on Raoul from 1936–1937 (Venables 1937). In 1937, a Government expedition led to the establishment of a meteorological station (Davison 1938; Sykes 1977) which still operates.

Currently Raoul Island is staffed by a team of five Department of Conservation rangers who are employed on one year, non-renewable contracts. A changeover period of 1-2 weeks in November each year allows knowledge and skills to be passed from one team to the next. Each year a team of 6–10 volunteers arrives to assist with the alien plant eradication programme for up to four months, usually during the winter.

Goats were eradicated by 1984 (Sykes and West 1996) after a prolonged Government-funded campaign that began in 1937 and intensified in 1972 (Parkes 1984). The goats were abundant and had a strong modifying effect on the vegetation of the island, including some of the alien plant species. Pigs, which were never abundant, were eliminated from Raoul Island in 1966 (Sykes 1977).

As a consequence of human occupation of Raoul Island, approximately 64% of the vascular plant flora comprises alien species. The total number of vascular plant species recorded for the Kermadec Islands is 317, of which 22 species are endemic (19% of the total native vascular plants). Many of the alien species have no impact on natural vegetation processes but since 1972 a number of species have been targeted for eradication (Devine 1977). Some of the alien plant species also have historic value, principally the tree species that were valued by the settlers as food sources. There is potential conflict between the requirement to preserve resources of historic significance and any impact that some of these species might have on natural ecosystems. In addition, the effects of *Rattus exulans* and *R. norvegicus* on alien plant species growth and regeneration must be considered as these species will be eradicated (along with cats) within the next few years. The history of the alien plant eradication programme is described in this paper and some of the technical difficulties are discussed.

METHODS

Alien plant categories

Since the beginning of the alien plant control operations on Raoul Island, all alien vascular plant species have been categorised according to the degree of threat they pose to the natural environment. In addition, some species have been protected because of their historic significance (e.g., a range of citrus species planted by the early European settlers and a group of *Araucaria heterophylla* planted by Thomas Bell). The first classification, in 1972, grouped the alien species into seven categories which included eradication, control, surveillance and protection (Devine 1977). Category A included those "species which so threaten (whether actually or potentially) the preservation of the natural state that their extermination is a desirable and feasible goal", and included six species (Table 1). The species in the other categories were not listed.

Revisions of the alien plant categories were undertaken in 1982, 1992 and 1996 (West 1996). Some species were substantially reclassified (e.g., *Hibiscus tiliaceus* and *Alocasia brisbanensis*), whereas others have always been targeted for eradication (e.g., *Caesalpinia decapetala* and *Psidium* species) (Table 1). The number of categories has been gradually reduced from seven to three, with the three categories defined in 1996 corresponding to eradication (A), effect on ecosystem minimal (B), and historically significant plants (C). In Category A, 17 species were recommended for eradication (West 1996).

Some reclassification is now warranted, based on improved knowledge of the behaviour of some of these species and because of the discovery of new alien plant species. For example, in 1998 *Selaginella kraussiana* was discovered on Raoul Island and was immediately targeted for eradication.

Table 1 Categorisation of target alien plant species on Raoul Island from 1972 to the present. Category definitions are given in the footnote.

Species	Year			
	1972	1982	1992	1996
Caesalpinia decapetala	A	A	A	A(i)
Psidium cattleianum	A	A	A	A(i)
Psidium guajava	A	A	A	A(i)
Olea europaea subsp. *cuspidata*	A	A	A	A(i)
Furcraea foetida	A	A	A	A(i)
Hibiscus tiliaceus	A	A	C	C
Senna septemtrionalis		A	A	A(i)
Passiflora edulis		A	A	A(i)
Anredera cordifolia		A	A	A(i)
Foeniculum vulgare		A	A	A(ii)
Alocasia brisbanensis		B	B	B
Stenotaphrum secundatum		B	B	B
Aleurites moluccana		C		C
Populus nigra		C	C	A(ii)
Araucaria heterophylla		C		A(i), C
Ricinus communis		C	C	A(i)
Gomphocarpus fruticosus		C	C	A(ii)
Phormium tenax		C		
Brachiaria mutica		C	C	A(i)
Cordyline fruticosa		D	D	C
Colocasia esculenta		D		
Prunus persica		D	D	C
Vicia sativa		E	C	B
Trifolium campestre		E	C	B
Senecio jacobaea		E	A	A(ii)
Cortaderia selloana			A	A(i)
Tropaeolum majus			C	B
Brugmansia suaveolens			C	C
Phyllostachys aurea				A(i)
Cirsium vulgare				B
Bryophyllum pinnatum				B
Vitis vinifera				C
Phoenix dactylifera				C

Location and marking of alien plant infestations

Raoul Island has been divided into 13 weeding blocks covering 24.6% of the island's area and including part of the Meyer Islands. The blocks delimit the area in which the target alien plants are known to be present and are located along the northern and eastern faces, the crater,

Footnotes to Table 1.

1982: Category A – weeds where threat is reversible and covered by a 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 historic 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.

1992: Category 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 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 might be protected.

1996: 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 and which must be eradicated. 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. 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.

Denham Bay and at D'Arcy Point (Fig. 1). With the exception of D'Arcy Point (where an infestation of *Senna septemtrionalis* was found in 1998), the distribution of these blocks reflects the past and present areas of major human use. The blocks contain from one (D'Arcy Point) to 30 plots (Denham Bay), ranging in extent from 0.01 ha to 54 ha. The large plots are termed null plots and are the balance of the area within a block that is not part of an active plot. Active plots are typically <1–<10 ha in extent. Active plots are searched at least twice each year and null plots are searched at least once in two years.

Grid searching is done by teams of 2–5 people walking along parallel lines 6–10 m apart, depending on understorey density, and stopping frequently to search the ground, subcanopy and canopy for alien plant species. The second grid search of a plot is done at right angles to the first where terrain permits. When an infestation is discovered it is marked with flagging tape and an estimated location is marked on a map. Grid searching provides for the most unbiased coverage of ground which is difficult but not impossible to traverse on foot. If this method was not used, workers would take easier route options and would most likely miss target alien species.

Not all terrain is suitable for grid searching, and inspection of the cliffs behind Denham Bay is done routinely using binoculars or a telescope from the flats below and from vantage points on the ridge above, especially when *Caesalpinia decapetala* is in flower (June–November). The cliffs behind Denham Bay are accessed using fixed ropes and abseiling equipment. Elsewhere on the island, areas of bluffs are searched and weeded from ropes (e.g., some parts of the *Anredera cordifolia* site at Fishing Rock and areas below *S. septemtrionalis* infestations).

Periodically, aerial surveillance is undertaken by helicopter if there is an opportunity when the Royal New Zealand Navy is involved with re-supply. Some flowering trees of *S. septemtrionalis* have been discovered in this way and aerial surveillance can also be useful for locating mature vines of *Passiflora edulis* or trees of *Olea europaea* subsp. *cuspidata*.

Control methods

All of the species targeted for eradication were initially highly visible with one or more dense areas of infestation. For almost all species the initial knockdown phase required considerable time spent cutting mature individuals and painting stumps with herbicide or scattering herbicide granules around them. Blanket spraying of dense, accessible infestations was undertaken and in the case of *Caesalpinia decapetala*, helicopter application of herbicide was used. Burning of areas of *C. decapetala* vines and fern-covered clearings was also undertaken, to hasten the decline of the seeds of this legume from the seedbank.

Following the initial control of dense infestation areas, grid searching in and around the areas of known alien plant infestation was used to detect most species. Most time is spent searching and when an area of dense seedling regeneration is encountered, considerable time can be spent hand-removing seedlings and adolescent plants. When a mature plant is encountered, all fruits are removed for destruction by burning, the stem is cut, and herbicide is applied to the cut stem.

For species with a persistent seedbank such as the legumes *C. decapetala* and *Senna septemtrionalis*, the ground cover is often cleared to maximise the amount of light reaching the soil and to promote germination of seeds from the seedbank. The potential longevity of the seeds of these species is not known but is estimated to be decades, so any disturbances which expose seeds to the light should expedite eradication of these species so long as there are no fresh inputs of seed to the seedbank.

Some species can resprout vigorously from cut stumps despite application of herbicide. Examples are *Psidium guajava*, *Ficus macrophylla* and *Prunus persica*. Return visits to treated stumps, and repeated cutting and herbicide application, are required to kill these individuals. The change from Tordon® granules to a wet herbicide mix has resulted in less regrowth from some of these species.

Eradication of *Anredera cordifolia* follows the same general pattern as the other species in terms of effort in relation to different activities but the detail of the method is different, given the biology of this species. On Raoul Island, *A. cordifolia* flowers but does not set seed, so there is no need to search for seedlings away from the current known sites. However, the species produces abundant, herbicide-resistant tubers which can disperse by gravity or water. After many trials, a herbicide formula which effectively kills foliage and stems, but not tubers, has been found (Escort® = metsulfuron 50 g, Roundup® = glyphosate 2 *l*, Pulse® = penetrant plus marker dye in 100 *l* of water). This is used to kill the foliage and thereby make the tubers more visible for hand removal. It is also hoped that repeated application of this mixture will eventually kill all regrowth from tubers that cannot be reached because of inaccessible terrain. Tubers are removed from the vines and soil surface and dug up with forks and hand trowels, packed carefully into large plastic bags inside large backpacks (designated for this job only), carried up a steep face to the road and transported back to the base. There the tubers are loaded into a desiccator that uses the heat from the generator exhaust for rapid desiccation. As a final precaution the dried tubers are burned in a fire pit nearby.

Reporting on alien plant infestations

In the early years of the alien plant eradication programme, reporting was variable; generally not a lot of detail was given but some information on the magnitude of the work undertaken could be gained. In recent years reporting has been more prescribed and has moved from text files in WordPerfect to an Access database (implemented in 1997).

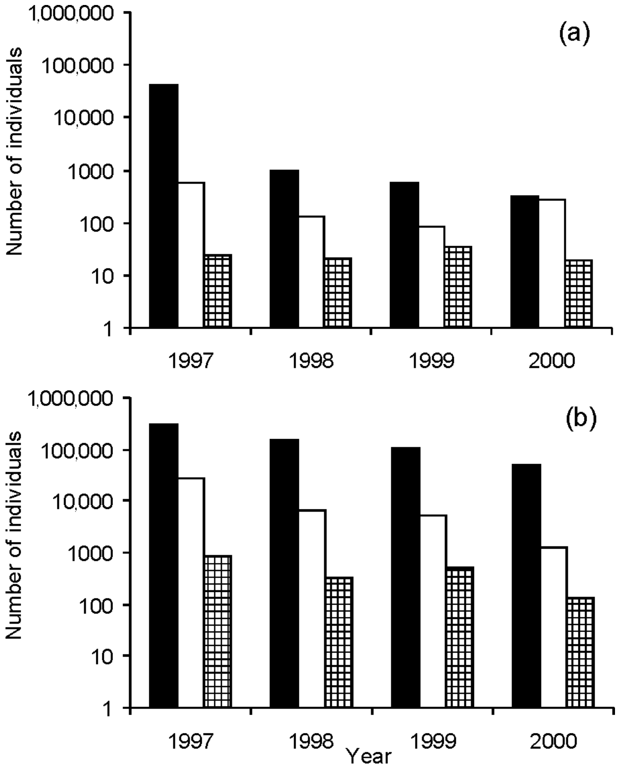

Fig. 2 Number of seedlings (black bars), adolescent (white bars), and mature plants (hatched bars) of (a) *Caesalpinia decapetala* and (b) *Senna septemtrionalis* removed from 1997–2000. Note the values on the y axis have been log transformed.

Key information recorded is the date, location and extent and age classes of an infestation, which species, action undertaken and the number of person-hours required to search and to treat each plot.

RESULTS

Each year the weeding blocks, occupying one quarter of the total area of Raoul Island, are grid-searched twice. In addition staff are always looking for alien plants when they are exploring the rest of the island during their time off (this is how the *S. septemtrionalis* infestation at D'Arcy Point was discovered). In the last six years, the staff have spent from 35–45% of their work time on weeding. In addition there is a huge boost to the eradication programme each year when 6–10 volunteers contribute labour for up to four months. The assistance of volunteers has approximately doubled the weeding effort in the past three years. The total weeding effort per year ranges from 7000 to 9000 person hours, including volunteer hours.

All alien plants targeted for eradication have been reduced considerably in number and extent. For example, *Caesalpinia decapetala* once occupied 22 ha of Denham Bay (Devine 1977) but in the last two years only 600–700 plants have been located and removed; the majority were seedlings (Fig. 2). Similar results have been obtained for *Senna septemtrionalis* which is the most widespread and still the most abundant target alien plant on the island. It occurs in 72% of the alien plant plots and it is the only target species on the Meyer Islands. Since 1997 the number of individuals located and killed has declined from >300,000 to just over 50,000 – a substantial reduction (Fig. 2). Although seedlings comprised the majority of the plants removed, many mature plants are still being found (e.g., 517 in 1999, 128 in 2000) (Fig. 2).

The database contains 29 species of which seven might by now have been eradicated (Table 2). *Furcraea foetida* occupied up to 0.5 ha in Denham Bay and *c.* 150 m^2 in the Dry Crater when eradication commenced in 1974. By 1982, only 11 plants were found in Denham Bay and in 1991, 12 plants were removed from the Dry Crater. In 1994, two terrestrial and one epiphytic plant were found in Denham Bay and several were epiphytic on *Metrosideros kermadecensis* in the Dry Crater (West 1996). In 1997, one adolescent plant was removed from Denham Bay. This species has not been seen since and, as it only ever reproduced vegetatively, it is possible that it has now been eradicated from the island.

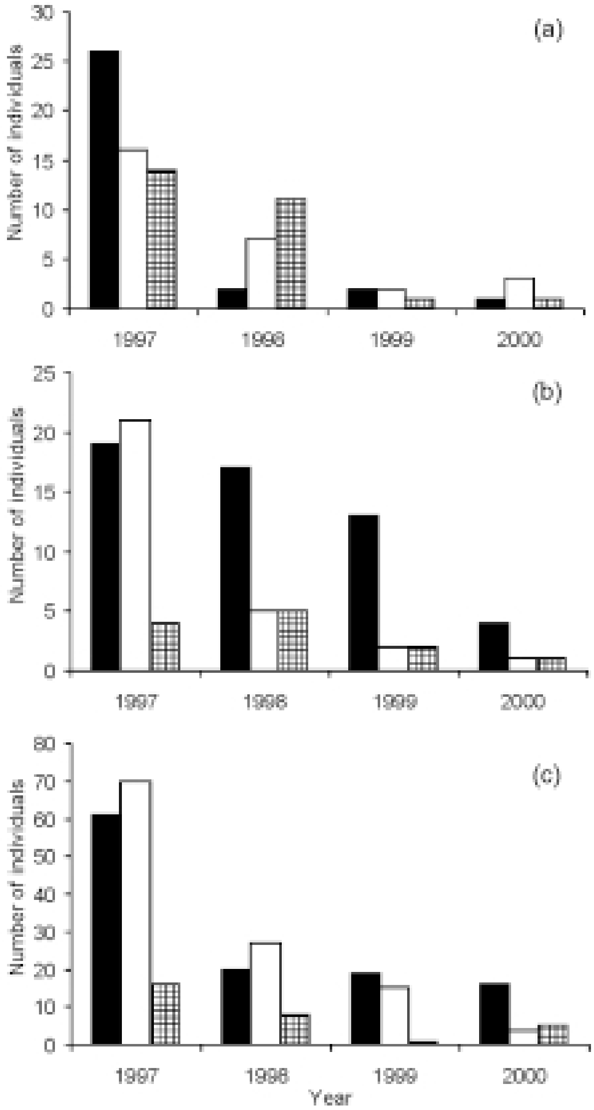

Fig. 3 Number of seedlings (black bars), adolescent (white bars) and mature plants (hatched bars) of (a) *Olea europaea* subsp. *cuspidata*, (b) *Psidium guajava* and (c) *P. cattleianum* removed from 1997–2000.

Table 2 Species listed in the alien plant database indicating when eradication commenced, whether they might have been eradicated, the total number of plants removed from 1997–2000 and the percentage of alien plant plots occupied by each species. * indicates that the measure used is kg.

Species	Common name	Eradication commenced	Eradicated?	Total number removed 1997–2000	% plots
Aleurites moluccana	candlenut	1993	no	827	2.1
Anredera cordifolia	Madeira vine	1995	no	*7410.6	2.1
Araucaria heterophylla	Norfolk pine	1974	no	959	1.4
Brachiaria mutica	Para grass	1996	no	97	0.7
Bryophyllum pinnatum	airplant	1998	no	4550	1.4
Caesalpinia decapetala	Mysore thorn	1974	no	44,877	18.2
Cortaderia selloana	pampas grass	1984	yes?	0	0
Ficus carica	fig	1996	no	43	2.8
Ficus macrophylla	Moreton Bay fig	1996	yes?	1	0.7
Foeniculum vulgare	fennel	1969	no	5	0.7
Furcraea foetida	Mauritius hemp	1974	yes?	1	1.4
Gomphocarpus fruticosus	swan plant	1979	no	9	2.1
Macadamia tetraphylla	macadamia	1996	yes?	17	1.4
Olea europea subsp. *cuspidata*	African olive	1973	no	86	19.6
Passiflora edulis	black passionfruit	1980	no	10,666	32.9
Phoenix dactylifera	date palm	1995	no	2	1.4
Phyllostachys aurea	bamboo	1996	no	1561	0.7
Populus nigra	poplar	1995	yes?	0	0.7
Prunus persica	peach	1994	no	4309	27.3
Psidium cattleianum	purple guava	1973	no	262	22.4
Psidium guajava	yellow guava	1972	no	94	11.9
Ricinus communis	castor oil plant	1990	no	208	7.7
Selaginella kraussiana	selaginella	1999	no	173	0.7
Senecio jacobaea	ragwort	1980	yes?	0	0
Senna septemtrionalis	Brazilian buttercup	1978	no	637,419	72
Tropaeolum majus	nasturtium	1999	no	2792	8.4
Vicia sativa	vetch	1996	no	1884	0.7
Vitex lucens	puriri	1997	yes?	3	0
Vitis vinifera	grape	1995	no	811	8.4

Cortaderia selloana was sown on Raoul Island to stabilise a retaining wall that was built to support the foxway winch shed at Fishing Rock. It was first recorded growing on that site in 1976 and all plants were removed when discovered in 1984 although, by then, one plant had flowered. If that was a hermaphrodite plant, some viable seed could have been set. Since 1984 at least 10 plants have been removed; one of these had flowered (Sykes and West 1996; West 1996). The last adolescent plant was removed in 1993 and none has been found since. Again, it is possible that this species has been eradicated from Raoul.

Some of the species which may now have been eradicated were relics of cultivation that were present in very low numbers but had the potential to spread once rats were eradicated. Examples include *Macadamia tetraphylla* which had begun to spread despite the heavy fruit predation by rats. In the last four years 17 individuals have been destroyed (Table 2), including four seedlings. Three trees of *Vitex lucens*, a species indigenous to northern New Zealand but not to Raoul Island, were also removed (Table 2). Experience from Tiritiri Matangi Island in the Hauraki Gulf had shown that *V. lucens* was unable to regenerate in the presence of *Rattus exulans* but seedlings were abundant after these rats were eradicated from that island (pers. obs.). The one large tree of *Ficus macrophylla* was cut and poisoned because *Pleistodontes froggattii*, the small wasp that pollinates this species, has arrived in mainland New Zealand (Gardner and Early 1996). If this wasp were to arrive on Raoul Island it might not be detected quickly enough to stop spread of *F. macrophylla* by seed.

Some alien plant species have persisted at very low levels for many years. Examples include *Foeniculum vulgare* and *Gomphocarpus fruticosus* (Table 2) for which the total numbers removed in the last four years are five and nine, respectively. Both species grow near the hostel buildings and have been part of the eradication programme since 1969 and 1979, respectively (West 1996). Other species have persisted at low levels, including *Psidium cattleianum*, *P. guajava* and *Olea europaea* subsp. *cuspidata* (Table 2; Fig. 3). Less than 100 individuals of *P. guajava* and *O. europaea* have been found and killed in the last four years whereas >250 *P. cattleianum* have been removed. All species are comparatively widespread (Table 2) but with greatest concentrations along the slopes near the hostel. All have grown in the crater and *P. guajava* has been removed from Denham Bay.

Not all of the alien plants removed can be recorded as numbers of individuals because many spread vegetatively. Reduction in area occupied is a more useful measure of effort and success but this measure has not yet been implemented for species such as *Bryophyllum pinnatum* and *Phyllostachys aurea*. A useful measure for the removal of *Anredera cordifolia* is the mass of tubers removed and killed. In the last four years *c*. 7.5 tonnes of tubers have been removed from Fishing Rock and Bells Ravine (Table 2), with 80% of that total achieved in the last two years.

DISCUSSION

Although the decline in abundance of target alien plants is obvious to regular visitors to Raoul Island (Sykes and West 1996; Sykes *et al*. 2000), and data collected in recent years show steady declines in the number of individuals removed each year, the programme will still have to continue for many years. The future term of the programme cannot be estimated easily because there are many factors to take into account. In a recent review, Myers *et al.* (2000) outlined six requirements for successful eradication programmes. It is useful to assess the Raoul Island alien plant eradication programme against these requirements as they address some of the acknowledged challenges of the eradication programme.

The first requirement is that resources must be sufficient to fund the programme to its conclusion. For the last five years, the programme has cost approximately NZ$250,000 per annum. The bulk of staff time is spent maintaining facilities – buildings, generators, foxway, road, tracks, etc. Much of the plant is old and breakdowns are frequent. Significant capital is required to scale down some of the facilities and upgrade them to more environmentally sound alternatives. If this was done, the ongoing annual costs of the programme could be reduced considerably thereby improving the likelihood of its continuation. To date, resources have been sufficient to fund the programme.

The second requirement is that the lines of authority must be clear and must allow an individual or agency to take all necessary actions. This requirement is clearly met by the Raoul Island alien plant eradication programme as just one agency, the Department of Conservation, is responsible for management of the island. In the past, part of the island was gazetted as a meteorological station and farm. The New Zealand Meteorological Service had total jurisdiction over that part of the island – an area of 111 ha that was the centre of origin of most of the target alien plants. Also, before the formation of the Department of Conservation three other agencies had involvement with the management of the island. The Department of Lands and Survey administered the Fauna and Flora Reserve and undertook alien plant control, the New Zealand Forest Service eradicated goats, and the New Zealand Wildlife Service monitored the indigenous bird species.

The third requirement is that the biology of the target organism must make it susceptible to control procedures. The susceptibility of each of the 29 species listed in the database (Table 2) varies considerably. Seven species stand out as the top priority species for control (recorded by Sykes *et al.* (2000) as the main woody alien plants) based partly on the difficulty of their control. Those species are:

- *Senna septemtrionalis* – rapid maturity, abundant seed production, long-lived seedbank, some dispersal of seeds other than by gravity;
- *Caesalpinia decapetala* – rapid maturity, abundant seed production, long-lived seedbank, lots of nasty thorns;
- *Anredera cordifolia* – abundant herbicide-resistant tubers, located on unstable cliffs, potential to be dispersed to new sites by sea;
- *Passiflora edulis* – rapid maturity, abundant seed production, bird-dispersed seeds;
- *Psidium cattleianum* – very cryptic seedlings and adolescents, abundant seed production, bird-dispersed seeds;
- *Psidium guajava* – extremely persistent regrowth from poisoned stems, bird-dispersed seeds;
- *Olea europaea* subsp. *cuspidata* – cryptic foliage, regrowth from poisoned stems, bird-dispersed seeds.

Knowledge of the biology of each species and tenacity in developing techniques to eradicate them are keys to successful management. For example, developing the desiccator to destroy *A. cordifolia* tubers was a breakthrough since the previous method of breaking the tubers down in drums using a composting accelerant was not fast enough – the vines could grow and produce tubers faster than they could be killed. A further breakthrough is required to eradicate this species on bluffs that are too unstable to be reached safely. Because of the resistance of tubers to herbicide, a programme to aerially spray these bluffs would be lengthy and costly with no guarantee of success.

For the legumes with a long-lived seedbank, removal of the undergrowth and disturbance of the soil can hasten depletion of the seedbank. Also, natural disturbances resulting in soil movement can expose deeply buried seeds. Mass movement of soil and flood debris can extend the range of these species. Consequently, the regular searching of null plots is very important.

Given that Raoul Island is predominantly forested, and that most of the target alien plants inhabit the forest, bird dispersal of seeds makes control difficult. This is because it leads to the extension of ranges in an unpredictable fashion. It has been suggested that *Senna septemtrionalis* was most likely dispersed to the Meyer Islands by birds (Sykes 1977) even though birds are not the primary dispersers of this leguminous tree. It is very important, therefore, for staff to be vigilant for alien plants when they are recreationally exploring parts of the island which are outside of the regularly searched alien plant blocks.

The fourth requirement, according to Myers *et al.* (2000) is that re-invasion must be prevented. This is definitely possible for the target species on Raoul Island. Most of the species were introduced to Raoul Island deliberately as food plants, or for fencing (*Caesalpinia decapetala*) or ornamental purposes (*Senna septemtrionalis*). Few of the target alien plants represent accidental introductions (e.g., *Selaginella kraussiana* and *Vicia sativa)*. Importation of new plants to Raoul Island is prohibited, consistent with management of the island as a Nature Reserve. The garden vegetables and herbs grown by the staff have been screened for their potential as alien plants or vectors for disease which could affect native plant species. Accidental transport of alien plants is greatly minimised by current quarantine measures. All visitors to the island are required to have clean footwear, clothing, and baggage. No soil or vegetation of any sort, other than fruit and vegetables for consumption, may be taken to the island.

The fifth requirement is that the pest be detectable at relatively low densities. Herein lies one of the major challenges of the Raoul Island alien plant eradication programme. For alien plants which have never spread beyond their initial focus of infestation, detection is not a problem as the area to be searched is small and the chance of detecting the alien plant is high (e.g., *Cortaderia selloana*, *Foeniculum vulgare,* and *Phyllostachys aurea)*. However, for more widespread species, it can be a problem, especially when these species are cryptic (e.g., *Psidium cattleianum* and *Caesalpinia decapetala)*. The detection of some species is increased when they flower (e.g., *C. decapetala* and *S. septemtrionalis*), but the challenge is to locate and remove flowering plants before they release a new crop of seeds.

One of the downsides to employing staff on one-year contracts is that they may not be sufficiently familiar with the target alien plant species to recognise them, especially when they are present in very low densities. In an effort to counteract this problem, one of each of the target plants is retained at the base as "pet" plants for training of staff. Exceptions are *Caesalpinia decapetala* where a "pet" plant is retained at Denham Bay and *Anredera cordifolia* which is still abundant at Fishing Rock. In addition there is an alien plant manual with colour photographs and clear descriptions of the plants, highlighting the key features for identification.

In terms of job satisfaction for staff, one of the hardest things is to grid search for prolonged periods without encountering any alien plants. Staff begin to doubt their own abilities to detect alien plants and can lose motivation. At this stage, alien plants can be missed – even mature, seeding specimens – and if this happens the whole programme can be set back considerably. Each team usually arranges their roster to provide some variety in the tasks undertaken as a safeguard against complacency or grid-searching burnout.

One of the difficulties experienced in this eradication programme has been the short life of the flagging tape in recent years. The eradication teams have noted in their reports that the newer supplies of flagging tape break down very quickly in sunlight. Also, in one report it was stated that a piece of recently-used flagging tape was found stuffed in a knothole, slashed by so many rat bites that the writing was barely legible. Use of GPS should overcome the difficulties associated with relocating most of the alien plant infestations. Since 1 May 2000, accurate GPS fixes have been available without the use of ground triangulation systems (a system that was unaffordable for Raoul Island) and many receivers will now work quite reliably beneath a forest canopy. In future, therefore, GPS will be used for relocation of alien plant infestations on Raoul Island.

Determining when a species is eradicated is difficult. Seven alien plant species may have been eradicated from Raoul Island. Of those listed in Table 2, we could probably remove the question mark from *Ficus macrophylla*, *Populus nigra*, and *Senecio jacobaea* because only one individual of each was ever detected as part of the eradication programme. Those plants are dead and no progeny have ever been observed. In the case of *S. jacobaea*, the one plant was pulled out before it had flowered (West 1996). We could probably remove the question mark from *Macadamia tetraphylla* and *Vitex lucens* also, since there were only a small number of those present (three trees of *V. lucens*) and they had a clumped distribution. No *M. tetraphylla* have been found in the last two years. It is just possible that *Cortaderia selloana* and *Furcraea foetida* have been eradicated too. The former has not been recorded since 1993 and the latter since 1997. The difficulty with being able to declare when an alien plant species has been eradicated is that seeds can persist in the soil and germinate many years after the last live plant has been seen. Also, unlike animals, plants tend not to leave a lot of sign of their presence.

The sixth requirement is that environmentally sensitive eradication might require the restoration or management of the community or ecosystem following the removal of a "keystone" target species. This is unlikely to apply to the Raoul Island alien plant eradication programme because the target alien plants form a small part of the total plant biomass on the island. The few native bird species do not rely on any of the target species but the rat species are probably benefitting the most from the alien plants. In terms of a rat eradication programme, this sixth requirement has driven the removal of some plant species which were not spreading (e.g., *Vitex lucens*). Species such as *Vitis vinifera* were vegetatively spreading and occupying large areas and control of these has commenced to ensure that no vines will flower and fruit once the rats have been eradicated, as it appears that rats eat all of the fruit produced by these vines.

Many of the species of historical value have begun to spread and will spread further and faster once rats are eradicated (e.g., *Citrus* spp., *Araucaria heterophylla*). Any conflict between preserving these species *in situ* for their historical value and removing them because of their threat to the endemic species and communities of the island will have to be resolved before the rats are eradicated, so that scarce conservation resources are not wasted. All of the *Vitis vinifera* cultivars and *Citrus* species located on the island and assumed to be of historical value are in cultivation on the mainland. Thus, if these species must be removed from the island, they can be restored into another more manageable setting to tell the story of the human history of Raoul Island.

CONCLUSION

The alien plant eradication programme on Raoul Island is, of necessity, a long-term project. Enormous effort has gone into the programme to date; all of the original target species are now much reduced in range, and some species have probably been eradicated. The improvements made to location, marking, and recording of alien plant infestations in the last decade have all benefited the alien plant eradication programme. Grid searching is an effective method of locating target plants in areas of known distribution and GPS will enable accurate relocation of known infestation sites. Wider surveillance both aerially and terrestrially is also an essential part of the eradication programme. A re-evaluation of priorities for management may be needed, especially with rat eradication planned for 2002–2003. The requirements for successful eradication of alien plants can be met on Raoul Island so long as resourcing is sufficient, and capable, motivated staff and volunteers are selected for the programme. The results of the alien plant eradication programme so far have been positive and any reduction of effort could result in lost ground. The programme must continue.

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