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Invited Review

Matching the strategy to the scenario; case studies of mink *Neovison vison* management

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Abstract. The invasive American mink (*Neovison vison*) preys on native fauna. The pilot phase of the Hebridean Mink Project (HMP) ran from 2001–2006 at a cost of £1.6 million and successfully removed the species from 1100 km^2 of the southern islands of the Hebridean Archipelago, the Uists. Mink were also controlled in South Harris to prevent reinvasion. 532 mink were removed, and no further animals were caught or recorded in the eradication area in the last six months of the project. The entire archipelago is now being trapped using techniques developed from the pilot phase. The programme used an adaptive approach, learning as the project proceeded. The lessons learned were also applied to two other scenarios. These included the Isle of Mull, where with limited resources, trapping is carried out by volunteers, and the development of a national management plan in Ireland, where the species is widespread and farmed. The strategies and techniques developed in the Hebrides were modified to fit these differing scenarios. These are discussed together with an exploration of how we can increase our capacity to manage the species over larger landscape scales.

Key words: control, eradication, invasive species, landscape ecology, strategy.

Invasive alien species (IAS) are regarded as one of the greatest threats to global biodiversity (Diamond 1984; Vitousek et al. 1997). They can have large impacts on offshore islands where endemic biotas are particularly vulnerable to extinction (Cronk 1997; Simberloff 2000). Island biotas form most of the world's biodiversity hot spots, accounting for 45% of all bird, plant, and reptile species (Krajick 2005). The protection of these ecosystems yield disproportionately large benefits and their management is recognized as the most cost-effective way of conserving global biodiversity (Myers et al. 2000a, 2000b). Eradication of IAS features highly as part of the conservation tools in these biomes (Atkinson 2001; Donlan et al. 2003; Genovesi 2005)

The complete eradication of IAS from an ecosystem is recognised as the preferred option as it is finite, requiring a single investment. However, eradications can fail due to a number of reasons such as; animals being missed, reinvasion, or lack of resources and time. To reduce these risks, authors have proposed criteria to be fulfilled in order for a planned eradication attempt to work (Bomford and Sinclair 2002; Genovesi 2005). This in turn influences choice of sites for eradication, or long-term control in circumstances where these criteria cannot be fulfilled. It is also a relatively uncommon action, in many cases the view may be taken that eradication is not feasible and no further action is taken. Most mammal eradications have taken place on small islands and their objectives reflect the discrete nature of these locations. Undertaking invasive species control in more open landscapes, too large for a species to be eradicated during the course of a single project, provides particular challenges (Robertson et al. 2017).

Due to the expense of eradication projects, and the inevitable aversion to failure that could result in difficulties in raising future funds, many organizations are reluctant to begin eradication projects in the absence of robust data or experience in similar environments. Many projects are delayed resulting in increased expense (Simberloff 2004; Simberloff et al. 2005) and greater impacts caused by invasive species on species of conservation interest. In the absence of such data, an adaptive approach is re-

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Table 1. A summary of the differing strategies and resource availability in the three case scenarios

Scenario	Hebrides	Mull	Ireland
Objective	Eradication or as close to it from a defined area as a pilot phase over five years	Maintain mink to below acceptable threshold. Prevent spread to outer islets, ongoing	Prioritize sites on basis of species vulnerability to predation. Planning stage, long-term
Resources	Well financed, with dedicated staff and resources	No funding, volunteer network	Planning stage only, not resourced
Mink population status	High density mink populations	Low population density. Threat from nearby mainland	Widespread and farmed until recently
Conservation species status	Widespread occurrence of critical ground nesting bird and wild salmon populations	Rare species both on Mull and even rarer breeding seabird populations on outer islets	Bird, fish, amphibian, and mammal species of European importance, vulnerable to predation
Focus	Focus all techniques and strategies on mink ecology and life cycle, year round	Focus on the breeding cycle of nesting birds, especially in outer islands, to ensure minimal predation during breeding seasons	Identify sites with the largest number of threatened species that are vulnerable as prey

quired, learning and gathering data from projects as they are carried out, and using new information and analysis to feedback into project monitoring and decision-making systems in order to fine-tune and improve project operations. This is particularly true as often the data that are required are under recorded in the literature, such as the effort required for species removal in terms of manpower and effort (Roy et al. 2008). In this paper we review three mink control programmes in the UK and Ireland to illustrate these points and the use of interim objectives in planning species removal programmes. In each, the strategy of the programme is outlined together with the techniques used to achieve them. These strategies are in turn described below and are summarized in Table 1; 1) Eradication or as close to eradication as possible from a defined area; 2) Maintaining populations to below acceptable thresholds; and 3) Removal of the species from high-priority sites of rich biodiversity vulnerable to mink predation. Some of the lessons learned and their transferability are then summarized in Tables 2 and 3 and synthesized in a graphic in Fig. 5.

Mink in the UK and Ireland

The American mink (*Neovison vison*) is a widely distributed invasive carnivore, occurring in 28 European countries having escaped from fur farms. The eradication of invasive Mustelids in general can be difficult due to their elusiveness, neophobia to objects such as traps, and low encounter rates with control mechanisms due to their wide-ranging behaviour (King et al. 2009). Most mink management projects in Europe are long-term control operations or eradications that are quite restricted in range at local river catchment level scales (Bonesi and Palazon 2007) or at a local catchment level in England (Reynolds et al. 2010). The increasing use of volunteers to reduce operating costs has allowed removal over increasingly large areas as seen in Scotland (Bryce et al. 2011; Robertson et al. 2017).

The main aim of this paper is to compare three different mink control programmes, their objectives, and the strategies deployed to achieve these. Firstly we explore the strategies and approach used in a pilot eradication scheme in the Outer Hebrides. We describe the adaptive approach used to develop the work and lessons learned. We then describe how this approach was adapted to develop a mink control strategy for Mull in the Inner Hebrides off the west coast of Scotland. Finally we look at how a strategy was developed for Ireland, and how this approached the challenges of managing the species at a nation-wide scale. The paper then concludes with conceptual developments that could make larger scale control more feasible, especially when combined with advances in technology.

Case study one; The Hebridean Mink Project 2002–2006

Having escaped from the fur farms on the Isle of Lewis in the 1950s (Fig. 1; Cuthbert 1973; Angus 1993), mink spread throughout the 2800 km^2 island archipelago through to the southern tip of South Uist within 40 years. Within this period unsuccessful attempts were made with the objective to stop them spreading across the main

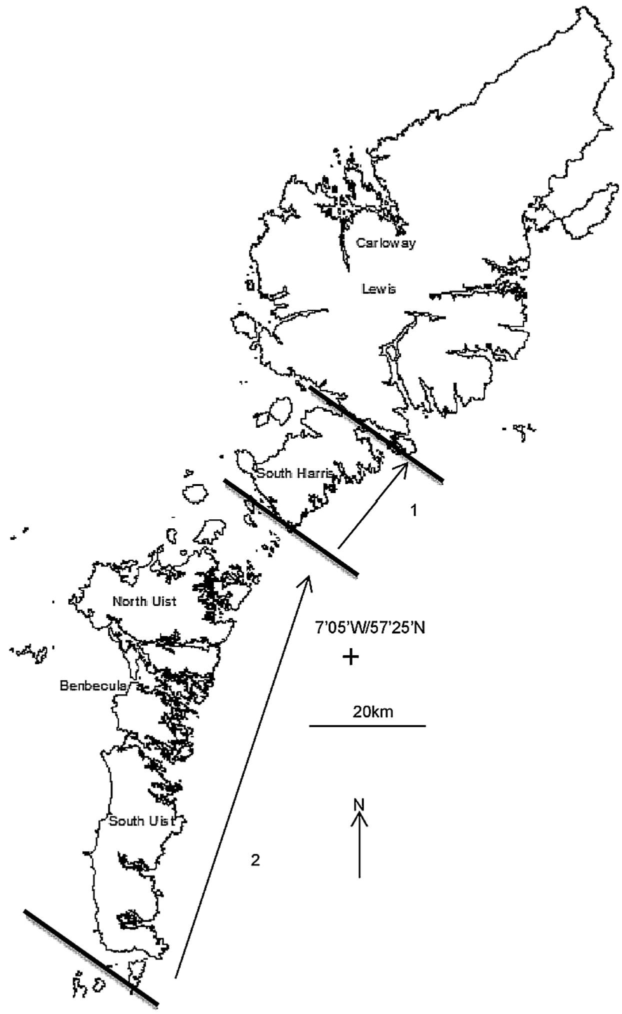

Fig. 1. A map of the Outer Hebrides showing Carloway, where the fur farms originally were, the buffer zone of Harris (1) and the removal zones of the Uists (2), taken from Roy et al. (2015).

water barrier between the islands of Harris to North Uist (Angus 1993).

Mink threaten a number of important natural resources, including important populations of ground nesting birds at critically important breeding sites. These sites or Special Protection Areas (SPAs) have been designated by the European Commission (EC) under the Birds Directive (Council Directive 2009/147/EC on the conservation of wild birds). In addition, mink are important predators of internationally important salmon populations at sites identified as Special Areas of Conservation (SACs) under the European Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora). Both the birds and habitats directives have resulted in a legally binding obligation for European Union member states to identify and protect key sites of conservation interest for species listed in the annexes in these pieces of legislation.

As well as threatening biodiversity, mink are an economic pest, damaging stock at fish farms and poultry in small holdings (Clode and MacDonald 2002; Areal and Roy 2006). The archipelago was considered too large, and the uncertainties too great, to aim for complete eradication as the project objective from the onset. Instead, an initial pilot phase was designed with the more limited objective of removing mink from North Uist, Benbecula and South Uist and to reduce mink density from neighbouring South Harris to minimise recolonisation of the Uists (Moore et al. 2003; Roy 2006, 2012). Following the success of the first phase and the information gained on the costs and methods required for success, the work has continued with the objective of the complete eradication of mink from the entire archipelago (Lambin et al. 2014).

The project used an adaptive approach from the outset; initially by collecting data from the literature on life history parameters and developing simple population models based on best estimates (Dunstone and Birks 1983; N. P. Moore et al. unpublished report). This formed an important component in a subsequent EU LIFE funded project.

Live trapping in riparian and coastal areas was the main technique used by the project. A total of 2545 live capture cage traps was dug into the ground during the first three months of the project, although only 10% was open at any one time, with the remainder left locked shut to prevent captures. All set traps were monitored daily. This was later supplemented by the use of den locating dogs. In the Uists this resulted in 100 824 trap nights over four years. Overall a total of 228 mink was caught in the Uists, with the last capture in March 2005. After this date, despite a further seven months of intensive trapping and searching effort, no further signs of mink were found and they were considered likely to have been removed from this region. After a cessation of trapping to secure further funding and continue with an island-wide eradication campaign, mink were subsequently re-discovered in the Uists, although it is not clear if these were recolonizers or relict populations (Lambin et al. 2014). In the buffer area of South Harris, 41 674 trap nights over four years resulted in 240 captures with few animals being caught by the end of the project. This effort greatly reduced the risk of recolonisation from this region, although there was still a possibility of extant isolated populations remaining within the region, particularly on offshore islets. Roy et al. (2015) provide a full description of the project.

Adaptations and lessons learned

As the project progressed, a number of logistic changes were made to maximise effectiveness and reduce costs. These included:

- The ease with which traps could be checked was improved by fitting them with solid metal, non-mesh doors, allowing the trapping staff to easily find traps and to determine from a distance if the trap had been triggered. It has been estimated that this has saved the project approximately £14 000 annually (Roy 2012).
- As mink numbers were reduced there was a need for cost effective methods of monitoring. By setting traps along the road networks and in other sites where they could be seen easily from vehicles and boats. This allowed a low density of traps to be maintained over large areas at reduced cost to help monitor mink presence or absence.
- It was found that some staff were more successful at setting traps to catch mink than others (Roy 2012). Staff were rotated between different areas to ensure these successful trappers viewed all of the different trap rounds on the islands and improved the quality of setting. They were also used to train others in their methods to spread best practice.
- It was found that mink had distinct seasonal patterns of behaviour depending on their breeding cycle, which influenced their vulnerability to traps (Dunstone 1993; Roy 2012; Roy et al. 2015). Some parts of the year they were highly mobile and easier to trap, while in others they were restricted in movement particularly when they were rearing young in their dens. We changed the seasonal profile of trapper effort to increase trapping effort during the periods when the animals were most vulnerable to this method, and instigated the use of scenting dogs during the denning season to identify den sites for targeted trapping.
- When initially placed, there were large between trapper differences in the density of traps used. Based on experience, we standardised the distance at which traps were set along waterways (400 m) to maximise the length of linear habitat covered by a given number of traps.
- Mink redistributed themselves and moved towards coastal habitats as their numbers were reduced. Stable isotope analysis carried out on carcasses showed that, as populations were culled, untrapped mink moved to secured, vacated, and nutrient rich coastal territories, increasingly relying on richer marine food as the population diminished (Bodey et al. 2010). This is despite constant trapping pressure on coastal and inland riparian habitats. To further corroborate the fact that coastal habitats provided more resources, it was seen that animals from coastal habitats had smaller home ranges (travelling less to secure more food) and were in better condition (Sandell 1989; Helyar 2005). We further increased trapping effort in coastal habitats as the work progressed as a consequence.
- Mink, like many mustelids, use scent to communicate. They have well developed scent glands, and early on in the project trials were carried out to test the efficacy of using the scent glands to bait traps. It was found that scent gland bait traps caught mink at a significantly faster rate than traps baited with fish alone (Roy et al. 2006). As a result, the use of scent glands became standard practice.

These lessons and techniques form the basis of a comparison table (Table 2), to show which of them could be transferred to the other scenarios explored in this paper.

Case study two; mink control on the Isle of Mull

A mink population was confirmed on the Isle of Mull (Fig. 2) in 2006, and at the request of Scottish Natural Heritage, a small-scale pilot study was carried out to

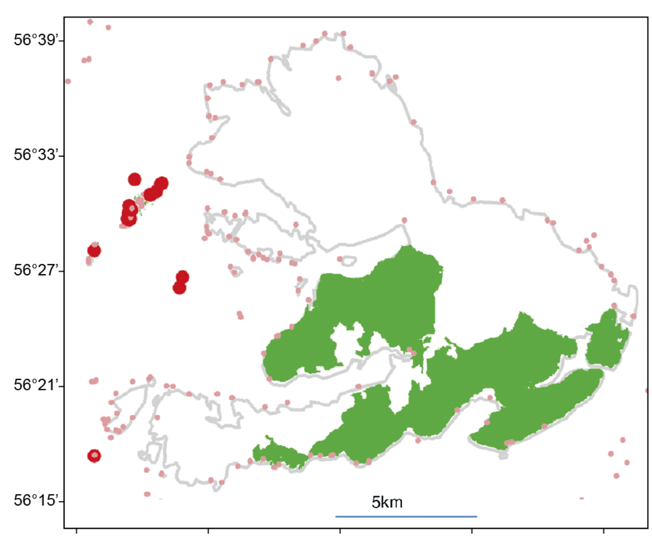

Fig. 2. Showing species richness of seabird species across Mull and adjacent islands (darker, redder spots show a greater number of seabird species). Areas in green are Special Protected Areas designated by the EU. The large red circles are areas where any mink presence at all would have very negative impacts on biodiversity, as even a few individuals in a low-density population could wipe out entire bird colonies. (Taken from Roy 2008).

Table 2. The transferability of techniques, in the three differing scenarios

Scenario	Hebrides	Mull	Ireland
Use of solid door metal traps for improved visibility	Well established from the beginning, in the first year	Would be easy to establish	Would be easy to establish
Use of roads	Used in the first year of project	Good road network and with resource limitations this would be an important technique	Should be used where possible, but difficult to build in to a strategy at this stage
Use of expert staff for training	Used as a technique half way through the project, year two	Trapping carried out by volunteers, need to hire in trainers	Should be used where possible, but difficult to build in to a strategy at this stage
Adapting trapping strategies to mink life cycle	Adopted early in the project, e.g., trapping at den sites, year two	Limited resources mean that trapping must be focussed on species of conservation interest	This would be easy to adopt in any large scale campaign
Adjusting trap density to 400 m	Possible because of resource availability and funding. Carried out in the third year of project	Not possible due to resource limitations, need to focus on breeding areas of conservation concern	Would not be realistic at a national scale, and would need to focus on sites of high priority
Changing operations according to how remaining animals redistribute themselves	Possible because the Hebrides has limited food availability and unique habitats. Adopted in the second year of project	Need to focus on areas of conservation concern	High availability of food varying seasonally. This means there are many food rich habitats and this would need to be assessed to see if mink would redistribute themselves to high quality habitats which may or may not exist
Use of scent gland	Established in the first year of project	Would be easy to establish	Would be easy to establish

explore the different control options available on this island (Roy 2008). Based on the density seen on the Outer Hebrides, the population was estimated at a carrying capacity of approximately 400 individuals estimated (Sugoto Roy 2007, unpublished report). However, the strategies that could be applied to this scenario are very different to those in case study one. Firstly, the reinvasion risk was considered very high as the Isle of Mull is within swimming distance of mink found on the mainland of Scotland, which is five kilometres away, without accounting for offshore islands in between the two land masses. Secondly, resources were very limited. Trapping was carried out by a handful of volunteers, with limited traps and money. Given the reinvasion risk, eradication was not an option, and the priority was to reduce the impacts of mink on species of conservation concern, in particular the important seabird colonies found off the West Coast of Mull. The objective was therefore to reduce predation on these colonies during the breeding season by reducing mink populations to zero at least around the periods of seabird breeding.

Transferrable techniques

A number of the techniques developed on the Outer Hebrides could be transferred to support the trapping campaign on Mull. Table 2 outlines the techniques from the Hebrides that could be transferred to this scenario.

The Mull programme cannot be described as an eradication, but if well executed it could keep the critical areas of the island mink free, at least during the seabird breeding season. The complete removal of a species from an area, albeit with the continued risk of reinvasion, is still different from ongoing control, while providing many of the benefits of true eradication at a local scale.

Case study three; managing mink on protected areas across Ireland

In the third case study, the different strategies that could be applied to the management of mink in Ireland were explored. This included a review of the possible techniques that could be utilized in the event of any nationwide control effort (Roy et al. 2009).

In this scenario, eradication was not an option as mink farms were still in operation in the Irish Republic. Animals were still escaping from these facilities, and sightings of feral mink often occurred in their vicinity (Fig. 3). As a result, there was a continuous source population from which re-invasion could occur. Also, the available resources were insufficient to carry out an eradication

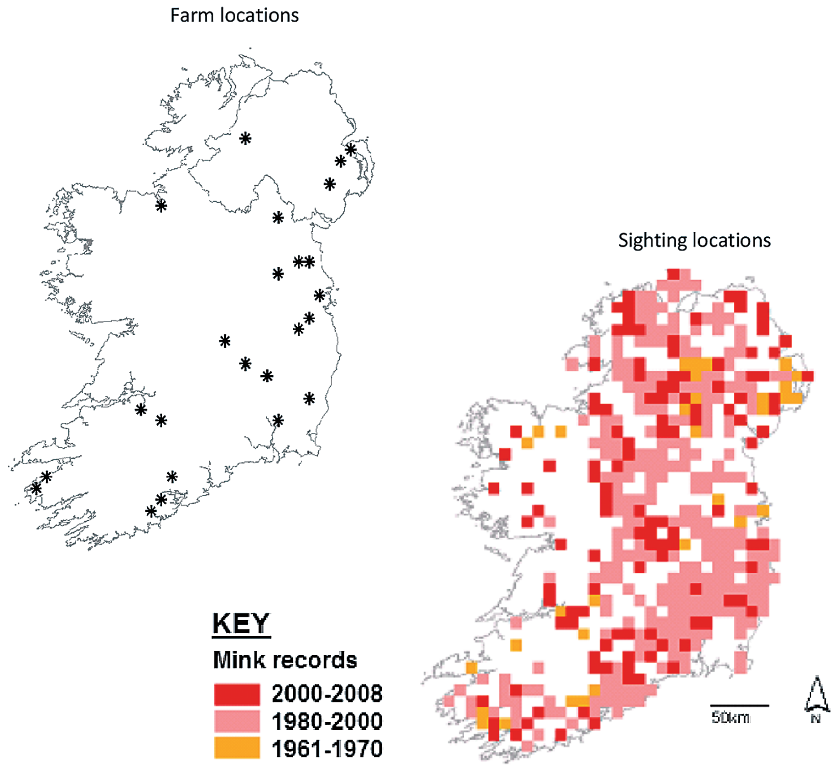

Fig. 3. Location of Irish mink fur farms 1900–1960 (left) and mink sightings (right) from 1961–2008. The figure is taken from Roy et al. (2009).

over an area of 840 000 km^2 (Robertson et al. 2017).

The objective of mink control in Ireland is to protect globally and regionally important species of migratory birds, such as ground nesting farmland birds and seabirds, together with freshwater species of fish and invertebrates that are protected under the annexes of the EU Habitats Directive. Any strategy for Mink control would need to be developed with a focus on protecting species of conservation concern.

Again in terms of techniques, many of those developed in the previous projects could be applied here and these are outlined in Table 2.

In addition to these approaches, a further method developed for use on slow flowing lowland waterways — the mink raft (Reynolds et al. 2010), — was also considered. This combines detection (through footprint tracking media) followed by subsequent trap operation to ensure the traps are only open when and where animals are detected, making large-scale trapping operations more economic.

The most feasible possible option available in this current scenario was to map out all protected areas in Ireland, and categorize them in terms of the protected species of conservation concern that they are designated for under

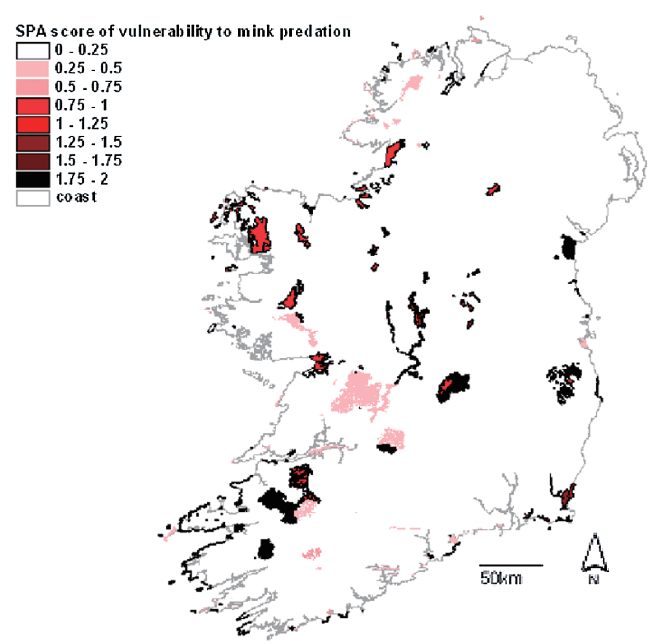

Fig. 4. A map of the SPAs in the Republic of Ireland, colour coded according to an index incorporating the number of Annex one species present on them and how vulnerable these species are to mink predation taken from Roy et al. (2009).

the EU Habitats Directive. These species were then classified on the basis of their vulnerability to mink predation based on size. These sites were then prioritized accordingly; i.e., protected areas with a large number of vulnerable species were given high priority and vice versa. The process is described in detail in Roy et al. (2009). Maps summarizing high-priority areas are given in Fig. 4. This programme is best described as on-going control using the terminology of Bomford and Sinclair (2002).

Programme objectives

The three case studies illustrate different objectives, reflecting the costs, feasibility, and scale of the different scenarios. These can be contrasted with the criteria for eradication proposed by Bomford and O'Brien (1995) to illustrate some of the choices faced by managers.

In the first case of the Hebrides, the long-term objective was to achieve true eradication from the entire archipelago, but this was considered too expensive and uncertain to be funded. Consequently, the objectives were reduced to the complete removal of mink from part of the island chain to a natural barrier. This reduced the costs and risks, and on the projects successful completion the work was extended to achieve eradication throughout the island chain. When dealing with large scale eradications such a step-wise approach is pragmatic, even though the individual elements to not meet all of the proposed criteria to achieve eradication.

The second case study, from Mull, had the objective of limiting damage to a resource, the seabird colonies, and true eradication was not considered feasible given the chances of reinvasion. However, it was considered possible to achieve complete removal of mink from the island with only the need to deal with incursions as they occurred. This is also a common situation on many islands, and a feature of larger programmes where the risk of reinvasion cannot be discounted. This strategy of maintaining an area as animal free is not eradications, but also does not fit comfortably in the definition of 'ongoing control' proposed by Bomford and O'Brien (1995).

The last case study of control in Ireland falls more clearly into the category of ongoing control, with a continued need to remove animals at a relatively small scale to protect local resources.

All three case studies demonstrate successful approaches to reduce the impact of mink, but with different objectives and costs. Maintaining a flexible approach to the choice of objectives while maintaining clarity in different cases is key to the successful management of IAS impacts. This need for flexibility is not uncommon in very large scale control programmes (Robertson et al. 2017).

Technological advancements

The choice of objectives is often determined by the availability and costs of available methods, and these constraints may change as technology develops. For mink control, the need to check traps daily for humaneness reasons imposes limitations on how far and wide an area staff can cover. The different case studies have been described using a schematic diagram in Fig. 5. Efficiency measures such as those described below, may be useful in changing the parameters and limitations dictated by resource availability. As a result, larger, more difficult, and more ambitious eradication can be undertaken. Countering these limitations is key and may be achieved through the development of new techniques as outlined below:

- Developing methods to detect animals that do not require their capture or daily checking. This is one of the fundamental aspects of the use of mink rafts (Reynolds et al. 2010). Here tracking systems associated with traps first detect the presence or absence of mink, and the traps are only opened once an animal is known to be frequenting the area. This can greatly reduce the need for daily checking.
- In addition, the use of alternative sources of data, such as data from public sightings, can be aggregated and used to identify areas with a high likelihood of presence or absence of a species during removal. This was carried out post-hoc for the Hebridean project, and analysis of sighting data suggest that they are a useful addition to other detection techniques (Faulkner et al. 2017).
- Remote checking of traps. Systems exist which can send a signal, for example over the mobile phone network, to give notification that a trap has been sprung (e.g., www.minkpolice.com). At present these systems are limited by cost and the availability of communications coverage which can limit their use. However, the cost of the equipment is likely to be outweighed by the savings in manpower, particularly when the rate of capture is expected to be low.
- Self-resetting traps. The use of lethal traps which kill rather than capture the animal may have different checking requirements and these can vary between

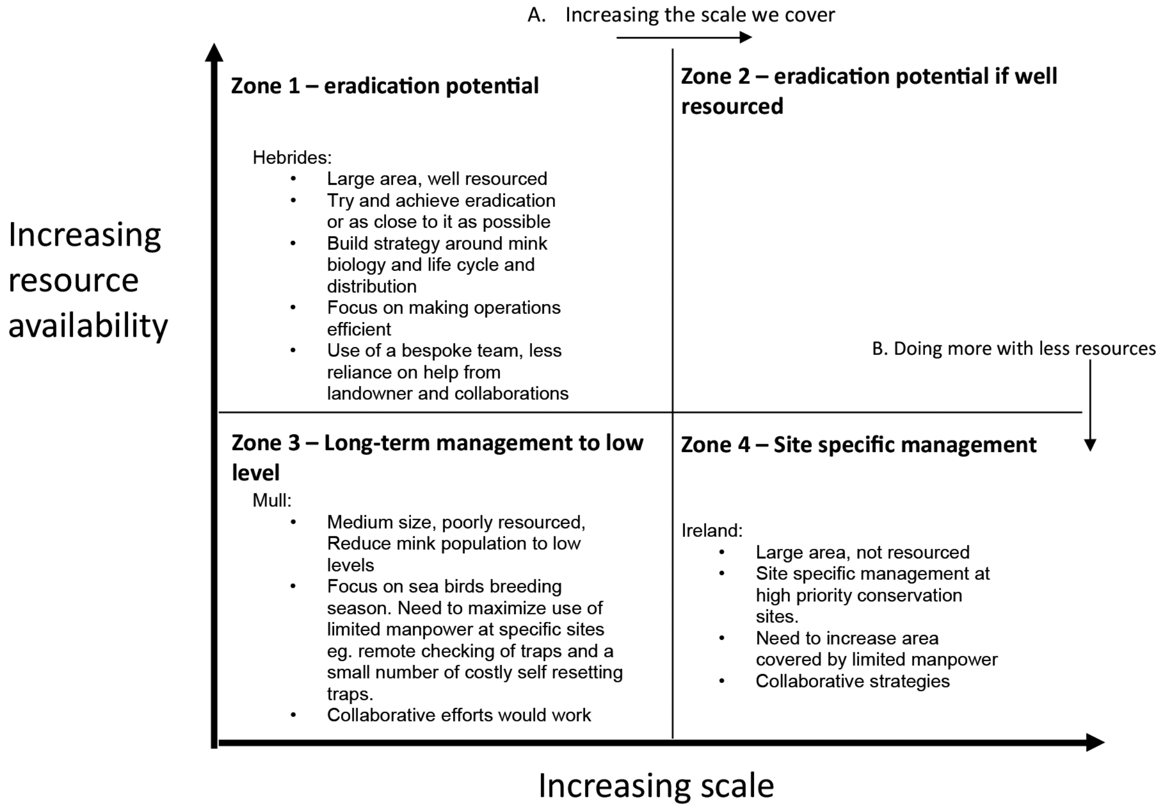

Fig. 5. A schematic diagram demonstrating how area and resource availability determines the overall strategy and approach to the management of mink. Where campaigns are well resourced and areas are not too large, such as in zone 1, eradication is possible. If areas are very large, a lot of resources will be needed to achieve eradication. In zone 3, where areas are relatively small, even if poorly resourced, mink populations can be maintained to low levels, especially if labour saving techniques are used. In zone 4, where areas are large and resources are limited, campaigns need to focus on interventions at high priority sites. Zone 1 can be increased by increasing the areas we can cover (denoted by A), e.g., through use of roads, checking traps from a distance etc. It can also be increased by making better use of existing limited resources (denoted by B), e.g., by using self-resetting or self-reporting traps, thus reducing manpower needs.

countries. However, traps still need to be visited to be reset. A variety of novel designs offer the potential for self-resetting traps (e.g., www.goodnature.co.nz) (Carter et al. 2016). Although lethal trapping options were not discussed here, if the risk for non-targets species is low, such traps would enhance the efficiency of trapping campaigns in terms of area, time, and staff resources. Traps could be left unattended for long periods of time and only checked periodically.

Strategic advancements

Fostering collaboration: In large landscape scale management operations, collaborative efforts between organizations and individuals can greatly enhance our ability to manage invasive species more effectively. An economic study carried out after the end of the project, explored different scenarios under which fish farms in the Scottish islands could more effectively manage mink (Areal and Roy 2006). It found that by acting together, the cost of mink control, in particularly the overhead costs and the initial outlay in equipment costs, could greatly reduce the financial burden on any one organization, and could increase the area over which operations could be undertaken. Joining together to develop management teams and equipment pools would greatly improve mink control at the landscape scale. This has also been found on the mainland Scotland where different landowners and volunteer forces have greatly improved our ability to manage the species (Bryce et al. 2011).

Better adherence to the precautionary principle (Wittenberg and Cock 2001): the precautionary principle advocates a hierarchical approach to invasive species management, starting from prevention all the way through to early detection and rapid response, eradication, and long term control. Improving systems at an earlier stage of invasion would greatly improve the cost-effectiveness of regional invasive species management strategies. A

Table 3. Technological and strategic developments that could greatly improve removal efficacy in the different scenarios

Scenario	Hebrides	Mull	Ireland
Improvements in detection technology	This would be useful especially at low densities, but only if unit costs were low as the area to be covered is large	This is a very appropriate techniques here, as Mull has a landscape with well-defined rivers. the area is smaller and trapping would focus on conservation specific sites	This is not appropriate as the costs over such a vast landscape would not be bearable
Using sighting data	Although analysed post-hoc, this would have been a useful addition to the project	This would be easy to gather and analyse	This would be easy to gather and analyse
Remote checking of traps	If costs were low enough to outweigh manpower costs, this would greatly improve trapping efficiency	This would enable the few volunteer trappers to check larger areas	If affordable it would enable site managers to cover larger landscapes
Self-traps	At low densities close to eradication, in conjunction with detection technologies this would be a great tool	This would enable trapping on seabird breeding sites offshore with little effort	Units are too costly for landscape scale management. It may be appropriate for site specific projects of high priority
Collaborative/cooperative projects	Bespoke trapping teams and equipment will always outweigh collaborative efforts, but in their absence this may work to reduce numbers	This would be one of the easiest ways to secure sufficient resources and manpower for this island	This would be a good strategy early on at a landscape scale to reduce numbers. It would not work for high priority conservation sites

number of species, some quite novel, are now being traded on the Internet (Parrott and Roy 2009), and species are being moved around from between the mainland of the UK and offshore islands deliberately. These include recent populations of pine martens on Mull and Skye (Solow et al. 2013), and fox sightings on the Outer Hebrides (Cramb 2006). The development of formal surveillance programs, the recording and reporting of early detection and sightings, and having in place rapid response teams and equipment with greatly enhance our ability to manage invasion.

A more useful way of developing regional strategies for invasive species management would be to apply all aspects of the precautionary principle to all situations. For example, any future planned eradication on Mull would need to incorporate preventative measures to stop animals coming in from the mainland, such as mink management on the adjoining Scottish mainland, early detection and rapid response of any invaders, formal eradication of defined areas of conservation importance, and longer term, but efficient, control strategies for the remaining areas. Similarly, any eradication of mink on the Outer Hebrides still requires surveillance of any remaining animals, or new invaders brought in through human agency. Using novel technologies, self-setting lethal traps or self-reporting detecting mechanisms could be used to make long-term surveillance more sustainable.

All the technological and strategic developments outlined above are summarized in Table 3, comparing their applicability to the different scenarios. These include techniques and ideas that have developed after the completion of the Hebridean project through post-hoc analysis, for example where sighting data was found to be a useful addition to field data. Ultimately, the objective of any species management campaign will be dependent on the area that needs to be managed and the resources available for management. Eradication is only possible where resources are sufficient and areas are not prohibitively large, as summarized in Fig. 5. If insufficiently resourced, alternative objectives, such as long term management or site specific control need to be developed, using labour saving techniques to improve efficacy with limited resources.

As a final note, engaging with policymakers to strengthen operational biosecurity measures on offshore islands, would help to maintain their biological status and uniqueness.

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References

Angus, S. 1993. A mink control programme for Lewis and Harris. Hebridean Naturalist 11: 78–84.

Areal, F. J. and Roy, S. S. 2006. A management decision tool for mink (*Neovison vison*) control in the western isles of scotland (UK). International Journal of Ecodynamics 40: 16–31.

Atkinson, I. A. E. 2001. Introduced mammals and models for restoration. Biological Conservation 99: 81–96.

Bodey, T. W., Bearhop, S., Roy, S. S., Newton, J. and McDonald, R. A. 2010. Behavioural responses of invasive American mink *Neovison vison* to an eradication campaign, revealed by stable isotope analysis. Journal of Applied Ecology 47: 114–120.

Bomford, M. and O'Brien, P. 1995. Eradication or control for vertebrate pests? Wildlife Society Bulletin 23: 249–255.

Bomford, M. and Sinclair, R. 2002. Australian research on bird pests: impact, management and future directions. Emu 102: 29–45.

Bonesi, L. and Palazon, S. 2007. The American mink in Europe: status, impacts and control. Biological Conservation 134: 470–483.

Bryce, R., Oliver, M. K., Davies, L., Gray, H., Urquhart, J. and Lambin, X. 2011. Turning back the tide of American mink invasion at an unprecedented scale through community participation and adaptive management. Biological Conservation 144: 575–583.

Carter, A., Barr, S., Bond, C., Paske, G., Peters, D. and van Dam, R. 2016. Controlling sympatric pest mammal populations in New Zealand with self-resetting, toxicant-free traps: a promising tool for invasive species management. Biological Invasions 18: 1723–1736.

Clode, D. and MacDonald, D. W. 2002. Invasive predators and the conservation of island birds: the case of American Mink *Mustela vison* and terns *Sterna* spp. in the Western Isles, Scotland. Bird Study 49: 118–123.

Cramb, A. 2006. Wildlife fears as foxes are sighted on islands. The Telegraph Online, 18th May 2006. (http://www.telegraph.co.uk/news/uknews/1518665/Wildlife-fears-as-foxes-are-sighted-on-islands.html)

Cronk, Q. C. B. 1997. Islands: Stability, diversity, conservation. Biodiversity and Conservation 6: 477–493.

Cuthbert, J. H. 1973. The origin and distribution of feral mink in Scotland. Mammal Review 3: 97–103.

Diamond, J. M. 1984. Introductions, extinctions, exterminations and invasions. In (Nitecki, M. H., ed.) Normal Extinctions of Isolated Populations, pp. 191–246. Chicago University Press, Chicago.

Donlan, C. J., Tershy, B. R., Campbell, K. and Cruz, F. 2003. Research for requiems: the need for more collaborative action in eradication of invasive species. Conservation Biology 17: 1850–1851.

Dunstone, N. 1993. The Mink. T. and A.D. Poyser, London, 232 pp.

Dunstone, N. and Birks, J. D. S. 1983. Activity budget and habitat useage by coastal living mink (*Mustela vison* Schreber). Acta Zoologica Fennica 174: 189–191.

Faulkner, S. C., Verity, R., Roberts, D., Roy, S. S., Robertson, P. A., Stevenson, M. D. and Le Comber, S. C. 2017. Using geographic profiling to compare the value of sightings vs trap data in a biological invasion. Diversity and Distributions 23: 104–112.

Genovesi, P. 2005. Eradications of invasive alien species in Europe: a review. Biological Invasions 7: 127–133.

Helyar, A. 2005. The Ecology of American Mink (*Mustera vision*); Response to Control. University of York, York, 230 pp.

King, C. M., McDonald, R. M., Martin, R. D. and Dennis, T. 2009. Why is eradication of invasive mustelids so difficult? Biological Conservation 142: 806–816.

Krajick, K. 2005. Winning the war against island invaders. Science 310: 1410–1413.

Lambin, X., Cornulier, T., Oliver, M. K. and Fraser, E. J. 2014. Analysis and future application of Hebridean Mink Project data. Scottish Natural Heritage Commissioned Report 42: 50 pp.

Moore, N. P., Roy, S. S. and Helyar, A. 2003. Mink (*Mustela vison*) eradication to protect ground-nesting birds in the Western Isles, Scotland, United Kingdom. New Zealand Journal of Zoology 30: 443–452.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J. 2000a. Biodiversity hotspots for conservation priorities. Nature 403: 853–858.

Myers, J. H., Simberloff, D., Kuris, A. M. and Carey, J. R. 2000b. Eradication revisited: dealing with exotic species. Trends in Ecology & Evolution 15: 316–320.

Parrott, D. and Roy, S. 2009. A Preliminary Assessment of a Non-native Species Pathway—The UK Internet Pet Trade. Central Science Laboratory, York, 33 pp.

Reynolds, J. C., Porteus, T. A., Richardson, S.M., Leigh, R. J. and Short, M. J. 2010. Detectability of American mink using rafts to solicit field signs in a population control context. Journal of Wildlife Management 74: 1601–1606.

Robertson, P. A., Adriaens, T., Lambin, X., Mill, A., Roy, S., Shuttleworth, C. and Sutton-Croft, M. 2017. The large-scale removal of mammalian invasive alien species in Northern Europe. Pest Management Science 73: 273–279.

Roy, S. 2008. Mink control on the Isle of Mull and Iona, pp. 1–49. Central Science Laboratory.

Roy, S. 2012. Strategies to improve landscape scale management of mink populations in the west coast of Scotland: lessons learned from the Uists 2001–2006. In (Veitch, C. R., Clout, M. N. and Towns, D. R., eds.) Island Invasives: Eradication and Management, pp. 114–117. IUCN, Gland.

Roy, S. S. 2006. Mink Control to Protect Important Birds in SPAs in the Western Isles. Central Science Laboratories, Stornoway, 60 pp.

Roy, S. S., Chauvenet, A. L. M. and Robertson, P. A. 2015. Removal of American mink (*Neovison vison*) from the Uists, Outer Hebrides, Scotland. Biological Invasions 17: 2811–2820.

Roy, S. S., Macleod, I. and Moore, N. P. 2006. The use of scent glands to improve the efficiency of mink (*Mustela vison*) captures in the Outer Hebrides. New Zealand Journal of Zoology 33: 267–271.

Roy, S., Reid, N. and McDonald, R. A. 2009. A Review of Mink Predation and Control for Ireland. Irish Wildlife Manuals, No. 40. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland, 65 pp.

Roy, S., Smith, G. and Russell, J. C. 2008. Identifying gaps in our knowledge in the management of invasive species. Human Wildlife Conflicts 3: 30–40.

Sandell, M. 1989. The mating tactics and spacing patterns of solitary carnivores. In (Gittleman, J. L., ed.) Carnivore Behavior, Ecology and Evolution, pp. 164–182. Springer, US.

Simberloff, D. 2000. Global climate change and introduced species in United States forests. Science of the Total Environment 262: 253–261.

Simberloff, D. 2004. Invasion biology: critique of a pseudoscience. Ecological Economics 48: 360–362.

Simberloff, D., Parker, I. M. and Windle, P. N. 2005. Introduced species policy, management, and future research needs. Frontiers in Ecology and the Environment 3: 12–20.

Solow, A., Roy, S., Bell, C., Milborrow, J. and Roberts, D. 2013. On inference about the introduction time of an introduced species with an application to the pine marten on Mull. Biological Conservation 159: 4–6.

Vitousek, P. M., D'Antonio, C. M., Loope, L. L., Rejmanek, M. and Westbrooks, R. 1997. Introduced species: a significant component of human-caused global change. New Zealand Journal of Ecology 21: 1–16.

Wittenberg, R. and Cock, M. J. W. 2001. Invasive Alien Species: A Toolkit of Best Prevention and Management Practises. CAB International, Wallingford, Oxon, UK, 228 pp.

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