KEYNOTE ADDRESS

Reflections on 25 Years of Global Conservation on Islands as We Enter into the U.N. Decade of Restoration

Gregg R. Howald
Island Conservation, Santa Cruz, California

ABSTRACT: Since the year 1500, islands have been home to over 75% of known bird, mammal, amphibian, and reptile extinctions. The majority of these have been caused by introduced species, particularly vertebrates such as rats, mice, cats, and ungulates. Arguably, the most damaging vertebrate taxon on island ecosystems is the rodents. Mice and rats have been implicated in around half of all bird and reptile extinctions. Rodents have been introduced now to over 80% of the world's islands. Over the last 70+ years, conservationists around the world have been working to recover species and island ecosystems from the impacts of invasive species, particularly rodents, developing systematic approaches and techniques that are guided by principles of island invasive species eradication. The eradication of rodents from islands is not only possible, but has been completed on over 600 islands, from small offshore rocks to 400,000-ha South Georgia Island, with hundreds of native species protected from the threat of extinction. Rodent eradication is becoming a mainstream tool used by managers worldwide. However, there are limits to current technologies and approaches, and, globally, we can only reach a relatively small number of islands and threatened island species. To protect and recover threatened species, conservationists must increase the scale, scope, and pace of eradication of invasive species from islands, and focus on innovation of new tools, techniques, and strategies to be allow restoration on larger and more complex islands. One of the biggest challenges to success is ensuring that the public is supportive and allows pest management tools to be used for conservation purposes. New technologies are on the horizon to improve invasive species eradications, including genetic tools and species-specific toxicants.

KEY WORDS: ecosystem restoration, extinction, invasive species, island conservation, management, mice, *Mus*, rats, *Rattus*, rodent eradication, tools, vertebrate pests

Proceedings, 29th Vertebrate Pest Conference (D. M. Woods, Ed.)
Paper No. 20. Published August 28, 2020. 6 pp.

INTRODUCTION

Representing just 5% of the earth's surface, islands support a disproportionate amount of the earth's biodiversity (about 20%), including 41% of all IUCN endangered and critically endangered species. Of all recorded extinctions linked to invasive species, 86% have occurred on islands. The majority of island extinctions have been caused by introduced (i.e., non-native invasive) species, particularly vertebrates such as rats, mice, cats, and ungulates. Introduced invasive species, particularly vertebrates, have been implicated in an estimated 60% of species extinctions worldwide (Bellard et al. 2016) and are predominantly the acute drivers of extinctions on islands (Tershy et al. 2015).

Invasive mammals, particularly cats (*Felis catus*) and commensal rats (*Rattus* spp.) are the most damaging for island species (Holmes et al. 2019). They are implicated in the vast majority of invasive species-caused extinctions. With a global introduction of >80% onto the worlds' islands and island archipelagos (Atkinson 1985), the commensal rodents (*Mus* spp. and *Rattus* spp.) are increasingly a focus of global conservation efforts to protect threatened species. Islands are whole functioning ecosystems and, with the removal of invasive mammals, threatened ecosystems and species can and do recover.

The eradication of invasive mammals from islands is a powerful and proven conservation tool with documented and unequivocal conservation gains (Jones et al. 2016). Approximately 1,200 invasive mammal eradication attempts from islands have been reported worldwide (DIISE 2020), at an overall 85% reported success rate. The commensal rats and/or house mice are the most frequently targeted invasive mammals and have been successfully removed from small offshore rocks to relatively large islands such as Macquarie Island (~15,000 ha) and South Georgia Island (~400,000 ha), from islands of the high latitudes to the deep tropics (DIISE 2020).

Invasive rodents are now being routinely removed from small, uninhabited islands with a high probability of success using the application of the accepted principles of eradication (Cromarty et al. 2002). All reported successful rodent eradications on islands >5 ha utilize bait containing a rodenticide, typically the second-generation anticoagulants, placed into every potential territory on the island. Bait is either placed in bait stations laid out in a grid pattern, broadcast by hand, or in the case of large islands or islands with steep topography, a fertilizer bucket slung from a helicopter guided by onboard computer and GPS (Howald et al. 2007, Keitt et al. 2011). Recently, drones have a demonstrated utility in application of bait on small islands (C. Hanson, pers. comm.). The potential improvements in payload capacity and power options may allow drones to have a role on larger and remote islands, with enhanced efficiency and safety relative to helicopters and will likely decrease project costs.

The ecological risks from the use of the second-generation anticoagulant rodenticides are well documented (citations in van den Brink et al. 2018) and eradication of rodents from islands is not taken lightly. Close evaluation of the risks and benefits, and necessary compliance with local, regional, and national laws, are all taken into account during the design phase of the project. Consequently, eradication projects take months to many years to understand the potential ecological risks and consequences of removing rodents and can require mitigation measures (e.g., captive hold and release) to ensure protection and persistence of insular at-risk species. Many projects, particularly in the United States, require extensive permitting from multiple regulatory agencies, and engagement with the public in compliance with the National Environmental Policy Act (NEPA) or equivalent (Feldman and Howald 2014). Ultimately, the benefits of the eradication of rodents must outweigh the costs. Consequently, project development, including the science and administrative time and cumulative financial costs, can be greater than the implementation time and investment. It is not uncommon for projects to develop over 5 to10 years from conception, with implementation measured in a matter of weeks or months depending on the approach (DIISE 2020).

Although eradication of rodents from islands is becoming a mainstream conservation tool, the numbers of islands cleared to date have not reversed native species' extinction curves. With repeated and demonstrated success of invasive species eradications from islands, land managers are increasingly prioritizing eradications for greater biodiversity returns on larger, more remote, and technically complex island ecosystems. However, to maximize the benefits of the tool, the eradication of rodents needs to be prioritized by more communities, and on larger islands. Unfortunately, the limitations to the scope, scale, and pace of eradications is limited by the current strategies and tools, especially on large and/or remote islands, including those with human habitation (Morrison et al. 2007a, Russell et al. 2018). With increasing island size, there is an increasing opportunity for greater biodiversity returns, but with potentially more significant complexities such as the presence of human inhabitants. As Campbell et al. (2015) notes, 50% of IUCN endangered and critically endangered insular tetrapods occur on islands with invasive rodents and with human populations greater than 10,000 people; this highlights the unique and unknown challenges that must be overcome to successfully remove invasive rodents at such scales. It is estimated that the current strategies and approaches to rodent eradication can only reach ~15% of threatened species. The conservation community needs to continue investing and improving the efficiency of rodent eradications that can be applied with less risk, in order to achieve the goal of increasing the scale, scope, and pace of island invasive species eradications to maximize the benefits for biodiversity conservation.

DISCUSSION

Principles Guiding Island Invasive Species Eradication

Eradication and control are sometimes used interchangeably to describe the removal of animals from their environment. In the context of island invasive species eradications, control and eradication are not synonymous, and each orients practitioners towards appropriate planning and action with a predefined objective. Cromarty et al. (2002) summarizes the definitions of eradication and control: *Control* manages "the impacts of invasive alien animal species by sustained harvesting of the invasive species populations (i.e., reduced numbers of animals leads to reduced impacts). They are not concerned with removing the 'last animal'." Regular, ongoing investment is required to sustain the control to a desired level of population or maintain the ecological benefit of the control. *Eradication* "permanently removes the impacts of invasive alien animal species by eliminating the entire population." (i.e., 100% of the individual animals of the target species are removed permanently from the ecosystem). Investments are made to protect the island from re-invasion.

The tools used in control and eradication programs are often similar, however, the duration and intensity of how these tools are deployed highlight the differences of the programs. Island invasive species eradications are guided by three fundamental principles (Parkes 1993):

1) Every individual must be put at risk with the proposed removal technique(s).
2) The technique(s) must remove individuals at a rate faster than they can replace themselves (i.e., breed).
3) Immigration must be zero, or effectively be managed to zero (i.e., identify and respond effectively to eliminate any re/introduction).

For rat and mouse eradications from islands, these principles have been defined (Howald et al. 2007):

1) Deliver a highly palatable bait containing a toxic rodenticide into every *potential* rodent territory.
2) Ensure bait is available for long enough that every rodent has access to a lethal dose.
3) Time the baiting operation to when the rodent population is most likely to consume the bait.
4) The short-term risks and impacts to non-target wildlife, people, and the environment from disturbance and the rodenticide is minimized wherever possible; i.e., the benefits of the eradication must outweigh the costs.
5) Biosecurity procedures must be able to sustain the eradication, with effective prevention, detection, and/or an effective response to any incursion.

The application of the principles of rodent eradications and the mechanics of implementation have been reported extensively in the literature (Veitch and Clout 2002, Howald et al. 2007, Veitch et al. 2009, 2011). Best practice guidelines (Keitt et al. 2015, Broome et al. 2017a,b) for rodent eradications have been developed and are in use globally.

Challenges of the Tools of Rodent Eradications

Approximately 90% of the reported successful rodent eradications have utilized the second-generation anticoagulants with ~72% using bait containing brodifacoum at either 20, 25, or 50 ppm (DIISE 2020). Brodifacoum is the most common rodenticide used in rodent eradications, primarily because it is highly toxic to mammals and the bait can be lethal to some rodents after a single feeding. Further, brodifacoum can move through, and persist in the food web (Howald et al. 2010, Pitt et al. 2015), resulting in cumulative secondary exposure events over time to individual rodents that avoided exposure via primary pathway. Bait is usually applied in a "one time" event. As long as rodents are confirmed to have been removed from the island, no additional bait application is necessary, and any residual rodenticide in the environment will eventually break down. The time lag to breakdown is dependent on the environmental compartment (e.g., soil, water, animal tissue) where the residue is found (Howald et al. 2010, Pitt et al. 2015).

The properties of brodifacoum that make it highly efficacious for invasive rodent eradication contribute to the corresponding risks to non-target species (Pitt et al. 2015). Brodifacoum has been classified by the U.S. Environmental Protection Agency as very highly toxic to birds and mammals, with documented laboratory toxicity to fish and some invertebrates, warranting caution and consideration of the potential for exposure in *a priori* risk assessments. It is difficult to deliver bait to all the rodents on an island without making the rodenticide available to non-target species in space and time. The consequences of brodifacoum to non-target species through primary and secondary exposure pathways is relatively well understood (Veitch and Clout 2002, Veitch et al. 2011, van den Brink et al. 2018, Veitch et al. 2019). Understanding the primary or secondary pathways of exposure *a priori* to the eradication are critical to developing mitigation measures to minimize, reduce, or eliminate risks (or, alternatively, accept risk) to non-target species. One such common and effective mitigation strategy is to time eradications when certain species at risk are absent, such as when birds migrate off the island or are not breeding (Howald et al. 2010, Wegmann et al. 2012, Gill et al. 2014). Another often used mitigation strategy for insular species is to capture and hold a subset or the entire population and then release once the risk period passes (Howald et al. 2010). Ultimately, risks to non-target species should be minimized or eliminated wherever possible; however, as long as impacts are not at the population level, impacted native species often do recover with little input by people.

The *a priori* prediction of brodifacoum residue, and its persistence, in island food webs over time can be difficult and not always accurate and presents inherent uncertainty for all projects that should be acknowledged. Outcomes from previous projects along with the known properties of brodifacoum can inform risks, but may not be relevant for all projects, as each island ecosystem is unique. For example, on Rat Island in the Aleutian Islands, ecotoxicological risk assessment predicted a negligible exposure risk and consequence to individual bald eagles. The eagles were predicted to forage on salmon within streams on other islands during the expected exposure window, as supported with data from a previous toxic field study in the Aleutian Islands. Unfortunately, however, one year after the bait application on Rat Island, 45 eagles and over 300 glaucous-winged gulls were found dead with 100% of those tested confirmed with brodifacoum exposure (Ebbert and Burek-Huntingdon 2010). Fortunately, within a decade, the breeding population of eagles and gulls recovered and exceeded pre-eradication numbers, highlighting the resiliency of native species recovery (Zilliacus and Croll 2020). Comparing Rat Island with a project in Haida Gwaii (Gill et al. 2014), with similar species composition as the Aleutian Islands and despite extensive carcass searching effort, there was no documented loss of bald eagles and only three gulls were found dead, suspected of brodifacoum exposure (Gill et al. 2014). These contrasting outcomes between projects with similar species composition reinforces that, despite the collective understanding of the properties of brodifacoum and its potential to move through food webs, no two island rodent eradication projects are the same. Therefore, brodifacoum use can have implicit uncertainty that should be accounted for with adaptive, robust, and redundant risk mitigation measures to ensure the persistence of valued non-target species.

Maximizing Chances of Success

The eradication of rodents from islands has a high probability of succeeding if the principles of eradication are followed; however, it is not without risk. Rodent eradications require extensive *a priori* planning and development and, in most cases, also require trials and testing, such as calibration of bait application rates (Pott et al. 2014), interspecies competition for bait (Wegmann et al. 2012, Gill et al. 2014), effects of climate on bait degradation rates (Wegmann et al. 2012) and palatability of bait. However, the risks of eradications extend far beyond the realm of ecotoxicology and technical planning (Morrison et al. 2007a,b, Howald et al. 2010). In addition to the biological factors, the social, political, legal, ethical, logistical, and financial elements of a project must be accounted for (Morrison et al. 2007a). Each of these carries its own unique risk profiles that must be managed within and among the component parts of a project.

Holistic and integrated project management (see http://www.pacificinvasivesinitiative.org/rk/intro/The_Project_Process_Overview.html) offers a model to maximize efficacy and minimize risks to non-target species. At the heart of all successful projects is the feasibility assessment (Island Conservation 2018). Using the principles of eradication, the feasibility assessment addresses if the project can be completed considering the technical feasibility; whether it is environmentally acceptable; sustainable (i.e., re-invasions can be managed to near zero); socially, politically, and legally acceptable; and the capacity to implement the project is in place or can be acquired, including enough allocated financial resources.

The feasibility assessment evaluates the probability of the project success based on the understanding of the ecosystem, and sociopolitical and legal environment at the time of evaluation. The assessment begins from the basis of the principles of eradication, with a series of assumptions that must be ground-truthed, tested, and affirmed or negated. The project is built systematically and the expectations underlying feasibility are continuously tested. This is the foundation of the adaptive management approach: as the levels of complexity are added, any changes to assumptions are evaluated for their impact on efficacy and risks (see Island Conservation 2018). Most everyone understands the benefits of removing rodents from islands on the outset, but once land managers and decision makers engage, they quickly become aware of the inherent challenges to projects, and must systematically work through the issues to solutions; the project development process has been described as a process of discovery. The stronger and more accurate the feasibility assessment, the less complicated the project planning. Thus, the development of the feasibility assessment utilizing comprehensive knowledge of local conditions at the outset lessens the impacts and necessity for changes as the project progresses, highlighting and reinforcing the essential value of multi-jurisdiction partnerships with a diverse knowledge base in all phases of project development.

Partnerships: Essential Elements of Success

Protecting the integrity of eradication as a viable conservation tool is an imperative outcome of every eradication project. The perceived success of any island invasive species eradication project can have implications for future projects locally, regionally, nationally, and even internationally. Thus, appropriate investment into project development and implementation is fundamental to ensure the project plan maximizes probability of eradication of the target species, and minimizes both ecological and abiological risks (e.g., reputational, legal, financial) (Morrison et al. 2007a,b). With few exceptions, every documented successful project has been built and implemented by an interdisciplinary team, with support and expertise from the land management agency, community, or project sponsor (Veitch and Clout 2002, Veitch et al. 2011, 2019). Additionally, the importance of sustaining the partnerships through project completion using appropriate technical, scientific, and implementation expertise to minimize the myriad risks that threaten project success is paramount.

Even though rodent eradications have a documented high success rate (upwards of 90-95% depending on the target species), they have periodically failed in the past (DIISE 2020), usually due to inadvertent noncompliance with the principles of eradication (Holmes et al. 2015). Failed rodent eradication attempts can incur irretrievable biological costs such as loss of non-target species, and abiological costs such as financial, reputational, and opportunity costs, without realizing the long-term ecological benefits of removing rodents from islands. To ensure the sustainability and confidence of eradications of rodents as a viable conservation tool, it is imperative that appropriate expectations are set within project teams, land managers, communities, rightsholders, and stakeholders, with a clear understanding of the risks and benefits of the project. Typically, criticisms revolve around the use of rodenticides (i.e., anti-pesticide sentiment) and animal welfare costs (Fisher et al. 2019); its delivery across the landscape and persistence in the ecosystem (Howald et al. 2010, Griffiths et al. 2012); potential risks to non-target species; and negative food web interactions or trophic changes that occur after the removal of rodents (Island Conservation 2018). However, the failure to remove rodents and the unexpected impacts to non-target species during high profile projects can risk the confidence in eradications as a viable conservation tool (Howald et al. 2010, Buckelew et al. 2012, P. Baiao, pers. comm.). This can potentially reduce the motivation of managers to undertake future projects or address how investments are made by funding sources and key permitting agencies (Morrison et al. 2007a). Success of a project is generally measured in biological outcomes, but social outcomes are equally, if not more, important due to the depth and breadth of social, legal, regulatory, and community engagements that are typically required for a project to proceed.

Project success depends on adequate leadership, engagement, support, and/or tolerance by local communities, their governments, NGOs, and businesses (Island Conservation 2018). With few exceptions, every significant island intervention success has involved alignment of rightsholder and stakeholder awareness and/or support to move projects from concept to planning and development to implementation, and ultimately to sustain the project into the future. Protecting the eradication investment requires adequate biosecurity that focuses on preventing incursion through management of potential vectors (e.g., boats at mainland harbors), including adequate monitoring and readiness to detect incursions, and to respond rapidly and, ideally, successfully remove individuals before populations re-establish. The strength of partnerships and alignment of communities, rightsholders, and stakeholders ultimately determine how islands are sustained as invasive-free and/or drives how communities respond to an incursion.

CONCLUSION

The Future of Rodent Eradications

Rodent eradications from small, uninhabited islands are already complex, multi-layered, and challenging socially, biologically, and legally. What the future holds for island rodent eradications on larger, inhabited, and more complex islands is uncertain. Currently, we have treated only 0.3% of all rodent-infested islands, and the current strategies, methods, and tools used in rodent eradications can help only about 15% of known threatened species (Campbell et al. 2015). Thus, we are hitting the upper limits of the tools and capacity to implement rodent eradications. A dramatic increase in the scale, scope, and pace of island eradications is necessary to reverse the impacts of non-native rodents on island biodiversity. The benefits of eradication of rodents from islands is unequivocal, yet there is a need for incremental and transformative innovation of tools to overcome current limitations.

New technologies are being developed and re-engineering of old chemicals is on the horizon to diversify the tools in the toolbox and improve rodent eradications. Some of these include fertility tools (e.g., Contrapest™, Senes Tech Inc., Phoenix, AZ), genetic tools, and species-specific toxicants. For example, norbormide, identified in the 1960s, is disproportionately toxic to rats and relatively low to nontoxic to birds and other mammals, but had limitations due to bait aversion. Ongoing development is focused on overcoming bait aversion challenges, thereby increasing the utility of this old compound maintaining efficacy and greatly limiting risk to non-target species (Shapiro et al. 2018). Harnessing the species specificity of genetic approaches is a relatively new and promising development: ribonucleic acid interference (RNAi) can be programmed to inhibit or disrupt protein production in the target species, and by design is species-specific (Horak 2020). Research is underway to evaluate if naturally occurring or engineered gene drives can be used to cause a selected trait to be rapidly spread through a population. Normally, genes would have a 50/50 chance of being passed on to the next generation; however, gene drives could increase that chance of inheritance up to nearly 100% of the time. The GBIRd (Genetic Biocontrol of Invasive Rodents) research consortium is investigating if it is possible to laboratory engineer a CRISPR mediated gene drive, or power up a naturally occurring gene drive associated with the T-allele in house mice, to bias inheritance to produce male or female only offspring. The GBIRd program is evaluating not only if it is possible but evaluating if it can be done safely and responsibly. A self-spreading gene drive that can successfully persist in an island rodent population could result in male or female only offspring that would ultimately lead to a self-limiting population, thereby eliminating the need for rodenticides and the challenges outlined above (Campbell et al. 2015). Critical questions and careful assessments need to be completed but should this be demonstrated as both safe and a responsible tool, gene drives could be a transformative innovation that will re-define how rodent eradications are implemented.

LITERATURE CITED

Atkinson, I. A. E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. Pages 35-81 *in* P. J. Moors, editor. Conservation of island birds. International Council for Bird Preservation, Cambridge, U.K.

Bellard, C., P. Cassey, and T. M. Blackburn. 2016. Alien species as a driver of recent extinctions. Biology Letters 12: 20150623

Broome, K. G, C. Golding, K. P. Brown, P. Corson, and P. Bell. 2017a. Rat eradication using aerial baiting: current agreed best practice used in New Zealand (Version 3.1). Internal document DOC-29396. New Zealand Department of Conservation, Wellington, New Zealand.

Broome, K. G., C. Golding, K. P. Brown, S. Horn, P. Corson, and P. Bell. 2017b. Mouse eradication using aerial baiting: current agreed best practice used in New Zealand (Version 1.0). Internal document DOC-3034281. New Zealand Department of Conservation, Wellington, New Zealand.

Buckelew, S., V. Byrd, G. Howald, S. Maclean, and J. S. Heppard. 2012. Preliminary ecosystem response following invasive Norway rat eradication on Rat Island, Aleutian Islands, Alaska. Pages 275-279 *in* C. R. Veitch, M. N. Clout, and D. R. Towns, editors. Island invasives: eradication and management. IUCN, Gland, Switzerland.

Campbell, K. J., J. Beek, C. T. Eason, A. S. Glen, J. Goodwin, F. Gould, N. D. Holmes, G. R. Howald, F. M. Madden, J. B. Ponder, D. W. Threadgill, A. S. Wegmann, and G. S. Baxter. 2015. The next generation of rodent eradications: innovative technologies and tools to improve species specificity and increase the feasibility of rodent eradications on islands. Biological Conservation 185:47-58.

Cromarty, P. L., K. G. Broome, A. Cox, R. A. Empson, W. M. Hutchinson, and I. McFadden. 2002. Eradication planning for invasive alien animal species on islands: the approach developed by the New Zealand Department of Conservation. Pages 85-91. *in* C. R. Veitch and M. N. Clout, editors. Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, U.K.

DIISE. 2020. The Database of Island Invasive Species Eradications. Developed by Island Conservation, Coastal Conservation Action Laboratory UCSC, IUCN SSC Invasive Species Specialist Group, University of Auckland, and Landcare Research New Zealand. http://diise.islandconservation.org.

Ebbert, S., and K. Burek-Huntington. 2010. Anticoagulant residual concentration and poisoning in birds following a large-scale aerial application of 25 ppm brodifacoum bait for rat eradication on Rat Island, Alaska. Proceedings of Vertebrate Pest Conference 24:153-169.

Feldman, G., and G. Howald. 2014. From planning to implementation: streamlining compliance for U.S. rodent eradications. Proceedings of Vertebrate Pest Conference 26:91-97.

Fisher, P., K. J. Campbell, G. R. Howald, and B. Warburton. 2019. Anticoagulant rodenticides, islands, and animal welfare accountancy. Animals 9:919.

Gill, C., L. Wein, G. Howald, and P. McClelland. 2014. Challenges associated with eradicating invasive rodents from islands: lessons learned. Proceedings of Vertebrate Pest Conference 26:118-124.

Griffiths, R., F. Buchanan, K. Broome, and B. Butland. 2012. Rangitoto and Motutapu: a starting point for future vertebrate pest eradications on inhabited islands. Proceedings of Vertebrate Pest Conference 25:22-27.

Holmes, N., R. Griffiths, M. Pott, A. Alifano, D. Will, A. Wegmann, and J. Russell. 2015. Factors associated with rodent eradication failure. Biological Conservation 185:8-16.

Holmes, N. D., D. R. Spatz, S. Oppel, B. Tershy, D. A. Croll, and B. Keitt. 2019. Globally important islands where eradicating invasive mammals will benefit highly threatened vertebrates. PLoS ONE 14(3):e0212128.

Horak, K. A. 2020. Island eradications of the future: RNAi as a selective tool. Proceedings of Vertebrate Pest Conference 29: paper no. 9.

Howald, G. R., C. J. Donlan, J. P. Galván, J. C. Russell, J. Parkes, A. Samaniego, Y. Wang, D. Veitch, P. Genovesi, M. Pascal, A. Saunders, and B. Tershy. 2007. Invasive rodent eradication on islands. Conservation Biology 21:1258-1268.

Howald, G., C. Donlan, K. Faulkner, S. Ortega, H. Gellerman, D. Croll, and B. Tershy. 2010. Eradication of black rats *Rattus rattus* from Anacapa Island. Oryx 44(1):30-40.

Island Conservation. 2018. Data matters: informing the eradication of invasive species on islands: North America and the Arctic region. Contractor's Report 2018-1. National Invasive Species Council Secretariat, Washington, D.C.

Jones, H. P., N. D. Holmes, S. H. M. Butchart, B. R. Tershy, P. J. Kappes, I. Corkery, A. Aguirre-Muñoz, D. P. Armstrong, E. Bonnaud, A. A. Burbidge, K. Campbell, F. Courchamp, P. E. Cowan, R. J. Cuthbert, S. E. Ebbert, P. Genovesi, G. R. Howald, B. S. Keitt, S. W. Kress, C. M. Miskelly, S. Oppel, S. Poncet, M. J. Rauzon, G. Rocamora, J. C. Russell, A. Samaniego-Herrera, P. J. Seddon, D. R. Spatz, D. R. Towns, and D. A. Croll. 2016. Invasive mammal eradication on islands results in substantial conservation gains. Proceedings of the National Academy of Sciences, U.S.A. 113:4033-4038

Keitt, B., K. Campbell, A. Saunders, M. Clout, Y. Wang, R. Heinz, K. Newton, and B. Tershy. 2011. The Global Islands Invasive Vertebrate Eradication Database: a tool to improve and facilitate restoration of island ecosystems. Pages 74-77 *in* C. R. Veitch, M. N. Clout, and D. R. Towns, editors. Island invasives: eradication and management. IUCN, Gland, Switzerland.

Keitt, B. S., R. Griffiths, S. Boudjelas, K. G. Broome, S. Cranwell, J. Millett, W. Pitt, and A. Samaniego-Herrera. 2015. Best practice guidelines for rat eradication on tropical islands. Biological Conservation 182:17-26.

Morrison, S. A., K. R. Faulkner, L. Vermeer, L. Lozier, and M. R. Shaw. 2007a. The essential non-science of eradication programmes: creating conditions for success. Pages 461-466 *in* C. R. Veitch, M. N. Clout, and D. R. Towns, editors. Island invasives: eradication and management. IUCN, Gland, Switzerland.

Morrison, S., N. Macdonald, K. Walker, L. Lozier, and M. Shaw. 2007b. Facing the dilemma at eradication's end: uncertainty of absence and the Lazarus effect. Frontiers in Ecology and Environment 5:271-276.

Parkes, J. P. 1993. Feral goats: designing solutions for a designer pest. New Zealand Journal of Ecology 17(2):71-83.

Pitt, W., A. Berentsen, A. Shiels, S. Volker, J. Eisemann, A. Wegmann, and G. Howald. 2015. Non-target species mortality and the measurement of brodifacoum rodenticide residues after a rat (*Rattus rattus*) eradication on Palmyra Atoll, tropical Pacific. Biological Conservation 185:36-46.

Pott, M., A. Wegmann, R. Griffiths, A. Samaniego-Herrera, R. Cuthbert, M. Brooke, W. Pitt, A. Berentsen, N. Holmes, G. Howald, K. Ramos-Rendón, and J. Russell. 2014. Improving the odds: assessing bait availability before rodent eradications to aid in selecting bait application rates. Biological Conservation 185:27-35.

Russell, J., C. Abrahão, J. Silva, and R. Dias. 2018. Management of cats and rodents on inhabited islands: an overview and case study of Fernando de Noronha, Brazil. Perspectives in Ecology and Conservation 16(4):193-200.

Shapiro, L., D. Rennison, M. Brimble, D. MacMorran, and C. Eason. 2018. Redevelopment of a rat specific rodenticide norbormide. Proceedings of Vertebrate Pest Conference 28:47-50.

Tershy, B. R., K. W. Shen, K. M. Newton, N. D. Holmes, and D. A. Croll. 2015. The importance of islands for the protection of biological and linguistic diversity. BioScience 65:592-597.

van den Brink, N. W., J. E. Elliott, R. F. Shore, and B. A. Rattner, editors. 2018. Anticoagulant rodenticides and wildlife. Springer, New York, NY.

Veitch, C. R., and M. N. Clout, editors. 2002. Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, U.K.

Veitch, C. R., M. N. Clout, and D. R. Towns, editors. 2011. Island invasives: eradication and management. Proceedings of the International Conference on Island Invasives. IUCN, Gland, Switzerland and CBB, Auckland, New Zealand.

Veitch, C. R., M. N. Clout, A. R. Martin, J. C. Russell, and C. J. West, editors. 2019. Island invasives: scaling up to meet the challenge. Occasional Paper SSC no. 62. IUCN, Gland, Switzerland.

Wegmann, A., E. Flint, S. White, M. Fox, G. Howald, and P. McClelland. 2012. Pushing the envelope in paradise: a novel approach to rat eradication at Palmyra Atoll. Proceedings of Vertebrate Pest Conference 25:48-53.

Zilliacus, K. M., and D. Croll. 2020. Eleven-year post rat eradication monitoring report: Hawadax (formerly Rat) Island, Aleutian Archipelago, Alaska. Report to Island Conservation, Santa Cruz, CA.