Scaling down (cliffs) to meet the challenge: the Shiants' black rat eradication

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Abstract A successful ground-based eradication of black rats (*Rattus rattus)* was undertaken on the remote, uninhabited Shiant Isles of north-west Scotland over winter (14 October–28 March) 2015–16. The rat eradication was carried out as part of the Shiants Seabird Recovery Project, which aims to secure long-term breeding habitat for protected seabirds and to attract European storm petrels and Manx shearwaters to nest on the Shiants. Throughout the eradication operation, teams were stationed on two of the three main Shiant islands (Eilean an Tighe, Eilean Mhuire), with access to the third (Garbh Eilean) via a boulder causeway from Eilean an Tighe. Bait (Contrac® blocks containing the anticoagulant bromadiolone 0.005% w/w), was deployed in a grid of 1,183 bait stations covering all areas of the islands and sea stacks. Bait stations were set 50 m apart, with intervals reduced to 25 m in coastal areas of predicted high rat density. Difficult areas were accessed by boat and cliffs of ~120 m in height were accessed by abseiling down ropes made safe using either bolted anchors or ground stakes. The team of staff and volunteers worked through difficult conditions, deploying bait and monitoring intensively for any surviving rats using a combination of tools. The islands were declared rat free in March 2018. This ambitious and challenging project has greatly enhanced UK capacity in rodent eradications for the purposes of conservation.

Keywords: biosecurity, conservation priority, eradicate, incursion, invasive alien vertebrate, island restoration, reinvasion

INTRODUCTION

The Shiant Isles is a group of small, uninhabited islands that lie in the Minch (57.9° N, 6.4° W), ca. 6 km east of the island of Lewis and Harris, north-west Scotland. Of the Shiants' three main islands, the largest two: Garbh Eilean (GE, 88 ha) and Eilean an Taighe (ET, 54 ha) are connected by a boulder causeway, and ~500 m to the east of GE lies Eilean Mhuire (EM, 31 ha). A chain of sea stacks, the Galtachan, lie to the west of GE (Fig. 1).

Archaeological evidence documents previous inhabitation of these islands by humans dating back perhaps to the Iron Age (Foster, 2000) but since the 18th century the Shiants have remained uninhabited, and the last remaining building (the 'bothy' on ET, close to the boulder causeway) is occupied only during visits by the islands' owners, or by tourists.

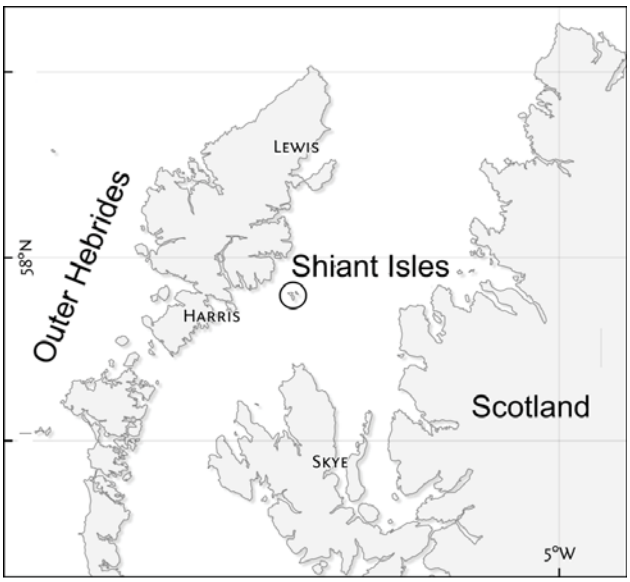

Fig. 1 Location of the islands in the wider area of north-west Scotland.

The Shiants consist mainly of dolerite sills, formed by intrusion of igneous rock between overlying sedimentary rock strata. These sills were then exposed to reveal impressive, columnar structures that now rise steeply to a height of ~ 150 m at their highest point on GE and have been eroded to form extensive boulder scree areas, particularly on the east side of GE (Walker, 1930). The smallest of the three main islands, EM, has cliffs rising to around 80 m, and more conglomerate substrate than ET and GE (Walker, 1930; Gibb & Henderson, 1996).

Habitats present on the islands range from blanket bog and wet heath across the interior of GE and ET, to fertile, species rich grasslands along the coasts of GE and ET and across ME. The maritime environment has a strong influence on the composition of the islands' vegetation and soils have been enriched by guano from centuries of seabird occupation and from past human cultivation. The three main islands have all been historically grazed by sheep (*Ovis aries*) (counts of sheep performed year-round gave estimates of 50 to 80 per island). A colony of grey seals (*Halichoerus grypus*) breeds on the islands, and both common seals (*Phoca vitulina*) and otters (*Lutra lutra*) are frequent visitors. Other than the sheep and an introduced population of black rats (*Rattus rattus*) there are no other known resident populations of terrestrial mammals.

The remoteness of the Shiants, their large amount of suitable habitat and proximity to feeding grounds makes the islands ideal breeding sites for various seabirds. Their importance is internationally recognised through designation as a Site of Special Scientific Interest (SSSI; site code 8575) and as a Special Protection Area (SPA; EU code UK9001041) for breeding populations of puffins (*Fratercula arctica*) (approximately 10% of the UK breeding population, Mitchell, et al., 2004), razorbills (*Alca*

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torda), common guillemots (*Uria aalgae*), European shags (*Phalacrocorax aristotelis*), black-legged kittiwakes (*Rissa tridactyla*), and northern fulmar (*Fulmarus glacialis*), and wintering barnacle geese (*Branta leucopsis*). The seabird assemblage also includes great skua (*Stercorarius skua*), black guillemots (*Cepphus grylle*), herring gulls (*Larus argentatus*), common gulls (*L. canus*), great black-backed gulls (*L. marinus*) and lesser black-backed gulls (*L. fuscus*). White-tailed eagles (*Haliaeetus albicilla*) returned to breed on the islands in 2014 after an absence of over 100 years, following the re-introduction of the species to Scotland (Love, 1983). Other seabirds such as European storm-petrel (*Hydrobates pelagicus*) and Manx shearwater (*Puffinus puffinus*) have not been recorded as breeding at the Shiants, despite the large amount of suitable habitat for these birds. Both of these species are of international conservation concern. At the last major census, European storm petrels breeding on the isles of the UK and Ireland were estimated to number 125,000 pairs, representing 3–11% of the global population. In the same census Manx shearwaters were estimated at 332,000 pairs breeding in the UK and Ireland, with the majority found on the islands of Rum, north-west Scotland (120,000 pairs), Skomer, Wales (102,000 pairs) and Skokholm, Wales (46,000 pairs, Mitchell, et al., 2004). A further survey of Manx shearwaters on Rum has also estimated 70,000 breeding pairs at the Rum colony (Murray & Shewry, 2002).

Rats (*Rattus* spp.) are among the highest risk invasive species, having had devastating effects on native wildlife on island groups such as New Zealand (Towns, et al., 2006) and worldwide through predation, and both competition for and modification of habitat (Jones, et al., 2008). Rats have been recorded on more than 80% of the world's island groups (Atkinson, 1985), but their successful removal from islands ranging in size from less than 1 ha to 12,875 ha has been pioneered in New Zealand and is being applied across the globe. In the UK, rats have been successfully eradicated from islands ranging in size from just one hectare (e.g. Inchgarvie, Firth of Forth, Scotland) to 1,300 ha (Canna & Sanday, Scotland) (Ratcliffe, et al., 2009; Thomas, et al., 2017a; Bell, 2019). Of the successful UK island rat eradications, all were of brown (Norway) rat (*Rattus norvegicus*) except in the case of Lundy, which included populations of both brown rat and black rat (Thomas, et al., 2017a; Bell, 2019). The removal of rats is essential where predation either limits productivity or threatens to lead to the complete loss of important seabird colonies.

Black rats were introduced to the Shiant Isles (accidentally, it is assumed) by humans, either through stock movements by previous island inhabitants or by shipwreck (e.g. Haswell Smith, 2004), though no evidence has established how the rats arrived. The rats are thought to have had negative impacts on the seabirds at these islands as follows. Diet analysis at the Shiants has indicated that rats consumed a range of material of marine origin (Stapp, 2002) as well as vegetation and invertebrates present at the Shiants (Stapp, 2002; Bell, 2013). The stable isotope ratios of carbon and nitrogen, extracted from rat tissues of individuals caught at seabird colonies were closer to those from tissues of seabird origin than those of rats caught from areas away from seabird colonies (Stapp, 2002). This indicated that in the seabird breeding season, coastal colonies of rats were likely to have fed upon on seabird eggs and chicks.

Following a detailed assessment of UK islands with invasive, non-native species the Shiant Isles were identified as being a priority site for rat eradication because of their abundance of potential petrel and storm-petrel breeding habitat (Ratcliffe, et al., 2009). A successful rat eradication at these islands would additionally benefit the existing colonies of protected seabirds. Since the islands lie approximately 6 km offshore and are uninhabited by humans, the risk of natural invasion by brown rats from the nearest islands of the Outer Hebrides is considered to be low. A feasibility study commissioned by the Royal Society for the Protection of Birds (RSPB), and undertaken by Wildlife Management International Ltd (WMIL) in April 2012, found that eradication of the black rat population at the Shiants was feasible (Bell, 2013).

Subsequently, the Shiant Isles Seabird Recovery Project (SSRP) was established as a four-year partnership between the islands' owners (the Nicolson family), RSPB and Scottish Natural Heritage (SNH). The four core aims of the project were: i) to eradicate the invasive black rat population; ii) actively encourage petrels (European storm petrel and Manx shearwater) to nest at the islands; iii) audit island biosecurity at UK SPAs and iv) increase UK capacity in island restoration. Funding for the project was provided by the EU LIFE fund (LIFE13/NAT/UK/000209 LIFE+ SHIANTS), SNH, and RSPB.

The eradication component of the SSRP was undertaken over the period 2015–2016. An open tender process was used to invite operators to bid for a contract to undertake eradication work at the Shiants. This resulted in the selection of WMIL to carry out the eradication operations. The eradication set up, methods and technical operations will be reported on here.

METHODS

Pre- and post-eradication monitoring

Monitoring of the two main islands' (ET and GE) existing seabirds, land birds, vegetation and invertebrates was carried out for one year before the eradication and for the subsequent three years post-eradication. The aims of this ecosystem monitoring were to detect changes, if possible, and hence assess the benefits of the eradication. Full methodology and results for this will be presented elsewhere. A population census of all seabirds, carried out by RSPB and SNH, was undertaken at the Shiants during June 2015, as part of SNH's programme of Common Standards Monitoring of protected areas (SSSIs and SPAs) (Taylor, et al., 2018). A pre-eradication assessment site visit was undertaken during July 2015 to finalise plans, logistics, and health and safety requirements.

Permits and authorisations

A Habitats Regulations Appraisal (HRA) was carried out by SNH to assess the likelihood of any adverse impact of the rat eradication on the qualifying features of the SPA. This required a full Appropriate Assessment under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended). In addition, a full assessment of the Operations Requiring Consent (ORC) was also undertaken for the Shiant Isles SSSI. Justification of the chosen rodenticide (bromadiolone) formulation, estimated quantity needed, and method of application was presented in the Appropriate Assessment and ORC application, detailing how the operation would be undertaken across all islands and sea stacks of the Shiants. A licence under the Wildlife & Countryside Act (1981) was granted to cover possible disturbance to breeding golden eagles (*Aquila chrysaetos*) and white-tailed eagles which are specially protected by Schedule 1 of the Act. Planning permission was obtained from the Comhairle na Eilean Siar (Western Isles Council) to allow the temporary installation of portable cabins on the island to store rodenticide bait and provide shelter for winter eradication teams. For the installation of two temporary moorings, a five-year marine license (issued by Marine Scotland) was granted for which an annual fee was paid to the Crown Estate. Assessments of archaeological sensitivity were carried out in person by experts from the Comhairle nan Eilean Siar and also by RSPB. Maps of archaeologically sensitive sites were used to ensure that these features were not disturbed by placement of cabins, bait stations or by the passage of workers around the islands during the eradication.

A detailed health and safety plan was written in collaboration by RSPB and WMIL. This outlined living and working protocols and the establishment of emergency procedures. As part of health and safety requirements, the islands were zoned to indicate areas considered too dangerous to access without the use of support ropes. Rope access was hence deemed necessary to place bait and to check bait stations on steep vegetated slopes or ground ending abruptly at steep cliffs.

Contracts with two local boat operators (Sea Harris Ltd and Engebret Ltd) were established in order to provide boat access to and around the Shiants through the winter operations. An invitation to quote was issued, with the subsequent selection of contractors based on project needs, cost, and suitability of boat service provision.

Rodent anticoagulant resistance tests

An assessment of potential resistance of the rats on the Shiants to bromadiolone rodenticide was carried out by Reading University (Vertebrate Pests Unit), using protocols developed to extract and sequence DNA for the identification of anticoagulant resistance mutations in brown rats (Pelz, et al., 2005; Prescott, et al., 2010). A similar protocol developed specifically for black rat rodenticide resistance testing was not available. However, the approach used represented the best option available because of the lack of rodenticide resistance work that had been undertaken on black rats at the time of the eradication. Rat DNA samples were collected by project personnel from ET in July 2015. Snap traps placed inside tunnels were set overnight and baited with peanut butter. These were visited early the next morning and any rat specimens caught were collected and dissected. A portion of the tail was placed in 100% ethanol for subsequent rodenticide resistance testing. Morphometric measurements (body length, tail length, hind foot length, ear length) were recorded. Stomach contents, sex and reproductive status were also assessed for all of these trapped rats (Bell & Boyle, 2015). All DNA samples were archived for reference in case of resistance or reinvasion by rats at the islands.

Equipment preparation

Off-island preparation of equipment included the construction of 0.75 m long bait stations (Fig. 2) from lengths of 10 cm diameter plastic drain coil. Help was sought from local community volunteers from the Isle of Harris and construction of approximately 700 bait stations was carried out over two days at the Harris Volunteer Centre in Tarbert. The remaining bait stations were constructed by project personnel off and on the Shiants. Bait stations and other equipment were airlifted to the Shiants over two days as part of the set-up phase of the eradiation.

Access to challenging terrain

Camps were established on ET and EM for the winter teams. Portable cabins were installed for safe storage of rodenticide baits and shelter for winter eradication teams. The flat-packed cabins were airlifted to the islands by helicopter in October 2015 and constructed on-site. The existing bothy on ET was re-roofed during the summer of 2015 and was also used as a base camp during the winter operation. Two moorings were installed close to ET, to improve safety for boat access. Boats were used to land on less accessible areas such as the Galtachan sea stacks, and a large rock to the east of EM.

Rope access training was undertaken by seven WMIL and RSPB personnel. Bolts were set in rock at the top of twelve rope access routes (eleven on ET and one on EM). A further eight routes (one on ET, two on EM and five on GE) were accessed using ropes secured by anchors manually set up using a series of three lashed metal stakes.

Non-target mitigation

Measures to prevent secondary poisoning of eagles were provided by the establishment of diversionary feeding protocols. Dead rabbits (*Oryctolagus cuniculus*, collected by manual trapping at a nearby site on the Isle of Harris) were attached to two tables located on GE, with motion activated cameras set up to monitor activity. The diversionary feeding was made available to the eagles from October 30, 2015 until March 17, 2016. However, no fresh food was attached to the table after 12 November 2015 because bait take had reduced to such low levels that the risk of secondary poisoning was deemed negligible. It was also noted that eagles were only intermittently present at the islands, and there was no evidence, e.g. from motion activated cameras, to suggest that diversionary food was utilised by any eagle. Wire clips were fitted to all bait stations after a raven was seen to open one and access the bait – no further instances of non-target vertebrate species accessing bait were observed.

Bait quantity

An estimate of the quantity of rodenticide needed for the eradication was calculated as follows during the planning phase. An application rate was assumed of 0.28 kg rodenticide per bait station (i.e. 10 blocks per station in 684 bait stations on a 50 × 50 m grid; 1.12 kg/ha) for the first four weeks, then 0.14 kg per bait station (0.56 kg/ha) for the subsequent four weeks and 0.056 kg per bait station (0.224 kg/ha) for the remainder of the operation, with consumed bait replenished at each check. Each application, or "round" of bait station checks was expected to take one day using a team of 10 people. It was expected to require at least 30 complete rounds (with replacement of bait) of each station to ensure the eradication of all the rats. At this rate, up to four tonnes of bromadiolone (LD50, oral ingestion 1.125 mg/kg, Meehan, 1978) were estimated to be required to cover the combined island area (171 ha) over approximately five months. Note, that although the stated LD_{50} for bromadiolone as given by the manufacturer is 0.525 mg/kg (Bell Laboratories Material Safety Data Sheet) this is based on laboratory-bred brown rats. Wild populations of black rats may be more tolerant to bromadiolone (Sridhara & Krishnamurthy, 1992). Individual and sex-specific variations in toxicity of bromadiolone to black rats have also been reported (Garg

Fig. 2 Bait station shown open, with rodenticide blocks wired in place.

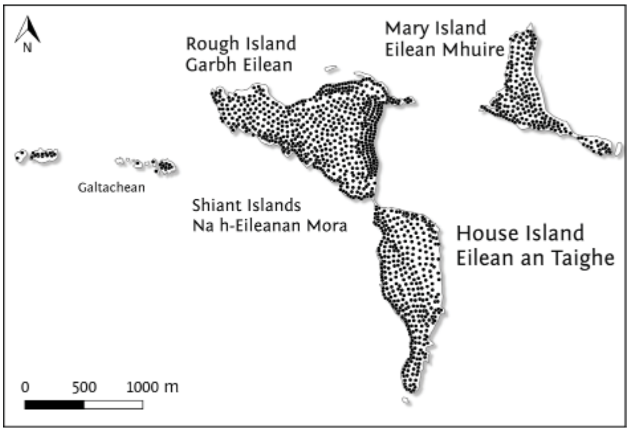

Fig. 3 Map of the bait station grid.

& Singla, 2014). Therefore, a higher LD_{50} was assumed here (Meehan, 1978), to account for these differences.

The actual application rates, bait station grid and number of days to complete a full bait station check during the eradication were different to those calculated in the planning phase due to operational requirements, predicted high rat density areas (i.e. coastal areas) and adaptation to both bait consumption and rat behaviour.

Bait application

Island-wide baiting grids with a total of 1,183 bait stations (Fig. 2) were established across all islands and sea stacks (347 on ET, 594 on GE, 207 on EM, 28 on Galtachan, four on Arch Island and three on Seann Chaisteal) during October 2015. Bait stations were spaced at 50 m intervals across the islands, and 25 m along coasts and through areas of boulder scree e.g. the large area of boulders known as Carnach Mhòr on GE (Fig. 3). This grid spacing has become the current UK best practice protocol for rat eradications (Thomas, et al., 2017b). Rodenticide bait and rat monitoring tools were placed on the Galtachan sea stacks on 17 October 2015.

A team of between two and four people was stationed on ET throughout the operation with a break of one week over the Christmas period. A second team of between two and three people was stationed on EM on a week on/week off schedule. Rotation of people within these teams occurred on a weekly basis, where weather permitted safe access for boat transfers. Baiting commenced at the islands on 4th November (Table 1). Cereal-based wax blocks (28 g Contrac® All-weather Blox™ (Cas No. 28772-56-7, EU 528/2012), containing the anticoagulant rodenticide bromadiolone at 0.005% w/w) were initially placed loose within bait stations. Regular checks were then made. Stations that were accessible on foot were checked between 16 and 23 times with an average of 6–8 days between checks (Tables 1 and 2). Rope access routes were checked between 3–13 times with an average of 10–15 days between checks (Tables 3 and 4). Frequency of checks at rope access routes was limited by the availability of trained staff on each island and the length of time required to check relatively few bait stations on the routes. The rodenticide blocks were wired in to bait stations starting from the seventh round of baiting on GE, round eight on EM and round nine on ET, with all bait wired in by 8 January 2016 (Tables 1 and 3). Records of bait application at each station were kept in waterproof notebooks and transferred to an electronic database each night. Bait was replaced if damaged by weather or slugs, or at the sign of rat incisor marks. An alternative bait, a soft block (100 g Romax® Rat CP™ (Cas No. 5836-29-3, UK UK-2016-1003), containing the anticoagulant coumatetralyl at 0.0375% w/w), was wired into bait stations (one block alongside the Contrac® blocks) during January and February 2016 (depending on the island) (Tables 1 and 3). This provided an alternative bait for rats not consuming the Contrac® blocks.

Monitoring

During baiting operations, personnel regularly searched for carcasses, including any dead or dying rats present at the surface. Systematic monitoring for surviving rats commenced at the islands on November 28, 2015 and continued for 14 weeks, in tandem with baiting. Monitoring stations were set up at every bait station and at intervals half way between bait stations. Monitoring tools employed included: non-toxic flavoured paraffin wax blocks (chocolate, peanut butter, peanut essence, aniseed); soap; tracking tunnels; snap traps and motion-activated cameras. After 14 weeks, intensive monitoring was reduced and permanent monitoring stations were established at key locations (Fig. 4, Fig. 5) on the three main islands where early detection of any surviving black rats, or an invasion of brown rats, would be likely. These comprised 44 commercially available Protecta™ boxes and ten wooden rodent motels baited with non-toxic chocolate wax blocks (Fig. 4). Monitoring stations were checked in winter of October 2016, January 2017, March 2017 and November 2017, with replacement of old blocks each time. Regular checks were also carried out in the summer (April–August 2016–2018) during island monitoring as part of the Shiants Seabird Recovery Project.

Following the placement of rodenticide and monitoring tools at the Galtachan sea stacks, subsequent checks on 4 November 2015 and 27 February 2016 revealed no rat sign or bait take. The sea stacks were assumed to be rat free and were not treated with further rodenticide during the eradication phase.

A database of all baiting, monitoring, and other activities was maintained throughout the eradication. Observations of potential non-target species, carcasses, and other relevant information were documented throughout the operation.

RESULTS

Bait consumption

Consumption of bait was higher around the coasts of all islands and was the highest around areas of known seabird colonies (Fig. 6). Rats consumed approximately 270 kg (or 9666 blocks) of Contrac® bait in total, mainly during the phase when blocks were loose in bait stations and available for rats to remove whole and cache (Fig. 7). Consumption of Romax® blocks by rats was zero.

An estimate of the numbers of rats present at the time of the eradication was made as follows. Assumptions were made that: each block removed by rats was consumed in its entirety by a single rat; all rats consumed between three and 24 times the lethal dose of bromadiolone (where a lethal dose is delivered by consuming 9.5 g of bait corresponding to approximately one third of a block, assuming an LD_{50} of 1.125 mg/kg for black rats). Hence, it is estimated that there were between 1,208 and 9,666 rats present on the Shiants at the start of the eradication (assuming between one and eight blocks were taken by each rat before death). The mean (± SE) of 4.6 ± 0.1 blocks consumed per bait station overall leads to the estimation that there were 2,099 ± 97 rats on the Shiants. This is lower than previous estimates for black rat on the Shiants; 22–85 rats/ha (3,762–14,535 rats) in 1998 (Key, et al., 1998) and 14–27 rats/ha (2,394–4,617) in 2012 (Bell, 2013). Methods used and timings of each of these population estimates vary.

Table 1 Bait application for stations accessible by foot – bait check, dates for each bait check, quantities deployed and schedule. All rodenticide used was Contrac® All-weather BloxTM unless indicated.

Baiting No	Eilean an Tighe	Garbh Eilean	Eilean Mhuire
1	4/11/15–5/11/15 (8 blocks)	6/11/15–7/11/15 (8 blocks)	7/11/15 (8 blocks)
2	9/11/15 (8 blocks)	11/11/15–15/11/15 (8 blocks)	9/11/15 (8 blocks)
3	16/11/15–17/11/15 (8 blocks)	18/11/15–19/11/15 (8 blocks)	11/11/15–12/11/15 (8 blocks)
4	20/11/15 (8 blocks)	22/11/15–27/11/15 (8 blocks)	22/11/15–27/11/15 (8 blocks)
5	22/11/15 (8 blocks)	30/11/15–2/12/15 (8 blocks)	28/11/15–29/11/15 (8 blocks)
6	28/11/15–29/11/15 (8 blocks)	10/12/15–15/12/15 (8 blocks)	30/11/15 (8 blocks)
7	3/12/15–4/12/15 (8 blocks)	1/1/16–4/1/16 (2 blocks wired in place)	12/12/15–13/12/15 (8 blocks)
8	5/12/15–6/12/15 (2 blocks wired in place)	8/1/16–11/1/16 (2 blocks wired in place)	8/1/16–11/1/16 (2 blocks wired in place)
9	8/12/15–10/12/15 (2 blocks wired in place)	14/1/16–16/1/16 (2 blocks wired in place)	22/1/16 (2 blocks wired in place)
10	17/12/15–6/1/16 (2 blocks wired in place)	19/1/16–21/1/16 (2 blocks wired in place)	24/1/16–25/1/16 (2 blocks wired in place)
11	12/1/16 (2 blocks wired in place)	28/1/16–5/2/16 (1 block wired in place)*	26/1/16 (2 blocks wired in place)
12	18/1/16 (2 blocks wired in place)	7/2/16–9/2/16 (1 block wired in place)*	3/2/16–6/2/16 (1 block wired in place)*
13	24/1/16 (2 blocks wired in place)	12/2/16–14/2/16 (1 block wired in place)*	7/2/16–9/2/16 (1 block wired in place)*
14	30/1/16–2/2/16 (1 block wired in place)*	17/2/16–21/2/16 (1 block wired in place)*	20/2/16–21/2/16 (1 block wired in place)*
15	6/2/16 (1 block wired in place)*	22/2/16–23/2/16 (1 block wired in place)*	9/3/16–11/3/16 (1 block wired in place)
16	11/2/16 (1 block wired in place)*	25/2/16–26/2/16 (1 block wired in place)	14/3/16 (1 block wired in place)
17	14/2/16–5/2/16 (1 block wired in place)*	29/2/16–1/3/16 (1 block wired in place)	
18	21/2/16 (1 block wired in place)*	5/3/16–7/3/16 (1 block wired in place)	
19	26/2/16–27/2/16 (1 block wired in place)	9/3/16–10/3/16 (1 block wired in place)	
20	4/3/16 (1 block wired in place)	16/3/16–20/3/16 (1 block wired in place)	
21	8/3/16 (1 block wired in place)		
22	12/3/16 (1 block wired in place)		
23	22/3/16–23/3/16 (1 block wired in place)		

* Romax® Rat CP™

Interference with bait stations by non-target species was low. Invertebrates, particularly slugs, consumed some bait (1.78 kg). Sheep were estimated to consume 19.6 kg of bait released by kicking up the stations. Ravens and crows were observed to take bait (10.9 kg) by pulling out wires and removing bait station lids, until a more secure wire fastening system was established. No evidence was found of non-target species being affected by the rodenticide.

No carcasses showing signs of anticoagulant ingestion were collected. An adult golden eagle carcass discovered on 15th November was autopsied and showed no signs of anticoagulant poisoning, and the state of decomposition suggested it had almost certainly died before the start of the baiting operation. Diversionary food provided throughout the operation was not removed by any species.

Table 2 Frequency of replenishment of bait stations accessible by foot. Mean number of days (± SE) between the first day of each bait station check; range in number of days to complete check and total number of checks given in parentheses.

Island	Number of days between the first day of each bait station check
Eilean an Tighe	6.2 ± 1.0 days (2–27 days; 23 checks)
Garbh Eilean	6.7 ± 1.0 days (3–22 days; 20 checks)
Eilean Mhuire	8.1 ± 1.8 days (2–27 days; 16 checks)
Total (all islands combined)	6.9 ± 0.7 days (2–27 days; 16–23 checks)

Table 3 Frequency of replenishment of bait stations accessed by rope. Mean number of days (± SE) between the first day of each bait station check; range in number of days to complete each check and total number of checks given in parentheses.

Island	Number of days between the first day of each bait station check
Eilean an Tighe	10.8 ± 1.7 days (4–24 days, 13 checks)
Garbh Eilean	13.5 ± 2.3 days (2–23 days,11 checks)
Eilean Mhuire	14.4 ± 3.2 days (2–29 days, 9 checks)
Total (all islands combined)	12.7 ± 1.3 days (2–29 days; 9–13 checks)

Table 4 Bait application for stations accessed by rope – bait check, dates for each bait check, quantities deployed and schedule. All rodenticide used was Contrac® All-weather Blox™ unless indicated.

Bait No	Eilean an Tighe	Garbh Eilean	Eilean Mhuire
1	17/11/15–29/11/15 (8 blocks)	19/11/15–3/12/15 (8 blocks)	11/11/15 (8 blocks)
2	5/12/15 (2 blocks wired in place)	6/12/15–7/12/15 (8 blocks)	23/11/15 (8 blocks)
3	12/12/15–15/12/15 (2 blocks wired in place)	17/12/15 (8 blocks)	14/12/15–15/12/15 (8 blocks)
4	5/1/16–6/1/16 (2 blocks wired in place)	2/1/16–4/1/16 (2 blocks wired in place)	8/1/16–9/1/16 (2 blocks wired in place)
5	15/1/16 (2 blocks wired in place)	14/1/16 (2 blocks wired in place)	6/2/16 (1 block wired in place)*
6	23/1/16–2/2/16 (1 block wired in place)*	16/1/16–21/1/16 (2 blocks wired in place)	8/2/16–9/2/16 (1 block wired in place)*
7	11/2/16–13/2/16 (1 block wired in place)*	8/2/16–14/2/16 (1 block wired in place)*	22/2/16 (1 block wired in place)*
8	15/2/16 (1 block wired in place)*	21/2/16 (1 block wired in place)*	11/3/16 (1 block wired in place)
9	25/2/16 (1 block wired in place)*	29/2/16 (1 block wired in place)	14/3/16 (1 block wired in place)
10	4/3/16–6/3/16 (1 block wired in place)	7/3/16 (1 block wired in place)	
11	8/3/16 (1 block wired in place)	17/3/16 (1 block wired in place)	
12	16/3/16 (1 block wired in place)		
13	22/3/16–24/3/16 (1 block wired in place)		

* Romax® Rat CP™

Bait stations near to coasts were affected by weather, with 60 washed away during large storms (resulting in a loss of 9.5 kg of bait). A total of 84 kg of bait (from 583 stations) was removed by hand because of damage by mould or dampness that could have rendered it unpalatable to rats.

Rat sign and monitoring

Four rats were found dead at the surface on GE (one fresh carcass on 7 November 2015, four days after baiting commenced); two fresh carcasses on 11 November 2015 (seven days after baiting commenced) and one desiccated carcass on 4 February 2016 (90 days after baiting commenced). Rat sign was recorded on flavoured wax at three monitoring points following the start of the initial baiting phase. These were at three different cliff stations on ET (on 13 December, on 14 December and on 26 February). Monitoring at these cliff stations through March 2016 did not yield any further rat sign. The detection of incisor marks on the flavoured wax block in February 2016, when other food sources were beginning to become available, was treated as a possible survivor from the eradication. To establish whether any rats had survived, in October 2016 rope access teams re-established 470 monitoring stations

Fig. 4 Rodent motel (lower) and ProtectaTM box (upper) monitoring stations.

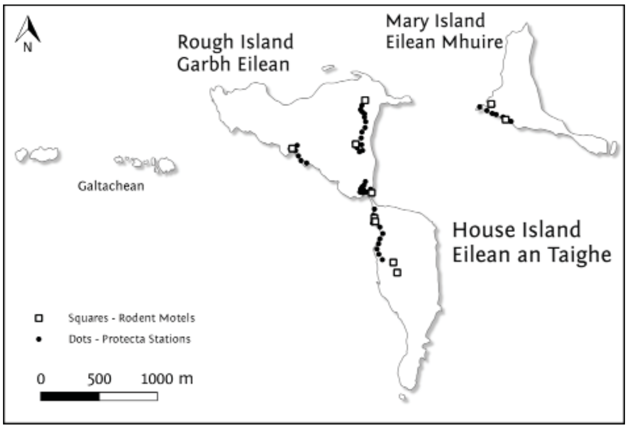

Fig. 5 Locations of permanent monitoring stations.

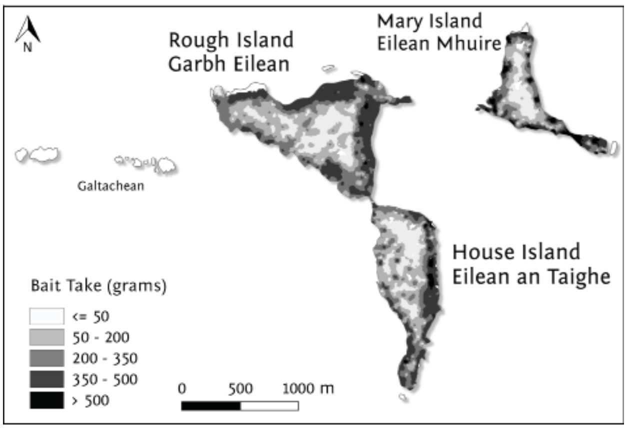

Fig. 6 Quantities of bait taken by rats during the eradication.

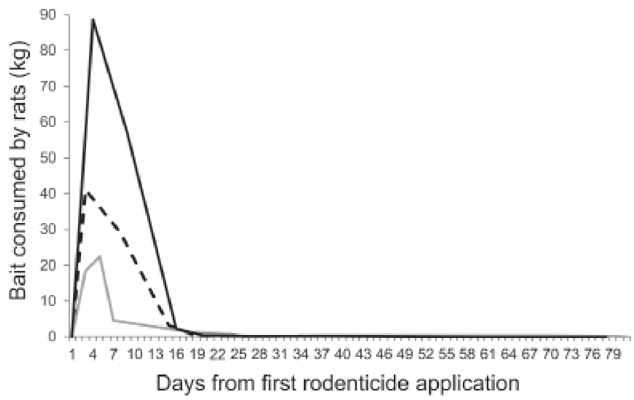

Fig. 7 Quantity (kg) of bait consumed by rats following each baiting application on each island. Solid black line = Garbh Eilean; Dashed line = Eilean an Tighe; Grey line = Eilean Mhuire.

across the three islands with a focus on the cliff stations on ET. Four checks were completed on EM and ET and three checks on GE, finding no sign of rat presence. Permanent monitoring stations on ET, GE and EM were checked monthly in the summer (April–August) and every three months outside the summer season until February 2018. A month-long intensive monitoring check was carried out on all islands and sea stacks in February 2018, with the declaration of rat-free status made on 2 March 2018.

Rodenticide resistance testing

Although some mutations were present within the section of genome sequenced, these mutations were not the same as brown rat mutations known to confer genetic resistance to bromadiolone.

DISCUSSION

Eradication of black rats at the Shiant Isles was one of the four core aims of the Shiants Seabird Recovery Project, now successfully achieved.

The Shiants black rat eradication was an ambitious undertaking on a remote, uninhabited island group, with no existing infrastructure or facilities except the bothy on ET. The operation required the establishment of safe working environments and the provision of shelter, for example, on EM where there are no existing structures on an island of 80 m height. The lack of sanitation, water supply and electricity necessitated basic living conditions and robust and appropriate waste management procedures. Weather influenced operations throughout, sometimes becoming so severe as to prevent access to various parts of the island group. The terrain of the Shiant Isles is steep across many sections of each island, hence the need for rope access at various points. The use of extensive rope access, in particular, allowed a neat solution to the problems of challenging access and a ground-based operation. Other methods, such as bait stations deployed at the end of lines, may have been more difficult to monitor and would also have necessitated the close approach to cliff edges (also requiring support ropes in order to comply with health and safety requirements). As well as the challenging access on foot, the need to address separate islands at the same time by boat presented further logistical and personnel considerations.

New challenges had arisen since the feasibility study (2012) including changes in the profile of the boulder causeway connecting ET and GE resulting in reduced access on foot to GE from the main camp on ET. White tailed eagles had established a breeding site at the islands and mitigation actions were required to address potential secondary poisoning of these predators, which had not been necessary at the time of the feasibility study. This highlights the need to review feasibility studies as an ongoing process within the planning phase.

A number of valuable lessons were learnt during the course of the eradication. In light of the challenges faced by working in difficult conditions, the operation was delivered to a high standard by an effective team. Rope access elements worked well as a result of the thorough training, and of equipment and safety considerations which were appropriate to the operation. Once established, procedures concerning training, preparation, boating and accommodation all worked well because conditions had been considered thoroughly as part of a detailed health and safety plan. Boat access arrangements allowed sufficient access to the separate islands to achieve baiting and monitoring throughout. The whole operation provided positive input into the nearby economy of Lewis and Harris over the winter months. At the end of the eradication phase, the establishment of permanent monitoring stations provided early detection capability, which is necessary as part of delivering long term biosecurity at the islands.

Periods of heavy workload for personnel involved in eradication preparations resulted from time and resource pressures during the preparation phase. There was a need for careful planning of logistics, the satisfying of legal obligations, the need to train local personnel and set up health and safety. As a result, UK-based capacity for undertaking eradications for conservation purposes has been greatly enhanced, and the need for detailed planning from early on has been highlighted. A dedicated logistics coordinator would have been a useful additional staff member to have had in place.

Technical rope access training required a further investment of time and resources and, although the number of trained personnel was sufficient to be able to carry out checks, this did limit the total number of checks possible. Successful communication between team leaders and volunteers took place regularly throughout the operation but has been noted as an area in which continued focus is important in complex operations. Lessons learnt from this eradication will form part of a full project review planned by RSPB.

A lack of work on the genetic resistance of black rats to bromadiolone posed a potential problem, since it was not possible from the start to confidently predict whether alternative bait types might be needed. However, the consistent lack of rat sign across the islands following baiting with bromadiolone, and zero take of the alternative rodenticide, indicates that there was no genetic resistance of rodents to bromadiolone at the Shiant Isles.

The project has contributed to building UK capacity for delivering rat eradications, biosecurity and incursion response through its training of staff. Local community members at the Western Isles were involved in bait station assemblage, service provision (e.g. boats) and volunteer work during eradication operations. Providing safe breeding habitat and maintaining rodent-free status at important island sites will be an important part of the long-term legacy of protection for UK seabirds.

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