Eradication of exotic mammals from offshore islands in New South Wales, Australia

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Abstract Operations to eradicate populations of exotic mammals – ship rat (*Rattus rattus*), house mouse (*Mus musculus*) and European rabbit (*Oryctolagus cuniculus*) – have recently been conducted on five offshore islands in New South Wales, Australia. Techniques involved the broadcast and bait-station application of cereal baits containing the anticoagulant brodifacoum. Brush Island (47 ha) was treated for rats using bait stations in July 2005 and declared pest-free in 2007 after monitoring failed to detect any rodents. Recent observations have revealed increased numbers of lizards, frogs and crabs, as well as the presence of the white-faced storm-petrel (*Pelagodroma marina*), a species not previously recorded breeding there. Montague Island (82 ha) was aerially baited for mice and rabbits in July 2007 and declared free of these pests in 2009. The removal of these exotic mammals was undertaken primarily to enhance restoration of seabird nesting habitat following the removal of invasive kikuyu grass (*Pennisetum clandestinum*). Broughton Island (144 ha) was aerially baited for rats and rabbits in August 2009. The same operation included aerial baiting of nearby Little Broughton Island (30 ha) and Looking Glass Isle (4 ha) to remove rats. Detector dogs were used to search for surviving rabbits on Broughton Island in November 2009, but failed to detect any sign of them. One month later Gould's petrel (*Pterodroma leucoptera*) was recorded breeding there for the first time. Monitoring for the presence of rats and rabbits is continuing. Knowledge sharing and the free availability of information have been pivotal to the success of the operations undertaken to date, and the experiences gained have greatly enhanced our local capacity to plan and co-ordinate more complex eradications.

Keywords: Brodifacoum, eradication, house mouse, *Mus musculus*, island, kikuyu, *Pennisetum clandestinum*, rabbit, *Oryctolagus cuniculus,* ship rat, *Rattus rattus*

INTRODUCTION

Introduced mammals have had severe impacts on island systems, causing the extinction or local extirpation of numerous species worldwide (Groombridge 1992). Their eradication from islands has generally been highly beneficial for many ecosystem components including seabirds, terrestrial birds, lizards, amphibians, invertebrates and plant communities (Newman 1994; Towns and Broome 2003; Howald *et al*. 2007). The range of exotic mammals that established populations on offshore islands in New South Wales (NSW), Australia, includes goat (*Capra hircus*), pig (*Sus scrofa*), cat (*Felis catus*), European rabbit (*Oryctolagus cuniculus*), ship rat (*Rattus rattus*) and house mouse (*Mus musculus*). The larger of these species were eradicated from NSW islands between 1980 and 2000, after which only rodents and rabbits remained (Table 1).

Exotic rodents can have devastating impacts on island ecosystems (Towns *et al.* 2006; Jones *et al.* 2008) and have long been acknowledged as a significant threat to the native ecosystems of South Pacific islands (Atkinson and Atkinson 2000). Rats prey on the eggs and chicks of land birds and seabirds, and can cause major declines in these species (Merton *et al.* 2002). Rats and mice also prey heavily on reptiles, snails, insects and other invertebrates (Towns 1991; Bergstrom and Chown 1999; Smith *et al.* 2002; Hadfield and Saufler 2009) and compete with native avifauna for food (Huyser *et al.* 2000). They consume quantities of flowers, fruits and seeds, which can reduce seedling recruitment (Shaw *et al.* 2005), leading to loss of species and changes in vegetation communities (Auld *et al.* 2010). By reducing seabird abundance, rodents can reduce the inflow of marine-derived nutrients which, in turn, can profoundly affect the productivity of insular vegetation communities (Bancroft *et al.* 2005). On Lord Howe Island, rats are implicated in the extinction of at least five species of endemic birds, 13 species of invertebrates and two plant species (LHIB 2009), and are a continuing threat to at least 13 other bird species, two reptile species, 51 plant species, 12 vegetation communities and numerous species of threatened invertebrates (DECC 2007).

The impact of rabbits on islands worldwide has been catastrophic, with many islands being virtually denuded (Watson 1961; Clapp and Wirtz 1975; Coyne 2010). Impacts have been less severe in NSW, although loss of vegetative cover through rabbit grazing and burrowing activities has rendered substantial areas of some islands vulnerable to erosion and weed invasion.

In 1997, rabbits were successfully eradicated from Cabbage Tree Island on the central coast of NSW (Priddel *et al.* 2000) to protect and restore the habitat of the endangered Gould's petrel (*Pterodroma leucoptera leucoptera*), an endemic subspecies that breeds principally on this island (Priddel and Carlile 1997a). Rabbits had removed the rainforest understorey, allowing pied currawongs (*Strepera graculina*) easier access to the forest floor, where they hunted and killed nesting petrels and their chicks (Priddel and Carlile 1995). The removal of the understorey also allowed the sticky fruits of the birdlime tree (*Pisonia umbellifera*) to fall directly to the forest floor, increasing the likelihood of petrels becoming entangled in them (Priddel and Carlile 1997b). Entangled birds are often unable to fully open their wings to fly, and die from starvation. Rabbits were also restricting the regeneration of many rainforest canopy species (Werren and Clough 1991). For example, seedlings of the cabbage tree palm (*Livistona australis*) survived only if they were caged to prevent grazing by rabbits (Carlile 2002). Lack of seedling recruitment over the 90 years that rabbits were present threatened the continued survival of this species on the island.

Following the removal of rabbits from Cabbage Tree Island, vegetation regeneration was so extensive that, in 2003, the NSW Government initiated a programme to remove mammalian pests from all NSW offshore islands. At that time, the only islands in NSW known to have populations of exotic mammals were Brush Island, Montague Island, three islands within the Broughton Island group, South Solitary Island and Lord Howe Island (Table 1). Operations

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Table 1 Populations of introduced mammals on NSW islands, and their eradication.

Island	Area (ha)	Spp targeted	Erad.	Method(s)	Year	Source
South Solitary	10	European rabbit	Yes	Shooting; myxomatosis	<1975	Lane 1975
Lord Howe	1455	Feral house cat	Yes	Shooting; trapping	1980	Miller and Mulette 1985
Lord Howe	1455	Pig	Yes	Shooting	1981	Miller and Mulette 1985
Bowen	50	European rabbit	Yes	Hand broadcasting of 1080-laced carrots; myxomatosis	1981	Martin and Sobey 1983
Montague	82	Goat	Yes	Shooting	1988	R.Constable (pers.comm.)
Bowen	50	Ship rat	Yes	Bait stations (50x50 m grid) containing bromadiolone (50 ppm) or brodifacoum (50 ppm) in wax blocks	1993–1995	Meek 2009
Cabbage Tree	26	European rabbit	Yes	Myxomatosis, rabbit haemorrhagic disease, aerial dispersal of brodifacoum (50 ppm) in cereal pellets	1997	Priddel *et al*. 2000
Lord Howe	1455	Goat	Yes[1]	Shooting	1999	Parkes *et al*. 2002; Priddel and Hutton 2010
Brush	47	Ship rat	Yes	Bait stations (25x25 m grid) with brodifacoum (50 ppm) in wax blocks	2005	This study
Montague	82	House mouse; rabbit	Yes	Natural outbreak of rabbit haemorrhagic disease; aerial dispersal of brodifacoum (20 ppm) in cereal pellets; hand-baiting buildings	2007	This study
Broughton	144	Ship rat; rabbit	Yes	Rabbit haemorrhagic disease; aerial dispersal of brodifacoum (20 ppm) in cereal pellets; hand-baiting in and around buildings	2009	This study
Little Broughton	30	Ship rat	Yes	Aerial dispersal of brodifacoum (20 ppm) in cereal pellets	2009	This study
Looking Glass	4	Ship rat	Yes	Aerial dispersal of brodifacoum (20 ppm) in cereal pellets	2009	This study
South Solitary	10	House mouse	No	Aerial dispersal of brodifacoum (20 ppm) in cereal pellets	Planned	
Lord Howe	1455	Ship rat; house mouse	No	Aerial dispersal of brodifacoum (20 ppm) in cereal pellets; hand-baiting and bait stations in settlement area	Planned	

[1] a few females remained after 1999 but these have since died out

to eradicate these pests have recently been conducted on all these islands except South Solitary and Lord Howe. In this paper, we document the procedures used, along with any observed non-target impacts, outcomes and biodiversity benefits. We also highlight some challenges encountered and discuss information gaps.

STUDY SITES

Brush Island

Brush Island (35°31´S, 150°25´E; 47 ha) is a nature reserve situated 370 m offshore from Bawley Point, 23 km south of Ulladulla on the NSW south coast (Fig. 1). Ship rats were common throughout the island and probably arrived when a steamer, the *Northern Firth*, ran aground in 1932. Direct human disturbance on Brush Island is limited, with little visitation and no record of recent human habitation.

Montague Island

Montague Island (36°15´S, 150°13´E; 82 ha) is a nature reserve situated 7 km offshore, 10 km southeast of Narooma on the NSW south coast (Fig. 1). The island is volcanic in origin, and comprises two sections (a southern section and smaller northern section), divided by a deep ravine. A building precinct, located at the highest point on the southern section, contains a lighthouse and accommodation built in 1881 for three lighthouse keepers and their families, as well as a number of outbuildings and associated infrastructure. Nowadays, the lighthouse is automated and the buildings are used as a museum and accommodation for maintenance workers, visiting scientists and eco-tourists.

The island once supported small trees, but the combined effects of timber harvesting for construction and fuel, the increased frequency of wildfire, and grazing by rabbits and goats have resulted in the loss of most woody vegetation (Heyligers and Adams 2004). Presently, the dominant

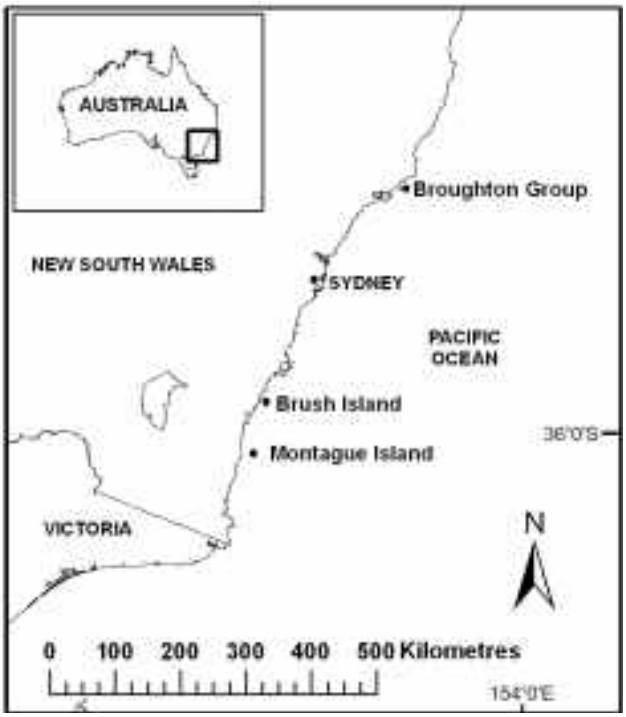


Fig. 1 Location of NSW islands where eradication operations were undertaken.

vegetation is spiny-headed mat-rush (*Lomandra longifolia*), bracken (*Pteridium esculentum*), coastal tussock grass (*Poa poiformis*) and introduced kikuyu grass (*Pennisetum clandestinum*). Kikuyu was spreading rapidly, and by 2001 it covered more than a third of the island (Weerheim *et al.* 2003). Since that time, an ongoing control programme has removed the majority of this invasive weed. Areas from which kikuyu has been removed have been replanted with native seedlings grown at local nurseries from local seed stock.

Mice were present throughout the island at densities varying from 59–160 per ha (Cory 2007), and all buildings were heavily infested. Intermittent control using rodenticide and snap traps had been attempted in and around buildings, with limited success. Rabbits were common, particularly around the rocky fringes of the island. Although the myxoma virus occurred on the island, as evidenced by periodic outbreaks of myxomatosis, it was seldom very effective, probably because the rabbits were largely surface dwelling and rabbit fleas (a prime vector) were not present (Silvers and Davey 1994). The only attempt at controlling rabbits was the periodic use of 1080-laced carrots before 1995.

In 2005, the numbers of rabbits dropped dramatically due, we believe, to an outbreak of rabbit haemorrhagic disease caused by the natural spread of calicivirus. At the time of the eradication operation in 2007, rabbits were in low numbers and, as far as could be ascertained, were confined to the northern section of the island.

Broughton Island group

The Broughton Island group is situated approximately 3 km offshore and 15 km northeast of the entrance to Port Stephens on the NSW central coast (Fig. 1). The group is volcanic in origin and consists of five islands totalling 182 ha: Broughton Island (144 ha), Little Broughton Island (30 ha), Looking Glass Isle (4 ha), North Rock (3 ha) and Inner Rock (1 ha). Broughton Island, the main island in the group, is part of Myall Lakes National Park; the other islands are nature reserves. Rats were present on Broughton Island, Little Broughton Island and Looking Glass Isle. As far as is known, rabbits occurred only on Broughton Island.

Broughton Island (32°36′S, 150°19′E), has been used as a base for commercial fishing since the mid 19th century (Clarke 2009). Two small settlements were established soon after the First World War; one of which was abandoned in 1939; the other, now a hamlet of seven huts, is occupied by recreational fishers and their families on a semi-permanent basis, with up to 50 persons present at any one time.

Rainforest once existed on the higher slopes of the island, but occupation led to a marked increase in the frequency of fires (Lane 1976) as fishermen would burn the island to control undergrowth and clear tracks (Clarke 2009). The increase in fire frequency has reduced the amount of woody vegetation, such that only scattered trees now remain (Lane 1976). The island supports a large and important population of green and golden bell frog (*Litoria aurea*), a species confined to southeastern Australia and listed as threatened in NSW (White and Pyke 1996).

Rabbits were taken to Broughton Island in 1906 when the Danysz Rabbit Inoculation Station was established on the island to investigate the potential for a new strain of *Pasteurella* bacterium to control rabbit numbers on the Australian mainland (Hindwood and D'Ombrain 1960). Unfortunately, although capable of killing rabbits, the bacterium failed to propagate through wild populations and, after twelve months, the project was abandoned (Rolls 1969). Subsequently, rabbits were trapped and shot for food by the island's inhabitants, but as far as we can ascertain the only attempted control was the introduction of myxoma virus some time after 1950.

Nothing is known about when or how rats came to Broughton Island; they were known to be present in the 1960s but probably arrived much earlier. In recent decades, rats were common within the vicinity of the huts, where they regularly contaminated foodstuffs. Their impact on nesting seabirds has never been investigated, but they are presumed responsible for the local extirpation of the white-faced storm-petrel (*Pelagodroma marina*), a species that is numerous on the outer islets of North Rock and Inner Rock. Control of rodents has been limited to activities in and around buildings, using rodenticide and snap traps.

Little Broughton Island (32°37′S, 150°20′E) is separated from the main island by a deep narrow channel. Much of the island is dominated by mat-rush although the peak is heavily wooded with coastal tea-tree (*Leptospermum laevigatum*), tuckeroo (*Cupaniopsis anacardioides*) and coast banksia (*Banksia integrifolia*). Access to the island is difficult and it is seldom visited. A brief inspection of the island in 1998 found rats to be particularly abundant, as evidenced from an exceptionally high density of droppings and a marked browse line about 15 cm above ground, below which all edible vegetation had been removed.

Looking Glass Isle (32°37′S, 150°19′E) is rocky and steep-sided. The dominant vegetation is ruby saltbush (*Enchylaena tomentosa*), mat-rush and the introduced prickly pear (*Opuntia* sp.). The presence of droppings in 2009 indicated rats were present. At low tide it is possible to wade between this isle and Broughton Island.

North Rock (32°35′S, 150°19′E) and Inner Rock (32°35′S, 150°18′E) are both vegetated, but there is no record of exotic mammals on either of these islets. However they are only 1.4 km and 0.5 km, respectively, from Broughton Island, well within the swimming range of rats. Public access to these islets is prohibited.

Potential non-targets

The only native mammals present on NSW offshore islands are fur seals (*Arctocephalus* spp.), frugivorous megabats (Megachiroptera) and insectivorous microbats (Microchiroptera). These animals are highly unlikely to consume cereal baits and thus were not considered to be at direct risk of rodenticide exposure. Seabirds (petrels, shearwaters and terns) occur on those islands where eradication operations were conducted, but were not considered to be at risk due to their piscivorous diet. Silver gulls (*Chroicocephalus novaehollandiae*) breed on some islands, but were absent during the time that baits were present.

The only land bird likely to consume baits was the buff-banded rail (*Gallirallus philippensis*), a nomadic species that fluctuates in abundance. At times, there have been up to 20 rails recorded on Montague Island, but when baiting was conducted, only two individuals were observed. Several raptors were potentially vulnerable to secondary poisoning by consuming contaminated rabbits and rodents, but all occurred in low numbers: white-bellied sea-eagle (*Haliaeetus leucogaster*), swamp harrier (*Circus approximans*), peregrine falcon (*Falco peregrinus*) and Australian kestrel (*F. cenchroides*).

Brodifacoum, an anticoagulant, was not expected to have significant effects on invertebrates as these organisms have different blood clotting systems to mammals and birds. Although invertebrates may feed on the bait, insectivorous birds and bats were not considered to be at risk because invertebrates are unlikely to accumulate high levels of brodifacoum as it is quickly eliminated through metabolism and excretion (Morgan *et al.* 1996). Very large numbers of contaminated invertebrates would need to be consumed in a relatively short period to cause mortality of insectivorous bats and birds (Morgan and Wright 1996).

METHODS

Brush Island

The eradication of rats from Brush Island was conducted in 2005 using bait stations constructed from 35 cm lengths of flexible drainage pipe (10 cm diameter). A 25x25 m grid was established across the entire island and a single bait station was placed at each of the 550 grid points. Rodenticide bait (Pestoff Rodent Blocks, Animal Control Products, Wanganui, New Zealand) containing the anticoagulant brodifacoum at 50 parts per million (ppm) was added to each bait station on 7 July 2005 (Day 0). Three of these wax blocks, each about 30 g, were threaded onto a short length of wire tied into each bait station. Baits were replenished approximately every second day for the first 10 days, with approximately half of the stations serviced on any one day. Bait stations were then inspected approximately 2, 4 and 8 weeks later and replenished (to approximately 90 g) as required. At each inspection, the weight of bait remaining in each bait station was recorded along with the weight of bait added. The total amounts of bait used and consumed during the operation were calculated. Carcasses found during baiting operations were removed to reduce the risk of secondary poisoning of non-targets. In October 2005, the bait stations and remaining bait were removed.

Monitoring to detect for the presence of rats was undertaken over a period of six weeks in late 2007. A total of 50 feed stations containing a measured number of non-toxic cereal pellets (Pestoff Rodent Bait 20R, Animal Control Products, Wanganui, New Zealand) were randomly distributed across the island. These stations were checked approximately weekly, and any loss of pellets recorded.

Montague Island

The eradication operation on Montague Island was conducted during winter (July 2007) when mouse densities were seasonally low and after rabbit numbers had been reduced substantially, probably by a natural outbreak of haemorrhagic disease. The operation involved two aerial applications of cereal-based bait (Pestoff Rodent Bait 20R) containing brodifacoum at 20 ppm. To investigate the efficacy of bait size in eradicating mice, the southern section of Montague Island was baited with 10 mm baits (~2 g pellets), and the northern section with 5.5 mm baits (~0.6 g pellets). There is sufficient brodifacoum in one small pellet to kill a mouse. Sowing rates for both sizes were 12 kg per ha for the first drop and 6 kg per ha for the second. The second application took place 10 days after the first.

Bait was delivered using a spreader bucket slung below a helicopter (Eurocopter AS350B3) equipped with a GPS navigation and guidance system (AG-NAV® Guía). The bucket provided an effective swathe width of 80 m for 10 mm bait and 70 m for 5.5 mm bait. Parallel flight lines were spaced at 35 m intervals for 10 mm bait and 30 m for 5.5 mm bait, giving a swathe overlap in excess of 50%. A 30 m exclusion zone around the building precinct was baited by hand. Bait stations were placed in each room of each building and in all accessible roof cavities. There were no under-floor spaces.

One month after the second baiting, 75 tracking tunnels (Connovation, Auckland) were strategically distributed alongside tracks on the island. Tunnels were monitored for mouse activity (footprints) and sampled at approximately 3-month intervals for 24 months. At each visit, new ink boards and attractant (linseed oil) were fitted to each tunnel, since their effective life was limited to about two weeks. In addition, up to 100 Elliott traps (baited with peanut butter and oats) along with seven remotely activated cameras were deployed near any reported sightings of mice. We also looked for fresh rabbit dung, grazing and diggings while conducting other work on the island. As a biosecurity measure, seven permanent bait stations have been set up on the island; these are also monitored for activity (and replenished if necessary) every three months.

Broughton Island group

Beginning in 2009, the rabbit population on Broughton Island was reduced using rabbit haemorrhagic disease. The virus, sprayed onto diced carrots, was distributed around the island on 15 April 2009; almost four months before baiting took place. This was done to minimise the likelihood of secondary poisoning of raptors (by reducing the number of poisoned dead or dying rabbits), and to increase the amount of bait available for consumption by rats, as well as the remaining rabbits.

In August 2009, all islands within the Broughton group were aerially baited twice with 10 mm Pestoff Rodent Bait 20R. Although rats and rabbits were not known to occur on North Rock or Inner Rock, as a precaution these vegetated islets were also baited. Each application was sown at the rate of 12 kg per ha. The second application took place 14 days after the first. Bait was delivered aerially using the same equipment and techniques used on Montague Island, except that swathe overlap was reduced to 50% (i.e. 80 m swathe and 40 m flight lines). A 30 m exclusion zone around the building precinct was baited by hand. Bait stations containing five pellets of Pestoff 10 mm bait were placed under and within all buildings, including in all accessible roof and under-floor cavities. These were replenished after 14 days and removed after 100 days.

Although brodifacoum is insoluble in water and is not known to affect frogs, as a precaution all pools known to contain green and golden bell frogs were monitored continuously throughout each bait drop, and any baits that fell into these pools were removed immediately.

During two days in November 2009, three trained detector (sniffer) dogs were used to search for surviving rabbits. An island-wide survey to search for fresh rabbit dung, grazing and diggings was also undertaken at this time. In November 2009, 30 tracking tunnels were randomly distributed across the island and six wax tags (Pest Control Research, Christchurch) were deployed around the buildings. These devices will be left in place and inspected quarterly until August 2011, when another island-wide survey will be conducted. Eight permanent bait stations have been set up around the huts and these will be monitored for activity (and replenished if necessary) every 3 months. If there is no evidence to the contrary, the operation will be declared a success in August 2011.

RESULTS

Brush Island

A total of 123 kg of bait was placed into the bait stations, of which 84 kg was consumed by rats. Rats began taking bait immediately, and more than 98% of total bait consumption occurred within the first 7 days. The remaining 2% was taken between Day 8 and Day 10. Although baits were checked periodically over the following three months, there was no further evidence of bait take and no sign of rats being present. The first dead rats appeared four days after baiting commenced and no fresh carcasses were found after Day 10. Judging from the bait take and carcasses found, the majority of rats died within the first week.

The eradication on Brush Island was declared a success in 2007 after monitoring failed to detect any rats. No pellets showed any sign of being gnawed and none were removed from any of the 50 feed stations during the monitoring period.

Anecdotal observations during subsequent visits have revealed an apparent increase in the numbers of southern water skink (*Eulamprus heatwolei*) and two species of amphibians: striped marsh frog (*Limnodynastes peronii*) and the eastern common froglet (*Crinia signifera*). Purple rock crabs (*Leptograpsus variegatus*) are also noticeably more common and the average body size appears to have increased. Two years after the eradication operation the white-faced storm-petrel was recorded burrowing on the island for the first time. These diminutive birds (~60 g) are highly vulnerable to rats and are likely to have bred on the island before rats arrived. The island's flora also appears to be recovering with, for example, banksia seedlings now much more prevalent.

Montague Island

Monitoring of the tracking tunnels during the 24 months after baiting failed to detect any mice, and none have been seen in any of the buildings. During the same period, surveys have failed to find any evidence of rabbits on the island. Several reports were received of a small black mammal being seen on the island, but tracking tunnels, cameras and traps failed to find any corroborative evidence. We now believe that these sightings were of buff-banded rail chicks. Montague Island was declared free of mice and rabbits in July 2009. The successful eradication of mice from both sections of Montague Island demonstrated that bait size was not crucial in this instance.

Broughton Island group

Three months after the baiting operation, trained detector dogs did not find any sign of surviving rats or rabbits. The concurrent island-wide survey also found no evidence of either species. To date (December 2010), the tracking tunnels, wax tags and permanent bait stations have not detected any evidence of rabbits or rats, and none have been sighted around the buildings.

In December 2009, a single Gould's petrel was found incubating an egg on Broughton Island. This is the first record of this species breeding on this island. Previous searches of the one small area of suitable breeding habitat (rock scree) had found birds ashore, but there had been no evidence of breeding. Presumably, rats had destroyed any eggs, and the removal of this predator may facilitate the establishment of a population of Gould's petrel on the island.

Non-target impacts

Apart from an independent study of the green and golden bell frog, no monitoring of potential non-target species was undertaken, so results are mostly limited to anecdotal observations. An osprey (*Pandion haliaetus*) – a rare and threatened species in NSW – was killed in a collision with the helicopter distributing bait on Broughton Island. However, there was no significant difference in the number of raptors (individuals and species) present on Broughton after baiting compared to immediately before. Similarly, there has been no change in the number of green and golden bell frogs. On Montague Island, the only other island where some monitoring of avifauna has been conducted (Fullagar *et al*. 2009 and references therein), there has been no noticeable decline in the numbers or variety of raptors, despite the removal of all mammalian prey. Buff-banded rails were present on Montague Island in March 2007, not seen the following year, but were again present in 2009. It is possible that the baiting may have killed the few birds present and the species subsequently re-established. However, no dead birds were found, and annual surveys conducted during the seven years prior to baiting had failed to detect buff-banded rails on three occasions (43%).

DISCUSSION

At the time of writing (December 2010), all five eradications appear to have been successful, with no sign of exotic mammals on any of the islands treated. However, as detection of any small relic population is exceedingly difficult, the Broughton operation cannot be declared a success until August 2011, when final checks will be completed. By this time, two years after baiting, the target species would have increased in distribution and abundance such that it would be readily detectable. Meanwhile, the fact that trained dogs did not detect rabbits and the absence of teeth marks on wax tags are encouraging signs that this group of islands may now be free of exotic mammals.

Rabbits have been successfully eradicated from at least two, and most likely three, NSW islands – Cabbage Tree, Montague and Broughton – using brodifacoum baits as the primary mortality agent after populations had been reduced through disease. This combination of techniques has been an efficacious and cost-effective method of removing rabbits from NSW islands. In operations conducted elsewhere, however, poisoning has not been effective in eradicating rabbits, with some having survived the baiting operation for reasons that are not fully understood (Merton 1987; Jansen 1993; Torr 2002).

Conservation benefits

The biodiversity outcomes of removing exotic mammals from NSW islands have not been quantified; to date most information is largely anecdotal. Recent observations on Brush Island have revealed apparently increased numbers of lizards, crabs and frogs, as well as the presence of a seabird not previously recorded there, suggesting that rats were suppressing the numbers of these species. Vegetation on Brush Island also appears to be responding to the removal of rats, with unusually prolific seed and fruit production on many plants as well as a flush of young seedlings. Vegetation communities may eventually benefit from increased quantities of nutrients brought ashore by increased numbers of breeding seabirds following their release from rat predation (Fukami *et al.* 2006).

In 2001, large tracts (37%; Weerheim *et al.* 2003) of Montague Island were covered by a dense mat (~1 m thick) of introduced kikuyu grass, but a long-term programme to eradicate this invasive species has reduced its extent considerably. Areas from which kikuyu has been removed have been replanted with native seedlings. This initiative has seen large areas of the island transformed from a monoculture of kikuyu to more biodiverse native vegetation communities. While present, mice and rabbits were slowing the re-establishment of native vegetation by grazing seedlings and consuming seeds. With these pests gone, the process of natural regeneration is expected to accelerate.

The white-faced storm-petrel breeds on several rodent-free islands along the NSW coast; thousands once bred on Broughton Island (Hull 1911) but disappeared after rats arrived (Hindwood and D'Ombrain 1960). Storm-petrels are among the smallest petrels and are particularly prone to predation by rodents (Towns *et al.* 2006). Now that rats have been removed, these birds have already colonised (or recolonised) Brush Island and it is likely that they will also return to breed on Broughton and Montague islands.

The lack of mice infesting houses, contaminating foodstuffs and destroying equipment on Montague Island has provided significant social benefits as well as enhancing the protection and preservation of historically significant buildings. Similarly, the removal of rats on Broughton Island has ended a long battle by fishers to exclude rats from buildings and food stores.

Operational challenges

Planning the eradications described herein relied heavily on published information and the collective experience of practitioners worldwide, as well as advice from suppliers of equipment and materials. Knowledge sharing and the availability of information have been pivotal to the success of operations undertaken in NSW. The most appropriate poison to use, the type of bait, and the techniques of distributing bait were all well documented and readily transferrable. Certain other aspects of the operation, however, were less prescriptive and required adaptation to suit the specific biology of each island. These included the optimal sowing rate (particularly for operations targeting more than one species) and the efficacy of bait of different sizes (especially for eradicating mice). Other aspects that we also needed to address were: i) the possible destruction of baits by heavy rain soon after baiting; ii) the consequent need to undertake an additional bait drop to replace these rain-damaged baits; iii) the requirement to have in reserve additional bait to undertake such a contingency drop; and iv) the disposal of surplus bait.

Sowing rate in aerial operations is one of the most crucial aspects of the eradication programme. If too little bait is used then all individuals of the target species may not encounter the rodenticide or consume a lethal quantity, thus causing the eradication to fail. Too much bait increases costs and unnecessarily puts additional poison into the environment. Where practicable, trials with non-toxic bait, impregnated with a bio-marker, during the planning phase of the operation can provide useful information about the quantity of bait required. For a baiting operation to be effective, bait should be available to the target animal for at least 3–4 days. The rate at which baits are removed is dependent on the type and density of potential consumers present.

For the eradication on Montague Island, we opted to use sowing rates of 12 and 6 kg per ha for the first and second drop respectively. These were higher than have been used successfully elsewhere (Broome 2009) but were deliberately set high because of the presence of rabbits, a relatively large mammal capable of consuming large quantities of bait, thereby denying mice access to it. Reduction in the density of rabbits, possibly through disease in the months before baiting, reduced the potential competition for bait.

For the Broughton group, we again opted to use a sowing rate of 12 kg per ha for the first drop and 6 kg per ha for the second. This time, however, we also purchased an additional 6 kg per ha as a reserve to re-sow any areas not covered adequately due to equipment malfunction or error in application. Rather than remove and dispose of any unused portion of this reserve, we elected to distribute it on the island as part of the second drop. The total sowing rate was therefore 24 kg/ha (12 kg per ha for each of the two drops). To have the flexibility to drop additional bait in this way it is important, through careful planning and forethought, to ensure that all permits and approvals include such provision.

To avoid the issue of heavy rain soon after baiting and the consequent need to undertake any additional bait drop, baiting was conducted only when a week of fine weather was predicted. This restriction was not a problem for NSW where the weather is generally fair and reasonably predictable, but may be more difficult elsewhere.

Operations to eradicate mice have experienced higher rates of failure than rat eradications, potentially linked to inadequate bait coverage and encounter rates (MacKay *et al.* 2007; Howald *et al.* 2007). However, this theory has not been adequately investigated. Mice typically have smaller home ranges than rats, and therefore have a lower probability of being exposed to bait. To overcome these challenges during a bait-station operation, smaller spacing between stations can be used. For aerial operations, bait coverage can be enhanced by either increasing the quantity of bait distributed (kg/ha) or by reducing the size of the bait pellet. For any specific sowing rate, the smaller the pellet the greater the number of individual pellets broadcast. On Montague Island both 10 mm baits (~2 g pellets) and 5.5 mm baits (~0.6 g pellets) were used, and both successfully eradicated mice.

There were some disadvantages associated with using 5.5 mm bait for the aerial operation. Whereas the 10 mm bait was easily visible from within the helicopter, the 5.5 mm bait was much more difficult to see when broadcast, especially on poorly contrasting substrates. Verification that bait was being broadcast required an observer in the helicopter. Another problem with the smaller bait was that it billowed from the top of the spreader bucket. We remedied this problem by fitting a transparent cover over the top of the bucket; this prevented billowing but still allowed the pilot and observer to see the quantity of bait remaining in the bucket.

Capacity building

To build local eradication capacity we opted not to engage an interstate or overseas helicopter company or pilot with previous experience in eradication operations involving aerial application of bait. Instead, aerial baiting was undertaken using helicopters and pilots from the NSW National Parks and Wildlife Service. Although these pilots and the assisting ground crew were highly skilled in all kinds of helicopter work, including pest control and agricultural spraying, they had no previous experience in eradication. Eradication operations are very different from control operations and thus require a different mindset (Cromarty *et al.* 2002), with all individuals of the targeted species needing to be exposed to bait. Instilling and maintaining this mindset in all participants throughout all aspects of the operation proved to be a considerable, but surmountable, challenge.

As far as is known, and assuming the Broughton operation is successful, South Solitary Island (10 ha) and Lord Howe Island (1455 ha) are now the only NSW islands with exotic mammals (house mice and ship rats) still present. Eradication planning is currently underway for both these islands. Ship rats do occur on Muttonbird Island, Coffs Harbour, but this is not a true island as it is now connected to the mainland by a man-made breakwater. Lord Howe Island is an oceanic island situated 580 km east of the Australian mainland and 1570 km northwest of New Zealand. It is a World Heritage Area containing a large number of endemic plants and animals threatened by the presence of exotic rodents (DECC 2007). Aside from a number of non-target issues, any eradication operation on this island is complicated by the presence of a human population of ~350 permanent residents in 150 households, as well as livestock, pets, and a well-developed tourist industry.

A draft plan for eradication of exotic rodents on Lord Howe Island has been prepared (LHIB 2009), peer reviewed and released for public comment (*http://www.environment.nsw.gov.au/resources/pestsweeds/draftLHIrodentplan.pdf*). This operation, the first on an island with a large permanent population, is complex and will require continuing input from a broad spectrum of experienced planners and practitioners if it is to be successful. However, the experiences gained from the eradications reported in this paper have greatly enhanced our local capacity to plan and co-ordinate such an operation.

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