The Global Islands Invasive Vertebrate Eradication Database: A tool to improve and facilitate restoration of island ecosystems

B. Keitt[1], K. Campbell[1], A. Saunders[2], M. Clout[3], Y. Wang[1], R. Heinz[4], K. Newton[4], and B. Tershy[4]

[1]Island Conservation, Center for Ocean Health, University of California, Santa Cruz, 100 Shaffer Road, Santa Cruz, C. 95060 USA. <brad.keitt@islandconservation.org>. [2]Landcare Research, Private Bag 3127, Waikato Mail Centre, Hamilton 3240, New Zealand. [3]Invasive Species Specialist Group, University of Auckland, Tamaki Campus, Private Bag 92019, Auckland, New Zealand. [4]Ecology and Evolutionary Biology Department, Center for Ocean Health, University of California, Santa Cruz, C. 95060 USA.

Abstract Islands are important for the conservation of biodiversity because they house 20% of terrestrial plant and vertebrate species, have suffered 64% of IUCN-listed extinctions and have 45% of IUCN-listed critically endangered species. Yet islands make up only about five percent of the earth's surface. The main cause of extinction and endangerment to biodiversity on islands is the presence of invasive vertebrates. Fortunately, many future extinctions can be prevented by eradicating invasive vertebrates from islands. To assess the current state of this conservation tool, we are compiling a global database of terrestrial vertebrate eradications from islands, including successes and failures. To date, in the Global Islands Invasives Vertebrate Eradication Database we have documented approximately 950 island eradication attempts involving 28 species of invasive vertebrates in 12 families. These are preliminary data and will be updated and checked for accuracy as part of the Island Invasives: Eradication and Management conference, Auckland 2010. Most eradication attempts have been of rodents (>350) and bovid ungulates (>160). Moderate numbers of eradication attempts have been of cats (>90), suid ungulates (>55), and rabbits (>45). Most projects have been on islands smaller than 500 ha (68%) and in temperate climates (72%). Targeting eradications on larger and more tropical islands would lead to the protection of more biodiversity. To this end, our vision is to maintain an accurate, web-accessible, regularly updated database that can be used to promote and improve the protection of island ecosystems by eradicating invasive vertebrates.

Keywords: Endangered species, threatened species, endemic species, biodiversity, alien species, extinction

INTRODUCTION

Islands are the epicentre of the extinction crisis. While islands make up only five percent of the earth's surface area, they support 20% of all biodiversity, including a disproportionately high level of endemic species (Kier *et al*. 2009). This biodiversity is particularly fragile and the vast majority of extinctions have been island species. For example, about 95% of bird, 90% of reptile and 70% of mammal extinctions have been on islands. These extinctions are primarily the result of the introduction of invasive vertebrates to islands. Fortunately, techniques to remove invasive vertebrates from islands are available and the practice is becoming an accepted conservation management tool. To better understand how this tool has been used, and to improve its future use, we developed, and are populating, a database of all vertebrate eradication efforts on islands (www.islandconservation.org/db).

The eradication of invasive vertebrates from islands is among the most challenging and beneficial actions land managers can take to restore islands and protect threatened species. Collating and understanding the lessons learned in previous efforts to eradicate invasive vertebrates are critical to improving and promoting this valuable conservation tool. Published global reviews of eradication efforts include regional approaches for all taxa (Clout and Russell 2006; Genovesi and Carnevali 2011; Lorvelec and Pascal 2005) and global approaches for individual taxa such as goats (*Capra hircus*; Campbell and Donlan 2005), cats (*Felis catus*; Nogales *et al*. 2004; Campbell *et al*. 2011), rodents (Howald *et al*. 2007), and mongoose (*Herpestes* spp.; Barun *et al*. 2011). These provide valuable reviews of the eradication efforts for these species and regions. Most importantly, these reviews provide land managers

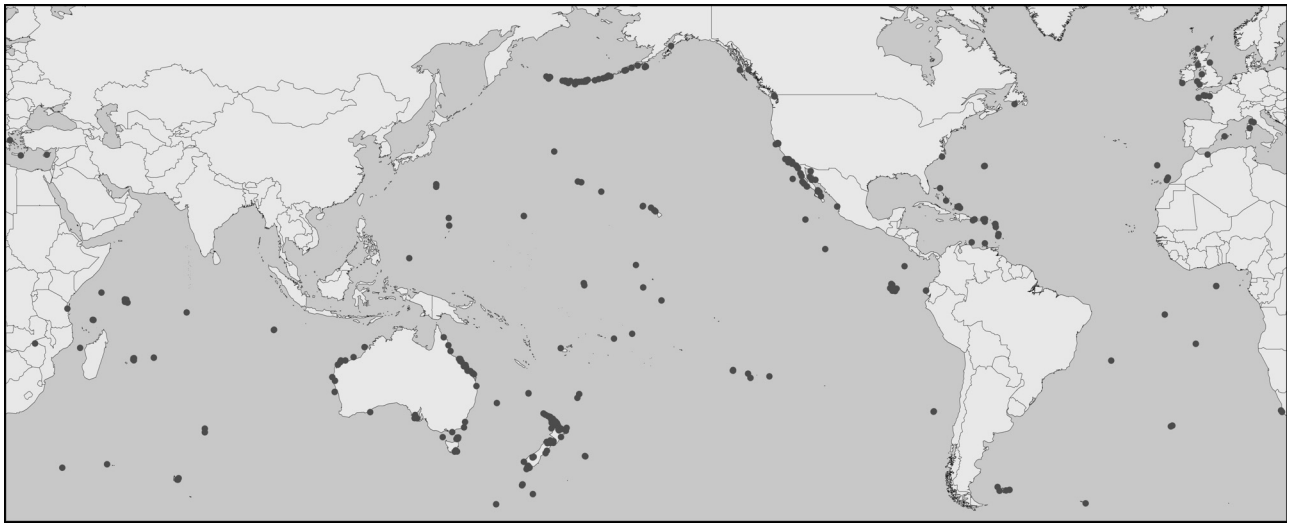

Fig. 1 Locations of all of the recorded eradications of invasive vertebrates from islands for which location data are available (n=664).

Pages 74-77 In: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). 2011. Island invasives: eradication and management. IUCN, Gland, Switzerland.

Table 1 Invasive vertebrates in the database assigned to omnivore, carnivore and herbivore categories.

Omnivore	Carnivore	Herbivore
Gallirallus australis	*Alopex lagopus*	*Bos taurus*
Macaca mulatta	*Canis familiaris*	*Capra hircus*
Mus musculus	*Felis catus*	*Castor canadensis*
Rattus rattus	*Herpestes javanicus*	*Equus caballus*
Rattus exulans	*Mustela vison*	*Lepus nigricollis*
Rattus norvegicus	*Mustela erminea*	*Myocastor coypus*
Sus scrofa	*Mustela furo*	*Oryctolagus cuniculus*
Trichosurus vulpecula	*Mustela nivalis*	*Ovis aries*
	Procyon lotor	*Petrogale penicillata*
	Suncus murinus	
	Vulpes vulpes	

with information on which combinations of island size, technique, invasive species, and non-target species are feasible, and which combinations may have a high risk of failure. However, to date, there has been no global review of all vertebrate eradications on islands.

Here we present our vision for a web accessible database, including an initial analysis that provides details on eradication attempts including data on island characteristics, methods used, and contacts. Our goal is to highlight the most successful techniques, assess trends in eradication methods, and facilitate communication between practitioners to improve success. The database allows analysis of eradication effort for individual target species, and facilitates analysis of trends across different target invasive vertebrates.

It is important to note that this is an unfinished product, and we report here on preliminary data as of 15 December 2009. The Island Invasives: Eradication and Management Conference of February 2010 was used as a forum to validate and improve the database followed by a more thorough analysis and presentation at a later date.

METHODS

Data were mined from the published, grey, and unpublished literature. The bulk of the database came from the published summary articles for rodents (Howald *et al*. 2007), goats (Campbell and Donlan 2005), and cats (Nogales *et al*. 2004; Campbell *et al*. 2011). Additional data were collected through web searches, telephone interviews, emails, and specific requests directed at practitioners.

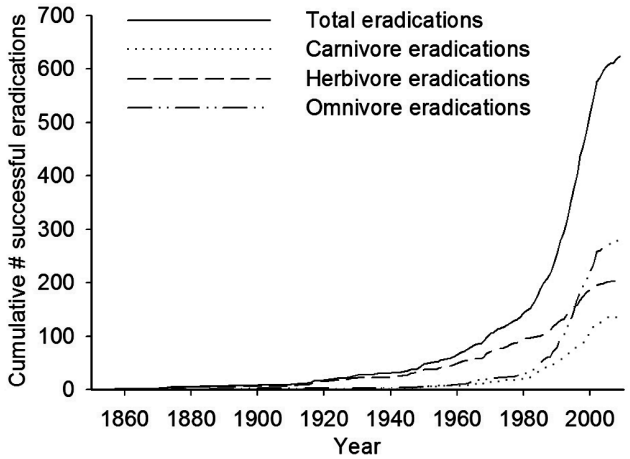

Fig. 2 Cumulative number of successful invasive vertebrate eradications on islands over time.

Table 2 Number of eradication attempts and success rate globally for select invasive vertebrates. An eradication event is defined as a successful or failed eradication attempt plus any follow up efforts on the same island.

Invasive vertebrate	Number of events	Failure rate %
Rattus	348	12.1
Goat	165	4.8
Cat	90	12.5
Pig	56	3.9
Rabbit	48	4.6
Fox	42	2.5
Mus	48	26.8
Mustelid	29	13.0*
Other	113	
Total	949	9.1

*50% of the eradication events in the database for mustelids list unknown for the eradication status so the reported failure rate is likely inaccurate for this group.

The database provides details of every documented eradication attempt, which is defined to include failures, successes, and follow up attempts on the same islands either after a failure or a reinvasion. Data categories were selected to provide information about each action, including specific details on methods, using drop down menus to facilitate analysis, and text fields to allow detail to be captured. For some analyses, all target invasive vertebrates were assigned a category of herbivore, carnivore, or omnivore (Table 1). Contact information and citations were provided where possible.

The methods used to populate the database have likely led to an underestimate of historical eradications, as those are less likely to be included in published papers or reports, and the people familiar with those projects are no longer involved in the field. The data also likely underestimate the failure rate for eradications, as failures are less likely to be reported. For these reasons, we tried to reach as many individual people as possible to encourage them to report older eradication efforts and failed eradications in the database.

Data on location (latitude and longitude), island size, country, and oceanographic region were extracted from the Global Islands Database (GID) (Depraetere 2007). For islands that were not in the GID we used the Meridian Data Global Island Database. Locations were verified using Google Earth and corrected if necessary.

RESULTS

As of 15 December 2009, we documented 949 vertebrate eradication attempts on islands globally (Fig. 1), involving 27 species of mammal and one species of bird. The three earliest documented eradication attempts were in 1673, 1686, and 1709. All three were of large ungulates and all three failed. The first documented successful eradication was of goats in 1857 on Norfolk Island, Australia.

Seven hundred and eighty six successful eradications were reported and 41 of those were later reinvaded. Fifty two eradications are listed as unknown, i.e. there was information indicating an eradication event took place but no data were available on the outcome, and eight were listed as incomplete. Ninety eradications were listed as failed

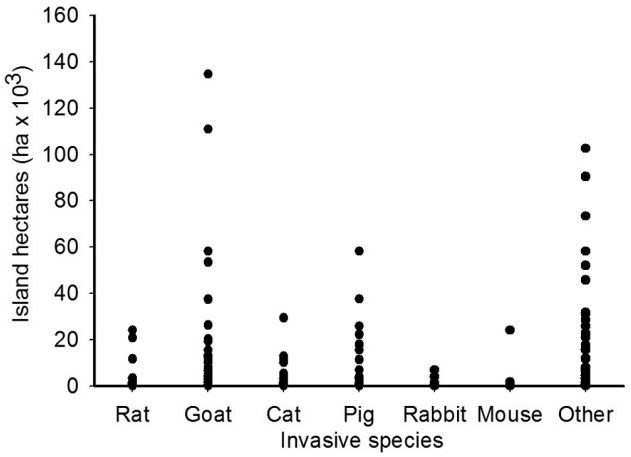

Fig. 3 Scatterplot showing area of islands where eradications have occurred for select species of invasive vertebrates.

eradication attempts. The success rate for all eradications with a known outcome was 91% (n=835, Table 2). Location data were available for 664 islands and the subsequent analyses that involve location data are restricted to these islands.

Since that first successful eradication over 150 years ago, rats (*Rattus* spp.) have become the invasive vertebrates most frequently eradicated from islands, with 348 reported eradication attempts, followed by goats with 165 eradication attempts (Table 2). The pace and scale of eradications have increased dramatically during this time (Fig. 2). After the first successful eradication in 1857 there were only 27 eradication attempts during the next 80 years (through 1940). From 1940-1980 there were 118 vertebrate eradication attempts, or about three per year. Since 1980, the rate of vertebrate eradications on islands has increased, with about 600 eradications between 1980 and 2009, or about 20 eradications per year (Fig. 2).

Along with increased frequency of eradications also came an increase in the size of islands from which invasive vertebrates were eradicated. The invasive vertebrate species that have been eradicated from the largest islands are goats, pigs and Arctic foxes (*Alopex lagopus*) (Fig. 3). Most of the largest islands had eradications implemented in the last 20 years (Fig. 4). Some of the attempts on large islands

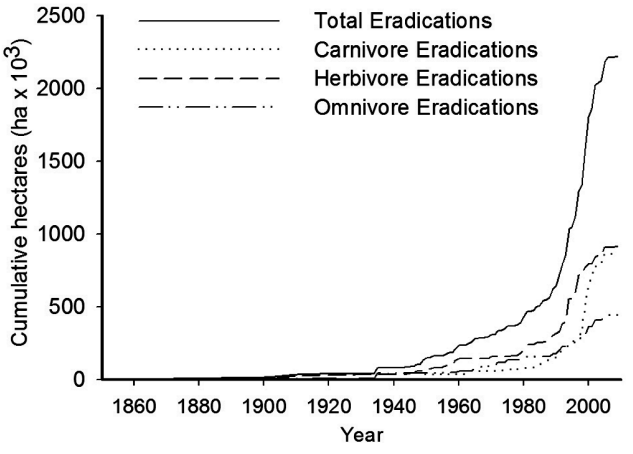

Fig. 4 Cumulative area in hectares of invasive vertebrate eradications over time for carnivore, herbivore and omnivore vertebrate eradications on islands.

are near completion (e.g., removal of goats from Isabela, 412,000 ha). Other more ambitious island projects are being planned such as the eradication of rodents, cats and brushtail possums (*Trichosurus vulpecula*) from Stewart (170,000 ha) (Beaven 2008).

Eradications have been attempted in 33 different countries, with New Zealand having 313 eradication events, followed by Australia with 154, and the United States with 139. France and Mexico have had 67 and 38 eradication events, respectively. The distribution of eradications is primarily in temperate regions. Of the 664 eradication events reported with latitudes for the islands, 436 have been attempted in temperate regions (23.5 to 60 degrees North and South latitudes) and only 180 in the tropics (between 23.5 and -23.5 degrees latitude). No eradications above 60 degrees latitude North or South were reported. Failure rate in the temperate regions was 7.6% (31 of 405) and 13.2% (21 of 159) in the tropics.

DISCUSSION

The first documented attempts to eradicate invasive vertebrates from islands were over 250 years ago, with the first successful attempt over 150 years ago in Australia. These early attempts to eradicate invasive vertebrate species began what is now a leading component of the conservation of island ecosystems and the protection of threatened species. Collecting details about current and historical vertebrate eradication attempts, including success rates, methods, costs, and island characteristics is required if this management tool is to be promoted and improved. The Global Islands Invasive Vertebrate Eradication Database project was designed to summarise information on all invasive vertebrate eradications and enable analyses that can: 1) help land managers and funders understand the applicability and limitations of eradication as a tool; 2) enable eradication practitioners to share information that facilitates iterative improvement, and 3) identify regions and target species for which eradication is under-utilised.

Preliminary analysis of the Global Islands Invasive Vertebrate Eradication Database indicates that the frequency of vertebrate eradications on islands is increasing. This demonstrates that conservationists, land managers, and funders have recognised and embraced the technique (Figs 2 and 4). Furthermore, the size of islands that have been attempted has increased. While not a perfect measure of cost, size of the island is positively linked to the cost of an eradication, thus the increase in size of islands with eradication is an indicator of the increased financial support for invasive vertebrate eradications from governments and funders.

New Zealand leads to protect island ecosystems, with 313 invasive vertebrate eradications attempted, which is more than the next three countries combined. This in part explains why a disproportionate number of eradications have been reported from temperate regions (Fig. 1). However, this concentration of eradications in temperate areas is unlikely to be the most efficient distribution of eradication effort to protect global biodiversity since most biodiversity is located in the tropics (Dirzo and Raven 2003).

Greater efficacy is also desirable in tropical latitudes. The rate of failed eradication efforts in the tropics is almost twice the rate in temperate areas. The reasons for this disparity are not known. However, the lack of seasonality in tropical environments may be a key factor. Many eradication campaigns take advantage of seasonal periods of reproduction and/or food stress for the target animal. For example, the over 40 Arctic fox eradications in the

Aleutian Islands, United States were undertaken during the winter when the target animal was primarily restricted to the coastlines (Ebbert 2000) The recommended strategy for rodent eradications is to apply bait when the target population is experiencing a food related, seasonal population decline (Howald *et al* 2007) and when reproduction is at its lowest. In tropical systems, these seasonal advantages are often more nuanced or completely absent.

It is not surprising that some invasive vertebrate species are harder to eradicate than others, based on success rates of eradication attempts (Table 2). Rodent eradications as a group experienced the highest failure rates, with 12.8%. This is likely due to the complexity of rodent eradications and the difficulty associated with putting every individual animal at risk during an eradication campaign. Surprisingly, at 12.5%, cat eradications had a similar failure rate to rodents. This is likely due to both the difficulty of detecting small numbers of cats on an island and the ability of cats to learn avoidance of available eradication techniques. The high failure rate for cats suggests a tendency among practitioners to underestimate the effort necessary to complete an eradication.

Invasive vertebrate eradication is becoming an increasingly accepted pathway to restoring native species and ecosystems, and is increasing in frequency, geographic distribution, size, and complexity. The Global Islands Invasive Vertebrate Eradications Database is designed to provide context for what types of eradications are simple or challenging and also to encourage communication between experienced practitioners and land managers that are protecting biodiversity on islands. It should not only be used by eradication practitioners, but also by island land managers, government agencies and foundations. However, its ongoing utility depends on everyone who conducts an eradication taking the time to input their own work and review other relevant entries.

REFERENCES

Barun, A.; Campbell, K.C.; Hanson, C.C. and Simberloff, D. 2011. A review of the small Indian mongoose management and eradications on islands. In: Veitch, C.R.; Clout, M.N. and Towns, D.R. (eds). *Island invasives: Eradication and management*, pp.XX IUCN, (International Union for Conservation of Nature), Gland, Switzerland.

Beaven, B. 2008. Scoping the potential to eradicate rats, wild cats and possums from Stewart Island / Rakiura. New Zealand Department of Conservation, Invercargill.

Campbell, K.J. and Donlan, C.J. 2005. Feral goat eradications on islands. *Conservation Biology 19*: 1362-1374.

Campbell, K.J.; Harper, G.; Algar, D.; Hanson, C.; Keitt, B.S. and Robinson, S. 2011. Updated review of feral cat eradications. In: Veitch, C.R.; Clout, M.N. and Towns, D.R. (eds). *Island invasives: Eradication and management*, pp. XX. IUCN, (International Union for Conservation of Nature), Gland, Switzerland.

Clout, M.N. and Russell, J.C. 2006. The eradication of mammals from New Zealand islands. In: Koike, F.; Clout, M.N.; Kawamichi, M.; De Poorter, M. and Iwatsuki, K. (eds). *Assessment and Control of Biological Invasion Risks,* pp. 127-141. IUCN, Gland, Switzerland and Cambridge, U.K., and Shoukadoh Book Sellers, Kyoto, Japan.

Depraetere, C. 2007. Global Islands Database (GID): A technical note on a global dataset of islands. In collaboration with Arthur Dahl, February 2007, Global Islands Network.

Dirzo, R. and Raven, P. 2003. Global state of biodiversity and loss. *Annual Review of Environment and Resources 28*: 137-167.

Ebbert, S. 2000. Successful eradication of introduced Arctic foxes from large Aleutian Islands. *Proceedings Vertebrate Pest Conference 19*: 127-132.

Genovesi, P. and Carnevali, L. 2011. Invasive alien species on European islands: eradications and priorities for future work. In: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). *Island invasives: Eradication and management*, pp. XX. IUCN, (International Union for Conservation of Nature), Gland, Switzerland.

Howald, G.; Donlan, C.J.; Galván, J.P.; Russell, J.C.; Parkes, J.; Samaniego, A.; Wang, Y.; Veitch, D.; Genovesi, P.; Pascal, M.; Saunders, A. and Tershy, B. 2007. Invasive rodent eradication on islands. *Conservation Biology 21*: 1258-68.

Kier, G.; Kreft, H.; Lee, T. M.; Jetz, W.; Ibisch, P.; Nowicki, C.; Mutke, J. and Barthlott, W. 2009. A global assessment of endemism and species richness across island and mainland regions. *Proceedings of the National Academy of Sciences 106*: 9322-9327.

Lorvelec, O. and Pascal, M. 2005. French attempts to eradicate non-indigenous mammals and their consequences for native biota. *Biological Invasions 7*: 135-140.

Nogales, M.; Martin, A.; Tershy, B.R.; Donlan, C.J.; Veitch, D.; Puerta, N.; Wood, B. and Alonso, J. 2004. A review of feral cat eradication on islands. *Conservation Biology 18*: 310-319.