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Maximizing Return on Investments
for Island Restoration with a Focus
on Seabird Conservation

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A Report Prepared for the
Commonweal Ocean Policy Program

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EXECUTIVE SUMMARY

Seabirds are among the most threatened groups of species. Seabirds are an important component of both marine and island ecosystems, and thus their conservation is inextricably linked with marine and island conservation. Invasive mammals are the major drivers of extinction and ecosystem change on islands and are the primary threat to seabirds. Three types of evidence suggest that the removal of invasive mammals from islands is an effective strategy of seabird conservation. First, impacts on seabirds by invasive mammals are pervasive and well documented, particularly for rats and cats. Second, over the past two decades, techniques have been developed and honed to safely, swiftly, and cost-effectively remove invasive mammals from islands. Emerging innovations in the removal of invasive mammals support the notion that island size will soon no longer be a limiting factor. Third, while seabird responses to invasive mammal removal campaigns are less well documented, available evidence demonstrates those responses to be consistently positive. In sum, evidence suggests that invasive mammal removal from islands can be a low-risk investment that routinely results in substantial seabird conservation gains. Integrating invasive mammal removal campaigns with other seabird restoration programs, such as seabird social attraction and translocation techniques, would likely increase conservation benefits. As conservation practitioners target larger and more biologically complex islands, they will face three main challenges: 1) minimizing impacts on non-target native species during invasive mammal removal campaigns; 2) increasing the cost-effectiveness of those campaigns; and 3) securing necessary social and economic capital. A research program targeted to address the first two points that is integrated into an active invasive mammal removal program will enhance conservation gains for a global or regional island restoration program.

Island restoration, like other sub-disciplines of biodiversity conservation, is in the early stages of adopting approaches such as return on investment (ROI) analysis. Doing so will increase effectiveness. A ROI analytical framework is a decision-support tool not a decision-making tool—it aims to help planners make decisions, not exempt them from applying judgment. A ROI approach to planning provides transparent guidance on how to allocate funds across a portfolio of potential actions over any span of time, and can serve as a foundation for a seabird conservation program that is flexible, modular, and scalable. While many aspects of seabird conservation are well known relative to other conservation scenarios, significant information gaps mean that estimates of both impacts and the benefits from abating those impacts will lack precision. Despite those gaps, sufficient information is currently available to proceed with a ROI analysis for global and regional priorities for invasive mammal removals. Further, uncertainty and lack of information can be explicitly incorporated into the ROI analysis and augmented by experience-based knowledge in the later stages of the process. Pragmatic constraints and opportunities can and should be built into the framework. By investing in an analytical prioritization process that focuses on return on investment, a global seabird conservation program will maximize conservation benefits and do so in the most cost-effective way possible.

INTRODUCTION

While conservation practice has matured as a field over the past four decades, justifications for proposed actions are still largely experience-based as opposed to evidence-based. Conservation practitioners, much like public health professionals, must often make decisions with a limited amount of reliable information. However in contrast to the public health sector, systematic monitoring, evaluation of effectiveness, and communication networks between researchers and practitioners are still rare and inefficient in conservation practice. That picture has begun to change in recent years. Planners and practitioners are beginning to embrace operating frameworks similar to the “effectiveness revolution” in medicine and public health. Rather than ignoring the economics of conservation practice, the conservation sector is beginning to adopt approaches such as return on investment (ROI) analysis.[1]

Island restoration, like other sub-disciplines of biodiversity conservation, is in the early stages of adopting those new approaches. Not embracing evidence-based approaches is a precarious strategy. Ignoring the economics of biodiversity conservation is acting as if money is no object. Adopting evidence-based and ROI approaches will increase effectiveness and transparency. Global reviews are emerging that synthesize island biodiversity impacts by invasive mammals (the main threat to island ecosystems) and the current state of invasive mammal removal techniques.[2] Largely absent, however, are systematic reviews of biodiversity responses to invasive mammal removal campaigns and discussions of maximizing return on investment. Economic costs are often ignored.[3]

Despite a lack of precise information and evidence regarding many aspects of island restoration, evidence-based and analytical return on investment frameworks will benefit island restoration programs. ROI approaches to planning, from which this report borrows, provide transparent guidance on allocating funds across a range of potential actions. **Those tools and frameworks are decision-support systems not decision-making systems—both disciplines aim to help planners make decisions, not exempt them from applying judgment.**

Box 1. **Island Restoration.** The majority of historical bird and mammal extinctions has occurred on islands and was caused by invasive (non-native) mammals.

Invasive Species Removal: the complete removal of invasive animals or plants.
Social Attraction: the use of seabird decoys and audio-playback of recorded colony sounds to encourage the passive recolonization of seabirds.
Species Reintroduction: the active introduction by humans of extirpated native species using techniques such as egg or chick translocation.

This report focuses on invasive mammal removal—the first step in island restoration.

The objective of this report is two-fold: 1) to review the evidence that the removal of invasive mammals from islands is an effective strategy for seabird conservation, and 2) to identify the opportunities, challenges, and research needs for developing a ROI analysis framework for an island restoration program focused on seabird conservation. We emphasize two steps of such a program: evidence and prioritization. We describe a path to a ROI prioritization framework in the second part of this report. First, we review the evidence on which those conservation strategies will be based.

PART I: THE EVIDENCE

Islands, Invasive Mammals, And Seabirds

Seabirds are among the most threatened group of species: 35% of the 341 species are at risk of extinction according to the World Conservation Union.[4] This is of global conservation concern, particularly since seabirds play keystone roles as apex predators in marine ecosystems and influence the ecology of terrestrial ecosystems where they breed. The overwhelming majority of seabirds breed on oceanic and coastal islands. Those ecosystems are threatened by invasive species. For example, predation by invasive rats, which are present on over 80% of the world's islands, is responsible for at least 50 global extinctions and many more local extinctions and population declines of native species.[5] Rats and other invasive mammals are the major drivers of extinction and ecosystem change on islands (Box 2). Likewise, they are the premier threat to seabirds, followed by fisheries interactions and habitat degradation.[6]

Tremendous progress has been made over the past two decades in the ability to restore island ecosystems by removing invasive mammals.[7] Twenty-five years ago, New Zealand conservationists were struggling to remove rats from islands the size of a football field. In 2002, they removed rats from an island the size of 16,000 football fields. That removal campaign on Campbell Island was run so efficiently that it serves as a national case study for innovation in the public service.[8] Halfway around the world, invasive mammal removals are taking place that were deemed impossible a decade ago. Goats were recently removed from two of the largest islands in the Galápagos archipelago. Those campaigns were swifter and more cost-effective than ever before: over 160,000 goats were removed from the two islands in less than five years for ~$18 per hectare.[9] Other practitioners have developed techniques to mitigate non-target impacts (i.e., native species susceptible to the toxins used to remove invasive rats), which have facilitated successful invasive rat removals on islands with native mammals.[10] From many perspectives, the bar for invasive mammal removal has been raised by magnitudes. Further, pre-removal impact and post-removal recovery studies are accumulating and support the alleged biodiversity benefits of removing invasive mammals from islands.

Consequently, the removal of invasive mammals from islands is one of society's most powerful tools for preventing extinctions and restoring ecosystems. Yet, outside of New Zealand and Australia, invasive mammal removals remain in the shadows of biodiversity conservation practice.[11] Policy makers and on-the-ground practitioners are uninformed of the current technology and techniques available to tackle this biodiversity threat. Few are aware that rats have been removed from an island the size of Washington D.C. and goats from an island the size of Rhode Island. At the same time, awareness of the impacts of invasive species has exploded over the past decade, creating significant research programs and opportunities (e.g., the U.S. government spent $635 million on invasive species in 2000). Yet, relatively few resources have been invested in actively removing invasive mammals from islands. Despite this, recent successes in invasive mammal eradications have sparked interest in a global strategy for island restoration.[12]

In this section, we review the available evidence for invasive mammal removals as an effective strategy for seabird conservation. We ignore other threats to seabirds (e.g., fishery interactions) and any integration of actions to abate those threats with invasive mammal removal strategies.[13] Our primary aim is to objectively present the evidence that supports invasive mammal eradications as

Box 2. Invasive mammals and their impacts on island biodiversity

Invasive Predators: Rodents (black, Norway, and Pacific rats, and house mice), feral cats, and mongooses have decimated endemic rodent, reptile, and bird populations, and extirpated seabird colonies on islands around the globe.


An Atlantic petrel that has been preyed upon by house mice

Invasive herbivores: Feral goats, rabbits, and donkeys have caused wholesale changes on island plant communities, as well as secondary impacts to animal populations via habitat degradation.


Goats overgrazing on Isabela Island, Galápagos

Feral Pigs, which are omnivores, feed on island plants, prey on island vertebrates, and raid nests of birds and sea turtles.

Box 3. Hierarchy of quality of research evidence adopted from public health sector[15]

Category I: strong evidence obtained from properly designed randomized controlled trials of appropriate size.
Category II-1: evidence obtained from well-designed controlled trials without randomization.
Category II-2: evidence obtained from well-designed case-controlled analytic studies.
Category II-3: evidence obtained from multiple time series or from dramatic results in uncontrolled experiments.
Category III: opinions of respected authorities based on descriptive studies, or reports of expert committees.
Category IV: evidence inadequate owing to problems of methodology.

a cost-effective intervention for seabird conservation. Such evidence has been accumulating over the past decade. For example, 201 seabird colonies were protected in western Mexico by removing invasive mammals from 26 islands for an average cost of $21,615 per seabird colony.[14] The more important question that follows—what strategies will maximize the effectiveness of invasive mammal removals as a seabird conservation tool?—requires in-depth analysis (see Part II). We present three types of relevant evidence. First, we review the evidence that invasive mammals affect seabirds. Second, we review the current state of removing invasive mammals from islands. Third, we review documented seabird responses to invasive mammal removal campaigns.

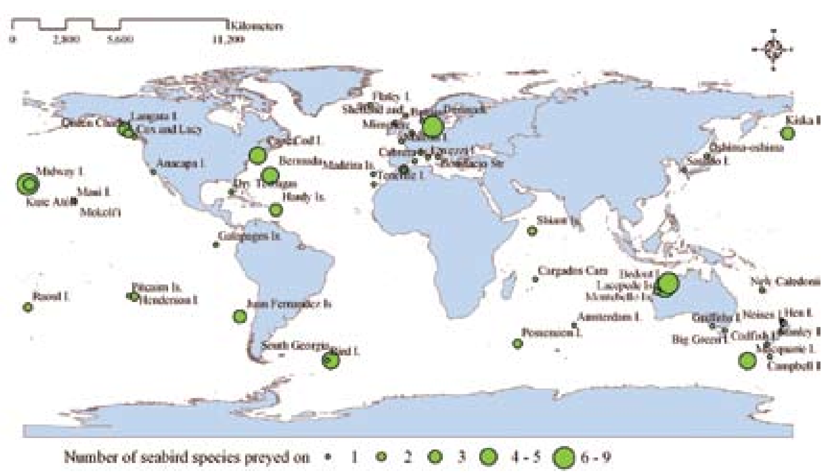
There is a growing body of evidence that invasive mammals have deleterious effects on seabirds; however, the majority of the evidence falls under Categories II-2, II-3, III, and IV (Box 3).[15] Compared to evidence of seabird impacts, data on seabird responses to invasive mammal removals is generally rarer and of poorer quality. However, the evidence is sufficient to predict the direction (positive)—but not the magnitude with a high degree of precision—of seabird responses to invasive mammal removal campaigns.

Impacts Of Invasive Mammals On Seabirds

Impacts on seabirds by invasive mammals are pervasive and well documented. The quality of evidence, however, varies among the species of seabird and invasive mammal. That evidence comes largely from observational and impact studies, along with impressive correlations between the presence of invasive predators and local, and to lesser extent global, seabird extinctions (Box 4). Indirect impacts on seabirds, both via habitat degradation from invasive herbivores and synergistic interactions, remain largely circumstantial and theoretical.[16]

Invasive Rodent Impacts: Direct predation on eggs, chicks, and adults by rodents are the most commonly reported seabird impacts by invasive mammals. There have been three global reviews on the biodiversity impacts of invasive rodents on islands over the past twenty years, including one that focuses exclusively on seabirds.[17] Atkinson collated data where the presence of rats on 29 islands precipitated major declines or extinctions of birds, including many seabird populations (however, the evidence is confounded since other invasive mammals were often also present on the islands). More recently, Towns and colleagues reviewed the evidence for biodiversity impacts of the three species of invasive rats in island ecosystems. They concluded that all three species "suppress some forest plants, and are associated with extinctions or declines of flightless invertebrates, ground-dwelling reptiles, land birds, and burrowing seabirds." The authors documented negative effects by invasive rats on at least 170 species of plants and animals on over 40 islands, including at least 50 extinctions.

Figure 1. Locations of rat-seabird impact studies reviewed by Jones et al. in press. Quality of evidence varies. Reproduced with permission.



A recent systematic review of the seabird and invasive rat literature provides some utility for assessing and characterizing impacts. Jones and colleagues collate 81 studies that report on the effects of rats on seabird populations, which included 69 seabird species from nine families (Figure 1). From a formal meta-analysis that combined objective and subjective data, the authors concluded that seabirds from the storm-petrel family and other small, hole-nesting species with long egg incubation times were most affected by invasive rats. They also noted a lack of experimental studies, particularly in tropical environments, and a general lack of information on the impacts of rats for a number of seabird families.[18]

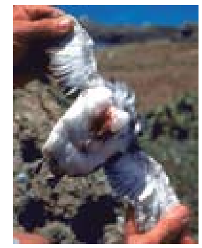
Impacts on seabirds by house mice have been less studied compared to invasive rats, and have often been thought to be negligible. However, a recent study in the South Atlantic Ocean suggests the contrary. Researchers on Gough Island (South Africa) recently documented house mice attacking and killing seabird chicks up to 300 times their mass, including Tristan Albatrosses and Atlantic Petrels. Mouse-induced mortality was a major contributor to record low breeding success for both species. House mice mortality on Wandering Albatross on Marion Island (South Africa) has recently been suspected.[19] On the Farrallon Islands (USA), seabird biologists suspect that house mice are playing an indirect role in the decline of Ashy Storm-petrels by acting as a winter food source for Burrowing Owls, which prey on seabirds in other seasons.[20]

Box 4. Examples of global* and local seabird extinctions driven by invasive predators (rats, cats, and mongooses).

Rhinoceros Auklet
Haidi Gwaii Island, Canada

Tufted Puffin
Langara Island, Canada

Cassin's Auklet
Coronado, San Roque, Asuncion Islands, Mexico



Fork-tailed Storm-petrel
Haidi Gwaii Island, Canada

Guadalupe Storm-petrel*
Guadalupe Island, Mexico

Leach's Storm-petrel
Coronado Island, Mexico

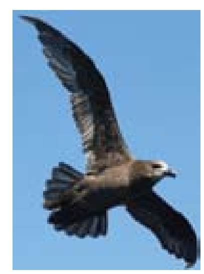
Antarctic Tern
Macquarie Island, Subantarctic

Manx Shearwater
Canna Island, Scotland

Great-winged Petrel
Saint-Paul Island, Subantarctic

Jamaica Petrel*

Common Diving-petrel
Marion Island, Subantarctic



Feral Cat Impacts: Feral cats have also had devastating impacts on island biodiversity. Due to their opportunistic diet, cats prey on a variety of mammals, reptiles, birds, and insects. Feral cats are responsible for many local (and global) bird and mammal extinctions on islands, including the Guadalupe Island Storm-petrel.[21] Cat predation impacts on seabird populations are well documented, particularly on subantarctic islands. Certain impact studies where researchers have estimated island-wide cat mortality have become entrenched in the literature and are highly cited; most commonly, feral cats killing 58,000, 450,000, and 1.2 million seabirds annually on Macquarie, Marion, and Kerguelen Islands respectively.[22] While those estimates are likely inflated due to the increasing evidence that feral cat foraging ecology is spatially and temporally variable (and often influenced by the presence of alternative prey)[23], more recent studies have reaffirmed the notion that cats can heavily affect seabird populations. For example, on Natividad Island (Mexico), empirical data combined with demographic modeling suggests that every 20 cats preying on the islands' breeding colony of Black-vented Shearwaters depresses the annual growth rate by ~5%.[24]

There is no systematic review of feral cat impacts on seabirds. A global review of feral cat diet and impacts on island ecosystems is underway; unpublished analyses suggest that feral cats prey on the full range of seabird sizes and life stages.[25] From the literature, it is clear that feral cat impacts on seabirds can be significant and variable.[20] For example, the same study that estimated feral cats killing 47,000 Antarctic Prions and 11,000 White-headed Prions on Macquarie Island (Australia) detected no cat impacts on the 24 additional seabird species that breed there. Cats have been reported preying on Rockhopper Penguins on Kerguelen Island but not Macquarie Island, and on both islands invasive rabbits make up ~¾ of the cats' diet. A recent observation suggests that the impacts of feral cats can also vary over time on a single island. Laysan Albatross colonized Guadalupe Island (Mexico) in 1983, and since then the colony has been growing exponentially. Feral cat predation was first recorded in 2002 when cats killed 35 of the 490 adults – which subsequently tripled the colony's nesting failure rate. The lack of cat predation observations prior to 2002 and following an intensive, localized cat control program suggests that individual cat(s) may have learned to prey on Laysan Albatross.[26] While those observations and theoretical work support the hypothesis that alternative prey and behavioral cues play important roles in the potential impact of cats on seabird populations, until comparative, synthetic, and experimental evidence becomes available, it will be difficult to predict the magnitude of impact with high precision.[27]

Mongoose Impacts: While there is little empirical or experimental evidence of mongoose impacts on seabirds, observational and anecdotal evidence suggests they can be significant. Published mongoose diet studies suggest birds make up a small percentage of invasive populations' diet. However, feeding trails demonstrate that mongoose will prey on bird eggs.[28] Mongooses are thought to have played a role in the extinction of the Jamaica Petrel. Similarly, mongooses are widely suspected to have played a role in the demise of many Hawaiian birds, including the Hawaiian Petrel and Newell Shearwater. In most cases, documentation is lacking, and in all cases the interaction is confounded by the presence of additional invasive predators. For example, a recent comparison study of Wedge-tailed Shearwater colonies on O'ahu Island (Hawaii) suggests cats, rather than mongooses, are responsible for depressed breeding success.[29] However, at least two studies have documented mongooses preying on Hawaiian Petrels. On Maui Island, a mongoose control program increased Hawaiian Petrel breeding success from 39% to 66% and reduced observed predation rates from 34% to 3%.[30]

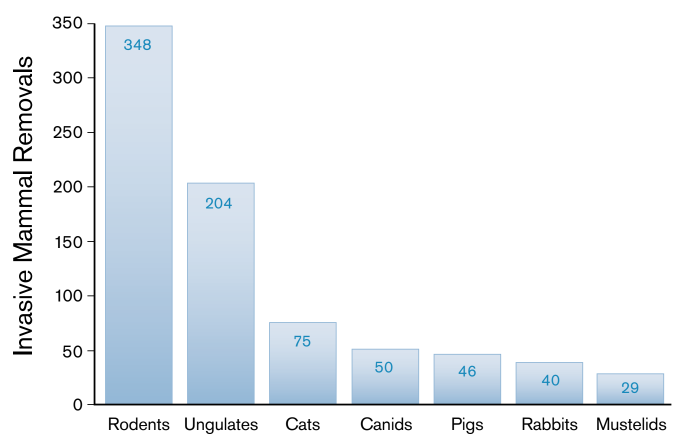
The introduction of foxes to the Aleutians Islands (USA) precipitated wholesale declines of nesting seabird populations. Historical records, including descriptive accounts by Olaus Murie, chronicle those declines. Many seabird colonies were completely extirpated by fox predation.[31]

On islands where macaques have been introduced and subsequently studied, they have had negative impacts on seabirds. Bird predation by macaques appears to be primarily on eggs, but chicks are also likely to be at risk and attacks on adults have been documented. On Desecheo Island (Puerto Rico), rhesus macaques, possibly in combination with black rats, have extirpated at least seven seabird colonies including the largest Brown Booby colony outside the Pacific Ocean basin.[32]

There is little reliable evidence that invasive herbivores commonly impact seabird populations. Anecdotal observations suggest, however, that impacts occur. Several researchers have reported or suspected European rabbits, goats, and other herbivores having negative impacts on nesting seabird populations via competition for nesting burrows and material (rabbits only) and a variety of forms of habitat degradation (e.g., overgrazing and burrow destruction).[33] Recent observations of European rabbits ejecting shearwater eggs from occupied burrows on the Juan Fernández Islands (Chile) suggest that they may compete with seabirds for burrows.[34] There is some evidence to suspect that rabbit populations can have indirect impacts on seabirds by acting as a primary year-round food resource for feral cat (and possibly rat) populations. This has been hypothesized by a number of researchers; anecdotal observations, natural history, and theoretical modeling are consistent with the notion that this dynamic – termed hyperpredation – may occur on islands.[35]

Feral pig impacts on seabirds are commonly reported; however, the evidence is largely observational and anecdotal.[36] On Clipperton Island, feral pigs reduced a population of thousands of Masked and Brown Boobies to 150 and 500 individuals respectively in less than 60 years. On Clarion Island (Mexico), pigs extirpated a breeding colony of Townsend's Shearwaters[37]; a single breeding colony of this species remains on the neighboring island of Socorro, where it is threatened by feral cat predation. Pigs have been reported feeding on adult and juvenile Galápagos and Hawaiian Petrels, as well as White-capped Mollymawks on Auckland Island (New Zealand). Anecdotal historical evidence suggests that feral pigs might have played some contributing role, along with other invasive mammals and man, in the decline of a suite of seabirds on Auckland Island; recent comparative research on the island in breeding colonies with and without pigs support the hypothesized impacts.[38] Feral pigs are opportunistic and generalist with respect to diet, and thus seabird impacts are likely to be variable and influenced by available prey. Diet studies support this: some birds (including Antarctic Prions) occur in small percentages in pig feces on Auckland Island, while seabirds were not recorded in pig diet studies on Santiago Island (Galápagos). Yet, pigs have been reported preying heavily on Galápagos Petrels on other islands in the Galápagos archipelago.

Figure 2.
Number of successful invasive mammal removals worldwide.



Removal Of Invasive Mammals From Islands

There have been close to 800 successful invasive mammal removals from islands. The number of successful removals and the current state of practice varies depending on the target species and the local environment (Figure 2).[39] Rodents and goats make up the majority of removal campaigns, while campaigns targeting rabbits, pigs, and mustelids (i.e., weasels, ferrets, minks, and stoats) are rarer. Lack of reporting on eradication campaigns, particularly failures, is problematic for systematic evaluation. However, estimated global failure rates are less than 20% and declining (with the exception of mongooses and monkeys; Table 1). Details of removal campaigns and economic costs are still largely absent from the literature. However, a number of recent global reviews characterize the current state for some target species.

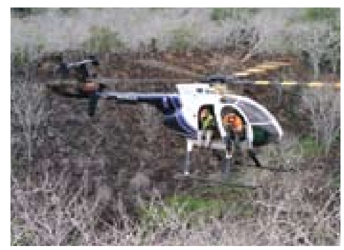
Invasive Rodent Removals: Worldwide, there have been 332 successful invasive rodent removals since systematic techniques were developed over two decades ago in New Zealand. A systematic review also identified 35 failed eradications and 20 campaigns of unknown result due to lack of monitoring.[40] Rats are removed from islands using a controlled application of rodenticide. Helicopters have become the most common method used to distribute rodenticide due to their cost-effectiveness; however, the method of distribution should be chosen based on a number of factors.[37] Based on tested protocols and previous successes, a multi-author review recommended that "land managers should routinely remove invasive rodents from islands <100 hectares that lack [native] vertebrates susceptible to non-target poisoning. For larger islands and those that require non-target mitigation, expert consultation and greater planning effort are needed."

Feral Cat Removals: Feral cats have been removed from 75 islands worldwide.[41] Trapping and hunting are the most commonly used methods in cat removal campaigns. The largest cat eradication to date was on Marion Island (29,000 hectares); however, the campaign lasted over 15 years and thus is likely of limited utility for planning a systematic island restoration program. The majority of cat eradication campaigns have been on islands less than 500 hectares; cats have been removed from only 10 islands larger than 1,000 hectares. Two recent campaigns, however, suggest that swift and large-scale cat removals are possible.[42] Cats were removed from Baltra Island (Galápagos) in less than three years for $61,000 using a systematic poisoning effort followed by trapping and hunting. Applied research in Western Australia is the most promising for scalable approaches. Using specially designed poisoned baits, cats were removed from Faure Island (5,200 hectares) in less than a year using an aerial baiting campaign and subsequent ground baiting, trapping, and monitoring programs. Using those same techniques, a 58,000 hectare island in Western Australia is now being targeted (Table 2).

Box 5. Recent large-scale, complex, and swift invasive removal campaigns

Campbell Island, New Zealand
Norway rats were removed from this large (11,300 hectares), remote island in three years for ~$1.7 million.

Santiago & Isabela Islands, Galápagos
Using a suite of techniques, ~79,000 goats were removed from Santiago (58,465 hectares) in less than 4 years for $5.8 million. Goats were removed (concurrently) from Isabela (~59,000 goats; 458,812 hectares) in less than 3 years for $3.5 million.



Santa Cruz Island, USA
~5,000 pigs were removed from this 24,900 hectare island using a suite of techniques over a period of 15 months of on-the-ground hunting activity.

Anacapa Island, USA and Barrow Island (and adjacent islands), Australia
Black rats were removed from these islands, where the presence of native mammals and birds of prey, both of which were susceptible to the rodenticide used, made these campaigns challenging and complex. A suite of mitigation techniques was developed and successfully implemented.

Other Invasive Mammal Removals: Feral goats have been removed from 129 islands, while sheep, deer, and equids (and cattle) have been removed from at least 17, 2, and 25 islands respectively.[43] Significant progress has been made in the ability to cost-effectively remove ungulate populations from large islands over the past decade (Box 5). During goat removal campaigns in the Galápagos Islands, an adaptive management framework based on a Geographic Information System was developed, along with new eradication techniques.[44] Both kill per unit effort and economic costs were closely tracked during those campaigns; this systematic bio-economic data collection should facilitate more cost-effective removal strategies for goats and other ungulates.

Unlike for rodents, cats, and goats, there is no systematic review of pig removals. There have been at least 46 successful campaigns.[45] Two recent projects demonstrate that large-scale, swift pig removals are possible.[46] After 25+ years of sporadic control programs, pigs were removed from Santiago Island (Galápagos) using a combination of ground hunting and poisoning techniques. More recently, ~5000 pigs were removed from Santa Cruz Island (USA)

Table 1.
Invasive mammal removals successes, failures, and the largest campaign to date.

Speices	Successful Removals	Failures (%)	Largest Island (ha)	Ref.
Black rat	159	15 (8%)	Hermite, Australia (1,022)	1
Norway rat	104	5 (5%)	Campbell, New Zealand (11,300)	1
Pacific rat	55	6 (10%)	Hauturu, New Zealand (3,083)	1
House mouse	30	7 (19%)	Enderby, New Zealand (710)	1
Goat	129	11 (8%)	Isabela, Ecuador (458,812)	2
Pig	46	1 (2%)	Santiago, Ecuador (58,465)	3
Cat	75	7 (9%)	Marion, South Africa (29,000)	4
Mongoose	4	2 (33%)	Fajou [Guadeloupe], France (115)	5
Monkeys	0	6 (100%)		6

References: 1. Howald et al. 2007; 2. Campbell & Donlan 2005; 3. Campbell & Donlan unpublished data; 4. Nogales et al. 2004; 5. Hanson 2007; 6. Campbell 2007

in fifteen months using specialized aerial hunting techniques (Box 5). European rabbits are present on at least 800 islands worldwide.[47] Rabbits have been removed from a number of islands (>40); however, removal campaigns have not been systematically reviewed. The techniques used include hunting and poisoning.

Trappers have removed invasive foxes from the majority of the Aleutian Islands (40 islands totaling over 500,000 hectares), where they were once widespread.[48] Despite their suspected high biodiversity impacts, there have been only six mongoose removals, of which two campaigns failed (all campaigns have been < 115 hectares). There have been a small number of other mustelid removals. Invasive monkey populations are present on at least 53 islands; there have been six reported monkey removal campaigns—all have failed.[49] Systematic reviews on removal campaigns are needed for pigs, rabbits, mustelids, canids, and monkeys.

Current State of Invasive Mammal Removals on Islands: A small number of large-scale invasive mammal removal campaigns over the past five years have contributed to a new emerging model for island restoration (Box 5). There is growing evidence to suggest that invasive mammals can be safely, swiftly, and cost-effectively removed from large islands. In fact, recent successes indicate that island size may no longer be limiting for the removal of species such as goats, pigs, and Norway rats. However, island size still appears to be a limiting factor for the removal of other invasive mammals such as house mice. Nonetheless, emerging innovations support the notion that island size will soon no longer be a limiting factor for invasive mammal removals (Table 2).[50] On that assumption, island conservation will face three main challenges as practitioners target larger and more biologically complex islands often with human inhabitants: 1) mitigating for impacts on non-target species; 2) increasing the cost-effectiveness of eradication campaigns; and 3) securing the necessary social and economic capital. Research targeted to address the first two points will enhance conservation benefits from a global or regional island restoration program.

Applied research on non-target species is needed. On tropical islands, ants and land crabs, though not affected by toxins used in removal campaigns, compete for bait with invasive rodents and cats. This is currently limiting the conservation potential of rat and cat removal programs in tropical environments. Some research is already underway to develop more methods to dispense poisoned baits selectively to target species.[51] Likewise, more research is needed on developing techniques to mitigate for undesirable impacts on non-target species during removal campaigns (i.e., native mammals, granivorous birds, and birds of prey).[52] The need for sound mitigation techniques will be increasingly important as practitioners target larger islands for restoration.

Economic reporting needs to become commonplace. Economic costs were reported for only 12% (n = 47) of the known rodent campaigns, and those reported costs vary in their inclusiveness.[48] Researchers need to develop eradication-costing models with input from on-the-ground practitioners. A small group of practitioners have

Table 2.
Innovation over the past two decades in the ability to remove invasive mammals from large islands. The largest eradication (in hectares) in the 1990s, 2000s, and currently planned.

Target Species	1990s	2000s	Planned
House mouse	710 Enderby, New Zealand	219 Frégate, Seychelles	12,800 Macquarie, Australia
Pacific rat	1,965 Kapiti, New Zealand	3,083 Hauturu New Zealand	
Black rat	800 St. Paul, France	1,022 Hermite, Australia	12,800 Macquarie, Australia
Norway rat	3,105 Langara, Canada	11,300 Campbell, New Zealand	27,800 Kiska, USA
Cat	29,000 Marion, South Africa	12,800 Macquarie, Australia	58,640 Dirk Hartog, Australia
European rabbit	1,421 Deserta Grande, Portugal	3,450 Norfolk, Australia	12,800 Macquarie, Australia
Goat	21,853 Santa Rosa, USA	458,812 Isabela, Ecuador	171,617 Galapagos archipelago (in progress)
Pig	21,118 Santa Catalina, USA	58,465 Santiago, Ecuador	45,975 Aukland, New Zealand

become adept at costing complex eradications, and thus general models could be developed as decision-support tools (see Part II).[53] Lastly, bio-economic models and new technology that focus on removing the last individuals is needed. For many invasive mammals, removing the majority of an island population is relatively inexpensive and straightforward, and removing the last individuals is expensive and challenging. Tools focused on efficiently removing those last individuals would significantly decrease the duration of invasive mammal removal campaigns and make them more cost-effective.[54]

Seabird Responses To Invasive Mammal Removals

Seabird responses to invasive mammal removals are rarely thoroughly documented, particularly when compared to impact studies. A positive seabird response is arguably the highest quality of evidence in support of invasive mammal removal as an effective seabird conservation strategy. Suspected impact of magnitude X may not necessarily translate into benefits of magnitude X. For example, the removal of cats from Huaturu Island (New Zealand) had a negative impact on Cook's Petrels because the population of Pacific rats, which cats preyed on, increased and subsequently had a greater impact on the seabird population.[55] Similarly, removing invasive mammals from islands where seabirds have been extirpated does not guarantee that seabirds will return.

In some cases, practitioners employ social attraction to aid in the seabird recolonization process.[56] While progress is being made in social attraction and translocation techniques for seabird restoration, those tools have not been systematically integrated with invasive mammal removal campaigns nor have their cost-effectiveness and programmatic potential been evaluated. Systematically integrating seabird colony restoration techniques with removal campaigns would likely increase conservation benefits. Nonetheless, the evidence available suggests that invasive mammal removal alone can be a low-risk investment that routinely results in seabird conservation benefits. However, due to lack of adequate seabird response studies, it is not yet possible to predict responses to invasive mammal removal with high precision.

Responses to Rodent Removals: Seabird responses to rodent removals are the most documented: there are at least 40 documented responses for 23 seabird species reported in the literature. There are a few reports of no or minimal seabird response following rat eradication; some of them are confounded by the presence of other invasive mammals.[57] The majority of the responses, however, are consistently positive. For example, on Ille de Possession (Crozet Islands), White-chinned Petrel breeding success increased to an average of 50% with intensive rat control compared to an average of 15% in the previous 16 years.[58] Documented responses vary widely in the quality of evidence presented.[59] Nonetheless, impressive conservation benefits are common, often within a short time period following a rat removal campaign. Table 3 provides some examples of such studies where breeding (or hatchling) success or nest predation were measured as the response variable before and after a rat eradication campaign. Other evidence includes increases in population estimates and recolonization of seabirds following the removal of invasive rodents (Box 6). For example, breeding populations of Mew Gulls, Arctic Terns, and Common Terns on Handa Island (Scotland) increased following the removal of Norway rats.[60]

Seabird responses to house mice removal campaigns have not been tracked; however, Diving Petrels re-colonized Mana Island (New Zealand) following the removal of house mice and the establishment of a seabird audio-playback system.[61]

Responses to Feral Cat Removals: There are fewer studies that quantify seabird responses to feral cat removals. However, the evidence suggests that cat removal from islands results in positive benefits to seabirds (Table 4). For example, research by Keitt and colleagues showed a 90% decrease in the mortality rate of Black-vented Shearwaters just one year following eradication. Similar to rat removal campaigns, research on Marion Island and elsewhere suggests that seabird benefits from cat removal are variable depending on the seabird species and other species present on the island (i.e., native and non-native alternative prey).[62] As mentioned previously, there is accumulating evidence that the removal of cats from islands where invasive rodents are also present may lead to a population increase in rodents that can potentially lead to heightened seabird impacts via rodent predation. Those potential dynamics need to be incorporated into island restoration planning and prioritization.

Table 3.
Seabird responses to invasive rat removals.

Seabird	Response Variable	% Change	Years of Data Before / After	Quality of Data Presented	Ref.
Cory's Shearwater	Breeding Success[1]	+81	1 / 2	Low	1
		+88	2 /5	High	2
Galápagos Petrel[2]		+93	2 / 2	High	3
Audubon's Shearwater		+ (>)7400	1 / 2	Low	1
Brown Noddy		+900	1 / 2	High	4
		+1440	1 / 2	Low	1
Bridled Tern		+900	1 / 2	High	4
		+ (>)5300	1 / 2	Low	1
Zino's Petrel[3]		+1731	3 / 12	High	5
Cook's Petrel		+141	16 / 3	High	6
Pycroft's Petrel		+71	2 / 7	High	7
		+90	5 / 4	High	7
Little Shearwater		+58	2 / 6	High	7
		+1020	3 / 3	High	7
Xantus Murrelet	Hatchling Success	+900	3 / 3	High	8
	Nest Predation	-870	3 / 3	High	8

[1] number of young fledged in relation to the number of active nests
[2] rat control program
[3] feral cat and rat control program

References: 1. Lorvelac & Pascal 2005; 2. Igual et al. 2006; 3. Cruz & Cruz 1987; 4. Pascal et al. 2004; 5. Zino et al. 2004; 6. Imber et al. 2003; 7. Pierce 2002; 8. Whitworh et al. 2005

Table 4.
Seabird responses to feral cat removals.

Seabird	Response Variable	% Change	Years of Data Before / After	Quality of Data Presented	Ref.
Zino's Petrel	Breeding Success[1]	+1731	3 / 12	High	1
Blue Petrel	Breeding Success[2]	+167	1 / 1	High	2
Great-winged Petrel		+1140	4 / 2	High	2
White-chinned Petrel		-39	1 / 1	High	2
Black-vented Shearwater	Mortality[3]	-90	1 / 1	High	3

[1] number of young fedged in relation to the number of active nests before and after a cat and rat control program
[2] defined as the percentage of total number of nesting burrows occupied at the start of the breeding season that were still being used towards the end of the season
[3] number of kills (carcasses) per month for the entire colony extroplated from four study plots

References: 1. Zino et al. 2001; 2. Cooper et al. 1995; 3. Keitt & Tershy 2003

Responses to Other Invasive Mammal Removals:
Documented seabird responses to invasive mammal removals, other than rats and cats, are lacking and circumstantial. Yet, some impressive observational accounts exist. In 1958, biologist Ken Stagger found a mere 500 Brown Boobies and 150 Masked Boobies on Clipperton Island (as opposed to the thousands of boobies previously reported). He also found 58 feral pigs and proceeded to shoot them. In 2003, seabird biologists estimated >25,000 Brown Boobies and >112,000 Masked Boobies on the island. Immediately following rabbit removal, Rhinoceros Auklets returned to successfully breed on the Farrallon Islands (USA) in 1974 for the first time in a century.[63] Researchers suspect the feral goat eradication and subsequent habitat recovery has played an important in role in recovery of the Hawaiian Petrel on Lanai Island (Hawaii). Similarly, following the removal of goats on Great Tobago Island (British Virgin Islands), expansion of Magnificent Frigatebird colonies have been observed and attributed to vegetation recovery.[64]

Summary Of Evidence

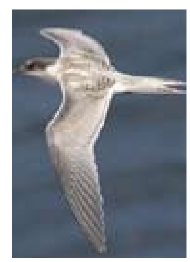
A large body of evidence points to the negative impacts on seabirds by invasive mammals, particularly those that prey directly on seabirds, such as rats and cats. **Over the past two decades, techniques have been developed and honed to safely, swiftly, and cost-effectively remove invasive mammals from islands.** Seabird responses to removal campaigns are less documented; however, available evidence demonstrates those responses to be positive. **The removal of invasive mammals from islands generally results in substantial conservation benefits for seabirds.** Further, removal campaigns result in additional biodiversity conservation benefits, including restoration of many endemic and threatened plants and animals. Those benefits are being increasingly documented.[65]

Box 6. Examples of population increases and recolonizations of seabirds following rat$ and feral cat* removal

$Roseate Tern
Chumbe Island, Indian Ocean

$Red-tailed Tropicbird &
Wedge-tailed Shearwater
Gabriel Island, Indian Ocean

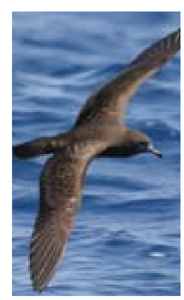
$Common Tern, Arctic Tern
& Mew Gull
Handa Island, Scotland



*$Cassin's Auklet
Coronados Island, Mexico and
Anacapa Island, USA

*White-throated Storm-petrel,
Blue Noddy, Audubon's Shearwater,
& Christmas Shearwater
Jarvis Island, Pacific

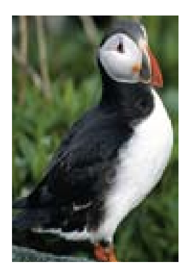
*Common-diving Petrel
Marion, Subantarctic



*Black Guillemot, Atlantic Puffin,
Manx Shearwater, European Shag
Ailsa Craig Island, Scotland

*Wedge-tailed Shearwater
Baker Island, Pacific

*Great-winged Petrel &
Macgillivray's Prion
Saint-Paul Island, Subantarctic



PART II: A PATH TO A RETURN ON INVESTMENT FRAMEWORK

"Conservation Biology cannot operate outside the reality of financial institutions"
– Westphal & Possingham 2003

A return on investment (ROI) framework provides an analytical decision-support tool for developing investment schedules to maximize cost-effective conservation benefits. A ROI approach to planning provides transparent guidance on how to allocate funds across a portfolio of potential actions over any span of time. Conducting a ROI analysis consists of six basic steps (Box 7).

A ROI framework can serve as a foundation for a conservation program that is flexible, modular, and scalable. Investment strategies can be explored under a number of different objectives. Analyses can be restricted to priority species, a certain group of seabirds, or a geographic region. It can also be integrated into related programs. For example, an ROI analysis for invasive mammal removals could be integrated with a similar analysis for a seabird bycatch reduction program, with a goal to assess conservation strategies in a single analytical framework. Lastly, ROI analysis can evolve as more information becomes available via monitoring programs or other sources.

Identify A Well-Defined Objective: The first step in conservation planning is to identify an objective. Unfortunately, conservation objectives are often vague, for example "maximize biodiversity outcomes", "minimize adverse impacts", or "restore ecosystem function." Nebulous goals such as those are of little utility for decision-making. A well-defined objective (or objectives) should be measurable. Analytical decision-theory techniques exist to explicitly incorporate single or multiple objectives into conservation planning and return on investment analyses.[66] For a seabird conservation program focused on invasive mammal removals, there could be a single or multiple objectives such as minimizing extinction risk, maximizing numbers of seabirds, or maximizing number of seabird colonies. The objectives might differ across seabird species, depending on their current status. Optimal strategies will differ depending on the objectives. The process of defining objectives may be informed by science, but it is not a scientific exercise. Rather, it requires an application of values.

Box 7. Return on investment in the conservation sector*

1. Identify a well-defined objective
2. Evaluate conservation opportunities
3. Incorporate estimates of benefits
4. Incorporate estimates of costs
5. Allocate portfolio
6. Incorporate pragmatic factors such as funding fungibility, intangible benefits, and investment risk

** Modified from Murdoch et al. 2007*

Evaluate Conservation Opportunities: In general, identifying islands where invasive mammals are present and could be removed with conservation benefits for seabirds is relatively straightforward, particularly for islands where threatened seabirds breed. Less is known about seabirds and invasive mammals on islands where threatened seabirds are absent or not known to be present. For the former, databases already exist with seabird breeding locations and the presence of invasive mammals.[67] Evaluating opportunities would consist of augmenting existing databases and collating the data into a useful format.[68] In some cases, fieldwork might be needed to verify the presence of invasive mammals or nesting seabird species.

Incorporate Realistic Estimates Of Benefits: In general, when benefits of conservation actions are estimated, those estimates are usually based on extrapolations from species-area curves or informed guesses by experts due to lack of adequate information. Commonly, even simple measures of conservation benefits are neither estimated a priori nor evaluated after conservation interventions.[69] In a relatively new trend, estimating and auditing benefits to conservation interventions is an area of active research, and new methods are being developed and tested. The basic approach begins with the counterfactual: what would have happened if there had been no intervention?

Estimating benefits to seabirds from invasive mammal eradications will be simpler than other conservation interventions, such as estimating benefits of a multi-site reserve network to a suite of species differing widely in their natural histories. Many invasive mammal removal campaigns will lack a significant social component since many seabird-breeding islands often are uninhabited. Additionally, current threats to seabirds on islands are often first-order interactions (e.g., rat predation); complex second-order interactions, such as impacts triggered by habitat fragmentation, are less documented. The former are much easier to characterize and estimate compared to the latter. Finally, many seabird species are well studied by biologists, providing the necessary biological information to estimate potential benefits with adequate precision.

For an example, the Tristan Albatross is listed as endangered by the World Conservation Union. Most conservation planners covet data such as that listed in Box 8—seabird biologists have done their job well.[70] Given available techniques, it would be relatively straightforward to develop a demographic model to estimate the benefits to Tristan albatross breeding populations from a portfolio of potential conservation actions, such as house mouse removal, a house mouse control program, or a bycatch reduction program. In fact, ecologists have been doing exactly that for many threatened species over the past 20 years, and the practice has matured into a sub-discipline called population viability analysis.[71]

Techniques to incorporate benefits for multiple species simultaneously will be more challenging but doable. Lack of information and inaccurate estimates for some species and islands will limit precision. Yet, that inaccuracy can be integrated into estimates rather than discarded, and uncertainty is not a valid argument against using a return on investment framework. Lack of information and uncertainty will be issues for whatever planning approach is adopted and highlight the need for systematic monitoring programs to support more precise revised planning.

Incorporate Realistic Estimates Of Costs: While costs are still largely ignored in conservation planning, they are often easier to estimate with greater precision than conservation benefits. More importantly, ignoring economic costs or incorporating them after potential conservation actions have been prioritized has been shown to lead to cost-ineffective conservation strategies.[72]

Accurately costing eradication campaigns is a complex endeavor that requires extensive on-the-ground experience. The three main components that influence the cost of an invasive mammal removal campaign are project development, on-the-ground implementation, and the monitoring and evaluation of outcomes (Box 9).[73] The first two components are greatly influenced by idiosyncratic local or regional factors, and all three are subject to economies of scale. Costing efforts must clearly distinguish between each component.

A recent example from the scientific literature provides an informative example of a well intentioned but misleading effort to develop a costing model for invasive mammal removal programs. The flaws in the analysis stem from a lack of detailed knowledge of the factors that influence the costs of eradication campaigns, along with a misunderstanding of what is currently possible.[74] For example, the researchers rely largely on island size and remoteness to estimate costs, ignoring important differences in fixed and non-fixed costs in campaigns. A suite of factors can greatly influence the cost of an invasive mammal removal campaign (Box 9).

Due to variable costs driven not by area or remoteness, rat removal on Anacapa Island (USA), a small island (300 hectares) near one of the busiest airports in the world, cost more than Campbell Island – a massive, remote island in the subantarctic (11,300 hectares). On Anacapa Island, the presence of non-target species and the need to safely mitigate for possible harmful effects, along with

Box 8. Compared to other threatened species, much is known about the biology and current status of the Tristan Albatross

- Breeding populations are restricted to four islands in the south Atlantic Ocean, and it is currently breeding on only two of those islands.
- The global population is estimated to be between 9,000-15,000, with 1,500-2,400 pairs breeding on any given year.
- Researchers using satellite-tagging technology have studied the impacts from long-line fishery interactions, and estimate ~500 birds are killed per year. Impacts from other near-shore fisheries have also been evaluated.
- Breeding populations have been studied and monitored for at least the past 8 years; population biology models have been developed.
- Impacts from invasive house mice on one breeding island have been documented and quantified. Record low annual breeding success of ~27% was estimated compared to typical values of 60-75%.
- On the island with the largest breeding population, overall biodiversity threats have been reviewed and recommendations made regarding conservation management.

Box 9. Factors that influence costs of invasive mammal removal campaigns

Project Development (Start-up Costs)
- Stakeholder buy-in (e.g., the presence of human residents and subsequent need for social programs)
- Level of environmental compliance required (e.g., U.S. National Environmental Protection Act)
- Other legal and political issues (e.g., methods available and allowed, such as toxicants, helicopters, firearms)

Implementation
- Target species
- Eradication methods (e.g., hunting, trapping)
- Non-target species and mitigation techniques available (e.g., native mammals, birds of prey, land crabs)
- Logistical requirements

Monitoring & Evaluation
- Verifying absence of target species
- Documenting potential short-term impacts on native species
- Documenting long-term responses of seabirds, other native species, and the ecosystem (when and where it is deemed desirable)
- Degree of biosecurity measures needed to minimize risk of reintroduction or reinvasion of target species

substantial environmental compliance requirements raised the cost of the eradication. Anacapa Island, which was the first eradication in the US in which rodenticide was broadcast by helicopter, also illustrates that start-up costs can be substantial for eradications in nations or regions where they have not previously been conducted.

Despite the complexity, however, a small group of practitioners that have managed large-scale eradication campaigns can estimate costs with sufficient accuracy to guide the development of a general costing model. This would be a fundamental first step in prioritizing islands (globally or regionally) for invasive mammal removals.

Allocate The Portfolio: While identifying islands for invasive mammal removals and estimating the cost-effectiveness of those interventions are critical steps, conservation planners have to allocate dollars across a suite of interventions (e.g., islands, seabirds, target species) in space and time to maximize conservation benefits. An optimal resource allocation approach provides a transparent analytical tool to help guide the allocation of available resources. Since conservation actions are not independent of each other in space or time, a resource allocation approach is superior to simple ranking schemes, which have been shown to yield fewer benefits per dollar.[75] As opposed to a ranking scheme that delivers a "what is in and what is out" list of priorities, resource allocation can deliver a guidebook for an investment schedule of a portfolio of conservation options (Table 5). The analysis can be customized to fit into either a static or dynamic decision-making framework, such as where to invest in single year compared to an investment schedule over several years. Conservation targets and benefits from multiple one-year investment planning is unlikely to match that from a total budget allocated in advance over several years.

Table 5.
A hypothetical optimal budget allocation at varying funding levels for removal of invasive mammals from seabird breeding islands. Since benefits accrue as discrete units (i.e., islands), the set of islands that will maximize conservation benefits for a target group of seabird species will differ depending on the total budget.

		Total Budget Allocation			
Seabirds	**Islands**	**$1 million**	**$5 million**	**$10 million**	**$15 million**
Seabird 1	Island A	$400,000		$400,000	$400,000
	Island B		$1,666,667	$1,666,667	$1,666,667
	Island C				
Seabird 2	Island A				
	Island B	$600,000	$600,000		
	Island C		$541,667		$541,667
	Island D			$5,675,000	$5,675,000
Seabird 3	Island A		$66,666	$66,666	$66,666
	Island B		$125,000	$125,000	$125,000
	Island C				$4,071,121
Seabird 4	Island A		$500,000	$500,000	$500,000
	Island B		$1,500,000	$1,500,000	$1,500,000
	Island C				$120,545
Seabird 5	Island A				$266,667
	Island B			$66,667	$66,667

Incorporate Pragmatic Factors: Pragmatic factors can and should be explicitly incorporated into a ROI analysis for seabird conservation including, investment risk, investment leverage, and intangible benefits (Box 10). Some factors that influence investment risk (i.e., the probability of an invasive mammal eradication failing) will be hard to capture within the estimated economic costs, largely because of unpredictability. Likewise, certain types of benefits that are not incorporated into benefit estimates might feed back to the defined objective in important ways (e.g., capacity building of invasive mammal removal practitioners). Those risks and benefits can be integrated into the ROI analysis by exploring different scenarios with varying constraints and opportunities.[76] For obvious reasons, this last step is critical, an ongoing process, and will rely on expert knowledge and experience. Similarly, an effective global seabird conservation program will need to balance a systematic prioritization plan with the flexibility to capitalize on unpredictable conservation opportunities that can drive on-the-ground conservation action. A suite of biological factors can also be added to analysis, such as aspects of diminishing returns (e.g., the marginal gain of conserving a breeding seabird population on a certain island declines as the population increases).

There will also be a series of factors that lies outside the formal ROI analysis and influences decision-making. For example, from a global perspective, on-the-ground capacity to eradicate invasive mammals from islands is currently limiting. Strategies need to be developed to build capacity and better coordinate existing capacity; those strategies will feed back into the portfolio allocation process.

It will also be important to encourage the technological innovations identified in Part I of this report. Leveraging technology has become increasingly important in both decreasing non-fixed costs of removal campaigns and increasing the ability to remove invasive mammals from larger and more biological complex islands.[77] Strategic investment into new technology and techniques would result in substantial cost-savings across an entire global program. Over the past twenty years, New Zealand practitioners have substantially decreased the costs of invasive rodent removals by leveraging technology, particularly through using helicopters to broadcast rodenticide.[78] A more recent goat removal campaign provides another example: 80,000 goats were eradicated from Santiago Island (Galápagos) for US$5.8 million; removing the last 1000 goats costs $2.4 million—41% of the entire cost of the campaign. Technology and applied mathematical models that focus on optimally detecting and removing the final animals in a removal campaign would substantial reduce costs.[79]

Lastly, a cost-effective auditing program is needed to quantify conservation return on investments; those results would also be used to refine ROI analyses for future investment decisions.

Box 10. Incorporating pragmatic factors that will influence investment risk and collateral or intangible benefits

Risk factors can influence realized objectives through timing (e.g., project delays) or unexpected inflated costs. Collateral or intangible benefits can feed back to objectives in non-linear ways.

Investment Risks
- Capacity of governance in target region
- Cultural climate (e.g., animal rights opposition)
- Bureaucratic climate
- Weather

Collateral / Intangible Benefits
- Pioneer projects in new geographic regions
- Capacity building of conservation practitioners
- Non-seabird biodiversity benefits

Recommendations

For many islands and seabirds, there are large gaps in precise, quantitative information. Despite those data gaps, sufficient data and knowledge are currently available to proceed with an ROI analysis for invasive mammal removals and seabird conservation. Further, uncertainty and lack of information can be explicitly incorporated into the ROI analysis and augmented by experience-based knowledge in the later stages of the process.

Once measurable objectives are clearly defined, the first steps in moving toward a formal ROI analysis would involve three concurrent projects: scoping the opportunities, estimating the conservation benefits, and estimating the economic costs. Scoping conservation opportunities for threatened seabirds will be relatively straightforward: where those species breed (or recently bred) is often well known. The status of invasive mammals on islands where non-threatened seabirds breed is often less well known, and thus there will be more uncertainty in identifying those conservation opportunities.

Translating known seabird impacts and potential actions to expected benefits will require specialized quantitative skills. Those skills and data, however, are readily available. The assessment would involve scoping and synthesizing seabird-specific impacts and conservation opportunities for seabirds. That information would then be used to develop population biology models to estimate the benefits of potential conservation actions. In circumstances where the magnitude of the actual impact is unknown (e.g., impact of rats on seabird X on island Y), they can be estimated by available data from others islands involving the same or a closely related seabird where data on impacts are known.[80] Once the necessary data are collated and confirmed, a small team of quantitative biologists could both estimate the conservation benefits and the uncertainty around those estimates for a suite of seabird species (e.g., gain in population growth rate or decrease in extinction risk).

Estimating the economic costs will require a slightly different strategy, since the “data” reside largely in the heads of a handful of practitioners. An intensive workshop that included key practitioners along with quantitative biologists would make important progress toward 1) costing eradications on islands identified by the global seabird assessment, and 2) developing a realistic general costing model for invasive mammal removal campaigns.

Once the ROI process evaluates opportunities and estimates cost-effectiveness, the analysis could proceed with the goal of developing investment schedules under a number of different scenarios that include pragmatic constraints and opportunities. **At all steps in the ROI analysis, uncertainty will have to be characterized, bounded, and always taken into consideration.**

In general, a ROI approach to prioritizing invasive mammal eradications for seabird conservation will require strong leadership down to the operational level to ensure that evidence-based information drives the initial process, and experience-based information is incorporated during the later stages. That leadership should also include individuals with extensive experience with invasive mammal eradications and seabird conservation. There will be a strong tendency to inject experience-based information and individual perspectives into the early steps of the ROI process; doing so will compromise the goal of the approach: to provide an evidence-based, transparent decision-support tool that forms a foundation for a systematic strategy to maximize conservation benefits. It will be critical to effectively incorporate the two types of knowledge—evidence-based and experience-based—at the right stages of the process. By properly investing a priori in an analytical prioritization process that focuses on return on investment, a global seabird conservation program will maximize conservation benefits and do so in the most cost-effective way possible.

ENDNOTES

[1] For discussion on conservation effectiveness and other sectors, see Pullin & Knight 2001. For a review on conservation planning tools, see Sarkar et al. 2006. For a review of economics and biodiversity conservation, see Naidoo et al. 2006. For return on investment frameworks in conservation, see Murdoch et al. 2007.

[2] See Nogales et al. 2004; Campbell & Donlan 2005; Towns et al. 2006; Howald et al. 2007; Jones et al. in press.

[3] See Wilcox & Donlan 2007 for example of a return on investment approach to seabird conservation and invasive species removals on islands. Also see Aguirre-Muñoz et al. 2007; Donlan & Wilcox in review.

[4] 102 of the 341 seabird species are considered globally threatened (IUCN categories Critically Endangered, Endangered, and Vulnerable). For information on the World Conservation Union and the IUCN Red List of Threatened Species, see http://www.iucnredlist.org. For analyses of threatened birds in particularly, see Birdlife International, http://www.birdlife.org. For a recent analysis on threatened seabirds, see Buckelew 2007.

[5] For discussions of the prehistoric, historic, and current biodiversity impacts of invasive species on islands, see Atkinson 1985, 1989; Towns & Ballantine 1993; Martin & Steadman 1999; Courchamp et al. 2003; Towns et al. 2006.

[6] See Buckelew 2007; Wilcox & Donlan 2007.

[7] The history of island restoration and invasive mammal eradication, which begins in New Zealand and Australia, is rich and underappreciated. See Thomas & Taylor 2002; Towns & Broome 2003; Howald et al. 2007; Donlan in press.

[8] See Wright & Joux 2003.

[9] All dollar figures in this report are US$. For Campbell Island, see McClelland & Tyree 2002. For Project Isabela in the Galápagos, see Cruz et al. 2005; Donlan et al. 2005a; Carrion et al. 2007; Cruz et al. in review.

[10] See Morris 2002; Howald et al. 2005.

[11] See Simberloff 2001, 2002; Donlan et al. 2003; Donlan & Wilcox in review for discussions.

[12] Over the past five years, there has been increasing calls for more cooperative management of island invasives (including from the Small Island Developing States through the Convention on Biological Diversity) and increasing interest from large conservation NGOs in the eradication of invasive mammals from islands. This stems partly from the increasing number of successful eradication campaigns, see Veitch & Clout 2002.

[13] An integrated approach with fisheries bycatch reduction programs would have some attractable advantages that would likely maximize conservation gains. See Wilcox & Donlan 2007; Donlan & Wilcox in review.

[14] See Aguirre-Muñoz et al. 2007.

[15] Adopted from Stevens & Milne 1997 and Pullin & Knight 2001.

[16] See Towns et al. 2006 for an interesting discussion. Also see Croll et al. 2005 and Fukami et al. 2006 for recently documented indirect ecosystem impacts driven by invasive species and seabird impacts.

[17] See Atkinson 1985; Towns et al. 2006; Jones et al. in press.

[18] Includes the seabird families Sulidae, Phalacrocoracidae, Spheniscidae, Fregatidae, Pelacanoididae, Diomedeidae. See Jones et al. in press.

[19] See Cuthbert & Hilton 2004; Wanless et al. 2007. Video showing introduced house mice attacking a Tristan albatross chick is available at http://www.journals.royalsoc.ac.uk/content/432783x7h8300733/rsbl20070120supp1.wmv.

[20] Jacob Shepard (Island Conservation), personal communication. Also see Sydeman et al. 1989.

[21] For examples of cat diet studies, see Kirkpatrick & Rauzon 1986; Konecny 1987; Fitzgerald 1988. For examples of local and global extinctions, see Moors & Atkinson 1984; Jehl & Everett 1985; Donlan et al. 2005b.

[22] See Jones 1977; Pascal 1980; Van Aarde 1980. For a synopsis on cat impacts on seabirds, see Moors & Atkinson 1984.

[23] Pontier et al. 2002 provides an example.

[24] See Keitt et al. 2002.

[25] The global review is being led Island Ecology and Evolution Research Group, Spain; Equipe Ecologie du Paysage et Biologie de la Conservation, France; and Island Conservation, USA. Cats have been observed or empirically documented preying on a minimum of 22 species of seabirds; this is surely an underestimate, Josh Donlan (Advanced Conservation Strategies), unpublished data.

[26] See Keitt et al. 2006. Also see Wanless et al. 2007 for an example of house mice potentially learning to prey on albatross.

[27] See Jones 1977; Bloomer & Bester 1990; Courchamp et al. 2000; Reed & Bowen 2001; Pontier et al. 2002.

[28] See Hays & Conant 2007 for a synoptic review of mongoose impacts on biodiversity. For the feeding trail study, see Carter & Bright 2002. Also see Yamada 2002.

29 See Harrison 1980; Smith et al. 2002.

30 Three-year study with two years of data with a control program (mean reported here) and one year of data prior. See Simons 1983. Also see Baldwin et al. 1952.

31 Nesting populations that were extirpated include the following species: Tufted Puffins, Leach's and Fork-tailed Storm-petrels, Cassin's Auklet, Ancient Murrelet, and Whiskered Aucklets. See Bailey 1993 and Williams et al. 2003.

32 See Campbell 2007.

33 See Gillham 1953; Ainley & Lewis 1974; McChesney & Tershy 1998.

34 At three study colonies on each island, recorded egg ejection rates were 14% and 0.2% on Santa Clara and Robinson Crusoe Islands respectively. Pink-footed Shearwaters, Juan Fernández Petrels, and Stejneger's Petrels breed on the Juan Fernandez Islands. See Hodum & Wainstein 2002.

35 When European rabbits are present on islands, they commonly make up a large percentage of feral cats' diet. See Towns et al. 2006 for a short discussion on hyperpredation. Also see Taylor 1979; Moller & Craig 1987; Courchamp et al. 2000; Imber et al. 2000.

36 For Clipperton Island, see Pitman et al. 2005. For studies on Galápagos and Hawaii, see Harris 1970; Coblentz & Baber 1987; Cruz & Cruz 1987b Harris 1970. For Auckland Island, see Challies 1975; Rudge 1976; Walker & Elliott 1999; Flux 2002 Challies 1975.

37 Rabbits may have also contributed to the decline via habitat destruction, see Martìnez-Gòmez & Jacobsen 2004.

38 Peter McClelland (Department of Conservation, New Zealand), personal communication.

39 Fig. 2 data sources: Nogales et al. 2004; Campbell and Donlan 2005; Howald et al. 2007; Karl Campbell (Island Conservation), personal communication. Also see Island Conservation's Database (http://www.islandconservation.org) and IUCN Invasive Species Specialist Group's Global Invasive Species Database (http://www.issg/org).

40 See Howald et al. 2007.

41 Nogales et al. 2004; Karl Campbell (Island Conservation), personal communication.

42 For the Baltra Island, see Phillips et al. 2005. For islands in western Australia and the Western Shield project, see Algar et al. 2002; Algar & Burrows 2004; Burbidge 2004.

43 Campbell and Donlan 2005; Carrion et al. 2007. Karl Campbell (Island Conservation), personal communication.

44 See Campbell et al. 2005; Campbell et al. 2007; Lavoie et al. 2007.

45 Karl Campbell (Island Conservation), personal communication.

46 See Cruz et al. 2005; Morrison et al. 2007.

47 Flux & Fullager 1992.

48 For the fox eradication program in the Aleutian Islands, see Ebbert & Byrd 2002.

49 For weasel eradications, see Hanson 2007. For other mustelid eradications, see Veitch & Clout 2002. For monkey eradications, see Campbell 2007.

50 For examples of innovations, see Algar & Burrows 2004; Parkes et al. 2005; Campbell et al. 2006; Lavoie et al. 2007. Table is from Donlan and Wilcox in review.

51 For examples, see Buckelew et al. 2006; Algar & Brazell unpublished ms.

52 See Howald et al. 2007.

53 In particular, this group includes persons that have managed recent large-scale, complex eradication campaigns: David Algar (Department of Environment and Conservation, Western Australia), Karl Campbell (Island Conservation), Gregg Howald (Island Conservation Canada), Norm MacDonald (ProHunt, Inc.), and Peter McClelland (Department of Conservation, New Zealand).

54 These models are beginning to emerge: Baxter et al. in press; Cruz et al. in review; Wilcox in review.

55 See Imber et al. 2003.

56 For reviews on social attraction and translocation techniques, see Kress 1997 and Gummer 2003. Also see Priddel et al. 2006.

57 See Towns et al. 2006 for a brief discussion on the variability of seabird responses to rat removals. See Ono & Nakamura 1994; Gaze 2000 for two examples.

58 See Jouventin et al. 2003.

59 Josh Donlan (Advanced Conservation Strategies), unpublished data.

60 See Stoneman & Zonfrillo 2005.

61 See Miskelly et al. 2004.

62 For Black-vented Shearwaters and Natividad Island, See Keitt et al. 2002; Keitt & Tershy 2003. For Marion Island, see Cooper et al. 1995.

63 See DeSante & Ainley 1980.

64 Jay Penniman, personal communication; N. K. Woodfield, personal observation cited in McGowan et al. 2006. For a summary of events on Clipperton Island, see Pitman et al. 2005.

65 For examples of documented non-seabird conservation benefits of invasive mammal removal campaigns, see Towns 1991; Hamann 1993; North et al. 1994; Towns 1994; Donlan et al. 2002; Veitch & Clout 2002; Keitt et al. 2005; Aguirre-Muñoz et al. 2007; Donlan et al. 2007.

66 See Westphal & Possingham 2003; Nicholson & Possingham 2006.

67 For three examples, see databases by Birdlife International (http://www.birdlife.org), Island Conservation (http://islandconservation.org), and IUCN Invasive Species Specialist Group (http://www.issg.org).

68 This exercise is in its early stages by a working group funded by the US National Center for Ecological Analyses and Synthesis directed by Josh Donlan (Advanced Conservation Strategies) and Chris Wilcox (CSIRO-Australia).

69 See Pullin & Knight 2001; Millennium Ecosystem Assessment 2005; Ferraro & Pattanayak 2006.

70 For research on Tristan albatross, see Ryan 1991; Ryan et al. 2001; Favaro et al. 2003; Jones et al. 2003; Cuthbert & Hilton 2004; Cuthbert et al. 2004; Cuthbert et al. 2005; Wanless et al. 2007.

71 Multiple volumes have been written that focus on the techniques and practice of Population Viability Analyses. See Morris & Doak 2002 for a recent example. For a seabird example that uses a return on investment approach, see Wilcox & Donlan 2007.

72 See Balmford et al. 2000; Naidoo et al. 2006.

73 For the planning approach developed by the New Zealand Department of Conservation, see Cromarty et al. 2002.

74 For example, the researchers treat cat, mongoose, and monkey eradications as if they are functionally the same both in terms of the current ability to eradicate and the economic cost required to do so. In reality, those costs differ substantially due to techniques used and available, as well as new techniques that would need to be developed due to differences in current ability (e.g., there have been zero successful monkey eradications). See Martins et al. 2006; de L. Brooke et al. 2007. Also see Donlan & Wilcox 2007 for a short critique on Martins et al. 2006.

75 See Wilson et al. 2006; Murdoch et al. 2007; Wilson et al. 2007.

76 Investment risks and collateral/intangible benefits could be integrated into the ROI analysis either qualitatively or quantitatively, depending on the amount of information available.

77 See Towns & Broome 2003; Campbell et al. 2005; Campbell et al. 2007; Lavoie et al. 2007.

78 See Towns & Broome 2003 for a discussion.

79 See Cruz et al. in review.

80 For an example, see Wilcox & Donlan 2007.

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