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Title: Guidelines for eradication of introduced mammals from breeding sites of ACAP-listed seabirds

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BACKGROUND

Most birds (111 of 127) known to have become extinct since 1500 were island endemics, with mammalian introductions implicated in many cases (Courchamp et al., 2003; Blackburn et al., 2004; Towns et al., 2006). The occurrence of introduced mammals on islands is therefore an issue of global conservation concern. It is also considered by many parties to the Agreement on the Conservation of Albatrosses and Petrels (ACAP) to represent a serious threat to the listed albatrosses Diomedidae and petrels *Procellaria* and *Macronectes* spp.

Of the various introduced vertebrates, by far the most widespread are Norway (brown) rat *Rattus norvegicus*, black (ship or roof) rat *R. rattus* and Polynesian rat or kiore *R. exulans*. In a recent review, Jones et al. (2008) concluded that the impact of rats was least on large, surface-nesting seabirds such as albatrosses, frigatebirds and larids, and greatest on small, burrow-nesters such as storm petrels; several studies indicated an impact of rats on breeding success of *Procellaria* petrels; and, kiore were known to have killed adult Laysan albatrosses *Phoebastria immutabilis*. Moreover, recent work at Gough Island (Tristan da Cunha) indicates that predation by introduced house mice *Mus musculus*, which were formerly not considered to pose a threat to large seabirds, reduces the breeding success of Tristan albatross *Diomedea dabbenena* to the extent that the population is unlikely to recover even if fisheries impacts on adult and juvenile survival were eliminated (Cuthbert et al., 2004; Wanless et al., 2007). Other introduced mammals considered to pose threats to ACAP species either directly through predation or indirectly through habitat degradation and destruction include pigs *Sus scrofa*, goats *Capra hircus*, cats *Felis catus*, rabbits *Oryctolagus cuniculus* and mustelids (Croxall et al., 1984; Croxall, 1991).

Given the threats posed by introduced mammals, some means of eliminating or ameliorating their impact is clearly desirable. As it happens, the islands on which ACAP species breed are usually sufficiently isolated that eradication is a practical option, given the very high chance that future re-introductions can be minimised. However, that isolation also increases the logistical challenges and therefore the cost, making it a greater challenge to secure sufficient funding compared with a similar island closer to a mainland. Accepting continuing decline of species of

conservation concern, or the (usually costly) control of the introduced mammals in perpetuity, are clearly much less satisfactory options. Moreover, pest eradication from islands will usually benefit other components of the ecosystem, including burrowing petrels not listed under ACAP, terrestrial birds, invertebrate and plant communities. On inhabited islands, agricultural productivity may be enhanced significantly.

Fortunately, the capacity to remove introduced vertebrates has increased enormously in recent decades, to a large degree because of the development of more effective poisons and bait delivery systems. Table 1 lists the largest islands cleared of various introduced mammals to date. An even more ambitious eradication campaign currently being planned is for rabbits, rats and mice on Macquarie Island (12,870 ha). The total cost is estimated at c. \$AUS 25 million over seven years, and will involve the aerial broadcast of Brodifacoum, scheduled for the winter of 2010 (see eradication plan in Online Resources below).

Table 1. The largest islands cleared to date of various introduced mammals (Nogales et al., 2004; Lorgelec and Pascal, 2005; Donlan and Wilcox, in press).

Introduced species	Largest island cleared
Norway rat <i>Rattus norvegicus</i>	11,300 ha (Campbell, New Zealand)
Black rat <i>Rattus rattus</i>	1,022 ha (Hermite, Australia)
Kiore <i>Rattus exulans</i>	3,083 ha (Little Barrier, New Zealand)
Rabbit <i>Oryctolagus cuniculus</i>	800 ha (St Paul Island, France)
House mouse <i>Mus musculus</i>	710 ha (Enderby, Auckland Islands, New Zealand)
Goat <i>Capra hircus</i>	458,812 ha (Isabela, Ecuador)
Pig <i>Sus scrofa</i>	58,465 ha (Santiago, Ecuador)
Cat <i>Felis catus</i>	29,800 ha (Marion, South Africa)

By 2007, rodents had been eradicated from at least 284 islands world-wide, most of which were relatively small (<100 ha) (Howald et al., 2007). The target species were mainly black rat (159 islands) and Norway rat (104 islands), and, to a lesser extent, kiore (55 islands) and house mouse (30 islands). Mice have proven the hardest to eradicate: 19% failure rate compared with 5-10% failure rates for attempted eradications of the three rat species, probably because mice have a smaller home range or different foraging behaviour, and bait densities may have been inadequate. Wild rats kill mice, and mice are actively deterred by rat odour (Karli, 1956). Rats therefore can, and do, suppress mice populations; a number of successful rat eradications have led to subsequent explosions in mice numbers from previously low or undetectable levels.

There are introduced mammals present on many islands on which ACAP species currently breed, and therefore many potential candidates for eradication programmes. In addition, there is clearly value in removing introduced vertebrates from islands that were formerly occupied, or could be colonised, by ACAP species. The purpose of this paper is to provide guidelines to assist with the development of plans for the eradication of introduced vertebrates from breeding sites of ACAP species, a selected bibliography and a list of online resources. These relate mainly to islands, but many of the same principles will apply to mainland sites. This should not be considered a substitute for obtaining appropriate and detailed advice from eradication experts.

GUIDELINES

- Despite recent high-profile successes, the effort and commitment required to eradicate introduced mammals, particularly from large islands, should not be underestimated.
- Good planning and management, clear lines of responsibility and authority, and public support will greatly improve the chances of success (Courchamp et al., 2003). The last of these is likely to be particularly important for breeding sites of ACAP species on mainlands or inhabited islands. In these cases, the local population needs to understand fully the necessary changes to lifestyles during the eradication, and the risks (which are generally minor as the poisons are not water soluble and show no long-term persistence in the environment). Insufficient public support may partly explain past failures, such as the attempted rat eradication on Pitcairn Island. There may also be health and safety concerns about spreading of poison baits and risks to people and livestock: this underlies the recent decision by the inhabitants of Tristan that they do not wish rodents to be eradicated by aerial baiting. Public resistance may be overcome by providing clear evidence of the impacts of introduced species on native biota (Towns et al., 2006), on public health, and on the economy (e.g. agriculture or tourism). Sufficient financial resources must be available or commitment made to complete any programme before commencing the project.
- Sufficient resources should be allocated to determine baseline (pre-eradication) levels and monitor the response (post eradication) of species that will benefit from the programme. Thorough documentation of the eradication process and outcomes is critical for determining issues leading to success and failure, and for building support for eradications elsewhere.
- For a successful eradication it is imperative that: all target individuals can be put at risk; target species cannot breed at a faster rate than they are killed; and, risk of reinvasion can be managed to at or near zero.
- Consider the probability of recolonisation – localised control may be more appropriate if reintroduction is likely.
- Assessment of biosecurity should be undertaken prior to an eradication program so that timely improvements can be implemented as required.

- Consider economies of scale, as concurrent eradications on adjacent islands may be a viable option. In a review of 41 eradication programmes for introduced mammals, Martins et al. (2006) concluded that rodent eradications cost 1.7-3.0 times those of ungulates, and that cost increased with remoteness (distance to nearest airport) (but for a critique see Donlan and Wilcox, 2007). Total cost increases but cost per hectare decreases with island size (Townes and Broome, 2003; Martins et al., 2006). Eradications are generally harder with increasing ruggedness of terrain and vegetation cover. Ungulates, cats and rats are easier to eradicate than mice and birds.
- The main methods used for eradication of rodents are poisoning, of rabbits are poisoning, shooting and detection by dogs, of ungulates are shooting, and of cats are trapping, shooting, poisoning and detection by dogs. A multi year follow up phase is critical after poisoning, particularly as it is unlikely that aerial broadcast of baits will kill all target individuals for rabbits and cats. The advantages and disadvantages of these and other methods are reviewed in Courchamp et al. (2003). Except for rats and mice, the best strategy will usually involve a combination of techniques.
- Information on the ecology of the target species (diet, movements, home range size etc.) can be useful in the planning process. However, the key information - the proportion that is likely to be eliminated initially, the mechanism for detecting survivors at very low density, and the means of ensuring that these last animals are exterminated - can often be predicted from other studies. Data on toxic bait palatability and preference are very important for poisoning campaigns.
- Consider potential mesopredator release effects (e.g. Caut et al., 2007), particularly of rabbits and rodents when cats are removed, or of mice when rats are removed. This is potentially a major problem for non-ACAP species. Ideally, all introduced vertebrates should be eliminated at once where techniques are available to do so.
- Identify, document and manage the risks for non-target species, particularly primary and secondary poisoning of such scavengers as skuas *Catharacta* spp., giant petrels and endemic marine and terrestrial birds (e.g. larids, rails, sheathbills, parakeets and passerines), some of which may be IUCN-listed, and potential predation of vulnerable native fauna by detection or hunting dogs during the eradication programme. Vulnerable non-targets may need to be translocated, taken into temporary captivity and (or) later re-introduced from a reservoir population. Active mitigation may be possible, for example removing baits in the vicinity of nests, or administration of drugs to reverse the effects of brodifacoum ingestion. The level of non-target mortality should be thoroughly documented.
- Many eradications take place during the winter when populations of introduced mammals are likely to be reduced because of low resource availability, and non-target species such as skuas and giant petrels will be absent or in low numbers. Disturbance of breeding birds (e.g. by helicopter overflights) can also be minimised, although some penguins

(gentoo *Pygoscelis papua* and a proportion of king penguins *Aptenodytes patagonicus*) may still be present in large numbers on land. Overflight trials conducted prior to the eradication programme may help refine the bait broadcasting strategy (e.g. recommended height) in ways that could help minimise disturbance.

- Preceding an eradication programme with a control phase may be counter-productive, as it could affect the characteristics of the remaining animals (e.g. by inducing bait aversion) and increase the required duration, cost, and chances of failure. A clear exception to this was the introduction of the feline panleucopenia virus onto Marion Island which greatly reduced the cat population and ensured the feasibility of the subsequent hunting campaign (van Rensburg et al., 1987)
- Contingency should be built in to cope with inclement weather, equipment failure, ruggedness of the terrain, and planning delays.
- Determine the most effective poison and bait-delivery system for one or multiple targets. This can be a combination of approaches including bait stations, hand and aerial broadcast. Use of bait stations has several advantages as it minimises exposure to non-targets, prevents general release of toxins into the environment, allows monitoring of bait uptake, and can be incorporated into a detection system using non-toxic baits or tracking boards. However, bait stations require continued effort for long periods (1-2 years), and are unlikely to be practical for large or remote islands. The largest island to date on which the successful eradication of rats was achieved by ground-based baiting was 3,100 ha (Langara Island, Canada: Taylor et al., 2000). Some target species may also be reluctant to feed on bait from ground stations.
- Bait drops and lines should be precisely controlled (e.g. using differential GPS) to ensure comprehensive and accurate bait coverage, density and accessibility for all targets. Eradication programmes for rodents on large islands and/or those with steep cliffs typically require aerial spreading of bait, with two applications (10-14 days apart). Baiting regimes should consider caching behaviour of some rodents that would reduce availability for other target species (e.g. mice).
- The ideal bait is palatable, highly effective after a single dose, affects multiple targets, binds to soils preventing leaching, and persists in the environment for long enough to expose all target individuals but not so long as to represent a long-term risk to non-target species. Second generation anticoagulants (such as Brodifacoum) have been used in almost all rodent eradications, but alternatives have been used on smaller islands and may be applicable to larger islands in the future (Donlan et al., 2003). The main poison used in cat eradications is 1080 (sodium monofluoroacetate) although new toxins are currently being developed. (Nogales et al., 2004). Bait that contains seeds needs to be treated to prevent germination.
- Strict quarantine measures should be taken to prevent reintroductions, particularly of rodents. Following ungulate eradications, some means must

be established to prevent release of domestic animals that could form a feral herd. This could include minimum fencing standards, sunset clause (i.e. a date by which all remaining animals should be removed), sterilisation, stock registration etc.

USEFUL FURTHER READING (available from the ACAP Secretariat)

Courchamp *et al.* (2003) provide an excellent review of the impacts of introduced mammals on islands and of the different approaches to control and eradication.

Nogales *et al.* (2004), Campbell & Donlan (2005) and Howald *et al.* (2007) review past eradication programmes for, respectively, feral goats, rodents and cats.

Towns *et al.* (2003) provide an interesting history of eradication programs on New Zealand islands, including of factors contributing to success.

Martins *et al.* (2006) review the costs of previous eradications, highlighting that these have gradually declined as technology has developed. However, note that many factors such as island size, remoteness, target species, mitigation for non-target species, approach (e.g. aerial or ground baiting, shooting, trapping etc.), local capacity and bureaucracy, and environmental compliance will all influence the economics of any campaign (Donlan and Wilcox, 2007).

Brooke *et al.* (2007) include various algorithms that might be used to prioritise islands for eradication programmes. Note that priorities for ACAP species may well be different.

ONLINE RESOURCES

<http://www.issg.org/index.html#ISSG> - Homepage of the IUCN Invasive Species Specialist Group (ISSG). The ISSG aims to reduce threats to natural ecosystems and native species by increasing awareness of invasive aliens, and of ways to prevent, control or eradicate them. There is plenty of useful information on the site, including: links to a searchable database providing information on biology, distribution and management of introduced species; the bi-annual newsletter (*Aliens*), and; the Proceedings of the International Conference on Eradication of Island Invasives, held at Auckland University in February 2001 (C. R. Veitch and M. N. Clout "Turning the Tide: The Eradication of Invasive Species").

<http://www.ntsseabirds.org.uk/File/Conference%20proceedings.pdf> - The proceedings (including abstracts) of the Invasive Alien Mammals conference held in Edinburgh in 18-19 September, 2007, which included talks on many successful eradications on islands and subsequent improvement in seabird numbers and breeding success.

<http://www.feral.org.au/> - Website and database containing information on vertebrate pest species in Australia and New Zealand

<http://www.invasiveanimals.com/> - Website of the Invasive Animals Cooperative Research Centre which aims to counteract the impact of introduced animals through the development and application of new technologies and by integrating approaches across agencies.

<http://www.invasivespeciesinfo.gov/international/main.shtml> - US Department of Agriculture National Invasive Species Information Centre.

<http://www.rspb.org.uk/ourwork/conservation/projects/tristandacunha/publications.asp> - Various reports on the impacts of introduced rodents, and the potential for their eradication from the islands of Tristan da Cunha and Gough.

http://www.falklandsconservation.com/wildlife/conservation_issues/rat_eradication-guidelines.html#An15 - Guidelines for the eradication of rats from islands within the Falklands (Malvinas) group, including a list of contacts.

http://www.parks.tas.gov.au/publications/tech/mi_pest_eradication/summary.html - The Plan for the Eradication of Rabbits and Rodents on Subantarctic Macquarie Island 2007.

http://www.acap.aq/en/index.php?option=com_docman&task=cat_view&gid=39&Itemid=33 - Includes Inf 3. which is an annotated bibliography of published material outlining eradication programmes for introduced mammals in New Zealand.

<http://www.doc.govt.nz/templates/summary.aspx?id=33329> - New Zealand Department of Conservation site with information on animal pests and their control.

<http://www.doc.govt.nz/upload/documents/science-and-technical/sfc282.pdf>
<http://www.doc.govt.nz/upload/documents/science-and-technical/sfc263.pdf>
<http://www.doc.govt.nz/upload/documents/science-and-technical/sfc040.pdf>
<http://www.doc.govt.nz/upload/documents/science-and-technical/DSIS59.pdf>
- NZ Department of Conservation reviews on factors influencing palatability and efficacy of toxic baits in rodents (2008), current knowledge of rodent behaviour in relation to control devices (2006), and baits and bait strategies targeting feral cats and multiple species (1996), and developing tools to detect and respond to new rodent invasions (2002).

<http://www.gisp.org> - Useful source of toolkits, training materials and publications from the Global Invasive Species Programme, which was set up by four founding partners to provide support to the implementation of the article relating to invasive species in the Convention on Biological Diversity.

<http://www.islandconservation.org/organization.html> - US-based organisation with experience of eradications in the US and Caribbean.

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