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COMMENTARY

Integrating seabird restoration and mammal eradication programs on islands to maximize conservation gains

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Abstract Colonial nesting seabirds frequently drive island ecosystem biodiversity by maintaining ecosystem functioning and community dynamics. Invasive mammal introductions to most of the world's islands have ravaged insular seabird populations and had associated devastating ecosystem-wide effects. Eradication programs remove invasive mammals from islands, with the goal of conserving and restoring island species and systems. However, most eradication programs rely almost exclusively on passive seabird recovery to achieve these goals. Unfortunately, the life histories of most seabird species are not conducive to passive recovery within a contemporary timeframe. Seabird restoration techniques can effectively overcome life history related issues and significantly reduce recovery times for insular seabird populations, thereby reducing associated ecosystem-wide recovery times. By integrating seabird restoration and eradication programs, practitioners can maximize conservation gains, expand funding opportunities, and restore island ecosystems and the biodiversity they support.

Keywords Eradication · Island · Restoration · Seabirds · Invasive mammals · Social attraction

Introduction

Colonial nesting seabirds frequently act as island ecosystem drivers, playing a major role in ecosystem functioning, community dynamics (Sekercioglu 2006; López-Victoria et al.

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2009), and other critical functions including seed dispersal (Ellis 2005) and maintenance of soil functioning (Bancroft et al. 2005). The substantial nutrient subsidies seabirds contribute through guano to otherwise nutrient-limited islands help support island biodiversity and have led to the islands on which seabirds breed being termed seabird islands (Croll et al. 2005; Young et al. 2010; Mulder et al. 2011). Unfortunately, through predation and habitat alteration, invasive mammals have ravaged insular seabird populations worldwide and are a primary cause for approximately one-third of all seabird species currently being listed as threatened with extinction (IUCN 2013; Croxall et al. 2012). The severe reduction, and sometimes extirpation, of many island seabird populations/colonies (Atkinson 1985; Hilton and Cuthbert 2010) has had devastating ecosystem-wide effects (Simberloff 1995; Jones et al. 2008).

Eradication of invasive mammals from islands has the putative goals of: (1) facilitating the recovery of threatened island species; and (2) restoring island ecosystems (Towns and Broome 2003). Unfortunately, most campaigns do surprisingly little beyond removing invasive species to facilitate recovery of threatened species and/or ecosystem functioning. Only nine of 442 successful island eradication campaigns of mammals (reviewed in Campbell and Donlan 2005; Howald et al. 2007; Nogales et al. 2004) were followed with seabird restoration projects (Jones and Kress 2012). Undoubtedly, some of these eradications were on islands without seabirds, but these data still underscore that most campaigns hope that threatened seabird populations and ecosystem functioning will recover passively (i.e. without further active intervention). However, passive recovery of seabird populations may not be sufficient for ecosystem restoration (see Croll et al. 2005; Jones 2010a) and except for islands with source populations within 25 km or with small extant populations that have withstood predation/habitat alteration, passive recovery following eradications is the exception rather than the rule (Buxton et al. 2013). Indeed, theory suggests islands may be stuck in an alternate stable state even after mammals are removed if seabirds do not recover or hysteresis requires active restoration to push the system beyond a tipping point (Scheffer et al. 2001; Fig. 1).

Many seabirds are threatened and are integral to island functioning, so it is surprising that seabird restoration has rarely been integrated with eradication projects. Here we review why many seabird species are poorly suited to passive recovery, provide examples of restoration techniques that can overcome this problem, present a decision framework to help managers decide when active restoration may be necessary, and encourage the island eradication and restoration communities to incorporate these techniques into eradication projects and enhance conservation/restoration outcomes.

Reasons preventing seabird recovery

Passive seabird recovery depends on species-specific responses to eradication efforts, including behavioral tendencies, colonizing ability, proximity to source populations, the number of similar species inhabiting the island, the size of the population at the time of the eradication, and whether or not the metapopulation population is stable or increasing (Buxton et al. 2013). Most accounts of seabirds passively re-colonizing islands following successful eradications involve islands with source populations within 25 km (Buxton et al. 2013) and/or species with relatively high reproductive rates, short pre-breeding periods, and that are not philopatric. For example, Glaucous-winged gulls (*Larus glaucescens*) recolonized Hawadax (formerly Rat Island), Alaska almost immediately after foxes (*Alopex lagopus*) were successfully eradicated (S. Ebbert pers. comm.).

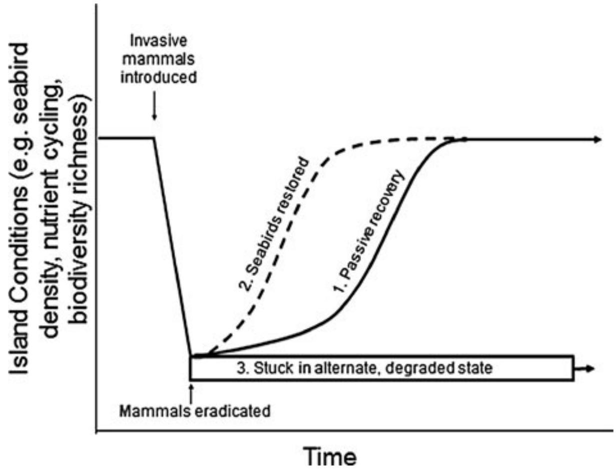

Fig. 1 Theoretical trajectories island ecosystems could take following mammal eradication. In trajectory 1 (*solid line*), island conditions improve to pre-invasion conditions passively. In trajectory 2 (*hatched line*) islands are locked into a degraded state until seabird restoration is initiated, after which the system recovers. In trajectory 3 (*box*) the island does not recover passively and since no further restoration is initiated, it remains in a mammal-free but degraded state

However, many seabird species have low reproductive rates/fecundity, exhibit intermittent breeding and high natal philopatry, and are subject to relatively strong Allee effects (Warham 1990; Jouventin et al. 2003), all of which makes recovery/re-colonization following eradications unlikely. Even when actively restored, species possessing these characteristics may take decades to build up sizable colonies. For example, Atlantic puffins (*Fractercula arctica*) took 27 years to reach over 100 breeding pairs (Kress 1998). If such species are left to recover passively, recovery to ecosystem–driving population levels may take centuries, an order of magnitude higher than is realistic for most restoration/management scenarios and funding sources, if it happens at all.

Because nutrient input by seabirds is greatly reduced and patchily distributed at low densities (Jones 2010a), dense colonies may be necessary to drive island-wide ecosystem recovery. Thus, even islands with small relic populations following eradications may not achieve densities sufficient to bring about ecosystem recovery unless additional restoration activities are undertaken. Indeed, even though nutrient dynamics may recover at low seabird densities (Jones 2010b), slower responding ecosystem components (e.g. vegetation and faunal composition) are likely to take much longer to recover (Bellingham et al. 2010). Given many seabird life histories favor slow recovery and many islands are not in close proximity to potential source populations, the current strategy of passive seabird recovery could be improved to produce better conservation and restoration outcomes.

Restoration techniques

Seabird restoration can be used to facilitate and expedite seabird recovery. Chick translocations and different combinations of social attraction (e.g. using acoustic playbacks, decoys, and mirrors, to replicate social signals of existing colonies), techniques have been successfully employed to restore a wide variety of seabird species (reviewed in Jones and Kress 2012). However, they are not always successful (e.g. Oro et al. 2011; McChesney

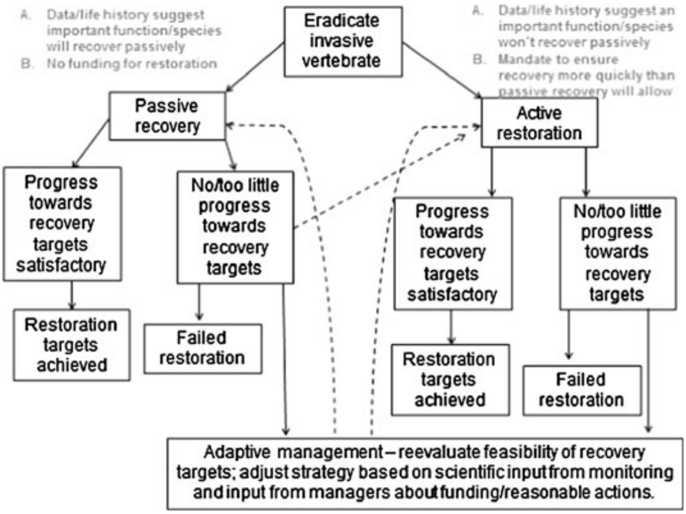

Fig. 2 Conceptual decision tree for how to proceed with restoration after invasive vertebrates are removed. Each *arrow* flowing from boxes represents one of two choices about how to proceed. *Text in gray* gives potential reasoning to choose a particular course. *Solid arrows* indicate monitoring is needed to inform the decision. *Hatched arrows* indicate refining recovery plans based on adaptive management. Restoration targets must be measurable and articulated prior to eradicating invasive vertebrates in order to be able to make informed decisions

et al. 2005) and are more effective with some species than others. Jones and Kress (2012) found 83 % of restoration projects targeting the Procellariidae were successful compared to only 29 % of projects targeting the Phalacrocoracidae. This highlights the importance of evaluating the unique circumstances of each eradication program, the life histories of the species involved, and identifying the appropriate restoration techniques before embarking on restoration efforts (see Guidance for managers; Fig. 2). However, where appropriate, these techniques not only speed the recovery of threatened seabird populations, but can also speed the recovery of island ecosystems themselves (Jones 2010a).

Given limited funding, seabird restoration can and should be integrated with eradication campaigns, when appropriate, into a single project targeting removal of invasive species followed by seabird restoration in order to promote ecosystem recovery. Integration should be particularly effective in situations involving at-risk species/populations that are unlikely to re-colonize passively (e.g. Procellariidae or islands with no nearby source populations) and situations where seabird populations have been extirpated or reduced such that they no longer contribute to ecosystem functioning. Incorporating the two efforts allows practitioners to initiate seabird restoration as soon after successful eradications as possible, thereby increasing the chances of luring any remaining birds with experience breeding at that location, a key factor in restoring seabird populations (Parker et al. 2007; Buxton et al. 2013).

Guidance for managers

We recommend practitioners follow the decision framework outlined in Fig. 2 during the planning phase of eradications to decide whether or not active restoration is necessary and revisit the framework throughout the recovery process. The schematic will apply to any island eradication program, even on non-seabird islands because it identifies the criteria for choosing when to restore any species or function deemed important. By adopting this practice, practitioners will have a more realistic picture of what will be necessary to achieve restoration in a timely manner, and a better sense of the funding and personnel necessary to achieve their restoration goals. A key feature of the decision framework is that monitoring is necessary to gauge how well restoration goals are being met (Kappes et al. 2011) and to improve our understanding of passive recovery (Buxton et al. 2013). Further, adaptive management is a necessary part of the process to ensure that progress toward restoration goals and the goals themselves are reevaluated according to input from science, society, and management throughout the process (Armstrong et al. 2007).

One of the limiting factors of whether to restore lies in the cost. In many cases, eradication programs cost millions of dollars (Donlan and Wilcox 2007; Martins et al. 2006) making it difficult to justify further expenditures beyond removing the disturbance. Nevertheless, oil spill mitigation councils, particularly in the United States, are one of the primary funders of island eradication programs, and often direct their funds be used strictly to benefit affected seabird populations. The American Trader Trustee Council partially funded the successful Anacapa Island rat eradication project in the Channel Islands to help the Scripps's murrelet (*Synthliboramphus scrippsi*) population that was reduced by the American Trader Oil Spill (American Trader Trustee Council 2001). Still others that fund eradications do so not to remove mammals *per se*, but to help island species recover and restore ecological balance. While the first task for any island restoration project is to remove invasive mammals that threaten native biodiversity, it is important for funding agencies to recognize that to meet the goal(s) of recovery and/or restoration, eradication will in many cases be merely the first in a long series of monitoring, restoration, and adaptive management steps (Fig. 2).

Eradication campaigns and post-eradication monitoring and restoration are often viewed as separate efforts with distinct funding sources, skilled professionals, and requirements. However, given the considerable time and money that is put into funding, public approval, planning, building infrastructure, and performing both eradication and seabird restoration, in many situations it may make sense to incorporate seabird restoration into eradication projects, rather than reinvesting time and money to initiate a separate projects. This strategy may also expand funding opportunities by combining current and future resource pools and giving funding sources a more realistic picture of what resources are necessary to achieve restoration.

Conclusion

While restoring seabirds is not a panacea for island restoration, it could help at-risk seabird populations and improve biodiversity gains following eradications. Eradicating invasive species from islands is a powerful conservation tool, and pairing it with seabird restoration could make even larger conservation gains. Relying on passive seabird recovery often misses a golden opportunity to restore threatened seabird populations, and fulfill the mandate of ecosystem restoration. We encourage practitioners to utilize the decision framework to help decide when restoration is most appropriate, and if it is, to integrate seabird restoration and eradication programs. In doing so, they will maximize the potential for conservation gains, expand funding opportunities, and truly restore island ecosystems and the biodiversity they support.

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