# ISLAND RESTORATION: EXPLORING THE PAST, ANTICIPATING THE FUTURE

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**SUMMARY**

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Predator control and eradication of introduced mammals affecting seabird populations has greatly accelerated since pioneering efforts by New Zealand biologists in the 1970s. The resulting dramatic recovery of seabirds inspired further research and more eradications on larger islands and helped set the Conservation Agenda for the 1990's: Removal of Alien Predators from Seabird Colonies by the Pacific Seabird Group, which in turn helped identify islands of the highest priority from which introduced organisms should be removed. That effort facilitated a number of eradication successes from smaller seabird islands in Mexico, Hawaii and the tropical Pacific, and the removal of Arctic foxes from the Aleutian Island Archipelago. Complete eradication was successful for large herbivores, rabbits, foxes and feral cats, but the eradication of rodents presented the greatest challenge. The development of a second-generation anticoagulant, brodifacoum, enhanced the rate of successful eradications and allowed larger areas to be cleared. By 2002, technical confidence developed to the point where sub-Antarctic Campbell Island (11 300 ha) was successfully treated with bait dispersed from helicopters. Many remaining potential eradication programs are challenged by remote locations, extreme weather, complex ecosystems, non-target species, proximity to human habitation, toxicant resistance, compliance with environmental regulations, opposition by animal rights advocates, and inadequate funding sources for large-scale programs. Once eradications are complete, monitoring and quarantines need to be guaranteed. Future techniques to exploit are fencing for large mainland areas and control or eradication of the enclosed pests, with exclusion of reinvasions. Finally, the use of biocontrol through genetic engineering and disease holds promise.

Key words: Island restoration, predator control, eradication, *Rattus,* seabirds, rodenticide labels, adaptive management, Pacific Seabird Group, IACUC, brodifacoum, quarantine, bio-sanitation

## INTRODUCTION

The conservation of seabirds requires maintenance and enhancement of their populations by reducing losses at sea and on breeding colonies. The two major methods of achieving this conservation goal use fundamentally different means. Limiting seabird mortality at sea, principally from oil spills or fishery bycatch, requires political and legal skills in dealing with industry, changing fishing techniques and gear types, and promptly responding to oil spills. Limiting seabird mortality on land, primarily caused by introduced competitors and predators, calls for ethical and sustainable poisoning, hunting and trapping techniques, and the political skills to obtain funding, to gain permission to work on public and private lands, and to navigate ethically controversial situations. Both of these approaches to seabird conservation have produced significant results in recent decades. Not only have seabird populations responded positively, but large-scale ecosystem shifts have also been detected. The current paper examines the past and future aspects of the developing field of predator eradication.

The scientific and conservation literature is replete with studies that chronicle the disastrous effects of introduced predators on indigenous species on oceanic islands (Moors & Atkinson 1984, Courchamp *et al.* 2003). Before the industrial age, most remote islands had been predator-free for millennia, thus offering sanctuary for nesting or roosting seabirds, migratory shorebirds, and other wildlife.

One of the earliest observations of the severe depredations of introduced predators on island birds was made during the 1840s US Exploring Expedition:

> The bird [Tooth-billed Pigeon *Didunculus strigirostris*] formerly abounded at the island of Upolu, one of the Samoan Islands, but now, it is considered a rare species by the natives, and one which will be entirely destroyed in the course of a few years, if the same causes exist which are now operating to their destruction ... A few years since a passion arose for cats, and they were obtained by all possible means from the whale ships visiting the islands, were much esteemed for a while, until the other pets were destroyed by them ; after which Pussy (a name generally adopted by the Polynesians for cats), not liking yams or taro ... preferring *Manu-mea,* and took to the mountains in pursuit of them. There the cats have multiplied and become wild, and live upon our *Didunculus,* or little Dodo, the *Manu-mea* of the natives, which is believed will in a very few years cease to be known ..." (Peale 1848).

The Tooth-billed Pigeon is very rare today in the mountains of Samoa.

Seabird life histories are the key to their vulnerability and also to why island restoration has been successful. Adapted to predator-free islands, seabirds have not evolved strategies for evading mammalian predators. Some small seabirds such as storm-petrels and murrelets have evolved nocturnal behaviors to avoid avian predators, but none are immune to introduced mammalian predators—particularly human commensal species such as rats and cats that are also nocturnal, predatory and prolific. However, the fact that seabird colony islands are often relatively small and isolated makes it is possible to eradicate predators, and not just control them, which was all that was possible on unfenced mainland sites until recently.

Removing introduced mammalian predators is a quick fix to enhancing seabird reproductive success. However, many non-native predator populations have been established for lengthy periods, often introduced by sailing ships decades or even centuries earlier as in the case of Pacific Rats *Rattus exulans,* which spread throughout the Pacific with the ancient Polynesians. Introduced predators dominate the simple trophic environments of islands; removing them can create unanticipated cascading ecologic effects.

Even with rigorous planning, eradications require adaptive management and flexibility to obtain results that often cannot be predicted (Courchamp *et al.* 2003). Eradications may create unforeseen, unintended consequences that could negate their purpose. Eradication efforts can also fail, temporarily disturbing trophic changes. However, even if actions fail, the lessons and insights obtained may shed light on how ecosystems respond—information that may prove valuable for future attempts.

## HISTORY

The conservation of seabirds and their island ecosystems developed as an organized practice from two lines of intellectual thought: the increasing appreciation of the effects of invasive species on native biota, and the development of the theory of island biogeography. One of the first books that identified the problems of invasive animals was published in 1934. *Rats, Lice and History: A Chronicle of Pestilence and Plagues* (Zinsser 1934) covered the concepts of rodent biology and their ability to spread disease; it also clarified why rats are the most destructive introduced species. A generation later, in 1950, Dr. Kazimierz Wodzicki of the Animal Ecology Division of the New Zealand Department of Scientific and Industrial Research published his *Introduced Mammals of New Zealand.* This book described how introduced species decimated crops, landscapes and fisheries in New Zealand. A landmark book was published in 1958: The Ecology of Invasions by Animal and Plants by Charles S. Elton described in detail the impacts of pests and weeds. Yet another visionary book published four years later had a more immedaite impact on the public. In 1962, *Silent Spring* by Rachael Carson was published. An indictment of over-reliance on pesticides, especially DDT (with its effects on birds), the book was credited with launching the modern environmental movement as a backlash against toxic pest control. A decade later, DDT was banned, and the discussion shifted to human overpopulation, habitat loss and oil pollution as ecologic perturbations. Invasive species were just starting to be appreciated for their ability to overcome ecologic and geographic barriers (Odum 1971).

Concurrent with the emerging recognition of invasive species was *The Theory of Island Biogeography* by MacArthur and Wilson (1967), which builds upon the principles of population ecology and genetics to explain how island remoteness and size regulate the balance between immigration and extinction in island populations. However, there was little appreciation of the role of introduced species on insular habitats and extinction rates. Addressing MacArthur and Wilson's theory in light of conservation practice, Simberloff and Abele (1976) suggested that their theory can be incorrect under a variety of biologic conditions, but they also did not include the effects of introduced species (Quammen 1996).

Most recently, the two philosophical tracks of invasive species and island biogeography approached each other, but did not merge, in the book *Collapse: How Societies Choose to Fail or Succeed* by Jared Diamond, a pioneering biogeographer and ornithologist. In his book, Diamond examined the cause of the collapse of the Polynesian society of Easter Island. He noted that rats were abundant on Easter Island and that they affected birds and vegetation; however, rats did not figure into his nine reasons for deforestation on Pacific Islands (Diamond 2005), suggesting that the scale of rodent impacts on island ecology remains underappreciated. In contrast, Hunt (2006) suggested that the fall of Easter Island's humans was directly related to rat predation of palm seeds—that is, humans doomed themselves (and the island's ecology) by either accidentally or purposely bringing in rats.

As the ecologic underpinnings of the science of eradication developed, the terminology relating to introduced organisms based on their impacts was in flux. In *Exotic Intruders: The Introduction of Plants and Animals into New Zealand,* Druett (1983) covered the topic of the acclimatization of species that have made the transition from country of origin to new habitat. Their value to humans, encompassed in the term "acclimatized," changed sequentially to "exotic," "introduced," "alien," and recently, "invasive." Each term explicitly reflects the historical perception of the ecologic damage done and implicitly reflects the rate of new introductions. The latest term, "invasive," applies to species that quickly acclimatize to new environments and spread uncontrollably, reflecting the need to quarantine, control or eradicate the destructive invaders.

Contemporaneous with the New Zealand–centric *Exotic Intruders* was Atkinson's (1985) paper "The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas." A New Zealander, Atkinson began publishing observations of rats in 1973. His seminal paper informed a new generation of seabird biologists with an increasingly international perspective.

Lines of thought and action began to converge in the 1970s on islands scattered throughout the former British Empire, including England, Australia, Bermuda and especially New Zealand, where island conservation quickly reached new levels of expertise within the federal Department of Conservation. New Zealand leadership in predator eradications was the result of excellent governmental planning supported by a rural-based population that could relate to the need for pest management. As an island nation with many extinct and endangered species, New Zealand lent urgency to the conservation of endemic species. Saving the world's most endangered bird, the Black Robin *Petroica traversi* impressed conservationists worldwide with New Zealanders' ingenuity and the lengths to which they would go to save their biologic heritage (Butler & Merton 1992). Hard-won knowledge was freely exported by New Zealanders, many of whom were Department of Conservation employees and who were either invited as speakers and trainers or received contracts and traveled worldwide to initiate other eradication programs, many in the United States.

In the United States, the management of invasive species falls under the jurisdiction of several agencies, particularly the Animal and Plant Health Inspection Service (APHIS) of the US Department of Agriculture (USDA). Historically, the USDA operated the Animal Damage Control Program that assisted livestock ranchers by controlling predators. Large-scale poisoning of livestock predators such as coyotes, hawks, eagles and other scavengers created a public backlash against wholesale "varmint" control at a time of growing public appreciation for native predators. Wholesale and indiscriminate poisoning campaigns, especially with the pesticide DDT, was a primary influence behind legislation banning its use and restricting the use of other toxicants in the 1972 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

It was from the shadow cast by the overkill of predators that the US program for introduced predator eradication had to emerge. Animal Damage Control Division changed its name to Wildlife Services in 1997 as an attempt to reflect a broader mission, including protection of rare native species from predation. Their expertise in field techniques, research, chemical analysis and toxicant registration make them an integral partner in US conservation projects, usually in conjunction with the US Fish and Wildlife Service (USFWS), which also has a responsibility for the management of invasive species.

The first and best example of USFWS leadership is the Arctic Fox *Alopex lagopus* eradication in the Alaska Maritime National Wildlife Refuge (Fig. 1), which had been an ongoing, albeit *sub-rosa,* effort since the 1950s and which clearly benefited seabirds (Bailey 1993). Up to 2007, Arctic Foxes had been removed from all but five of the 450 Aleutian Islands to which they had been introduced—a total of more than 202 000 hectares cleared of foxes. Seabirds responded dramatically, increasing by a factor of at least four to five within 10 years of fox removal. The Aleutian Canada Goose *Branta canadensis leucopareia,* increased from fewer than 1000 birds in 1975 to more than 100 000; the subspecies was subsequently removed from the US list of endangered species (Ebbert & Byrd 2002).

This concerted effort provided the framework and foundation for other archipelago-wide eradication efforts, but could inspire only a knowing few, because information about the program was deliberately withheld from the public in case animal rights groups should intervene with the permitting agencies to stop the killing of foxes. Those who needed to know or needed to be persuaded were informed. The strategy worked, and the resulting increases in bird populations were such that no scientific argument could be advanced against the efficacy of the approach.

**Fig. 1.** Arctic Fox *Alopex lagopus* killed in the Aleutian Islands, held by Graeme Loh. Photo by Mark Rauzon.

The fox eradication program also provided new insights into ecology on a geographic scale. Introduced foxes had altered the vegetative ecology by eating the seabirds that fertilized the islands with guano. With decreased guano, the grasslands succeeded into scrubby tundra (Croll *et al.* 2005). The removal of foxes also released introduced Norway rat *Rattus norvegicus* populations from predation, which was especially noticeable on Kiska Island, Alaska, where the world's largest auklet colony is located.

Island restoration is not limited to eradication. During the last 30 years, the techniques of social attraction pioneered in 1973 by Stephen Kress of the National Audubon Society matured and spread to many parts of the world (Kress 1997). The translocation of chicks from a healthy colony to start or regenerate another colony has been supplemented with other techniques, such as the placement of decoys and mirrors to create the illusion of increased density, and call playback to attract exploring birds to artificial burrows. In addition, vegetation control (fencing, weeding, burning, grazing) to enhance colony sites and control of native competitors and predators (gulls, Raccoons *Procyon lotor*) helped new colonies to survive the early years and to develop attendance patterns that promote stability.

However, with more than 90% of the world's islands invaded by rats (Towns *et al.* 2006), it is obvious why rodent eradication heads the list of restoration actions (Jones *et al*. 2008). Island birds constitute 67% of the world bird species threatened with extinction, compared with 30% of continental birds. The disparity between islands and continents also highlights a fundamental difference between control and eradication. Moors (1985) set out the operating definition of eradication:

> The objective of eradication is to kill every last individual, whereas control aims merely to reduce numbers to some acceptably low level. Eradication demands a long-term commitment, together with perseverance for field operators. It is also essential that administrators and those supplying finance for the operation understand the distinction and do not stop the campaign when few rats are left and the cost becomes increasingly high for each rat killed. The last few rats are certainly most expensive and exacting to destroy, but they are obviously the most vital if the campaign is to succeed.

Defining the choice that must be made to limit or eliminate invasive species is based on future projections of labour and funds. Programs that function on a fluctuating annual budget may be unable to commit sufficient funds and therefore limit the choice to control. In their 25-year study of Cory's Shearwater *Calonectris diomedea,* Pascal *et al.* (2008) determined that control is less cost-effective than eradication is. Within six years, eradication cost was lower than control cost and conferred several ecologic advantages. Foremost was that the average breeding success after eradication (0.86) was 11% higher than the success after rat controls (0.75).

In the 1980s, with the development of "second-generation" rodenticides, it became easier to do more than just control rats. Unlike first-generation poisons (warfarin, for instance) that required multiple feedings that risked creating bait avoidance, the new rodenticides (e.g. brodifacoum) allowed rodents to consume a lethal dose in fewer meals (Cromarty *et al.* 2002). Although the first known insular rodent eradication was on Rouzic Island (3.3 ha), France, in 1951 (Lorvelec & Pascal 2005), it was the eradication of rats in 1987 from Breaksea Island (170 ha), New Zealand, an early successful application of brodifacoum, that engendered public interest (Taylor & Thomas 1993). Many important lessons were learned from that effort, and it helped to launch a series of carefully planned and successful follow-on eradications that developed in-depth information and experience with international implications.

The first successful US rodent eradication program on an island occurred during 1990–1992, with the eradication of Pacific Rats at Rose Atoll (7 ha) by the USDA and the US Wildlife Service. Lessons learned at Rose Atoll were applied to Kure Atoll (105 ha) in 1993. Ship or Black Rats *Rattus rattus* were next eradicated from Midway Atoll during 1994–1997. First, Eastern Island (133 ha) and Spit Island (0.8 ha) and then, in 1996, Sand Island (486 ha) were cleared of rats; the House Mouse *Mus musculus* remains, however. Since that pair of island eradications, Bonin Petrels *Pterodroma hypoleuca* are increasingly abundant at both Kure and Midway atolls.

## COMMUNICATION

A leading nongovernmental organization promoting island eradication is the Pacific Seabird Group (PSG). Formed in 1972, the PSG's long-term commitment to save seabirds from predation culminated in *A Conservation Agenda for the 1990's: Removal of Alien Predators from Seabird Colonies* (Harrison 1992). The agenda called for PSG members to identify islands and situations of the highest priority from which rats, foxes and other introduced mammals should be removed in Alaska, British Columbia, Washington, Oregon, California, Hawaii and western Mexico. The PSG worked with managers, advocating for funding, with a goal of removing all predators within a decade. The effort was largely successful.

In January 1995, the PSG held a symposium on seabird enhancement through animal and vegetation management at its annual meeting in San Diego, California. Through a grant from the US Fish and Wildlife Service under the auspices of the North American Free Trade Agreement, the PSG invited speakers from New Zealand, Mexico and other Pacific Rim countries and held a special workshop in Mexico immediately after the conference. With logistics support from Pro-Esteros and Universidad de Baja California, 28 biologists from throughout Mexico participated in a course at the University of Ensenada that was designed by New Zealand predator control experts (Fig. 2). The significant outcome of the session was compilation by the group of an atlas describing the Mexican islands with predators, the affected animal resources, current researchers and other contact people. During the open discussion phase of the workshop, many issues were raised and recommendations made. One idea was to present the information contained in the draft of the atlas for use by a national island coordinator.

After that meeting, the Island Conservation and Ecology Group (ICEG), associated with the University of California at Santa Cruz, took up the cause of island restoration in Mexico and on the US west coast. The ICEG started as a network of conservationists in 1994 and received US nonprofit status in 1997, later changing its name to Island Conservation. It has been responsible for removing introduced mammals from numerous islands in Mexico: San Benitos Islands (rabbits, goats and burros), Todos Santos South (rabbits and cats), North Coronado (cats), San Roque, Asunción (rats and cats) and Natividad Island (cats), benefiting the survival of nesting Black-vented Shearwaters *Puffinus opisthomelas* (Keitt & Tershy 2003). Since its inception, Island Conservation has emerged as one of the world's leaders in eradications, working in Alaska, Hawaii and Micronesia.

Also founded in 1994, the Endangered Species Recovery Council (ESRC) brought New Zealand predator control expertise to North America. In 1996, ESRC began to control feral Cats *Felis catus* at Wake Atoll (739 ha), one of the most isolated islands in the world (Figs. 3 and 4). That control project led to a collaborative eradication effort between ESRC, Wildlife Management International of New Zealand and Marine Endeavours. The Wake Program, implemented on a military base, was funded in 2000 because of support at the highest federal level. In February 1999, President Clinton signed Executive Order 13112 requiring each federal agency to prevent, detect and respond to the introduction of invasive species; and to monitor and control invasive species and to provide for restoration of native species and habitat. It became easier to obtain funding because federal agencies now had a mandate to manage invasive species. In July 2003, team members began a concerted effort to remove feral cats from this remote military base and, by January 2004, approximately 170 cats had been removed from the atoll. By late 2007, two feral cats remained, but no cat reproduction has been noted for several years. Seabird and shorebird populations have greatly benefited (Rauzon *et al.* in press).

Another nonprofit conservation group, Oikonos–Ecosystem Knowledge, was founded in 2001. Since then, it has restored beach vegetation at Año Nuevo Island, California, and sponsored,

**Fig. 2.** Dick Veitch of New Zealand shows Mexican students how to set traps during a Pacific Seabird Group training session in Ensenada, Mexico, 1995. Photo by Mark Rauzon.

**Fig. 3.** Terns' wings: evidence of cat depredations on Wake Atoll. Photo by Mark Rauzon.

using local experts, a Ship Rat eradication project on islets off the southern tip of Stewart Island, New Zealand. Its entry into eradication work evolved from earlier PSG efforts to promote communication of eradication successes and advocate for more programs. When the PSG held the *Exxon Valdez* Oil Spill Seabird Restoration Workshop in 1994, it identified limitations in how penalty fines from oil spills could be used (Warheit *et al.* 1997). Initially, the resource recovery funds were limited to spill sites, and so *Exxon Valdez* seabird recovery funds could not be used to remove predators from locations in the Aleutian Islands where the affected species were nesting, and where the conservation dollars would best mitigate loss, but only in the affected area of seabird wintering grounds. Petitioning by the PSG eventually led to a broader area of consideration. In 2005, the *Command* oil spill trustee council funded a proposal by Oikonos to remove rats in New Zealand after many thousands of Sooty Shearwaters *Puffinus griseus* were oiled in Monterey Bay, California (www.oikonos.org/projects/titi.htm).

At many sessions and symposia at numerous conferences on the topic of predator eradication, consultants, federal and state agency representatives, and federal and state land managers have come together to develop strategies for large-scale seabird conservation efforts. The theme of those meetings has increasingly focused on rodents. The first "rat summit" occurred in July 2000 in San Francisco, bringing island-based managers together with a range of experts to focus on protecting island ecosystems through the management of non-native rodents. That meeting was followed by the International Conference on Eradication of Island Invasives, held at the University of Auckland in February 2001. Many PSG members attended the New Zealand conference that also produced a landmark book, *Turning the Tide: The Eradication of invasive Species,* containing 52 papers and 21 abstracts (Veitch & Clout 2002).

The "rat summit" and the New Zealand conference set the stage for the eradication of rats on Anacapa Island, Channel Islands National Park, California. Island Conservation implemented the project in 2002 using funds derived from an oil spill settlement and making use of technology developed in New Zealand for scattering poisoned bait from a helicopter. It resulted in a well-executed program, the first of its kind in the United States, carried out despite public protest and agency pressures. Significantly complicating the project was the presence of native rodents on Anacapa Island. Before the bait could be deployed, several hundred endemic Deer Mice *Peromyscus maniculatus anacapae* were captured and maintained in captivity, They were successfully reintroduced following the eradication. Xantus's murrelets *Synthliboramphus hypoleucus,* a seabird severely threatened by the Ship Rats, began to recolonize quickly and successfully bred.

Several significant setbacks have also occurred in the US program. An attempt to eradicate Ship Rats from Palmyra Atoll (230 ha) failed in 2002. Led by USDA's Wildlife Services, in cooperation with The Nature Conservancy and the USFWS, the Palmyra project was complicated by the large number of islets (25), the heat and high rainfall of the Intertropical Convergence Zone, dominant stands of lush coconut trees, abundant bait-stealing crabs (including Coconut Crabs *Birgus latro*), and a reliance on volunteer effort. At the same time, a poorly planned and executed trial aerial broadcast in a Hawaiian rainforest killed feral pigs, causing concern about the potential for human poisoning through consumption of contaminated pig meat (K. Swift pers. comm.) These issues forced a reevaluation of all US rodent control and eradication projects, with the outcome that additional research, tighter oversight of the US program and more careful planning were needed for future projects.

In accordance with this new protocol, a workshop was held in Homer, Alaska, in February 2004 to provide guidance to the rat program being developed by the USFWS's Maritime National Wildlife Refuge. In 2003, the Maritime Refuge hired Peter Dunlevy from National Wildlife Research Center's Hawaii field station to develop a rat eradication program for the Aleutian Islands. The Homer workshop invited federal land managers, officials with the US Coast Guard, ship captains and biologists to discuss how to respond to rat spills and to outline a logical sequence of island eradications in the Aleutian Islands. Groundwork was laid for Norway Rat eradication at Rat Island, Aleutian Islands, as a prelude to rat control and eradication on nearby Kiska Island, one of the world's largest seabird colonies (Fig.5).

A second "rat summit" was hosted in October 2004 by the National Wildlife Research Center in Fort Collins, Colorado, and a third summit that also considered other vertebrate pest issues was held in 2007 at the National Wildlife Research Center. A conference relating to tropical rats also took place at the University of Hawaii, Honolulu, in 2007, and a rodenticide conference in the summer of 2008 will also take place in Honolulu.

The net result of all this planning, coordinating, communicating and implementation is that at least 318 successful rodent eradications

**Fig. 4.** Feral cat in box trap on Wake Atoll. Photo by Mark Rauzon.

**Fig. 5.** Rat-killed Crested (*Aethia cristatella*) and Least (*A. pusilla*) Auklets, and a Norway Rat *Rattus norvegicus* on Kiska Island, Alaska. Photo by Mark Rauzon.

have taken place worldwide (Howald *et al.* 2007), more than 90 of them in New Zealand (Towns & Broome 2003). The size of the islands from which rats have been eradicated has increased from Maria Island (1 ha, 1960) in New Zealand to St. Paul Island (800 ha, 1996) in the Indian Ocean, to Langara Island (3105 ha, 1995) in the Queen Charlotte Islands, British Columbia, Canada, where the Canadian Wildlife Service, with New Zealand adviser (Rowley Taylor) eradicated Norway Rats. At that time, Langara Island was the largest island cleared of rats entirely by ground crews. In 2002, the largest island eradication was accomplished by means of an aerial bait drop (Campbell Island, New Zealand; 11 300 ha; Fig. 6). In addition, about 50 cat eradications have been accomplished in the last 30 years (Nogales *et al.* 2004).

Island restoration in Asia has been lagging in comparison with the rest of the world, but Japanese attendance at the "rat summits" have resulted in a landmark Ship Rat eradication campaign. In 2007, success was declared at Nishijima Island (49 ha), in the Ogasawara (Bonin) Islands. (T. Yabe pers. comm.). With additional Japanese experience and international support, the most desirable target for future rat eradication is Torishima Island, the site of the world's largest colony of Short-tailed Albatrosses *Phoebastria albatrus.* Torishima is infested with Ship Rats and House Mice, and while the mice are not direct predators of the endangered albatross, they chew vegetation that exacerbates erosion, already a significant problem on the island, and affect Threatened Tristram's Storm-Petrels *Oceanodroma tristrami.* Planning is also underway to help another critically endangered Asian seabird through the elimination of rodents from the Matsu Islands of Taiwan, the nesting site of Chinese Crested Terns *Thalasseus bernsteini.*

**QUARANTINE**

Lagging behind other efforts are quarantine regulations for Asian fishing vessels. The history of rodent invasions from Asian ships is notorious. The Rat Islands in the Aleutians were named after the 1780 shipwreck of a Japanese sailing ship. More recently, Pierce *et al.* (2006) reported that "it is likely the invasion of McKean Island by Asian rats occurred following the grounding of the Korean vessel F/V *Chance 301* in *c.* 2001." In 1996, two confiscated Philippine fishing vessels were anchored and abandoned at Helen Reef, Palau. Ship Rats escaped and swam to land, attacking Great Crested Terns *Sterna bergii* and Black-naped Terns *Sterna sumatrana.* In 2001, brodifacoum was hand-cast over the island (3 ha) by staff of the Palau Sanitation Division. The eradication was successful. Another example from Palau involves the so-called *Ting Hou* rat, a Norway Rat invasion that resulted from the wreck of the Taiwanese vessel *Ting Hou.* (A. Weggman pers. comm.). At Christmas Island, Pacific Ocean, Ship Rats accidentally arrived around 2000 and spread rapidly from their introduction site at a newly constructed wharf visited by Asian fishing vessels (Fig. 7). Rats also appeared about 2000 at Clipperton Atoll after two ships were wrecked there (Pitman *et al.* 2005).

Preventing rodent invasions is a critical course of action. For many years, biologist Art Sowls had been leading a quarantine project at the Pribilof Islands to prevent rodents from becoming established at this critical seabird colony. Extensive public education was promoted to inform the islanders and mainland press about the potential dangers of rat spills (DeGange *et al.* 1995). Alaska state officials have recently issued new regulations for ports and harbors that might serve as entry points for invading rodents (Fritts 2007). The action plan and new state regulations are extensions of previous anti-rat policies in Alaska that developed from the Alaska Maritime National Wildlife Refuge. This program educates industry and islanders alike about the risks of rodent invasions and monitors for rat sign at strategically placed trapping and tracking stations. If rodents are discovered, emergency responders, registered with the state, are trained in the use of toxicants to prevent the spread of rats. This program is essential in Alaska because of the thousands of vessels following the great circle route from American to Asian ports, bisecting the treacherous Aleutian Island Archipelago.

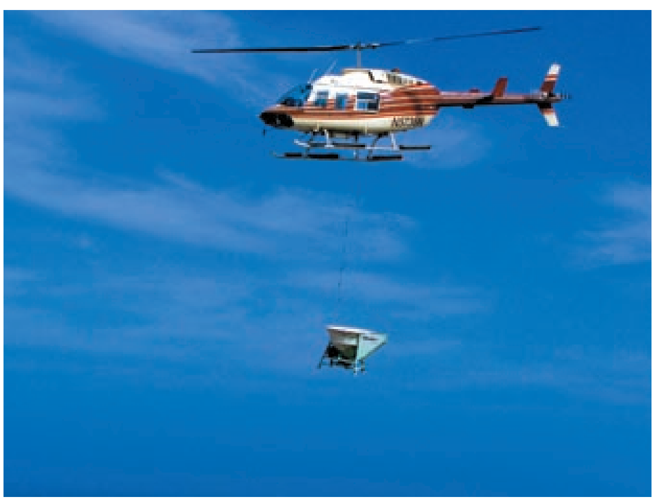

**Fig. 6.** Aerial rodenticide is dispersed using a modified agricultural fertilizer spreader bucket carried by a helicopter, navigating by a differential global positioning system. Photo courtesy of Island Conservation. See new photo.

**Fig. 7.** Pacific Rat *Rattus exulans* and Phoenix Petrel *Pterodroma alba* egg eaten by rats on Christmas Atoll. Photo by Mark Rauzon.

Bio-sanitation, another name for quarantine, has become standard operating procedure for research work in the Pacific/Remote Islands National Wildlife Refuge Complex. Pioneered by Elizabeth Flint for the USFWS, each visit to an island in the Complex requires that equipment and clothing either be new or frozen for 48 hours (sometimes both) to kill insects. The items are then inspected for seeds and other biomaterial that might spread invasive species between the main Hawaiian Islands and each island refuge. This protocol has evolved into the use of easily frozen plastic buckets to transport material to the remote and difficult-to-access islands.

## COMPLIANCE

As eradication programs grow in size and complexity, the environmental effects of rodenticide use have come under greater scrutiny by regulatory agencies, the public and interest groups such as bird conservation and animal-rights groups. Given these circumstances, eradication practitioners must hold themselves to standards of legal compliance that match those that have been applied to commercial and agricultural users. The use of rodenticide is governed by the US Environmental Protection Agency (EPA) under FIFRA. Each rodenticide carries a "label of registration" that specifies exactly how much may be used and in what manner. The restrictions are meant to prevent accidental poisoning of secondary targets including, but not limited to, humans and human companion animals and the environment. Any use of toxicants that does not comply with the label conditions is illegal.

The two anticoagulant poison types most commonly used in conservation are diphacinone and brodifacoum. The choice for eradications is based on technical considerations that rank the advantages and disadvantages of the two poisons. Diphacinone is a first-generation anticoagulant. It is less toxic than the second-generation anticoagulant brodifacoum and requires more doses over a longer period of exposure to obtain the necessary lethal efficacy; it therefore limits non-target kills. Brodifacoum requires fewer doses to reach lethal levels, and therefore incurs greater non-target loss and other unintended consequences such as persistence in the environment. A non-anticoagulant, bromethalin, has also been used in a few island control and eradication projects. In the United States, a trend against brodifacoum and bromethalin use is appearing because of secondary poisonings of predatory birds (K. Swift pers. comm.).

The EPA has a risk model to assess the effects of pesticides. As is the case for all new pesticide labels, efficacy tests are required to show that the methods for delivery of the compound work on the target species, and also to show the effects of the compound on non-target animals, humans and the environment. Research money is needed for those tests, and maintaining a compound's registration also requires an annual fee. Rodenticides for conservation use are a very minor part of the market, and so only a few manufacturers financially support registration for conservation use. Ongoing dialogue with the EPA before and during the registration process is crucial to ensure that the final label is useable for wildlife managers, while also being protective of non-target species.

The EPA strictly regulates distribution for any type of rodenticide compound. Registration, or legal use, falls under the following categories defined in FIFRA:

A. Section 3: National Registration [e.g. Raid (SC Johnson, Racine, WI, USA)]

B. Section 24 C: Special Local Need

C. Section 18: Emergency Exemption

D. Experimental Use: Permit needed for the experimental application of a rodenticide over 10 acres.

Until recently, US eradications have used either the emergency exemption or loose interpretations of the commensal-use pattern which allows for placement of bait stations "in and around" buildings and other structures. The most important outcome of the 2000 "rat summit" in San Francisco was the decision by the Pacific Islands Fish and Wildlife office of the USFWS to pursue Section 3 labels for the control or eradication of rats on islands for conservation purposes. The USDA–Wildlife Services–National Wildlife Research Center in Fort Collins was contracted for this purpose and is the registrant for all of the national conservation labels. A diphacinone label was finalized and approved in December 2007. Two brodifacoum labels were also submitted to the EPA and are being reviewed.

Each state, territory, possession and commonwealth is responsible for adopting the national label and regulating its use (K. Swift pers. comm.). For example, Hawaii also has Section 24C registrations for diphacinone in bait stations and for hand and aerial broadcast of a larger 6.5-g pellet primarily for rainforest use, designed to ensure that the pellets are large enough to penetrate the dense canopy and reach the forest floor.

Additional regulatory compliance for rodenticide use in the United States requires consultation with the USFWS under Section 7 of the Endangered Species Act and either an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) in accordance with the National Environmental Policy Act. An example of how compliance coordination is critical comes from Hawaii, the state with the largest rodent control program for conservation purposes. USFWS coordinator Katie Swift works closely with all of the potential users and regulators. The USFWS, with the Hawaii Department of Agriculture, Pesticides Branch, are in the process of preparing a statewide programmatic environmental impact statement for their rodent control program and are conducting a Section 7 consultation under the Endangered Species Act to cover the national and Hawaii labels for Hawaii ESA species. Each agency in Hawaii will still have to undertake a small EA, tiered into the umbrella EIS, for specific projects on a case-by-case basis.

Each hand and aerial broadcast application in Hawaii will require prior review and approval from a panel consisting of the Pesticides Branch, the State Department of Land and Natural Resources, USDA–Wildlife Services and the USFWS coordinator. In addition, under Section 24C, Hacco, the rodenticide manufacturer, will accept bait orders only directly from USFWS or Wildlife Services for the Hawaii broadcast and from the USDA–Wildlife Services, Pocatello Depot, for the national label. All of these safeguards ensure that projects are designed and executed with the highest standards of safety to ensure the greatest chance of success.

Once registrations are in effect, responding immediately to a rat spill or another conservation emergency by spreading rodenticide will be legal. Aerial application techniques in the United States will also be facilitated, so that larger and larger islands can successfully be cleared of rodents.

**WHAT REMAINS TO BE DONE?**

The USFWS is compiling a list of potential sites and applicators, but an international master plan is needed to identify problems and opportunities, and to prioritize actions so as to efficiently marshal necessary resources for successful eradications. One of the more important sites is in American Samoa National Park on the island of Ta'u, the only US-managed nesting population of Tahiti Petrels *Pseudobulweria rostrata* occurs. Large-scale, high-elevation, remote, crab-infested tropical islands such as this will challenge the next generation of eradication practitioners.

Aerial broadcast of rodenticide may allow an island of any size to be a possibility, as long as ship assistance is available. Military vessels that carry helicopters are best suited to this type of remote work because flights may be used as training exercises. In isolated tropical areas (i.e. the rat, rabbit, and cat–infested Phoenix Islands of the Central Pacific Ocean), tuna ships often carry helicopters (but using them for bait dispersal or project logistics may be impossible). The complexity and expense of the logistics involved in such operations require extensive detailed planning and oversight if success is to be achieved. Failure translates into control, and instead of attempting eradication and failing, control alone might be more suitable in large, remote, high-latitude islands with wet cold weather, such as rat-infested Kiska Island, Alaska.

House Mice are the next frontier in rodent eradications. These small rodents require closer bait placement and have survived rodent eradications at Midway Atoll and elsewhere. Mouse eradication is contemplated for Southeast Farallon Island, California, a national wildlife refuge located in a national marine sanctuary, where mice may be affecting survivorship of Ashy Storm-Petrels *Oceanodroma homochroa.* Techniques will need to be fine-tuned for application of rodenticide at sub-Antarctic Gough Island (6734 ha), where giant carnivorous House Mice threaten the petrel populations with local extirpation (Angel & Cooper 2006).

Ants and crabs pose other challenges on tropical islands. Christmas Island in the Indian Ocean, Palmyra Atoll in the Central Pacific, and islets off Oahu have infestations of "tramp ants," several species of invasive ants that erupted once rodents were removed from the ecosystem. Ant control or eradication requires the use of pesticides that invariably poison native land crabs that are central to the ecosystem function of these islands. Crabs also challenge the ability to remove rodents through baiting. Crabs are not neophobic or bait-shy. Also, they are not subject to secondary poisoning, and like ants, they can consume bait in large quantities, thereby limiting access by the real target species. Bait stations designed to exclude hermit crabs are now on the market. One example, the Rat-Go (Marine Endeavours, Oakland, CA, USA) is shown in Fig. 8.

A developing alternative to control and eradication is selective eradication in bio-sanitized areas. "All-pest-proof" fencing was pioneered in New Zealand to preserve biodiversity hotspots by creating mainland islands. The Xcluder Fence (Xcluder Pest Proof Fencing, Cambridge, New Zealand; www.xcluder.co.nz/default.asp) is designed to prevent all animals from passing over or under. Once an area is fenced, all predators are removed and the conservation-dependent species are managed.

The first enclosure to be used in the United States is planned for the Kaena Point Natural Area Reserve on Oahu, in Hawaii. Laysan Albatross *Phoebastria immutabilis* and Wedge-tailed Shearwaters *Puffinus pacificus* nesting here on the main island are subject to feral dog attack as well as cat, rat and motor vehicle disturbance. Six endangered plants and the endangered Hawaiian Monk Seal *Monachus schauinslandi,* plus other seabirds, will find refuge in the 59-ha peninsula enclosed by 500 m of "all-pest" Xcluder fencing. Public access will be permitted through a set of double doors. Fencing is costly in the short term, about \$300 000 per kilometer versus ongoing rat control costs of \$81 200 per square kilometre. At Kaena Point, the approximate cost of predator removal and ongoing maintenance puts the breakeven point at 11 years (DLNR 2007). Funding for the predator-proof fence was obtained from USFWS in 2006 and is expected to begin in 2008. (L. Young pers. comm.). Another Hawaiian project under consideration will protect the Newell's Shearwater *Puffinus newelli* on the Island of Kauai from pigs, rats, cats and potentially Mongooses *Herpestes auropunctatus,* which may have already arrived on Kauai. Specifically, Limahuli Valley, Kauai, a very steep mountain valley, is a potential site for the Xcluder, because shearwaters, Hawaiian Petrels *Pterodroma sandwichensis* and Harcourt's Storm-Petrels *Oceanodroma castro* may all benefit.

Future techniques still under development are novel baits, anise-flavoured wax baits, improved bait stations and snap traps, and new rodenticides. Chemosterilants—synthetic rodent pheromones to create same-sex populations—are showing special promise. The identification of a sex-associated protein in the preputial gland of *R. rattus* offers the possibility of developing a pheromonal trap for rodent management in the future (Kamalakkannan *et al.* 2006).

**FUNDING**

All of these new approaches require a level of funding not previously available. Howald *et al.* (2007) speculate that cost and public acceptance may be the only limiting factors in eradicating any given species on any given-sized island. Large-scale eradications are likely to cost several millions of dollars and require a specific (non-operating budget) funding source. One such revenue source is fines levied after natural resource damage assessments (NRDA) from oil spills and other pollution events. The successful aerial-based eradication of Ship Rats at Anacapa Island was

**Fig. 8.** Rat-Go bait station (Marine Endeavours, Oakland, CA, USA) with Ship Rat *Rattus rattus* on Palmyra Atoll. Photo by A. Wegmann.

funded by the *American Trader* trustee council, consisting of the California Department of Fish and Game, the National Oceanic and Atmospheric Administration, and the USFWS. The eradication of Norway Rats from Rat Island (2800 ha), Alaska, may be funded in part from the fines levied on the *Selendang Ayu,* a freighter that wrecked in the Aleutian Islands and Alaska Maritime National Wildlife Refuge in 2004. This large and complex project, planned for late 2008, will be only the second US effort to broadcast the rodenticide brodifacoum from a helicopter. The proposed aerial House Mouse eradication on the Farallon Islands and a rat eradication project on the Queen Charlotte Islands, Canada, may also be funded by the California State Oil Spill NRDA funds from the *Luckenbach,* a sunken vessel that continues to leak oil off the coast of San Francisco.

Another revenue stream that may enhance control and eradication programs has recently been proposed. Compensatory mitigation is a novel means of "taxing" fisheries for an expected level of bycatch mortality of seabirds, the money from which would then be used to create predator-free habitats where the birds can flourish on land. Wilcox and Donlan (2007) evaluated the potential costs and benefits using the case study of Flesh-footed Shearwater *Puffinus carneipes* bycatch in Australia's Eastern Tuna and Billfish Fishery. They concluded that a bycatch tax, in conjunction with direct mitigation efforts, are an efficient, enforceable, and cost-effective (if controversial) approach to aid seabird conservation. The proposed tax is consistent with the Convention on Biological Diversity, in that offsets would not replace direct mitigation or avoidance; rather, they would be used to address residual bycatch under the hierarchy of "avoid, mitigate, offset" (Donlan & Wilcox 2008).

Finally, the David and Lucile Packard Foundation has changed the landscape of seabird conservation. Packard is a significant new funding source for high–conservation priority island restorations (B. Heneman pers. comm.). For example, Island Conservation recently received a $575 000 grant from Packard to develop plans and infrastructure to support their future growth. With the arrival of large private funding comes new "analytical decision-support tools to develop investment schedules to maximize cost-effective conservation benefits" (Donlan & Heneman 2007). A return-on-investment analysis for invasive mammals could be integrated with a similar analysis for seabird bycatch with the goals of assessing conservation strategies within a single framework.

## ETHICS

With the success achieved by eradications, animal rights groups and agencies charged with oversight of animal research have brought greater scrutiny to eradication programs. Even in New Zealand, resistance by the public to introduced predator control and eradication campaigns has grown since the late 1980s. The United States has its own suite of legal and regulatory complications as outlined earlier, but in addition, animal rights committees at universities limit the tools used for eradications by groups associated with the university, in consideration of humane treatment of target animals.

According to US federal law, institutions that use laboratory animals for research or instructional purposes must establish an institutional animal care and use committee (IACUC) to oversee and evaluate all aspects of the institution's animal care and use program. The IACUC ensures that regulations are followed, often affecting research into control efficacy at universities and affiliated institutions. Killing in the name of conservation must be justifiable, humane and approved. Although admirable in intent, the implementation of such regulations is inconsistent and may postpone conservation actions to the extent that vulnerable species or populations needlessly decline.

IACUCs are located at universities where animal research is conducted. Here, more subtle impediments to conservation may be found: the inherent tension between research and management. In real-world terms, it means the relatively few conservation dollars to aid a species are funnelled into studying the problem rather than to aggressively eliminating the source of the problem. In the financially limited restoration environment, there is a balance to be struck between having enough information to eliminate a threat and seeking new insights into how a threat functions in the ecosystem. Adaptive management based on concurrent research and management action has been one answer to this creative tension.

## CONCLUSION

The past few decades have been a period of tremendous progress in the field of predator eradication to regenerate seabird populations. The present paper focused on rodent eradications, but similar progress has been seen with other invasive plants and animals: examples include the eradication of *Cenchrus* grass from Laysan Island; cat removal from the equatorial US possessions; pig removal from Clipperton Atoll; rabbit eradication in the Farallon Islands and from Lehua, Hawaii; donkeys and burros removed from Mexican Islands; and pigs, goats and sheep removed from the Channel Islands in California and goats from two of the largest islands in the Galapagos archipelago are just some of the success stories during the period (Rauzon 1985, Donlan & Heneman 2007, Donlan & Wilcox 2008). No estimates of the number of seabirds created by eradication programs exist, but hundreds of thousands is a reasonable assumption, and future gains are likely to be much larger.

Practitioners of predator eradication have benefited from information exchanges generously begun by New Zealand specialists and later transmitted through the expanded networks of the PSG, including federal agencies and nonprofit organizations. Failures and setbacks have been used to improve both the technical and the regulatory aspects of the US rodent control and eradication program. Even so, it is important to recognize that all parameters can never be known, that adaptive management is essential and that unintended consequences will occur regardless of planning. Large, complex ecologies support almost infinite relationships between predators, prey and primary producers, that are impossible to predict and (especially) to manage.

Each eradication program has moments when the target presents itself and its time to take the best shot, or to risk a miss and a failed eradication. For success to happen, boldness of vision and action are necessary. At the heart of the practice of eradication is a motivation to selectively manage certain species over others, and weeding the garden, in and of itself, will always lead to conflicts of values. Anthropocentric emotional attachment to familiar species will pose obstacles to practitioners, manifesting themselves in a decreased flexibility in the means of eradication, the timing and the location. Eradication and control are attempts to return to an earlier stage of environmental evolution, before landscapes were invaded, and as such, they buck the dominant trend of globalization. During the last 20 years, the world's human population has increased

34%, and trade is almost three times greater, thus increasing the risk of spreading invasive species to more islands (UNEP 2007). With the increasing movement of goods and the rats (and diseases) they may carry, seabirds are more vulnerable than ever before. To maintain the considerable strides that have made in global seabird conservation, all avenues for funding, advocacy, communication and action must continue to be promoted.

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