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Ferals — some remote Australian island experiences

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Abstract

Australia's remote islands present striking examples of the impacts of feral animals and demonstrate dramatic ecological responses when feral animals are removed. Though posing daunting challenges, they have been the targets of remarkably successful pest eradication programs at the forefront of invasive species management. Norfolk Island had feral animals 600 years before James Cook discovered the island. Nearby Phillip Island was severely impacted by 1796. Lord Howe Island's fauna had been depleted by mid-1788 but the worst impacts occurred after rats arrived in 1918. Sub-Antarctic Macquarie Island, discovered in 1810, was the haunt of sealers who brought a suite of feral animals before 1900, with catastrophic results for the island's birds. The stories of these islands provide some lessons of global importance.

Introduction

Islands are an important resource for preserving biodiversity, but the value of many has been compromised by the accidental or deliberate introduction of invasive species (Dowding et al., 2009).

Island species and communities are in the forefront of the precipitous decline in biodiversity. Island biotas, especially oceanic islands, characteristically differ from continental biotas in four ways. First, they have small numbers of species; they are "impoverished." Second, they have relatively few species for the available environmental range; they are "unsaturated." Third, they exhibit taxonomic bias (meaning they have an uneven sample of those taxonomic groups to be found on mainland source areas); they are "disharmonic." Finally, they harbour disproportionately numerous endemic species. High endemism means that island species are crucially important to global biodiversity, while the first three traits are often seen as causing island species and communities to be particularly fragile. A disproportionate fraction of endangered and recently extinct species are island species. This is the island dilemma: great biodiversity, much not found elsewhere, but in great danger (Simberloff, 2000).

The islands discussed here conform well to the general pattern. Macquarie Island has only 45 native plant species, in contrast to, for example, Murramarang National Park (NSW) which is a similar size but has more than 400 species. Australia has 70 genera of the family Myrtaceae, amounting to about 1700 species, including about 900 eucalypt and related species dominating a wide variety of environments, yet Lord Howe Island has only 5 native species of the Myrtaceae (two of which have links to New Caledonia or New Zealand, not to Australia), while the family is unrepresented in the native flora

1 The author established the Australian National Parks and Wildlife Services (ANPWS) office on Norfolk Island in 1978, but is now retired. [Ed.]

of Norfolk, Phillip and Macquarie Islands. Phillip Island, less than 3 km^2, has at least six endemic species, while Norfolk Island has 40 endemic plants (22% of its plants) and almost half of Lord Howe Island's plants are endemic. Norfolk and Lord Howe Islands have remarkably rich, endemic land snail faunas, with a combined total of about 130 unique species (Hyman, 2022).

Invasive species are the greatest threat to Australia's biodiversity, in terms of the proportion of species threatened (Legge et al., 2023).

The islands discussed here have all demonstrated ecological fragility when invaded by feral animals. Only two of Australia's 89 biogeographic regions have comparable numbers of extinct species to Norfolk and Lord Howe Islands (Legge et al., 2023), but those bioregions have vastly more species (5654 and 4234 plant species, including introduced species, compared with Norfolk Island's 182 and Lord Howe Island's 241 native plant species). Despite the extinction of some species, the islands retain great biological value, which has been recognised in the extremely difficult but successful programs to eradicate the feral animals from three of them: Phillip Island, Lord Howe Island, and Macquarie Island.

Norfolk Island — the first report

2 April 1788, 66 days after the First Fleet arrived in Sydney Cove, must mark the first Australian record of harm from feral animals. With just six months of provisions, the British settled on Norfolk Island, half way between Sydney and Fiji, on 6 March 1788, only six weeks after British settlement of mainland Australia began. The island was uninhabited, yet four weeks later, the tiny community on Norfolk Island was already troubled by feral animals.

A week after arriving on the island, the settlers had already cleared and fenced an area, prepared a garden and sown vegetable seeds — of high priority to secure a critical food supply. On 2 April the commandant, Philip Gidley King, wrote, "I was this day so unfortunate as to discover that the Rats had eaten a number of ye Indian Corn Shoots, close to ye ground." This must be the first recorded impact from feral animals in Australia.

Although unrecognised, the rats were evidence of prior settlement of Norfolk Island. Polynesian voyagers and *Rattus exulans* colonised Pacific islands together (Roberts, 1991). About 800 years ago, Polynesian travelers arrived at Norfolk Island and established a small settlement there. Possibly additional separate Polynesian arrivals and settlements followed over the next two centuries. They must have brought the Polynesian rat, *R. exulans* (Smith et al., 2001).

To understand the impact of the Polynesian rats, it is necessary to consider the geophysical history of the broader Norfolk Island group of islands and the climate during the last 100,000 years or more. Norfolk Island is the largest of three neighbouring islands and other offshore rocks. These islands sit near the centre of the eroded top of a shield volcano dating from twenty million years ago. The volcano's top forms a platform about 100 km long and 35 km wide, up to 75 m below the present sea level. Norfolk Island and Phillip Island, 6 km away, were created by volcanic activity between 3 million and 2 million years ago and geologically they are very similar. The channel between the two islands is up to 40 m deep. The third island in the group, Nepean, was largely formed from windblown sand dunes during the last two ice ages (Coyne, 2009).

Several ice ages, which climaxed about 350,000, 250,000, 150,000 and 20,000 years ago, each lowered sea level by more than 100 m, exposing the entire platform and creating a single island about 100 km long, with Norfolk and Phillip Islands being the highest of ten conspicuous hills or mountains. At sea levels 50 m below the present level, the exposed island would have been about 35 km long, with the two present islands surrounded and connected by land. Thus Norfolk and Phillip Islands were joined as part of a much larger island for more than half of the last 600,000 years and for 66,000 of the last 76,000 years. They have most recently been separated for less than 10,000 years.

These two islands (Figure 1), only 6 km apart, have similar geological composition (mainly basalt and tuff of similar age) and fairly similar topography, so they must have provided similar habitats. It therefore seems unlikely that plant or animal species would be endemic to just one of them. Possibly, even probably, two plant species recorded only on Phillip Island originally also occurred on Norfolk Island. They are *Streblorrhiza speciosa* (an endemic legume genus in the family Fabaceae, now extinct) and *Hibiscus insularis* (Phillip Island hibiscus). *Achyranthes margaretarum* (Amaranthaceae) discovered on Phillip Island in the 1980s, might also have once been on Norfolk Island too. Animals living on Phillip Island but never seen on Norfolk Island include two lizards — a skink *Oligosoma lichenigerum* and a gecko *Christinus guentheri*; a large centipede *Cormocephalus coynei*;[2] a cricket *Nesithathra philipense*, and two snails *Matthewsoconcha phillipii* and *M. grayi*. The gecko also lives on Nepean Island and some of the vegetated rock stacks off the north coast of Norfolk Island. Fossils show *M. grayi* was

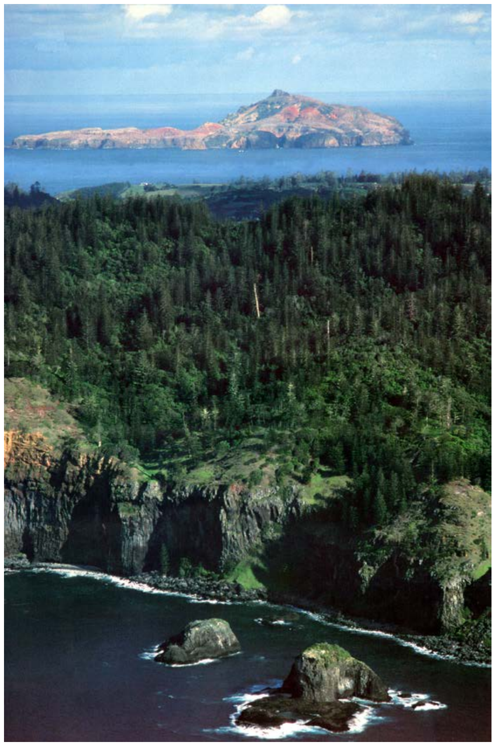

Figure 1: Norfolk Island (front) contrasted with Phillip Island in 1980, although they were joined as parts of a single, much larger, island for 66,000 of the last 76,000 years (photo by author)

2 The specific name is not a coincidence. The author explains, "Although the centipede was known from convict times, apparently I was the first to collect a specimen for science, which I sent to Lou Koch at the WA Museum. He asked me to collect more specimens in order to describe it (Koch, 1984). He recommended searching at night in wet conditions. Descending the cliffs at 2 a.m. in the rain was a bit too exciting. Although the centipede was known, it was extremely rare while the rabbits prevented almost any plant growth. Six hours searching by two of us that night in optimal habitat produced only one juvenile centipede. It seems amazing that now the centipedes are significant nutrient recyclers on Phillip Island." [Ed.]

once common in the Cemetery Bay area of Norfolk Island. These fossil deposits date from prior to Polynesian settlement. The key historical threat to *M. grayi* was predation by introduced rats. *M. phillipii* appears to have been known only from Phillip Island so might never have been on Norfolk Island, but the lizards, centipede and cricket are sufficiently mobile that they could be expected to have also been on Norfolk when Polynesians arrived. Paleontologists have confirmed the gecko was present on Norfolk Island when the rats arrived (Rich et al., 1983) but it was apparently absent by 1788.

In addition to those species, paleontological research has identified bird species which were present on Norfolk when the rats arrived, but no longer occur there (Holdaway & Anderson, 2001). Some — known and unknown — were probably extirpated from Norfolk Island by the Polynesian rat before Europeans arrived. Two of those species are believed to have been eliminated on Lord Howe Island by rats (DECC, 2007). The few Norfolk Island land birds are mostly endemic. Holdaway & Anderson (2001) considered that *R. exulans* was probably responsible for the extinction of several of the smaller, terrestrial birds on Norfolk Island for which no record exists, an expectation consistent with experience on other islands. Maori introduction of the Polynesian rat into New Zealand resulted in eradication of several species of terrestrial and small seabirds. The species has been implicated in many of the extinctions that occurred in the Pacific.

Extinction of the cricket *Nesithathra philipense* on Norfolk Island (genus and species now endemic to Phillip Island), plausibly caused by rats, has also been attributed to competition from a more recently arrived feral animal, the cockroach *Periplaneta americana* (Rentz, 1988).

Campbell & Atkinson (2002) found that *R. exulans* depresses recruitment of diverse species of coastal trees on northern offshore islands of New Zealand, some to local extinction. The elimination of *Streblorrhiza speciosa* and *Hibiscus insularis* from Norfolk Island by *R. exulans* would be consistent with that experience.

Norfolk Island was abandoned from 1814 to 1825 and left to feral animals. When the island was reoccupied in 1825 for a penal settlement, pigs, goats, chickens, pigeons, cats, rats (*R. exulans*), and mice were very numerous (Backhouse, 1843). The black rat (*Rattus rattus*) reached the island in the 1940s, while *R. exulans* persists. Invasive animals have continued to arrive, the Asian house gecko and Argentine ant arriving in the last twenty-five years. Considerable effort has been devoted to the removal of the gecko and ant, and to control rats in the national park.[3]

Phillip Island — spectacular damage, dramatic response

By March 1790, the shortage of food in Sydney, of which no more than four months remained, was such a crisis that the governor sent both the colony's ships to Norfolk Island with 270 convicts and marines and limited supplies. HMS *Sirius*, flagship of the First Fleet, was driven onto the reef while unloading, and wrecked. The loss of the *Sirius* was catastrophic, leaving the tiny HMS *Supply*, the smallest First Fleet

3 See Evans et al. (1976), Hermes (1985), Coyne (2011), and https://parksaustralia.gov.au/norfolk/pub/plant-brochure.pdf for photos of birds and plants of Norfolk Island. [Ed.]

vessel, as the only means of contact between Sydney and Norfolk Island and the outside world. Worse, Norfolk Island was desperately short of food to accommodate the new arrivals, including the stranded crew of the *Sirius*, who had more than trebled the population. The people subsisted by eating seabirds — hence the name Providence Petrel — and had barely three weeks' food remaining when help arrived in August. Another catastrophic consequence of the shipwreck must be, at least partly, the feral animal damage to Phillip Island.

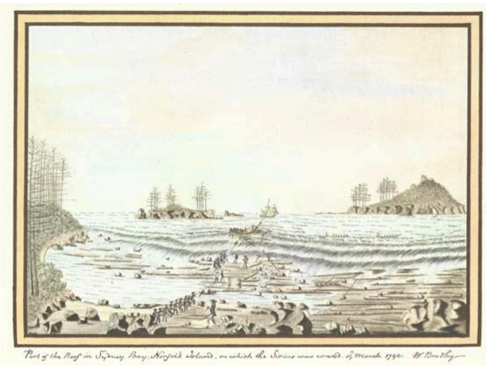

Figure 2: William Bradley's 1790 drawing showing Norfolk Island on left, Phillip Island on right and Nepean Island. Salvage efforts from the Sirius wreck in the foreground. Phillip Island appears covered in hardwood forest, with some Norfolk Island pines (*Araucaria heterophylla*) and the highest peaks apparently bare. Mitchell library, State Library of NSW

In 1788 Phillip Island, just 6 km away, must have been very similar to Norfolk Island, although it is much smaller (about 260 ha) and more precipitous. In 1789 King described the soil of Phillip Island as equally as good as of Norfolk Island (ANPWS, n.d.). David Blackburn, master of the *Supply*, described the soil of Norfolk Island as "rich beyond description." Phillip Island's soils must have been similar. Drawings by stranded *Sirius* officers William Bradley and George Raper show Phillip Island covered by hardwood forest except for the highest peaks (Figure 2).

Degradation

In August 1793, some privately-owned pigs were released on uninhabited Phillip Island. They thrived. By March 1795, Colonial Secretary Collins recorded: "Swine were increasing so rapidly on Phillip Island, now stocked by government, that Mr. King thought he should be able for some time to issue fresh pork during four days in the week." In October 1796 the pig population on Phillip Island was at least 317, when King (cited by Nesbitt, 2009) wrote: "… a great resource for animal food has been found in Philip [sic] Island,[4] which has abounded with the best of food for swine, many having been raised and brought from thence. The great drought during the first part of this year, and the quantity of swine on the island, has destroyed a great part of the weeds and grass on which they feed."

Abandoned in 1814, Norfolk Island was resettled in 1825. By 1830 goats and rabbits had also been released on Phillip Island, possibly as a food source but appreciated by the officers for sport shooting.

Captain Frederick Howard, of HMS *Herald*, wrote in 1856, "Two officers landed

4 There has been some confusion over the spelling. The author explains: "Philip Gidley King named Phillip Island on 29 February 1788: 'it was not till eleven in ye forenoon that, we made ye largest of the two Isles which lye off ye S.W. end of Norfolk Isle bearing [blank space] & to which I have given the name of Phillip's Isle, in honor of His Excellency, Governor Phillip.' When I was on Norfolk (1978–83) it was always called Philip Island, presumably after P. G. King. The spelling was subsequently changed to Phillip, recognising that that was the original intention." [Ed.]

on Philip [sic] Island the other day and in about an hour shot 24 rabbits … The island is very barren, there is no grass whatever growing on it and although in one part rather thickly wooded, the whole island is of a brick red colour a great contrast to the green slopes of Norfolk Island." (Coyne, 2009).

Figure 3: John Beattie's photograph of Phillip Island, apparently taken in 1906, showing the remains of some of the last forest trees and two surviving remnant trees. Mitchell library, State Library of NSW

The pigs and goats died out due to elimination of food or were shot out, apparently well before 1900, their demise unrecorded. But rabbits remained, preventing vegetation developing, eating seedlings as soon as they emerged from the ground. By 1900, Phillip Island was starkly different from Norfolk, being mostly bare, eroded, ground. Photographer John Beattie visited Phillip Island in 1906. His photographs all show completely bare ground, devoid of vegetation apart from a few remnant trees and the decaying remains of a few other trees (Figure 3).

Eradication

Removal of the rabbits was attempted in 1953 by release of myxoma virus but further introductions were abandoned due to the difficulty of landing on the island (Watson 1961). Without determined follow-up, that attempt was unsuccessful.

In 1978, when work towards rabbit eradication began, the island was very similar to Beattie's images but with fewer remnant trees and some obvious further erosion. The rate of erosion was extraordinary. Measurements at eight locations from April 1979 showed erosion ranging from 20 mm to 62 mm, with an average of 42 mm, in just under a year. Rainfall during that period was only 83% of the mean for 1890–1974. The loss of material during the previous century is difficult to conceive. Some remaining trees stood on their exposed roots up to 2 m above the ground (Figure 4).

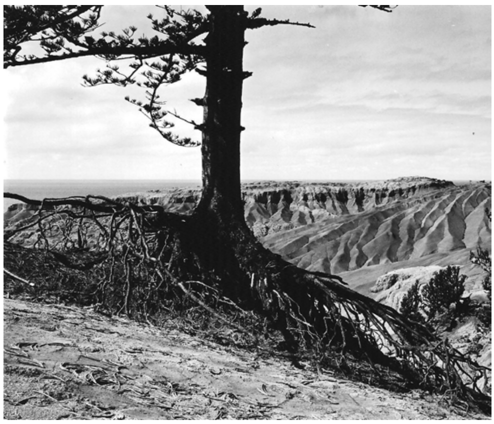

Figure 4: A remnant Norfolk Island pine, roots exposed by erosion, in a bare landscape (photo by author)

Because of some opposition to rabbit eradication in the island community, from some members of the elected Norfolk Island Council and even from a government scientist, a cautious beginning was necessary. In 1961, Watson wrote that "All soil has gone except from a few flat areas and screes, and removal of rabbits will not now alter the island except in a very minor way." (Figure

5.) Also in the 1960s, the Norfolk Island Agricultural Officer, Brian a'B. Marsh, wrote that Phillip Island no longer provided a medium for plant growth. He said, "This island is a rocky arid desert incapable of reclamation" (ANPWS, n.d.). In an unpublished report for the Australian National Parks and Wildlife Service (ANPWS) in 1978, CSIRO scientist Peter Fullagar recommended no action against the rabbits on Phillip Island be undertaken because he considered the island ecosystem, as it was then, was "a balanced ecosystem of a highly modified environment." He stated, "There seems to be no reason to remove rabbits on grounds of conflict with avifauna nor for the gecko [the skink was still unknown there then] … The flora is so depleted that there seem no real grounds so far advanced to consider grazing by rabbits as a serious impediment to gradual revegetation, if only by alien species." (Coyne 2009). The Council asked the ANPWS to undertake a three-year experimental program to assess the damage being caused by the rabbits and to investigate the potential for regeneration on the island.

Figure 5: The sea around Phillip Island turned red after rain. Photo taken in 1979 (photo by author)

That program was difficult and dangerous, in the first year requiring 600 m of heavy wire netting, bundles of steel fence posts and trays of potted tree seedlings to be unloaded onto the slippery intertidal rock platform from an open boat moving in all three dimensions, carrying it all up cliffs (Figure 6) and negotiating the often steep and slippery terrain. Experimental exclosures, amounting to 1900 m^2, were established in a diversity of environments. Some had no treatment except fencing, some had tree seedlings planted, both inside and outside, and in some, soil nutrient trials were undertaken using NPK and complete fertiliser in addition to controls. Everything planted without protection from the rabbits was quickly eaten. Despite the previous soil loss leaving a depauperate medium for planting, and the extreme exposure, native tree seedlings protected from rabbits thrived.

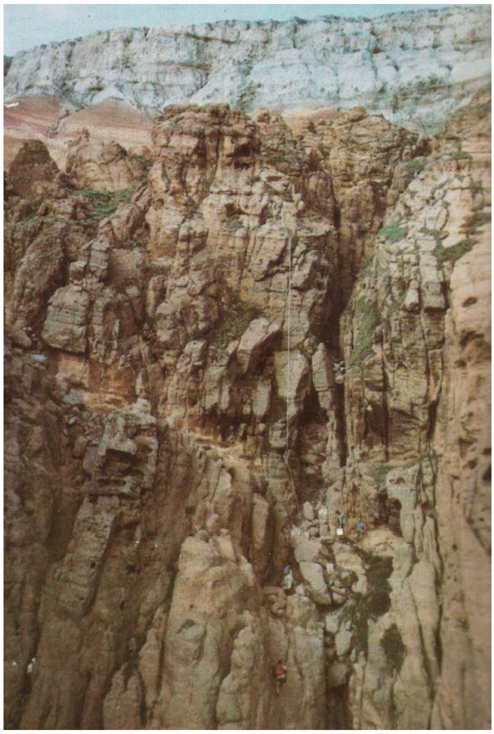

Figure 6: The access route was quite a climb. Four people are shown (photo by author)

Unexpectedly, the exclosures soon showed abundant presence of plant seeds, with a mix of native species and weeds quickly establishing wherever protected from grazing. Two exclosures contained twenty-two and twenty species within months (Figure 7).

Figure 7: An experimental exclosure where nothing was planted, fenced in 1979 and photographed seven months later. Twenty plant species were present, five native to the island. The only difference between inside and outside is rabbits (photo by author)

The experimental program provided such spectacular evidence of the damage caused by the rabbits, and the capacity of the island to support vegetation again, that the Norfolk Island government decided after only one year to eradicate the rabbits. Rabbit eradication would be difficult, but the great benefits provided a powerful incentive to vigorous effort. The Phillip lsland parrot (*Nestor productus*) can never return from extinction. Even the other land bird species which originally lived on Phillip Island might be unable to survive there again for a long time but, without cats and rats, the island could be a refuge (Coyne, 1982).

Eradicating the rabbits was sure to be very challenging. The rugged terrain meant some areas of rabbit habitat had been considered inaccessible, but that had to change. The first method to kill the rabbits was the highly virulent, laboratory-bred, Lausanne strain of the *Myxoma* virus. It was so deadly that development of resistance was unlikely, but it was too virulent to survive in the rabbit population. An effective vector and repeated release of the virus was necessary. Before introduction of the virus, European rabbit fleas (*Spilopsyllus cuniculi*) were released in all habitat areas. One large area was accessible only by swimming, but huge underwater boulders meant the boat could not approach within 100 m of the shore — and this area is renowned for the abundance of sharks. Another large area, bound by 240 m-high cliffs, had been inaccessible, but rock-climbing experts and techniques enabled that area to be reached and, using ropes, the fleas were widely distributed there. Some other inaccessible habitat remained inaccessible. Fleas were distributed to those by fitting a glass vial containing fleas to the steel head of an arrow which was shot with a longbow. From the highest areas the range was adequate to reach those habitats and the fleas were generally released when the glass broke on impact. The well-vegetated experimental exclosures were used as traps to catch rabbits on which the fleas were released directly.

Introduction of the virus rapidly decimated the rabbit population and widespread plant regeneration was visible for the first time. Unfortunately, laboratory problems in Canberra stopped the supply of virus too early. By the time the decision was made to discontinue that approach, the rabbit population was rebounding.

A massive poisoning program began, using 1080 (monosodium fluoroacetate). Some 350 bait stations were established, with pre-feeding before poisoning commenced.

This was highly effective but required access to habitat areas which had, until then, been considered inaccessible. The poisoning was supplemented by shooting, gassing and trapping. By mid-1984 the accessible parts of the island appeared to be free of rabbits and the program was complete in early 1986, with the rabbits apparently exterminated. A single rabbit was seen two years later, in a very inaccessible, cliff-bound, location — it was the last rabbit and was killed (Coyne, 2010).

Regeneration

Substantial plant regeneration began as soon as rabbit numbers declined. Seedlings which could not be identified by staff were a species (*Abutilon julianae*, Norfolk Island abutilon, Malvaceae) last seen, on Norfolk Island, in 1912 and considered extinct. It had been recorded on Phillip Island only in 1804. Another species found when the rabbits had been eliminated had never been seen before. It was named *Achyranthes margaretarum* (Amaranthaceae) in 2001.[5] The native white oak (*Lagunaria patersonia*),[6] the most common remnant tree, regenerated prolifically (Figures 9 and 10). While a diversity of native species regenerated, so too did weed species. African olive (*Olea europea* ssp. *strenuous*) had been present and expanding for decades before rabbit eradication but its expansion accelerated when grazing ended.

Fauna quickly benefitted too. During the experimental phase, a well-vegetated hilltop exclosure contained many geckoes, while outside it none could be found. In the summer, this exclosure also had many sooty tern (*Sterna fuscata*) chicks sheltering within it while few were outside (Coyne 2010). The geckoes appeared to become much more abundant as vegetation developed after the rabbits were extirpated. So, too, the *Cormocephalus coynei* centipede. In 1980 it was extremely hard to find. Six hours' searching by two people at night in wet weather produced only one small specimen. The largest specimen then known was 15.4 cm long; now the median length is 19 cm. The centipede has become an important part of nutrient cycling on the island. It kills and eats lizards and young seabirds. The centipedes are the principal cause of black-winged petrel (*Pterodroma nigripennis*) nestling mortality, with annual rates of predation varying between 11.1% and 19.6% of nestlings (Halpin et al., 2021).

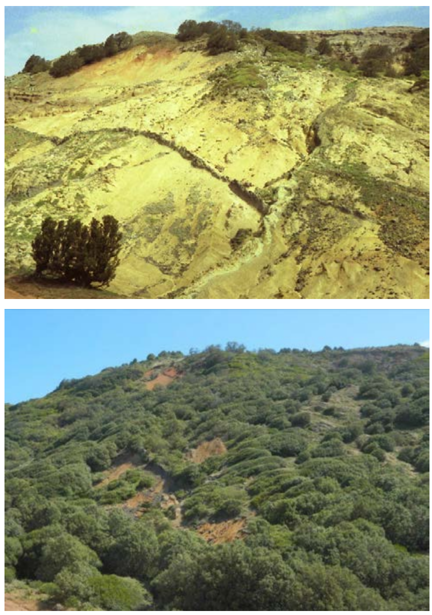

Figure 9: (top) 1981: Trees are white oaks and some small shrubby olives are shown higher up. Rabbit-resistant ground cover is *Wollastonia biflora* (syn. *Wollastonia uniflora*); (bottom) 2015: Low forest of white oaks (photos by author)

5 See Lange & Murray (2001). [Ed.]

6 Widely cultivated in Australia and abroad, this is known as the Norfolk Island hibiscus or cow-itch tree, family: Malvaceae. [Ed.]

Figure 10: (top) 1981: The ground cover is ephemeral *Commelina cyanea* or scurvy weed; (bottom) 2015: Low forest of white oaks (photos by author)

A survey of birds of Norfolk Island in November 1978 recorded thirteen species on Phillip Island. A similar survey in November 2005 recorded twenty-five species, with terrestrial species increasing from three to eleven. Much of the increase appears to be a consequence of vegetation development. In addition to the increase in species numbers, populations of some seabird species have increased considerably with development of new habitat. By 2005, black-winged petrels were nesting in burrows under the new forest of white oak where there had been insufficient soil before rabbit eradication. Red-tailed tropic birds (*Phaethon rubricauda*) nest under many white oaks in the new forest, and black noddies (*Anous minutus*) nest on new trees. Kermadec petrels (*Pterodroma neglecta*) were first recorded breeding on Phillip Island, under vegetation, after the rabbits were eliminated. White-necked petrels (*Pterodroma cervicalis*), which breed on only one other island (Macauley in the Kermadecs) and possibly, in small numbers, on Vanua Lava, Vanuatu (*BirdLife International* 2023), began breeding on Phillip Island after rabbit eradication, but may not have been responding to increasing vegetation as they nest under remnant white oaks.

The vegetation will continue to evolve as natural succession occurs, and as currently bare areas revegetate (Figure 11). Some fauna might be adversely affected while others benefit from the changes. For example, sooty terns were initially favoured, as vegetation provided shelter from the sun and from traditional egg collecting for consumption, but dense vegetation could restrict sooty tern nesting.

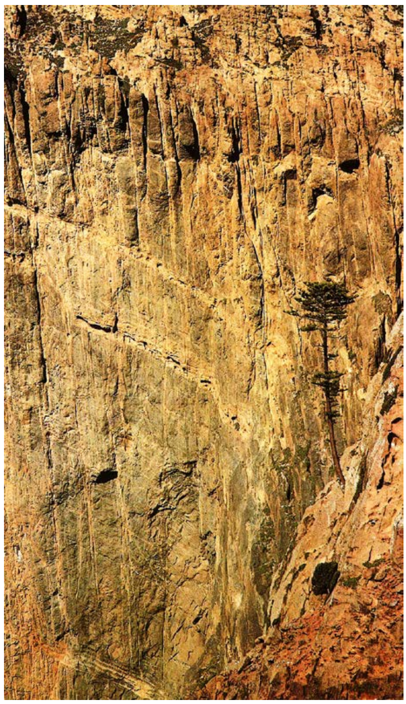

Figure 11: Dwarfed by the vast cliffs of Phillip Island, one of only seven Norfolk Island pines still surviving there in 1980 clings to life and to the rocks from which it somehow draws the water and nutrients it needs (photo by author)

Management since eradication of the rabbits has included planting of seedlings and distribution of seed but the vast majority of regeneration is natural.

Lord Howe Island — a human community

Degradation

Lord Howe Island, 780 km north-east of Sydney, was discovered on 17 February 1788 when the first colonists were on their way to Norfolk Island aboard HMS *Supply*. It was immediately seen as a source of fresh food, and *Sirius* captain Hunter recorded that the crew "Caught many excellent Turtle upon a Sandy Beach, This Island also abounded with a Variety of Birds which were so unaccustom'd to being disturbd that the Seamen came near enough to knock down with sticks as many as they wanted." In March 1788 surgeon White wrote that they also found there, in abundance, "a kind of fowl, resembling much the Guinea fowl in shape and size but widely different in colour, they being in general all white … These not being birds of flight, nor in the least wild, the sailors, availing themselves of their gentleness and inability to take wing from their pursuits, easily struck them down with sticks." That species is extinct[7] and had probably been hunted to extinction before the island was colonised in 1833. The Lord Howe Island woodhen (*Hypotaenidia silvestris*), now Endangered, also appears to have been valued for food. In May 1788 Governor Phillip recorded: "they brought off a quantity of fine birds, sufficient to serve the ship's crew three days; many of them were very fat, somewhat resembling a Guinea hen, and proved excellent food." The fresh food collected on Lord Howe Island was critical for the population in Sydney, with many afflicted by, and dying from, scurvy. It was also eagerly sought by crews of some of the First Fleet ships returning to England. The decline of Lord Howe Island's biota was well under way by the middle of 1788.

House mice (*Mus musculus*) arrived about 1860 and black rats arrived in 1918, refugees from the wreck of the SS *Makambo*. The rats quickly had a dreadful impact.

The Tasman starling (*Aplonis fusca*) had been the most common bird on Lord Howe Island, was still common in 1914, but was extinct by 1918. The Lord Howe thrush (*Turdus poliocephalus vinitinctus*) was extinct by 1924. The Lord Howe gerygone (*Gerygone insularis*) was also considered common but was last recorded in 1928. The Lord Howe grey fantail (*Rhipidura fuliginosa cervina*) declined rapidly and was extinct by about 1928. The robust white-eye (*Zosterops strenuous*), also endemic and abundant before rats arrived, was apparently extinct within ten years of the rats' arrival.

The Lord Howe southern boobook (*Ninox novaeseelandiae albaria*) became extinct because of the rats, but by an indirect cause. Three species of owls (the eastern Australian subspecies of the southern boobook *N. n. boobook*, masked owl *Tyto novaehollandiae* and barn owl *Tyto alba*) were introduced to Lord Howe Island between 1922 and 1930 in an unsuccessful attempt to control the rats, and the native owl appears to have suffered from competition with the introduced owls. In addition, the rats may have eaten the eggs and owlets of the southern boobooks. Not only would rats have preyed on owl eggs and chicks, they also extirpated the phasmid,

7 Possibly the white swamphen (*Porphyrio albus*) [Ed.].

possibly one of the owl's major prey items (Priddel & Carlile, 2010).

Rats are believed to be the reason two sea bird species, the Kermadec petrel (*Pterodroma neglecta*) and the white-bellied storm petrel (*Fregetta grallaria grallaria*), which previously bred on the main island, are now restricted to breeding on Balls Pyramid (DECC 2007).

In addition to the birds, the rats are considered responsible for the loss of at least 13 species of endemic invertebrates and two plant species (Segal et al., 2022).

Saved

Probably the best-known extinction the rats caused is the Lord Howe Island phasmid, (*Dryococelus australis*). It was abundant on Lord Howe Island, with 68 individuals found inside a single tree hollow, but it disappeared rapidly from the island after the introduction of black rats. Live specimens were last seen on Lord Howe Island in the 1920s (Priddel et al., 2003).

In 1964, a rock climber found a dead adult female on Balls Pyramid, 24 km from Lord Howe Island. Balls Pyramid is a precipitous basaltic pinnacle 551 m high, much taller than it is wide. In 1969, incomplete remains of another two individuals were recovered near the summit of Balls Pyramid. An expedition to search for the phasmid was mounted in early 2001, following a relatively dry year. A daytime search found about thirty shrubs of the endemic *Melaleuca howeana*, one of which provided significant evidence of relevant insect activity. Nicholas Carlile and Dean Hiscox climbed to the area of that shrub, about 65 m above sea level, at night and found three phasmids on the shrub but none on other shrubs. Another nocturnal survey of the same area in March 2002, after a wetter year, found 24 live phasmids, all on *M. howeana* shrubs within a small area. Little other potentially suitable habitat exists elsewhere on the Pyramid, which is mostly bare rock (Priddel et al., 2003).

Figure 12: Lord Howe Island stick insect. Cropped version of photo by *Granitethighs* (https://commons.wikimedia.org/wiki/File:Lord_Howe_Island_stick_insect_Dryococelus_australis_10June2011_PalmNursery.jpg) (CC BY-SA 3.0 Deed)

In 2003, two breeding pairs of the phasmid were collected from Balls Pyramid to commence a captive-breeding program to try to save the species. One pair, named Adam and Eve, was entrusted to Zoos Victoria. After being nursed through a critical illness, Eve eventually laid 248 eggs. By the end of 2018 the entire captive population was descended from those two original founders (Zoos Victoria, probably 2019). Now nearly 19,000 phasmids have been hatched over 16 generations since Adam and Eve (Figure 12). In late 2022, 800 adults and 3500 nymphs were in captivity at Melbourne Zoo, at Lord Howe Island and at the Bristol and San Diego Zoos (NSWDPE, 2022). Reintroduction of the phasmid to Lord Howe Island was intended when rats were eliminated and conditions were suitable.

The two species of introduced rodents on Lord Howe Island continued to threaten at least 13 bird species, two species of lizard, 51 plant species, plus 12 vegetation communities, and numerous species of threatened invertebrates (DECC, 2007).

Eradication

The feasibility of eradicating rodents from the Lord Howe Island Group, assessed in 2001, found eradication was feasible. A cost/benefit analysis also considered eradication feasible and calculated that the costs of eradication would be recouped, through higher yields of palm seed, within five years (DECC, 2007). The cost/benefit analysis demonstrated the rodent eradication program would have a benefit-to-cost ratio of 17:1 (Walsh et al., 2019).

Control of rats and mice had been undertaken since 1920, and required substantial amounts of poison every year. When the eradication program was being considered, the baiting program required more than 4.5 tonnes of baits annually to treat about one-tenth of the island (Walsh et al., 2019).

Despite the promising feasibility and economic studies, the eradication program was not undertaken until eighteen years after feasibility was demonstrated. Even with the considerable physical challenges, the need to protect threatened species at risk from the program, and the presence of pets, livestock and people, the greatest impediments to eradication of rodents were the opinions of island residents. Consideration of the program caused bitter division in the island community, requiring an intensive and extensive consultation and information process from 2008 to 2015, which still almost failed to gain approval to proceed. That decision was made in 2015 after an options paper was distributed to every person on the island registered on the electoral roll. Although rodent control had been undertaken there for almost a century, of 196 responses, 20 did not consider the island had a rodent problem which needed to be addressed. Only 108 favoured an eradication program while 93 preferred ongoing rodent control. On the basis of that slim majority, the Lord Howe Island Board decided to proceed with eradication (Greig and Alexandre, 2015; Walsh et al., 2019).

Two threatened endemic bird species, the woodhen and the Lord Howe currawong (*Strepera graculina crissalis*), were considered at considerable risk from poisoning during the rodent eradication program. The entire woodhen population (about 230 birds) and 129 currawongs (an estimated 30–40% of the population) were captured and kept in captivity on the island for the entire risky period (*Australian Geographic*, 2020; Segal et al., 2022).

About 100 beef cattle were reduced progressively to zero and all poultry were eliminated from the island before baiting began, to be replaced by imported animals afterwards. The dairy herd of 14 cows was protected from exposure to baits (Wilkinson & Priddel, 2011).

The rodent eradication program conducted in 2019 was a massive undertaking, involving:

- approval from seven government departments and agencies;
- individual property management plans for private property;
- after trials involving smaller numbers of birds, capturing the woodhens and currawongs, transported by helicopter from isolated areas;

- maintaining those birds in rodent-proof enclosures over the period of baiting and subsequent risk;
- two helicopters in June and July to distribute bait over uninhabited parts of the island, with eight ground crew;
- 19,000 bait stations in a 10 × 10 m square grid and fifty ground baiting crew May to November;
- 9,500 hand-broadcasting points in the areas of overlap between the aerial application and bait station network;
- rodent-detection dogs and their handlers for monitoring for two years after baiting (LHIM, 2022; Segal et al., 2022).

No signs of live rodents were detected from the end of September 2019 until April 2021, when an island resident saw two rodents. These were thought to be new arrivals rather than survivors of the eradication program. By July 2021, 78 rats had been caught (LHIM, 2022). The 2021 response appears to have eliminated rats from the island (Invasive Species Council, 2022).

Regeneration

The benefits from the rodent eradication are being monitored and significant increases in birds, invertebrates and plants are being recorded. By early 2023 there were more than 1100 woodhens (Siossan, 2023). Residents reported increases in emerald doves (*Chalcophaps longirostris rogersi*) and other land birds. Seabirds also appear to be increasing the range where they breed (LHIM, 2022).

With rodents removed, more than 30 threatened plant and animal species found on the island are recovering. The masked booby (*Sula dactylatra tasmani*)[8] is breeding on the main island for the first time since rodents arrived. The Lord Howe wood-feeding cockroach (*Panesthia lata*), presumed extinct on the main island, has been rediscovered at a site in the north of the island (Siossan, 2023).

Lord Howe Island has Australia's highest diversity of land snails, with around 70 endemic species. The snail populations suffered heavily from rodent predation. Several species are considered extinct and five are Endangered or Critically Endangered. Extremely rare species were soon more numerous after rodent eradication (Hyman, 2021).

Jack Shick, a fifth-generation Lord Howe Islander, said "There has been an unbelievable rebound of birds, plants and insects since rodents started being removed in 2019. … The amount of seedlings from native plants popping through has to be seen to be believed" (Invasive Species Council, 2022).

Lord Howe Island, a World Heritage Area, is the largest populated island to eradicate rodents.

Macquarie Island — multiple ferals

Macquarie Island, 34 km long and 5.5 km wide, is spectacular. Between Tasmania and Antarctica, the outstanding significance of this remote island is recognised through its World Heritage listing, for its exceptional geoconservation significance, exceptional natural beauty, and superlative natural phenomena including extensive congregations of wildlife (PWS, 2014).

Macquarie Island supports vast congregations of wildlife, including breeding colonies of elephant seals and fur seals, and

8 This bird was known as *Sula dactylatra fullageri* until Steeves et al. reclassified it in 2010. [Ed.]

numerous seabird species, including four species of penguins, four species of albatrosses, two species of giant petrels, and a variety of burrow-nesting seabirds. There are also resident breeding populations of terns, cormorants and skua (PWS, 2014).

Figure 13: Royal Penguins (*Eudyptes schlegeli*) on Macquarie Island west coast. Cropped version of photo by *Hullwarren* (https://commons.wikimedia.org/wiki/File:MacquarieIslandRoyals.jpg) (CC BY-SA 3.0 Deed)

The 45 species of vascular plants, four endemic, comprise small grasses, herbs, cushion plants, ferns, orchids, mega-herbs and large tussock grasses (Bryant & Shaw, 2007).

Degradation

The island was discovered in 1810; over the next 70 years, rats, mice, cats and rabbits were introduced by sealers. Weka (*Gallirallus australis scotti*) were also introduced and established, initially as a food source for sealers.[9] The impact of ferals was catastrophic. At their height feral cats were killing an estimated 60,000 seabirds a year (Olive, 2021).

Penguin and elephant seal populations are recovering, but invasive mammals led to the extinction of the endemic rail and parakeet, and massive declines in seabirds. By the 1970s, several burrowing petrel species were locally extinct and those remaining were declining rapidly. The birds and their eggs were preyed on by cats, weka and rats, while rabbits destroyed nesting habitat and exposed burrows more to predation by skuas. Of 14 petrel species known or likely to have bred on Macquarie Island, only three species remained on the main island by the 1970s, while another three were confined to offshore rock stacks (Brothers & Bone, 2008; NESP, 2021a).

By the 1960s concern about rabbit damage to vegetation was increasing. The catastrophic effects of rabbits were due primarily to selective grazing of the dominant and stabilising plant species. Those species were soon eliminated from plant communities. The residual short turf of mosses and minor species provided little protection for the underlying peat. On steep slopes, the conversion of only a small area of *Poa* grassland to minor herb communities often initiated a land-slip which eventually led

9 The weka, also known as the Māori hen or woodhen is a flightless bird species of the rail family. It is endemic to New Zealand. It is the only extant member of the genus *Gallirallus*. [Ed.]

to the stripping of an otherwise stable and undamaged slope (Costin & Moore 1960).

Eradication

Management of rabbits commenced in 1968 with introduction of the European rabbit flea but, with annual releases, it took 10 years for the flea to become widespread. The rabbit population peaked in 1978, the year when the Lausanne strain of *Myxoma* virus was introduced (Bergstrom et al., 2009; Springer, 2018). Myxomatosis caused rapid decline in rabbit numbers. By 1990 the condition of the vegetation was clearly improving. Annual release of the myxoma virus was effective for controlling rabbits for about 20 years, but production of the virus ended in 2000 and supplies dwindled. Annual releases ended in 2006 (PWS, 2014).

By 1988, weka had been eradicated by shooting (Springer, 2018).

Myxomatosis resulted in reduced food availability for cats, and cat predation of petrels intensified (Brothers & Bone, 2008). By the mid-1980s cats were having significant detrimental impacts on seabird populations. Cat eradication commenced in 1985, was expanded in 1998, and the last cat was killed in 2000. A total of 6298 field days and 216,574 trap nights were recorded in cat eradication (Robinson & Copson, 2014). After that, rabbit numbers increased rapidly and substantially altered large areas of vegetation (AAP, 2009).

The successful eradication of cats from Macquarie Island, being the second largest then achieved, provides valuable experience for cat-eradication attempts on other large remote islands (Robinson & Copson, 2014).

Some regeneration but further eradication

A number of species showed immediate benefit from the rapid reduction, then eradication, of cats. Although this implies that cats were the most destructive of these pests, it was cats in combination with rabbits and weka that were responsible for the demise of so many indigenous species (Brothers & Bone, 2008).

Eradication techniques for rodents and rabbits on an island the size of Macquarie were unavailable when cat eradication was deemed necessary (Dowding et al., 2009).

With cats and weka gone, despite rats remaining, a number of species attempted to re-establish. Such activity did not occur when cats were prevalent (Brothers & Bone, 2008).

Grey petrels (*Procellaria cinerea*) were confirmed breeding on the island in 2000 after an absence of over 80 years. Cape petrels (*Daption capense*) were recorded breeding for the first time, soft-plumaged petrels (*Pterodroma mollis*) appeared to be colonising for the first time, and blue petrels (*Halobaena caerulea*) and fairy prions (*Pachyptila turtur*) were re-colonising from refugia on off-shore stacks (Brothers & Bone, 2008).

Rabbit numbers then increased rapidly, and in about five years they had substantially altered large areas of the island. It has been suggested that eradication of cats led to an increase in rabbit abundance. However, both reducing *Myxoma* virus and variation in climate may also have affected abundance (Bergstrom et al., 2009), while rebounding vegetation after myxomatosis increased food supply (Springer, 2018).

The incidence of landslips in areas of high rabbit damage increased in 2002–2007.

Rabbit grazing and burrowing appeared to destabilise steep slopes (Bryant & Shaw, 2007).

Rabbit grazing led to loss of breeding habitat for seabirds. Loss of vegetation contributed to the exposure of burrow entrances and landing platforms (Bryant & Shaw, 2007). Rats preyed on seabird chicks and eggs, killing petrel adults and chicks in their nest burrows and predating on blue petrels, forcing them to breed only on off-shore rock-stacks. White-headed petrels (*Pterodroma lessonii*) were highly susceptible to disturbance by rabbits (Brothers & Bone, 2008). In one season half the island's albatross nests failed and the breeding success of six petrel species was impacted by both rats and rabbits (Olive, 2021).

From 1979 to 1999, there was an 89% decline at a sooty shearwater (*Puffinus griseu*) colony that originally contained about one-third of the total island population. That site had suffered severe rabbit damage over the 20-year period (Brothers & Bone, 2008).

The serious impact on petrels of habitat destruction from rabbit grazing was far more detrimental to petrels than increased skua (*Catharacta lonnbergi*) predation, predicted to occur during rabbit eradication (Brothers & Bone, 2008).

The impact of rabbit browsing on six threatened burrowing petrel species and its likely threat to five flora species supported the need to urgently commence rabbit eradication (Bryant & Shaw, 2007).

The planning phase of the project to eradicate rabbits, rats and mice was complex, with over 30 separate state and federal permits and approvals required (PWS, 2014). Approximately 29 people were employed for the aerial baiting phase, and annual field teams of up to 15 staff were used for three years of fieldwork following aerial baiting (PWS, 2014).

Toxic baiting of rabbits, rats and mice using aerial baiting from helicopters was expected to take around four months and be completed during the winter of 2010. Late arrival due to shipping delays, followed by extended bad weather conditions, seriously curtailed helicopter flying time. Only a small portion of the island (about 8%) was successfully baited during the 2010 winter season. The decision was made to suspend the baiting program until the following year (PWS, 2014).

The baiting undertaken in 2010 was very successful in killing the target species in the areas covered but, as expected, there was incidental mortality of non-target seabirds: skua, kelp gulls (*Larus dominicanus*), northern and southern giant petrels (*Macronectes halli*, *M. giganteus*), and Pacific black ducks (*Anas superciliosa*) and mallard (*A. platyrhynchos*). Concern about non-target mortality caused refinement of the approach (PWS, 2014).

Calicivirus (or Rabbit Haemorrhagic Disease Virus) was introduced to Macquarie Island in February 2011. An estimated 80–90% of the rabbit population was killed in the weeks after the virus release (PWS, 2014). Importantly, this greatly reduced the number of rabbits killed by poison and consequently prone to causing secondary poisoning of scavenging birds.

Whole-of-island baiting by four helicopters resumed in May 2011 and was completed within seven weeks (PWS, 2014). Staff collected and buried poisoned carcasses (target and non-target species) during and after the baiting period to reduce the risk of secondary poisoning to scavenging seabirds (PWS, 2014).

The hunting phase of the project then commenced, with teams deployed to locate and kill any remaining rabbits that survived the baiting. Teams included twelve rabbit-detection dogs and three rodent-detection dogs (Springer, 2018). This follow-up phase was critically important to ensure that every individual of the three target species was eliminated. Though planned for three years, this phase took seven months (PWS, 2014). No rodents or rabbits were seen after May 2011 (rats), June 2011 (mice), and December 2011 (rabbits) (Springer & Carmichael, 2012).

After the last rabbit was killed, the monitoring phase began in April 2012 to search for any evidence of live rabbit or rodent presence on the island. Monitoring continued for two years, with staff recording more than 92,000 km travelled between August 2011 and March 2014 (PWS, 2014).

Regeneration

By 2014, vegetation regrowth was progressing well. Recovery of *Poa litorosa* was noted in areas where it was previously unreported. Extensive regrowth of *Poa cookii* occurred on areas of the plateau and escarpment where it had not previously been recorded (PWS, 2014).

Significant recovery across favourable sites has been recorded for the dominant species, muttonbird poa (*Poa foliosa*), the Macquarie Island cabbage (*Stilbocarpus polaris*, Araliaceae), and the silver-leaf daisy (*Pleurophyllum hookeri*, Asteraceae), while the prickly shield fern (*Polystichum vestitum*) is regrowing. Numerous grassland and smaller herbfield plants are demonstrating significant recovery (Springer, 2016). *Poa litorosa*, known from only four restricted populations on Macquarie Island prior to 2014, has increased dramatically. Existing populations have expanded and new populations have been recorded (Williams et al., 2016).

Some species of burrowing and surface-nesting petrels are again breeding on the main island. Notable breeding activity and increased breeding success has been recorded for the soft-plumaged petrel, blue petrel, grey petrel, white-headed petrel, cape petrel and diving petrel (*Pelecanoides urinatrix*), while the Antarctic tern (*Sterna vittata*) has begun breeding on cobblestone beach areas. Species impacted by the baiting such as northern giant petrels and kelp gulls (Springer & Carmichael, 2012) soon showed signs of recovery. Skuas were expected to reach a lower population equilibrium than previously, given the removal of one of their key prey species — rabbits (Springer, 2016).

Populations of the two species that survived invasive predators were estimated to be about 160,000 breeding pairs of Antarctic prions (*Pachyptila desolata*), and 12,500 breeding pairs of white-headed petrels. The recolonising species, blue petrels and grey petrels, had reached 5,500 pairs and 250 pairs respectively, and are increasing rapidly. Common diving-petrels are breeding on the main island for the first time, and new breeding locations were found for soft-plumaged petrels, fairy prions and grey-backed storm-petrels (*Garrodia nereis*) (Bird & Shaw, 2021).

Rabbits were an important part of the brown skua's diet during their breeding season. Skuas dropped to their lowest breeding population size on record following rabbit eradication due to prey-loss in some areas of the island but, in other areas, to secondary poisoning. Nest numbers dropped by almost half after eradication of rabbits. In the absence of rabbit prey, penguins became the primary prey for nearly all skuas on the island. (IMAS, 2021). The brown skuas are now showing strong signs of recovery (NESP, 2021b).[10]

Naturally abundant petrel populations drive primary production on islands and their coastal waters by collecting nutrients over vast ocean catchments and depositing them in their guano, influencing the entire island ecosystem. Conspicuously, suitable breeding habitat on Macquarie Island is greatly under-utilised. If petrels increase to fill all suitable areas at the same densities found in their current colonies, populations could number in the hundreds of thousands or millions. Such numbers tally with other islands throughout these species' ranges (Bird & Shaw, 2021). Populations on Macquarie are not yet sufficiently abundant to fulfil this important ecological role. Full recovery of populations, and restoration of the ecological functions they provide, may take decades (NESP, 2021a).

Macquarie Island is the largest island worldwide where these three species have been eradicated (Springer, 2018).

Removal of rabbits, ship rats and especially house mice from Macquarie Island was ambitious and challenging. Its success despite many challenges is a significant milestone in global island eradications and will hopefully encourage similar measures on other islands where pests are causing significant impacts. Crucially, biosecurity measures need to be robust and maintained at a high level in perpetuity if conservation and biodiversity gains are to be realised long term (Springer, 2016).

Conclusion

The islands discussed here have suffered severely from feral animals, with consequent extinctions and spectacular land degradation. Removing the feral animals induced rapid ecological responses, although full recovery will take many decades and extinct species can never return. Biologically, the outcomes have well justified the effort and cost. The pest eradication programs on Phillip, Lord Howe, and Macquarie Islands all faced extraordinary difficulties, but they succeeded, extending the scope of what is possible. These experiences have shown the importance of thorough planning, dedicated personnel, adequate resourcing and extreme diligence in ensuring no pests remain. Trained dogs were crucial to find the last remaining pests. Lord Howe Island has shown the critical importance, for populated islands, of ensuring the island community completely understands the issues early in developing the pest-eradication program. Early community engagement (not information sharing) to gain support needs to be the top priority for future eradications on populated islands (Walsh et al., 2019). Threatened birds at risk during rodent extermination were kept secure in captivity and released when safe. With the will to try, even an invertebrate with a population reduced to about 30 individuals can be saved from extinction and, hopefully, restored to its important ecological role. The Macquarie Island program was made more difficult by different agencies having somewhat conflicting legal objectives, so while the program had a long-term purpose, some legislation was focused too narrowly. Reducing the rabbit

10 See also Travers et al. (2021) [Ed.]

population with calcivirus before beginning poisoning minimised secondary poisoning of scavenging birds. Pest control and eradication on Macquarie Island demonstrated possible cascading consequences — rabbit control increased cat predation on birds; cat eradication removed a constraint on rabbit numbers; and rabbits then caused great damage to the island and its birds. Only eradication of all the vertebrate pest species enabled ecosystem recovery. Monitoring after pest eradication is important, so planning and funding should be included in the eradication project. Comprehensive documentation of programs facilitates their contribution to future efforts.

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