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Turning Back the Tide of American Mink Invasion in Partnership with Communities

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ABSTRACT: Successful eradications of harmful invasive species have been mostly confined to islands while control programs in mainland areas remain small, uncoordinated, and vulnerable to recolonisation. To allow the recovery of threatened native species, innovative management strategies are required to remove invasives from large areas. We took an adaptive approach to achieve large-scale eradication of invasive American mink in North East Scotland. The project was centered on the Cairngorms National Park (Scotland), with the primary aim of protecting endangered water vole populations. The project was initiated by scientists and supported and implemented through a partnership comprising a government agency, national park authority, and local fisheries boards. Capitalising on the convergent interests of a diverse range of local stakeholders, we created a coordinated coalition of trained volunteers to detect and trap mink. Starting in montane headwaters, we systematically moved down river catchments, deploying mink rafts, an effective detection and trapping platform. Volunteers took increasing responsibility for raft monitoring and mink trapping as the project progressed. Within 3 years, the project removed 376 mink from 10,570 km² (4,081 mi²) with the involvement of 186 volunteers. Capture rate within sub-catchments increased with greater connectivity to mink in other sub-catchments and with proximity to the coast, where there is more productive habitat. The main factor underpinning the success of this project was functional volunteer participation. The project is a reason for optimism that the tide of invasion can be rolled back on a large scale where the convergent interest of local communities can be harnessed. A successor to this project using the same volunteer-based approach and partnership between conservation practitioners and academic scientists is now expanding to up to 20,000 km² (7,722 mi²). The research of the expanded project component now focuses on compensatory processes operating in very-low-density populations.

KEY WORDS: compensation, invasive species, mink, *Neovison vison*, non-native species, participatory management, population dynamics, Scotland, trapping, volunteers

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INTRODUCTION

The spread of invasive non-native species has a devastating impact on native biodiversity. Many alien, opportunistic predator species have caused fundamental changes in ecosystems via their impacts on native species (Simberloff 2001). There is a growing realisation of the need for active management to minimise such impacts. Eradication of vertebrate aliens is increasingly achieved on oceanic islands through the use of toxins that can be spread aerially (Saffer and Calver 2001, Parkes et al. 2006). Poisoning is also used in sparsely populated areas of mainland Australia and New Zealand to suppress introduced carnivore (Cromarty et al. 2002, Parkes et al. 2006). However, owing to its higher human population density, diversity of land use and smaller size of protected areas, poison-based eradication programs of carnivores would not be possible in Europe (Bertolino and Genovesi 2003). Management of vertebrate aliens in Europe must therefore be undertaken with the support, and possibly active involvement, of local communities using techniques such as live trapping.

Despite an improving success rate and greater boldness with eradications of invasive vertebrates from islands, most mainland areas remain badly affected. Whilst there is a consensus that reversing continental scale invasions remains unfeasible, there is little consensus on the feasibility and cost-effectiveness of region-wide eradications (Bomford and O'Brien 1995). Where management interventions fall short of eradication, they must be sustained

in perpetuity, with potentially ongoing expenditure owing to recolonisation from uncontrolled areas. One approach to contend with this is the systematic use of citizen volunteers. Indeed, it has been argued that eradication programs which require manual labour are likely to be impossible in developed economies without the use of volunteers (Wittenberg and Cock 2001). Here, we update a previously published account of the approach and achievement of a recent large scale eradication of breeding American mink (*Neovison vison*) from 10,000 km² (3,861 mi²) of North East Scotland that credits the use of volunteers as the crucial element underpinning the project's success. The project is the largest mainland invasive species eradication effort worldwide and, through an adaptive management approach, used the convergent interests of local communities to maximum benefit to secure an invasion-free area at such a scale as to considerably reduce recolonisation.

MATERIAL AND METHODS

The Focal Invasive Non-Native Species

The American mink (hereafter 'mink') is a semi-aquatic, medium-sized mustelid that originates from North America (Dunstone 1993). Mink have been introduced to Europe, South America, and Asia, mostly through the activity of fur farming, and feral populations have established due to intentional releases and escapes from these farms (Bonesi and Palazon 2007). Mink have been present in Scotland since 1938, when the first fur farm was

Figure 1. Distribution of mink sightings in Scotland collected from historic and current data sources up to July 2010, (black circles), and of sightings of other mustelids (grey circles) shown to convey the sampling coverage.

established in Southern Scotland (Cuthbert 1973). Following a post-war industry growth, the number of farms reached around 100 all over Scotland but had decreased to 29 by 1971 after the introduction of the Mink Keeping Regulations (Destructive Imported Animals Act 1932) in 1962 (Cuthbert 1973). However, the overall number of ranched mink did not show the same decline, as it was mostly the smaller farms that closed down (Cuthbert 1973). The earliest record of feral mink in the wild was in 1938, and there were several other casual records until the first record of mink breeding in the wild in 1962 (Cuthbert 1973). The actual number and location of all mink farms in Scotland is unknown, but farms were well distributed throughout much of the Scottish mainland as well as on the islands of Lewis to the west and Shetland to the north. In 1973, feral mink were found in all but the two northernmost Scottish mainland counties (despite there being farms there in the 1960s) (Cuthbert 1973). The invasion of mink in Scotland has been aided by high and widespread propagule pressure and human affiliation. If farms were widely distributed, and if all of Scotland was equally suitable for invasion, then the expectation is that mink should be found all over Scotland, though the invasion seems as yet incomplete (Figure 1).

A Participatory Project Involving Scientists and Local Communities

The project was initiated by scientists with support from Scottish Natural Heritage, a governmental body; The Cairngorms National Park Authority; and three fisheries trusts, with additional funding from a NGO, the Tubney Charitable Trust; and from a research funding body, the Natural Environment Research Council. The strategy of the project consisted of coordinating and optimizing the efforts of an existing, local and skilled workforce with convergent interests to deliver coordinated, systematic, sub-catchment by sub-catchment eradication and monitoring of mink, so as to achieve maximum conservation benefit on a scale not previously attempted anywhere worldwide.

A key component of the strategy was to promote the systematic use of mink rafts: floating platforms with a footprint-recording plate made of moist clay and sand under a wooden tunnel (Reynolds et al. 2004). Mink rafts are designed to act both as a monitoring device and as a trapping site for American mink. Traps are placed in the tunnel of the raft, subsequent to mink footprints being recorded during fortnightly checks. Rafts thus provide a targeted, highly-effective method of mink trapping. Repeated scoring makes it possible to evaluate both mink persistence and the impact of control activities in the area. Raft monitoring also provides feedback on the impact of trapping, which helps to motivate project partners.

The strategy of the project was to expand mink control spatially and establish a “rolling carpet”, deploying rafts and recruiting volunteers to operate them in each sub-catchment, moving downstream from the headwaters of the 5 main river catchments that flow from Cairngorms National Park, but retaining the network of rafts behind the expanding control front to ensure detection and removal of immigrants. Each raft was in essence adopted by a different volunteer. Volunteers were encouraged to become “citizen conservationists”, acting as guardians of a specific stretch of waterway to detect and act upon mink presence. **Our long-term management goal was to achieve sustainable catchment-wide removal of mink, hence creating suitable conditions for the recovery of the focal native species on a large scale by promoting ownership of biodiversity resources by local communities.**

The project was initiated with only partial knowledge of upland mink populations. Specifically, we did not know how large an increase in mink trapping effort, beyond the baseline level, was required so as to bring about a sustained decline in the local mink population. We thus chose to use an adaptive management approach, with information gained in the early stages used to optimize the project’s conservation benefit, sustainability, and cost effectiveness. It was thus essential to systematically collect data from all aspects and participants of the projects to inform management. Volunteers were trained in the use of rafts. Project staff monitored mink rafts where volunteers were unavailable. Volunteers were instructed to set cage live-traps on rafts whenever mink footprints or sightings were recorded and/or contact a project officer or named volunteer to carry out trapping and dispatch of mink. Those willing were trained to dispatch mink humanely using air rifles or pistols of sufficient power. A key fea-

Figure 2. Distribution of all mink detection rafts deployed as of December 2011.

Figure 3. Distribution of female mink captures (denoted by stars) and of all other mink (unknown and as yet not sexed) as of December 2011 showing the distribution being largely restricted to lowland areas and valley bottoms.

ture of the project is the seamless integration of science and management, something much talked about but rarely achieved in practice.

RESULTS AND DISCUSSION

Within 3 years, the project removed 376 mink from 10,570 km² with the involvement of 186 volunteers. By the end of 2011, the cumulative number of mink removed exceeded 750, more than 620 volunteers were active, and an area approaching 15,000 km² (5,792 mi²) was actively managed (Figure 2). The proportional contribution of volunteers to the project increased steadily over time. By the end of 3 years, volunteers monitored 86% of all rafts and trapped 51% of mink removed.

Mink were caught in large numbers in all river catchments, but the distribution of females, especially adults, was restricted to the lower lying patch of the catchment with only a small number of adult individuals caught in upland areas over the course of the projects (Figure 3). This is despite the fact that mink have previously occupied the whole of the area controlled and were regularly caught

in the moorland areas 200 m above sea level by game keepers (Figure 1). The pattern is suggestive of a source-sink dynamics, with the depletion of lowland populations restricting the invasion pressure in less productive higher elevation areas. Low invasion pressure of the uplands, rather than any lack of susceptibility to mink invasion in those habitats, has contributed to those areas acting as a partial refuge for water voles (*Arvicola terrestris*) (Aars et al. 2001).

Using capture-recapture survival analysis techniques, borrowed from wildlife ecology and demography, we analyzed the retention of different types of volunteers involved in the mink control project according to profession and duration of involvement in the project. The overall probability that a volunteer remained actively involved in the project per 6-month period was 86.8%, but this varied according to profession. We discovered that game keepers had constant but lowest, and fisheries staff had the highest “survival” as volunteers, while the retention rate of other classes of volunteers improved over length of involvement, suggesting that after attrition of some volunteers with low motivation, a highly motivated hard-core group is retained. This pattern, converse to that expected under senescence, is analogous to that revealed by demographic studies of heterogeneous frailties in animal populations (e.g., Cam et al. 2002). This evidence contributed to our increased reliance on fisheries staff as volunteers, which greatly facilitated the expansion of the project to whole catchments, owing to their concern for Atlantic salmon (*Salmo salar*), a species that makes use of whole rivers, from the headwaters to the sea. This contrasted with game keepers, who manage primarily red grouse (*Lagopus lagopus scoticus*) populations restricted to upland moorland areas in the headwaters of river catchments.

The project had both scientific and conservation delivery objectives. The academic aim of the first project was to use predator-prey theory and new empirical data to optimize the effectiveness of a management program to control invasive mink for conservation. Prior to our coordinated conservation project, and using carcasses collected semi-opportunistically from game keepers and conservationists approached during pilot work, we investigated the genetic structure of invasive American mink in Scotland in relation to geographical features that may influence dispersal. Our analyses based on microsatellite genotyping suggested that gene flow by mink is restricted by landscape features (mountain ranges), and that eradication attempts should break down the connectivity between management units separated by mountains, in the first instance (Zalewski et al. 2009). The work was greatly facilitated by the presence of a strong genetic differentiation between the genetic makeup of mink established on the east and west coast of Scotland, probably reflecting different provenance of stocks in fur farms and the small number of mink generations of feral breeding.

Subsequently, and using mink carcasses culled as part of the conservation project over a study area of unprecedented size for any previous medium size carnivore, we characterized the population structure and abundance and patterns of dispersal of mink in order to characterize the effectiveness of the compensatory response of mink to culling through dispersal. Mink were genotyped us-

ing 15 microsatellites selected amongst 104 available to maximize power. By combining genetic and age information obtained from mink carcasses, together with the location of mink capture and the trapping effort data, we were able to reconstruct mink genealogies and litters, using the software COLONY (Jones and Wang 2010), and subsequently measure the extent to which litters spread through the environment. Of the 365 mink included in the analysis, 205 were assigned a relative and 50 litters were identified. We characterized patterns of mink dispersal prior to large-scale culling when the population was approximately at saturation density. Our data revealed high levels of dispersal, with a mean natal dispersal distance of 16 km (9.9 mi). However, there was a clear effect of time, such that mink appeared to continue to move further apart in space with increasing time at an average rate of 90 m (295 ft) per day. Some individuals that had 5 years to move dispersed up to 100 km (62 mi). Strikingly, in the first stage of control, 25% of parent-offspring, or full-sibling, pairs had individuals culled in different major river catchments, providing further evidence of long distance dispersal when mink populations are saturated (M. Oliver, unpubl. data).

To develop, parameterize, and evaluate models to determine what control effort would achieve a sustained reduction in the abundance of mink, we modeled variation in the number of mink captured within each river sub-catchment according to connectivity by the focal catchment to all other sub-catchments, weighed by an estimated dispersal parameter reflecting the mobility of mink. As predicted, the number of mink trapped increased with connectivity to mink in other sub-catchments, with a time delay of 12 months. This analysis demonstrated that reducing mink density over large scales is necessary for overcoming the compensatory response to culling. These insights, although presented at the time in a non-formalized manner, convinced funders of the project and its project steering board to sanction expanding the project to whole catchments, instead of holding an arbitrary control line at the periphery of the Cairngorms National Park (Bryce et al. 2011).

Despite potentially significant consequences for multi-species persistence, how habitat heterogeneity influences the dynamics of indirect inter-specific interactions was mostly unexplored in large-scale natural landscapes. In a novel, large-scale test of theory on indirect inter-specific interactions, illustrating the scientific value of working in partnership with stakeholders, we showed how the persistence of a native prey (water vole) is determined by the spatial distribution of an invasive prey (European rabbit, *Oryctolagus cuniculus*). We also directly inferred how this was defined by the mobility of a shared invasive predator (mink). In areas where mink were present, connectivity of water vole habitat patches to rabbit habitat had a clear and dominant negative effect on the probability of water vole habitat patch occupancy. Water vole patches least connected to rabbit habitat were predicted to have approximately a 30% probability of occupancy, which declined rapidly towards zero for patches that had average to high levels of connectivity to rabbit habitat. Mink mobility could strongly couple water vole and rabbit habitat patches separated by distances as great as 10 km (6

mi), with the detectable effect of the largest rabbit habitat patches persisting up to 50 km (31 mi). This study uniquely demonstrated that variation in habitat connectivity in large-scale natural landscapes creates spatial asynchrony, enabling coexistence between apparent competitive native and invasive species (Oliver et al. 2009).

Informing Ongoing Control – Short of Eradication – with Population Ecology: Future Opportunities

While the first project was initiated and led by a university-based academic, a follow-on, expanded project described above known as the Scottish Mink Initiative (SMI) is a partnership now lead by an NGO (Rivers and Fisheries Trusts of Scotland, RAFTS) with a strong economic interest to complete mink eradication, following a deliberate handover. The partnership involves a government body, Scottish Natural Heritage; a conservation NGO, Scottish Wildlife Trust; a local authority, the Cairngorms National Park Authority; and 14 rivers trusts. It now employs 5 conservation delivery staff, to instigate, coordinate, and motivate an expanded network of ~600 volunteers from across rural communities who are involved in monitoring, trapping, and humanely dispatching re-invading mink. The new project, like its predecessor, has both scientific and conservation delivery objectives, owing to a continued partnership between scientists and conservation practitioners and dual funding from conservation charities, rural development funds, and UK and European research councils.

Given the conservation project area is surrounded by uncontrolled mink populations, it is exposed to re-invasion from its periphery in a process not dissimilar to the initial invasion and to the spread of species in a new range. When combined with the large work-force provided by volunteers systematically monitoring rivers over an area now well exceeding 10,000 km², this offers a unique opportunity to further our understanding of fundamental ecological processes, as well as conservation delivery. Thus, the starting point of the underpinning ongoing research is that understanding the ecological dynamics of populations at range margins, where populations may be patchy and at low density, is fundamental for our understanding of how range expansion can ensue and how invasive species spread. Indeed, both species of conservation concern and introduced species in the early stage of invasion are, by definition, found at low densities. Therefore, understanding processes causing low density populations to perform poorly is fundamental to conservation and management. While there is a rich body of theory predicting its impact on species spread and persistence, empirical studies of depensation are scarce, owing to the inherent difficulty in studying populations at very low density. Allee effects, however, have been detected in a range of invasive species. Strikingly, even though depensatory processes define the early demographic spread of invasive species, it is only very recently that modeling studies have started considering depensation in the management of established invasive species. The aim is to improve the link between theory and practice and, in doing so, improve both our ecological understanding of depensation and test its potential as an effective tool for invasive species management. We thus have a unique opportunity to test predictions on pat-

terms of immigration and demography over a large spatial scale in a natural setting normally inaccessible to investigation, making it possible to gain an empirical understanding of processes operating at low density. Furthermore, following initial removal of mink, immigration now takes place in an environment of known productivity that can be quantified, based on the demographic structure of mink populations during the initial eradication. Our first specific research objective is to compare, over time and space, patterns of dispersal and reproduction in low-density mink populations immigrating from the periphery of the (expanding) project area with patterns from saturated populations, to quantify the distance travelled by mates. Our second objective is to determine whether individual dispersal decisions, as revealed by observed settlement conditions, could lead to emergent depensation. This may arise due to the process of “range pinning” described by (Keitt et al. 2001), whereby where an Allee effect occurs within patches (e.g., because of mating failure in unproductive patches). It can also be compounded in nascent invading populations establishing outside of their native range because within such isolated colonies, population loss due to emigration may not be compensated for by immigration. Our third objective is to compare fluxes of immigrants in situations where culling short of eradication took place and where “attractive sinks” were created in productive areas. We will do this by modelling immigration rate in relation to productivity (the maximum number of litters detected in an area in any year) and control effort history (based on raft coverage), with immigrants and litters being inferred from genetic pedigree reconstruction.

The continued happy marriage between ecological research and conservation delivery not only delivers substantial benefits in terms of access to sources of funding and ultimately increases effectiveness, but we also view it as an important contributor to the motivation of staff involved and the enthusiasm of volunteers to contribute through vigilance to detect infrequent reinvasions by mink. Great efforts are thus made to convey the findings of the research through newsletters, a web site, and shortly a bespoke “mink-app” delivering contextualised feedback to volunteers, following reports of mink raft checks, sightings, and attempted or successful mink captures.

CONCLUSIONS

Our use of the “active adaptive management” approach, using new understanding to refine strategies that safeguard a species of acute conservation concern by removing mink from the Cairngorms National Park in collaboration with conservation practitioners and managers of wildlife resources, has been a success. We delivered substantial conservation benefits and informed policy, while simultaneously delivering excellent academic research. Initial expectations for the coverage, stakeholder involvement, and eradication efficiency have been surpassed. Not only has the future of an endangered species (the water vole) been secured in the Cairngorms National Park and surrounding lowlands, but the project has also demonstrated to the world that large-scale eradication can be achieved, and that the involvement of communities with vested interest represents the most effective way of conserving local biodiversity. Indeed, the Scottish Mink

Initiative is one of the largest invasive eradication projects worldwide.

The main factor underpinning the success of this project was functional volunteer participation. Optimizing the effectiveness of the volunteer workforce was thus central to the use of functional participation. The technical simplicity of the mink raft method is conducive to its use in a community conservation project. Other contributors to the success of the project were an adaptive approach to suit local conditions, the strategic use of topography to minimize recolonisation, and an ambitious vision – elements that are applicable to other invasive species and areas. It is a strong testament to what can be achieved when empowering local communities to take a stake in their local biodiversity, and thus a reason for optimism that the tide of invasion can be rolled back on a large scale where the convergent interest of local communities can be harnessed.

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