Conservation Letters
A journal of the Society for Conservation Biology
Open Access

LETTER

Maximizing Return on Investment for Island Restoration and Species Conservation

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Keywords
Invasive mammals; eradication; British Columbia; rats; raccoons; seabirds; prioritization.

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Received
12 January 2014
Accepted
10 July 2014

Editor
Nicholas Dulvy

doi: 10.1111/conl.12126

Abstract

Conservation practitioners are increasingly embracing evidence-based and return on investment (ROI) approaches. Much evidence now exists that documents island biodiversity impacts by invasive mammals. The technical ability to eradicate invasive mammals from islands has increased exponentially; consequently, strategic planning focused on maximizing the ROI is now a limiting factor for island restoration. We use a regional ROI approach to prioritize eradications on islands for seabird conservation in British Columbia, Canada. We do so by integrating economic costs of interventions and applying a resource allocation approach. We estimate the optimal set of islands for eradication under two conservation objectives each with a series of increasing thresholds of population sizes and breeding locations. Our approach (1) identified the most cost-effective interventions, (2) determined whether or not those interventions were nested with increasing thresholds, and (3) helped justify larger investments when appropriate. More often than not, conservation decisions are made at a regional scale, and decision-makers often must make choices on how to allocate funds across a number of potential conservation actions. A regional, ROI framework can serve as a decision-support tool for organizations engaging in discrete interventions in order to maximize benefits for the minimum cost.

Introduction

While the practice of biodiversity conservation has matured over the past decade, decisions for proposed actions still commonly lack evidence-based and return on investment (ROI) frameworks. That picture, however, is beginning to change. Planners and practitioners are beginning to embrace operating frameworks similar to the "effectiveness revolution" in public health (Keene & Pullin 2011). Relatedly, rather than ignoring the economics of conservation practice, planners and practitioners are adopting approaches that incorporate the costs of interventions into prioritizations (Naidoo *et al.* 2006). Not embracing evidence-based approaches is a precarious strategy, and ignoring the economics of biodiversity conservation is acting as if money were no object (Ferraro & Pattanayak 2006).

Island conservation, like other subdisciplines of biodiversity conservation, is increasingly embracing evidence-based and ROI approaches (Veitch *et al.* 2011). Global reviews now exist that synthesize island biodiversity impacts by invasive mammals—the main threat to island ecosystems—and the current state of invasive mammal eradications (Nogales *et al.* 2004; Campbell & Donlan 2005; Howald *et al.* 2007). As important, preremoval impact and postremoval recovery studies now support the alleged benefits of removing invasive mammals from islands (Towns *et al.* 2006; Lavers *et al.* 2010). Tremendous progress has been made over the past three decades in the ability to restore island ecosystems (Veitch *et al.* 2011). Invasive mammal eradications are now taking place on large islands that were deemed impossible a decade ago: the technical ability to eradicate certain invasive mammals (e.g., rats and goats) has increased exponentially

(Carrion *et al.* 2011). Today, island size is often no longer the limiting factor for removing invasive mammals from islands; rather, it is reducing the operational cost of eradication campaigns and strategic planning focused on maximizing the ROI (Donlan & Wilcox 2008).

Researchers are increasingly developing prioritization algorithms to help guide decision-making on which islands should be targeted for restoration via invasive mammal removal (de L. Brooke *et al.* 2007; Ratcliffe *et al.* 2009; Capizzi *et al.* 2010; Harris *et al.* 2012). Yet, the economic costs of invasive mammal eradication have yet to be accurately incorporated into prioritizations due to the challenges around a lack of data and the complexities of costing. Here, we build on previous island prioritization work by integrating economic costs of conservation interventions and applying a resource allocation approach to island prioritization (Wilson *et al.* 2009). We also take a regional approach to prioritization, which is the most common scale at which island conservation decisions are made (Towns & Broome 2003; Aquirre-Muñoz *et al.* 2008; Carrion *et al.* 2011). Despite imprecise information regarding some aspects of island conservation practice, adopting a ROI approach should increase effectiveness and provide transparent guidance on allocating funds across a range of potential actions.

We use an ROI approach to prioritize invasive mammal eradications on islands for seabird conservation in British Columbia (BC), Canada (Figure 1). The islands of BC are known for their globally important seabird breeding populations (Drent & Guiguet 1961). Invasive mammals are the leading threat to the viability of many seabird species in the region (see Supporting Information). We develop a ROI model to explore optimal investment strategies at a regional level with two seabird conservation objectives. We do so to illustrate an approach that can be used broadly to help inform planners and decision-makers on how to allocate funding across a number of potential interventions to maximize conservation benefits focused on a suite of target species.

Methods

Our analysis included all BC islands where one or more of the following invasive mammals are present: black rat (*Rattus rattus*), Norway rat (*R. novergicus*), raccoon (*Procyon lotor*), and mink (*Neovison vison*). We established a dataset that included (1) island size, (2) presence of invasive mammal(s), and (3) presence and estimated population sizes of seabird species. Data were compiled from multiple sources (see Supporting Information). While 10 seabird species breed on the islands in the region, we included only the six species with strong evidence of negative impacts by invasive predators in our analysis (Table 1). Rat and raccoon impacts on seabirds and population recovery from their removal (or control) are well documented in the region. While biodiversity impacts by mink are less understood, negative impacts by mink on seabirds have been documented. See Supporting Information for evidence of negative impacts from invasive mammals.

Table 1 Breeding seabirds of British Columbia, Canada. The return on investment analyses was restricted to seabirds with strong evidence of negative impacts by invasive predators (in bold). See Supporting Information for evidence of negative impacts.

Common Name (Scientific Name)
Ancient Murrelet (*Synthliboramphus antiquus*)
Cassin's Aucklet (*Ptychoramphus aleuticus)*
Fork-tailed Storm-petrel (*Oceanodroma furcata*)
Glaucous-winged Gull (*Larus glaucescens*)
Horned Puffin (Fratercula conriculata)
Leach's Storm-petrel (*Oceanodroma leucorhoa*)
Pelagic Cormorant (*Phalacrocorax pelagicus pelagicus*)
Pigeon Guillemot (*Cepphus columba*)
Rhinoceros Auklet (*Cerorhinca monocerata*)
Tufted Puffin (*Fratercula cirrhata*)

We adopted an ROI approach that consists of five basic steps (Murdoch *et al.* 2007):

1. Identify a well-defined and measurable objective.
2. Evaluate conservation opportunities.
3. Incorporate estimates of benefits.
4. Incorporate estimates of costs.
5. Allocate portfolio.

Identify a well-defined and measurable objective

Our overarching goal was to improve the conservation status of six at-risk seabirds in BC for the minimal cost. We treated the desired change as a constraint, and optimized conservation actions (i.e., invasive mammal eradications) in order to meet that constraint for the minimum possible cost. We evaluated two different approaches to the constraint. First, we found the decision that gave the minimum cost for protecting a certain population size for each target species. In this case, we use population size protected (i.e., number of individuals) as our objective. Second, we found the decision that gave the minimum cost for protecting a certain number of breeding locations for each target species. In this latter case, we take a metapopulation perspective and use number of breeding locations protected as our objective.

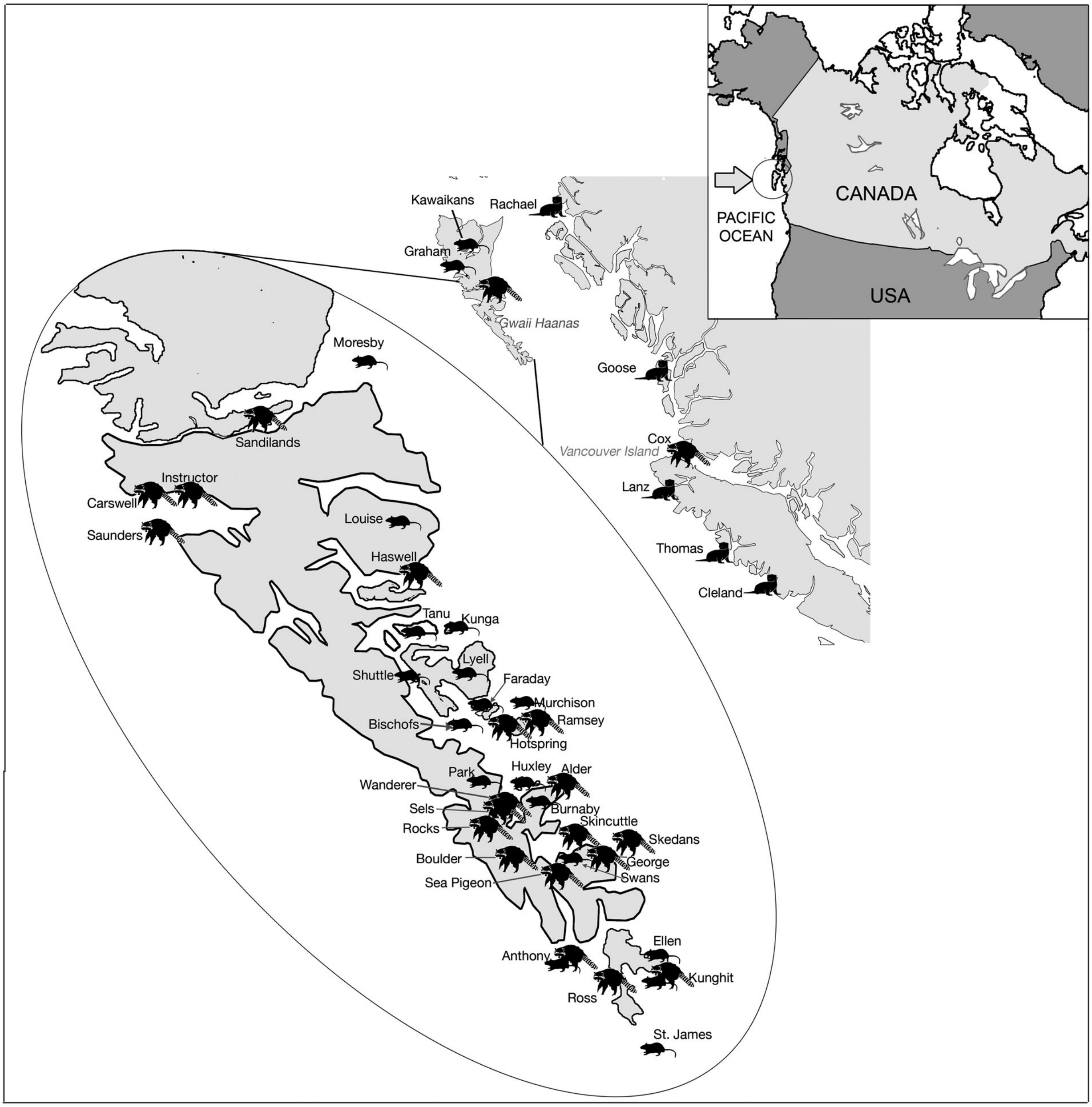

Figure 1 Islands of British Columbia, Canada, where black rats, Norway rats, raccoons, or mink are present. These 42 islands represent potential conservation opportunities via invasive mammal eradication at a regional level.

Evaluate conservation opportunities & incorporate estimates of benefits

We defined a conservation opportunity as an island under 15,000 ha where raccoon, rat, or mink populations are present, and where breeding seabirds, belonging to the six target species, are also present. Islands larger than 15,000 ha were considered currently unfeasible to eradicate the target invasive mammals (Veitch *et al.* 2011).We assigned four thresholds and subsequent benefits for the two conservation objectives: 1, 100, 1,000, and 10,000 individuals of each of the six species for population size, and 1, 2, 5, and 10 breeding locations of each seabird species for the breeding locations objective. For example, if the threshold was to secure two breeding locations, the allocated portfolio of islands would secure two breeding colonies of each of the six seabird species at the lowest cost. The lower bound of the thresholds (one individual and one breeding location) was used as a starting point to explore the nestedness of the results. In cases where the threshold exceeded the available breeding locations (or population size) for a species, all islands with that species would be included in any solution. Due to lack of data resolution, we treated breeding records (and population estimates) from islands as a single breeding location. This, however, is a minor issue given that invasive mammal eradication is a binary event—invasive mammals are removed from the entire island or not. We assumed a conservation opportunity and its subsequent benefit was binary: (1) a seabird species (and its population size) on an island was protected when an eradication was conducted, and (2) if an eradication was conducted, all invasive mammals on that island were eradicated.

Incorporate realistic estimates of costs

There are three main components that influence the cost of an invasive mammal eradication campaign: project development, on-the-ground implementation, and the monitoring and evaluation of outcomes (i.e., confirmation). Since the islands included in our analysis occur in a single geo-political unit and share many of the same characteristics (e.g., geography, environmental compliance requirements, etc.), we ignored fixed costs of the three components as they are likely to be similar across islands or to scale with the other island size-dependent costs that we do include (Donlan & Wilcox 2007). By focusing on the major variable costs for rat, raccoon, and mink eradications, we provide relative cost estimates that are accurate enough to incorporate into prioritizations. Our cost estimates, however, are not inclusive and thus should not be taken at face value. Rodenticide bait and helicopter time are the major variable cost for rat eradication campaigns. In contrast, labor (i.e., hunting and trapping) is the major variable cost of raccoon and mink eradications (Table S1). Cost estimates were calculated in collaboration with practitioners with extensive experience in eradications. See Supporting Information for details of cost estimations.

Allocate portfolio

We identified a single set of islands that would meet a set of conservation thresholds at minimal cost. Our model assumed that there were M islands indexed by m, N native target species (i.e., seabird) indexed by n, and I threats (invasive mammal or combinations of mammals) indexed by i. The biodiversity values in the system are described by a matrix of 1 s and 0 s, B, with each island and seabird that is impacted by a threat that can be removed via a conservation action (i.e., eradication). A binary vector E of length M describes a possible action, with mth entry corresponding to a conservation action (i.e., 1 or 0 for eradication or not) on the mth island. The biodiversity benefit of a set of actions can then be described by

$$G = \sum_n \mathrm{EB},$$

where the multiplication sign implies the vector product of the decision vector E and the benefit matrix B. The constraint on the optimization is that any solution vector E describing the eradication strategy must yield $G_n \geq \gamma_n$, where γ_n is the minimum acceptable number of breeding locations for each of the n native target species. The extension to minimum population sizes is similar, with the B matrix containing abundances instead of binary values. The cost of removing invasive predators from the mth island is an element of the vector C, c_m. The total cost of a particular eradication strategy E, is then

$$T = \mathrm{E}'\mathrm{C},$$

where the E' denotes the transpose of the decision vector E. The goal is then to choose an eradication strategy E, which meets the constraint on G for the minimum total cost T. We conducted our analysis using integer programing implemented in the Lpsolve package in the R statistical language (R Development Core Team 2005). Our R code was deposited in the Dryad repository (Wilcox *et al.* 2014).

Results

Of all BC islands, 42 were identified with invasive mammals. Thirty-eight were under 15,000 ha: five islands with nonnative mink, 18 with raccoons, four with black rats, two with Norway rats, one with both black and Norway rats, six with unidentified *Rattus* spp., and two with both raccoons and rats (Figure 1). Island sizes ranged from 2 ha to 12,330 ha. Of those 38 islands, 25 contained at least one breeding population of the six target seabird species. A total of 63 breeding locations-species combinations were identified, with a total estimated population of 186,000 birds. Eight breeding accounts of Storm-petrels were not identified to species (either Fork-tailed or Leach's Storm-petrel), and we excluded those accounts from the prioritization.

One island, Cleland, was selected as the optimal set to minimize cost while reaching the threshold of protecting at least one individual for each species (Figure 2). The optimal set of islands was largely nested as the population size targeted for protection increased. Estimated costs increased nonlinearly as the threshold increased. Invasive mammals could be removed from three islands for the estimated base cost of $110,216 to protect at least

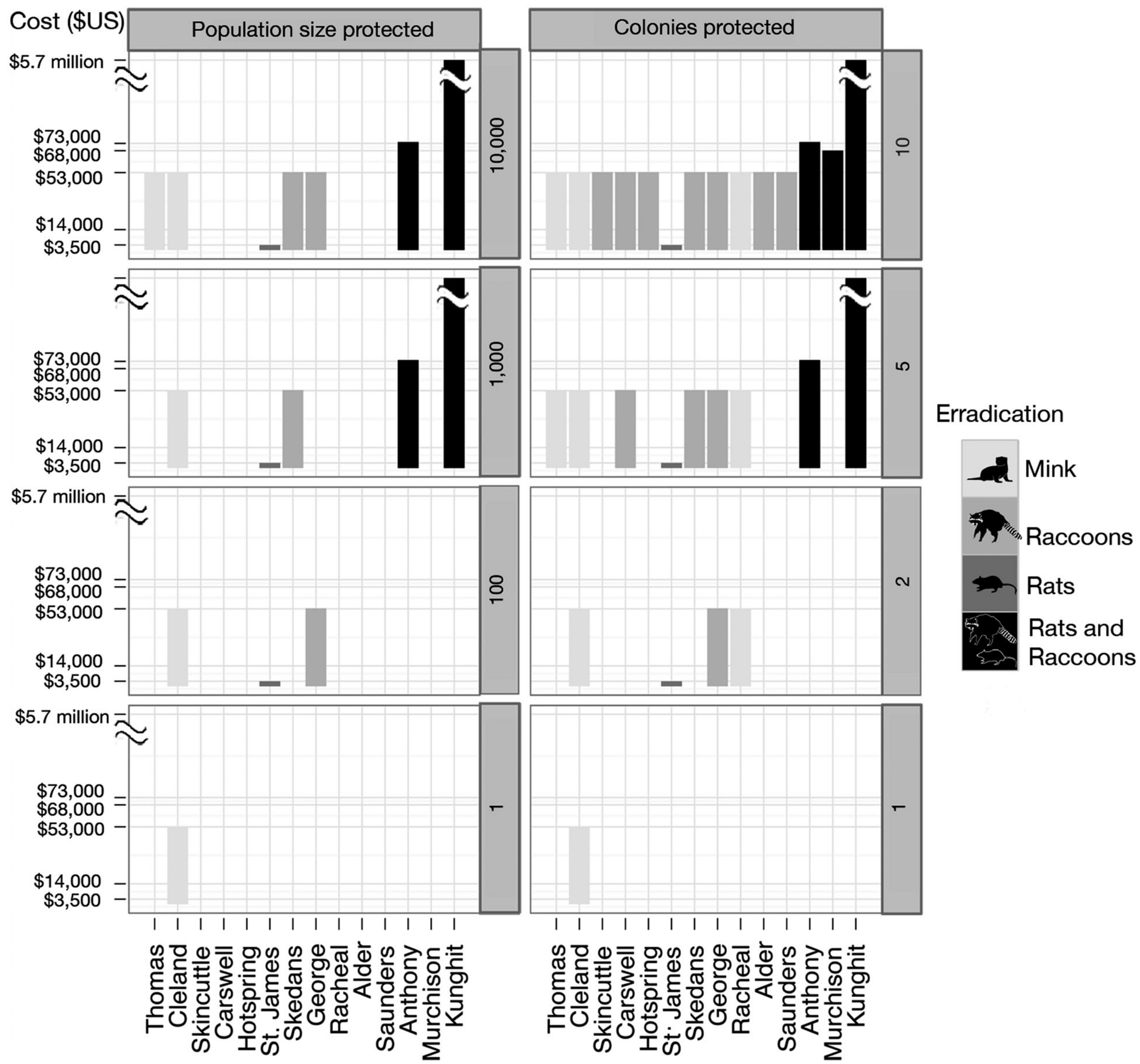

Figure 2 Set of islands to remove invasive mammal populations in order to protect a number individuals and breeding locations of six seabird species for the minimum cost. Islands are listed by increasing size moving from left to right.

100 individuals of each six species, while eradications on five islands would be required to meet the 1,000 individuals threshold for a base cost of $5.2 million (Figure 2).

When breeding location was the objective, Cleland Island was also the optimal set when protecting a single location of the six seabird species was the target (Figure 2). Compared to population size thresholds, results then diverged as the threshold number of breeding locations targeted for protection increased. Breeding location targets yielded solution sets that were also nested: islands chosen at lower thresholds were always included as the threshold level increased (e.g., 2 to 10 colonies).

A total of 14 islands were identified as high priority conservation targets across all conservation objectives and thresholds (Table 2). All seven islands identified with population size as the objective were also selected in the portfolio of islands identified with breeding locations as the objective. In general, the costs were comparable: a base costs of $5.3 million to meet the 10,000 individual threshold and $5.7 million to meet the 10 breeding locations threshold.

Table 2 Optimal set of invasive mammal eradications on islands in order to protect a number of individuals or breeding locations for six seabird species[a] at the minimum cost. Invasive predators: BlR = black rat, NoR = Norway rat, Rsp = Rattus. sp., Rac = Raccoon

			Individuals protected				Breeding location protected			
Island (invasive predator)	Size (ha)	Base cost	N = 1	N = 100	N = 1,000	N = 10,000	N = 1	N = 2	N = 5	N = 10
Instructor (Rac)	2	$53,370								
Thomas (Mink)	2	$53,370				X			X	X
Cleland (Mink)	8	$53,370	X	X	X	X	X	X	X	X
Skincuttle (Rac)	8	$53,370								X
Carswell (Rac)	17	$53,370							X	X
Hotspring (Rac)	17	$53,370								X
St. James (NoR)	22	$3,476		X	X	X		X	X	X
Skedans (Rac)	38	$53,370			X	X			X	X
George (Rac)	42	$53,370		X		X	X	X	X	X
Racheal (Mink)	48	$53,370						X	X	X
Alder (Rac)	54	$53,370								X
Saunders (Rac)	55	$53,370								X
Anthony (BlR, NoR, Rac)	130	$73,910			X	X			X	X
Kunghit (BlR, NoR, Rac)[b]	12,330	$5,000,000			X	X			X	X
No. of islands			1	3	5	7	1	4	9	14
Total cost			$53,370	$110,216	$5,184,126	$5,290,866	$53,370	$163,586	$5,397,606	$5,799,512

[a]Seabird species: Ancient Murrelet, Cassin's Auklet, Fork-tailed Storm-petrel, Leach's Storm-petrel, Rhinoceros Auklet, and Tufted Puffin.
[b]Estimated cost for rat eradication: $1,948,140. Rat and raccoon eradication is estimated at $5,000,000; this is likely a conservative estimate.

Discussion

The results of our ROI framework and analysis provide a transparent and flexible foundation on which to base seabird conservation strategies and design eradication programs. Considering two conservation objectives with varying thresholds, the 42 islands in BC known to have both invasive mammals and breeding seabirds were reduced to a set of 14 islands that (1) included the most at-risk seabird species, (2) were feasible in terms of eradication, and (3) have the greatest potential ROI with respect to the conservation objective (Table 2). Which of those 14 islands should be the highest conservation priority will depend on the objective, threshold, and total availability of funds. Once an initial set of islands is identified, planners can then incorporate real-world and pragmatic factors (e.g., funding fungibility and co-benefits). Those factors will often be dynamic and depend on local socio-economic conditions. For example, pragmatic factors for invasive mammal eradications might include sensitivities and perceptions by stakeholders regarding animal welfare (e.g., aerial broadcast of rodenticides, Sergio 2014). Our framework and model are flexible, and can be updated as new data becomes available and as conservation objectives are modified. For example, the model can be easily adapted to include other seabird species of interest, weigh certain species greater than others, update new seabird breeding information, and update cost information as eradication operations become more cost-effective.

An ROI approach can help identify the most-cost effective and inexpensive conservation interventions, while also justify larger investments. We were able to demonstrate that broad conservation gains can be made at a relatively modest cost with respect to invasive mammal eradication. For example, decision-makers could protect at least two locations for each of the at-risk seabird species by conducting eradications on four small islands (<50 ha) at an estimated base cost of $163,586. Alternatively, if seabird species richness were used to identify four priority islands (i.e., Anthony, Cleland, Kunghit, Murchinson), the estimated cost would be $5.2 million due to the inclusion of Kunghit Island (12,330 ha). Our approach also identified where large investments may be necessary as conservation targets become more ambitious: Kunghit Island was consistently identified as a priority for invasive mammal eradication in the analysis for higher thresholds. For seabirds, whose diversity and abundances do not necessarily correlate with area of breeding locations, the inclusion of large islands in a prioritization is not necessarily intuitive. Thus, an ROI approach may be particularly useful when there is high variability in the costs of potential conservation interventions and the relationship between cost and conservation benefit is not linear, continuous, nor simple.

It addition to identifying the optimal set of islands for a given conservation objective, we identified whether results led to nested sets as conservation targets became more ambitious. When island sets are nested, decision-makers are able to incrementally add additional islands as funds become available while still pursuing an optimal allocation of resources at every investment level. On the islands of BC and with the six seabird species as conservation targets, optimal sets of islands were nested, suggesting that islands could be incrementally added as funds become available. This is encouraging for organizations or agencies that have limited annual budgets or face fundraising challenges—two common scenarios. Nestedness, however, may not always be the case, as it will be influenced by biogeography and the species being targeted for conservation action (Donlan *et al.* 2005).

We made a number of simplifications to make our analysis more tractable. First, eradications are an all or nothing decision: all invasive mammals on an island are either removed or not. This simplification is justified since multispecies eradications are becoming best practice (Glen *et al.* 2013). Second, we did not explicitly consider the probability of eradication failure. Rather, we controlled for eradication failure by conservatively excluding islands that were larger than what is considered highly feasible using best practices (Veitch *et al.* 2011). We justify this simplified approach because global eradication failure rates are low, and the few recent eradication failures have been concentrated in tropical environments (Howald *et al.* 2007; Varnham 2010). Third, the conservation gains in our analyses ignore any uncertainty, assuming gains are acquired permanently with investments. Not only does this ignore reinvasion, but also the need for ongoing monitoring and biosecurity measures. Reinvasion potential can be an important factor for some islands and invasive mammals (Russell *et al.* 2010). Lastly, our consideration of the conservation benefits as a binary outcome is also relatively simplistic. From an extinction or ecological function perspective, gains are more likely to be continuous functions of density that will relate to the impact of the threat reducing a population. Other processes threatening the species under consideration will also complicate these effects. If data were available, some of these factors could be incorporated into an ROI model. For example, any necessary ordering of eradication could be integrated into the optimization if reinvasion probabilities could be assigned (e.g., distance to adjacent islands). The probability of eradication failure could also be incorporated as a multiplier on the cost of eradication or a reduction in the benefit. Addressing additional factors, however, require additional information and resources. Thus, the benefit-cost ratio of adding additional complexity into an ROI model will depend on the local biological, conservation, and sociopolitical needs and conditions.

While our eradication cost estimates are not inclusive, they are accurate estimates of the major nonfixed costs from conservation practitioners intimately involved in eradications. Since the islands included in our analysis mostly occur in a single geopolitical unit, we are able to ignore fixed costs since they are likely to be similar. This is one advantage of conducting ROI analyses at the regional level, and is particularly relevant to invasive mammal eradications because the first eradication in a country involves substantial "entry" costs (e.g., environmental compliance and bait registration). See Supporting Information for more on eradication costs.

Despite the simplification discussed above, the potential utility of our ROI approach and model to decision-makers and conservation investors is substantial. First, it allows for the quantification and comparison of conservation gains for specific interventions. This is useful for stakeholders across the environmental sector, such as foundations developing investment strategies, nonprofit organizations raising funds for their work, or government agencies justifying specific interventions or spending. As programs and budget appropriations become increasingly outcome-focused, an ROI approach will help conservation programs maximize their "bang for the buck," as well as justify specific strategies. Second, our regional ROI approach is flexible in the sense that it provides a foundation on which local complexities can be either integrated into the mathematical model or injected into the overall prioritization once high ROI interventions are identified. Lastly, the approach could be used by nonprofit organizations or government agencies in a bounded geographic area to help inform a long-term strategic plan (e.g., 10-year seabird conservation plan for BC). Moreover, organizations and agencies could invest in a single plan and coordinate their interventions in an integrated fashion.

More often than not, conservation decisions and actions are made at a regional level, as opposed to a global scale. This is certainly the case with respect to invasive mammal eradications: the majority of government agencies and nonprofit organizations conducting invasive mammal eradications are making decisions within regional geographies or island archipelagos (e.g., Towns & Broome 2003; Aquirre-Muñoz *et al.* 2008; Carrion *et al.* 2011). Conservation decision-makers and practitioners often must make choices on how to allocate funds across a number of potential conservation actions with a goal of maximizing benefits for target species. Our ROI framework presented here can serve as a decision-support tool for agencies and organizations engaging in discrete conservation interventions in order to maximize conservation benefits for the minimum cost.

Acknowledgments

We thank Gregg Howald of Island Conservation for his input and supporting our initial research. We also thank Karl Campbell for detailed feedback on eradication campaign costing information.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

1. Evidence of invasive predator impacts on seabirds breeding on islands of British Columbia.
2. Estimating costs of eradication campaigns.

Table S1. Cost projections for raccoon and mink eradications for the major variable cost of labor. All costs are in $US2013.

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