It's not all up in the air: the development and use of ground-based rat eradication techniques in the UK

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Abstract Eradication techniques using ground-based devices were developed in New Zealand in the early 1970s to target invasive rodents. Since then, different bait station designs, monitoring tools and rodenticide baits have been developed, and changes in field techniques have improved and streamlined these operations. The use of these techniques has been taken around the world to eradicate rodents from islands. Eradication technology has moved rapidly from ground-based bait station operations to aerial application of rodenticides. However, regulations, presence of and attitudes of island-communities and presence of a variety of non-target species precludes the aerial application of rodenticides on islands in many countries. As such, ground-based operations are the only option available to many agencies for the eradication of invasive rodents from islands. It is important to recognise that the use of ground-based operations should be a valid option during the assessment phase of any eradication proposal even in countries that can legally apply bait from the air; in many instances the use of ground-based techniques can be as economic and rapid. The use of ground-based operations can also facilitate opportunities for in-depth monitoring of both target and non-target species. Using examples of the techniques and developments used in five ground-based rat eradication operations from the UK demonstrates how these methods can be used safely and successfully around the world, even on islands in the order of hundreds of hectares and those with communities.

Keywords: bait station, ground-based, inhabited, island, rodenticide

INTRODUCTION

Albeit unanticipated, the eradications of rats from Rouzic Island, France in 1951 and Maria Island, New Zealand in 1960 were the first successful rat eradication operations on islands anywhere in the world (Towns & Broome, 2003; Lorvelec & Pascal, 2005; Howald, et al., 2007). These unintentional eradications spurred efforts in New Zealand to develop and perfect eradication techniques (Cromarty, et al., 2002; Thomas & Taylor, 2002; Towns & Broome, 2003). Between 1965 and 1986, New Zealand wildlife managers, ecologists and scientists used a range of experimentally designed operations to determine the best methods to consistently, successfully eradicate rats from islands (Cromarty, et al., 2002; Towns & Broome, 2003). Seabirds and other native species on islands are particularly vulnerable to invasive mammal species, particularly rats. The eradication of invasive mammals is considered the first step in island restoration and the subsequent recovery of native species and biodiversity. Since these early ground-based operations, rats (*Rattus rattus, R. norvegicus, R. exulans*) have been successfully eradicated from over 400 islands ranging in size from 1 to 12,850 ha, around the world, using the full gamut of methods and technology (Moors & Atkinson, 1984; Atkinson, 1985; Towns & Broome, 2003; Howald, et al., 2007; Jones, et al., 2008; Parks & Wildlife Service, 2008; Parks & Wildlife Service, 2014, DIISE, 2015). Of these rodent eradications, the largest ground-based rat eradication operation, was on Langara Island in British Columbia at 3,100 ha, and the largest ground-based rat eradication in the United Kingdom (UK) was on the Isle of Canna at 1,300 ha (Taylor, et al., 2000; Bell, et al., 2011; DIISE, 2015).

Techniques and technology developed in those early eradications have since moved on from ground-based hand-broadcast and bait station operations to aerially-applied rodenticide operations and these have now been used across the globe. Advances in, and alterations to, techniques and tools have streamlined ground-based operations. Lessons learnt from each eradication have improved the next operation. However, in several countries, including the United Kingdom (but excluding the United Kingdom Overseas Territories), methods to eradicate rats are restricted to ground-based methods. The presence of critical non-target species, sensitive habitats, island communities and legislative requirements have restricted methods and tools for island eradications in these countries. This paper describes the history and development of ground-based rat eradications using bait stations in the United Kingdom using five eradication operations as examples and covers lessons learnt and how local communities have been involved.

INVASIVE *RATTUS* SPECIES ON UK ISLANDS

Both black (*Rattus rattus*) and brown (*R. norvegicus*) rats are present in the UK (Nowak, 1999; Long, 2003). Black rats were presumed to have been introduced by the Romans (c. 110 AD) and the brown rat via shipping between 1720 and 1728 (Thomas, 1985; Corbet & Southern, 1977; Yaldwen, 1999; McCann, 2005; Parslow, 2007). Brown rats were first recorded in the Isles of Scilly in 1728 after several shipwrecks occurred that year (Thomas, 1985; Parslow, 2007). Although the brown rat displaced the black rat throughout most of the UK, black rats can still be found in a small number of locations, particularly port cities such as London, Edinburgh and Falmouth (Matheson, 1962; Bentley, 1959; Twigg, 1992; Long, 2003). The brown rat is still present on 56% of UK islands over 100 ha (Long, 2003).

Rats are known to have very detrimental effects on seabird populations through predation and competition for food and habitat, causing local and global extinction of birds on islands throughout the world (Moors & Atkinson, 1984; Atkinson, 1985; Courchamp, et al., 2003; Towns, et al., 2006; Jones, et al., 2008; Bell, et al., 2016). The eradication of introduced predators from islands has become one of the most important tools in avian conservation in recent times and, with an initial investment, significant long-term restoration benefits such as increased productivity and population increases of seabirds and other native species as well as the establishment of new seabird species can be achieved. The eradication of rats from seabird islands is recognised as a prerequisite for the restoration of seabird populations (Atkinson, 1985; Moors, et al.,1992).

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Seabird populations on many UK islands have been recorded in decline and in at least four cases rats have been identified as one of the contributing factors for these declines (Campbell, 1892; Brooke, 1990; Mitchell, et al., 2004; Brooke, et al., 2007; Swann, et al., 2007; Dawson, et al., 2015; Hayhow, et al., 2017). Many species such as puffin (*Fratercula arctica*) which is listed as threatened due to their declining population status (IUCN, 2017), Manx shearwater (*Puffinus puffinus*) and the European storm petrel (*Hydrobates pelagicus*) may have limited distribution due to the impacts of, and predation by, rats (Heaney, et al., 2002; Mavor, et al. 2008). Currently, the majority of the UK puffin and all European storm petrel populations nest on rat-free islands (Mavor, et al. 2008, Ratcliffe, et al., 2009). The protection and enhancement of UK seabird breeding habitat has been recognised as an important conservation priority, including under international conservation agreements (Brooke, et al., 2007; Ratcliffe, et al., 2009; Dawson, et al., 2015; Thomas, et al., 2017a).

Rat eradications have occurred on over a dozen islands around the UK with brown rats being the most common target species (Bell, et al., 2011; Thomas, et al., 2017a; Bell, et al., 2019a; Pearson, et al., 2019). Black rats have been targeted on Lundy Island and the Shiant Isles (Lock, 2006; Appleton, et al., 2006; Thomas, et al., 2017a; Main, et al., 2019). Many of the eradications have occurred on islands with permanent staff or the presence of small communities (Bell, et al., 2011; Bell, et al., 2019a; Pearson, et al., 2019). These operations demonstrate how ground-based eradication techniques can be utilised on both inhabited and uninhabited islands around the UK.

Pre-1998: the early eradication operations

Despite an early attempt to eradicate rats from Ailsa Craig in 1925, the first documented successful rat eradication did not actually occur in the UK until 1968 on Cardigan Island in Wales (RSPB, 1924; RSPB, 1925a; RSPB, 1925b; Johnstone, et al., 2005; Thomas, et al., 2017a). This makes the UK the first country to intentionally undertake a rat eradication operation anywhere in the world. Four other rat eradications occurred between 1968 and 1998; Inchgarvie (Firth of Forth), Scotland in 1990, Ailsa Craig, Scotland in 1991, Handa Island, Scotland in 1997 and Puffin Island, Wales in 1998 (Ratcliffe & Sandison, 2001; Zonfrillo, 2001; Zonfrillo, 2002; Johnstone, et al., 2005; Stoneman & Zonfrillo, 2005; Thomas, et al., 2017a). Warfarin was the primary active ingredient used in each of these eradications with difenacoum used as a secondary option in the Puffin Island rat eradication (Ratcliffe & Sandison, 2001; Zonfrillo, 2001; Zonfrillo, 2002; Stoneman & Zonfrillo, 2005). All of these early eradications used ground-based methods, but focused on applying bait in holes, burrows, under rocks and vegetation and in isolated wooden bait stations or under inverted fish bins, rather than in a systematic grid pattern (Ratcliffe & Sandison, 2001; Zonfrillo, 2001; Zonfrillo, 2002; Stoneman & Zonfrillo, 2005; Thomas, et al., 2017a).

This method of baiting made it difficult to monitor bait consumption by rats and non-target species. There were no accurate records of bait take by rats or other species from any of these operations (Ratcliffe & Sandison, 2001; Zonfrillo, 2001; Zonfrillo, 2002; Stoneman & Zonfrillo, 2005; Thomas, et al., 2017a). Monitoring was limited: in most cases it didn't occur; used chewsticks across the island immediately following the eradication (it has been noted that chewsticks can be difficult to interpret sign accurately); or was determined by the recovery of the seabird or rat populations without any quantifiable measures (Zonfrillo, 2001; Ratcliffe, et al., 2009; Thomas, et al., 2017a). In the case of Inchgarvie and Puffin Islands eradication was not confirmed until years after the operation. Unfortunately, there have been recent reports of rats on Inchgarvie and rats reinvaded Handa in 2012 (Thomas, et al., 2017a).

The later operations (post-1999)

The use of toxins and the risks these presented to non-target species and the environment led to the development of Best Practice and Standard Operating Procedures for eradication operations in New Zealand in the 1990s and these documents are revised as new techniques and tools are developed (Cromarty, et al., 2002; Broome, et al., 2011). Robust protocols for eradication operations included detailed planning, operational requirements, implementation protocols, monitoring guidelines and biosecurity requirements (Cromarty, et al., 2002; Broome, et al., 2011). These best practice and standard operating techniques developed in New Zealand were followed and adapted during the UK eradications undertaken by Wildlife Management International Ltd (WMIL).

Five major eradications directed by WMIL have occurred in the UK since 1999; Ramsey Island, Wales (brown rat) in 1999/2000, Lundy Island, England (black and brown rat) in 2002–2004, Isle of Canna, Scotland (brown rat) in 2005/2006, St Agnes and Gugh, Isles of Scilly, England (brown rat) in 2013/2014 and the Shiant Isles, Scotland (black rat) in 2015/2016. In addition to these five sites, eradication attempts have also been made on Looe Island in 2006, the Calf of Man in 2012 and Caldey Island in 2015, which have not been included here because Looe Island was reinvaded by rats three years later and the Calf of Man and Caldey Island eradications are still on-going (Thomas, et al., 2017a).

These five eradications used ground-based techniques with bait stations placed out across the islands on either 25 m × 25 m, 25 m × 50 m, 50 m × 50 m, 90m × 90 m or 100 m × 100 m grids depending on the target species and type of habitat or risk areas. The smaller grid sizes (between 25 and 50 metres spacing) were used to target black rats and the larger grid sizes (between 50 and 100 metres spacing) used to target brown rats, with the smallest spacings used in high risk areas (such as around properties, seabird colonies, wharves, farms and restaurants).

A simple yet effective bait station design has been used in each of these five eradications in the UK. Although a range of commercially available lockable stations have been used in selected locations (e.g. residential homes, farm buildings, schools, etc.) during these eradications, and for on-going biosecurity to reduce the risk to the public, particularly children and the possibility of tampering with these long-term stations, the main bait stations were made from corrugated drainage pipe. This design is cost-effective and widely available. For the 1999/2000 Ramsey Island rat eradication, 500 mm lengths were used. However, these stations were found to be too short as they allowed carrion crows (*Corvus corone*) access to the bait. The stations were made longer by adding 250 mm lengths to one end. The standard length for each bait station in all subsequent eradications was 750 mm long with an access hole cut in the centre for placement of the bait (Fig. 1). This access hole is covered with a short section of drainage pipe. During the 2002–2004 Lundy Island rat eradication, crows learnt to flick the lids off the stations to reach the bait, therefore another length of wire was put around the centre of the station to hold the lid tightly in place. This "crow clip" became standard on all bait stations on any island with either carrion crows, hooded crows (*C. cornix*) or ravens (*C. corax*) present (Fig. 1).

Technological advances in GPS and GIS-linked systems helped streamline the positioning of bait stations during the grid establishment stage of eradications, as well

Fig. 1 Example of the main bait station in position with the crow clip holding the central lid in place, as used in the five ground-based eradications in the United Kingdom that were directed by Wildlife Management International Ltd. [Credit: Elizabeth Bell, WMIL]

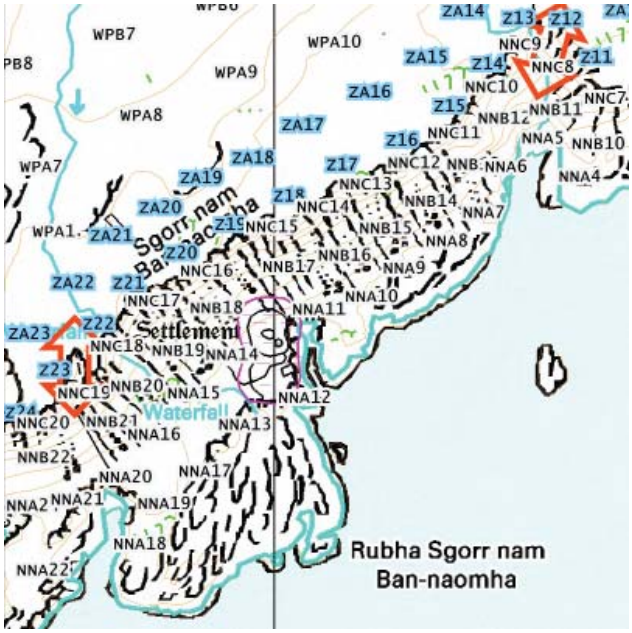

Fig. 2 An example of a detailed bait station map as used by eradication teams during the Isle of Canna operation. Where alphanumeric codes related to bait station positions (e.g. WP = West Plateau, A = line A, 9 = bait station 9; Z = Boundary line Z (two lines of stations at the top of the cliff section above the coastal slopes), 19 = bait station 19; NN = Nunnery, B = line B, 6 = bait station 6), double ended red arrows = safe access routes up or down to the coastal slope areas, pink shaded areas = important archaeological site (e.g. The Nunnery).

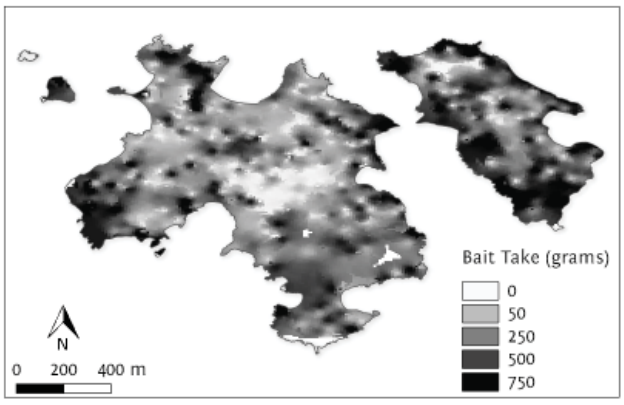

Fig. 3 Example of a heat map of bait take (g) by rats using the results from the St Agnes & Gugh brown rat (*Rattus norvegicus*) eradication.

as monitoring the level of bait take by rats and non-target species. Detailed maps can be produced for the eradication team that can give additional information such as sensitive sites like archaeological structures, location of rare plants, seabird colonies and white-tailed sea eagle (*Haliaeetus albicilla*) nesting sites and locations of access points for steep terrain where more care needs to be taken (Fig. 2). This intimate knowledge of the stations and island make it easier for the eradication team to monitor bait take by rats as the data can be linked to the specific station and activity levels can be recorded on the spatial map. These maps created by the GIS-linked database offer the team the opportunity to monitor the decline in rat numbers throughout the operation and could allow the eradication personnel to react instantly to hotspots or problem areas on the island. Specific bait take information can lead to detailed activity which shows bait take by rats throughout the operation and detailed heat maps showing complete bait take by rats at the end of an eradication (Fig. 3).

Cereal-based bait blocks (containing the anticoagulant diphacinone, bromadiolone or difenacoum) were used. Each eradication used one bait formulation as the main bait with a second option available to target 'fussy' (i.e. those rats that will not eat the primary bait for whatever reason) or surviving rats. This gives the option to adapt the project if rat behaviour or taste preference becomes an issue during the eradications. This has been shown to be important in certain eradications as demonstrated by the Isle of Canna brown rat eradication where the last surviving rat was targeted successfully using the alternative bait. Bait was placed loose in the bait stations for the first three weeks of the eradication operation. This allowed rats to cache bait in burrows for feeding themselves and any breeding females. Once bait take has reduced, bait is wired securely into the stations (Fig. 4) and any rat sign on these blocks is used to identify the presence of a surviving rat or monitor high risk areas, such as seabird colonies or farm buildings.

Although aerial application operations generally have a range of higher implementation costs compared to ground-based operations due to the requirement of a helicopter, sowing bucket and need for ground crew, engineer and other legal requirements for use of aircraft, the implementation time of the operation is often reduced compared to a ground-based operation. Except for the Lundy Island eradication (which took a second winter),

Fig. 4 Example of the main bait station in position showing the open bait station (with the lid off) with the bait wired in place, as used in the five ground-based eradications in the United Kingdom that were directed by Wildlife Management International Ltd. [Credit: Elizabeth Bell, WMIL]

rats were successfully targeted within 21 to 64 days (Bell, et al, 2011; Bell, et al., 2019a; Bell, et al., 2019b; Main, et al., 2019).

The use of rodenticide baits to complete eradications has enabled strong relationships to be established between bait manufacturers, eradication operators and local agencies in the UK. This has enabled open and in-depth discussions about the bait in regard to problems with formulation, taste and longevity that were identified during eradication operations. Issues such as the bait blooming (i.e. swelling and splitting after moisture on the bait) or rapidly going mouldy in the Lundy eradication were relayed to the manufacturers who altered the wax content for later operations. This meant the bait became much more robust in the damp winter conditions during the later Scottish operations, reducing the overall bait quantity required for those eradications.

European Union (EU) regulations require Bitrex™ (denatonium benzoate) or an alternative bittering agent to be added to all rodenticides to deter human consumption. Rats are not intended to be put off by Bitrex™, although research suggests that some rats can detect it even at very low concentrations, and preferentially choose bait that does not contain Bitrex™ (Veitch, 2002). Three rats actively avoided bait containing Bitrex™ on Lundy Island and, by working with the UK bait manufacturer, dispensation for a small amount of Bitrex™-free bait was obtained and was used to successfully target the rats at those sites (Bell, 2004). Despite the bait manufacturer disputing the fact that rats could detect and avoid Bitrex™ bait, they were open to experiment, assess the issue and work together with WMIL and Royal Society for the Protection of Birds (RSPB) towards a solution. Without the engagement of the bait manufacturer from the beginning of the project and open and frank discussions about the possibility of this issue with Bitrex™, the Lundy operation could have failed.

There have been recent regulatory changes to the purchase and use of rodenticides in UK. The Health and Safety Executive (HSE) require reassurance that biocide products can be used without unacceptable risk to wildlife and other non-target species and in July 2015 implemented the UK Rodenticide Stewardship Scheme. This scheme covers all rodenticide products sold to, and used by, professionals when applied outside buildings and in open areas and operates under a Code of Best Practice developed by the Campaign for Responsible Rodenticide Use (CRRU) group (CRRU, 2015). All professionals must have proof of competence at the point-of-sale for rodenticide baits (i.e. have completed certification for rodenticide control and/or eradication by completing an approved training course) as well as comply with the best practice. These regulations generally relate to urban control operations, pest control operators and farmers, but eradication programmes must also follow these regulations. RSPB, in conjunction with CRRU, have developed an eradication-specific registered training course under the UK Stewardship Scheme.

Ground-based operations facilitate longer, wide-scale monitoring compared to aerial operations; not only using the bait itself, but also using a range of monitoring tools such as flavoured wax blocks, soap, tracking tunnels and trail cameras. Monitoring can be established at the same locations as the bait stations, as well as between the bait stations to intensify the scope of monitoring and ensure every micro-habitat is covered. Having non-toxic monitoring devices out in the open (pegged to the ground) and using a range of options gives more chance for any surviving rats to interact with at least one type of monitoring tool. This can also identify if a percentage of the rat population or rats at a specific location are avoiding the bait stations for any reason. This intensive effort can be used to detect any survivors and the operator can adapt the eradication to successfully target those last individuals. WMIL developed a range of flavoured wax blocks that have proved to be very effective in detecting the presence of surviving rats at the final stages of eradication (Fig. 5). These blocks have been freshly produced by the eradication team on-site to a standard recipe as the operation progresses. This flavoured wax recipe has been widely shared amongst the eradication industry.

This period of intensive island-wide monitoring allows the eradication operators to be much more confident that the eradication has been successful prior to leaving the island. By being able to detect and respond to surviving rats immediately, this reduces the likelihood of eradication failure (as any rat that is detected during this period can be targeted) and thus the need for a second eradication attempt (which can cost as much as the original operation). This intensive monitoring period in these five UK operations occurred for up to four months, depending on the size of the island and time required to initially target the rats during the baiting phase. Additional monitoring is completed at least quarterly for two years prior to the intensive final check phase and rat-free declaration following standard international eradication protocols for temperate operations (Broome, et al., 2011).

The use of volunteers has been an asset to these five UK eradications by giving passionate conservationists the chance to be involved in a project they feel strongly about, increasing the national (e.g. RSPB) capacity in eradication methodology, and engagement with the local communities. However, the use of volunteers can reduce the awareness of managers, decision makers and funders of the true cost and effort required to complete ground-based eradications.

The costs of these five ground-based eradications ranged from £76,000 up to £900,000, including planning, implementation, key species pre-and post-eradication monitoring, monitoring for survivors or incursions for two

Fig. 5 Examples of flavoured wax as used for monitoring in the five ground-based eradications in the United Kingdom that were directed by Wildlife Management International Ltd. [Credit: Jaclyn Pearson, RSPB]. Where the left (blue) block is aniseed flavour, centre (brown) block is chocolate flavour and right (fawn) block is peanut flavoured and each block is pegged to the ground with a piece of fencing wire and marked with a short piece of flagging tape for visibility.

years post-eradication and confirmation monitoring ('final check') prior to the declaration of rat-free status (Dr R. Luxmoore, NTS, pers. comm.; P. St Pierre, RSPB, pers. comm.; Lock, 2006).

There can be difficulty associated with accurately recording the entire costs of eradications; in many cases reported costs do not include in-kind or match funded expenses by the agencies involved (National Trust for Scotland, RSPB, etc.). In many cases, it can be difficult to accurately record these costs against the eradication operation as they relate to administration and corporate expenses.

BEST PRACTICE FOR ERADICATIONS

It has long been recognised that every island is different when it comes to planning and implementing an eradication operation. As such, although the NZ best practice gave an important starting point for the UK operations, it needed to be adapted for the local situation to become more relevant and effective, particularly in regard to local legislation and animal welfare regulations.

The RSPB, in partnership with UK-based governmental and non-governmental organisations working in island restoration, with input from international experts in this field produced The UK Rodent Eradication Best Practice Toolkit which is hosted on the Great Britain Non-Native Species Secretariat website (Thomas, et al., 2017b).

This toolkit was developed as an advisory resource to provide systematic planning and implementation protocols for ground-based rodent eradications and biosecurity in the UK (Thomas, et al., 2017b). It aims to give UK organisations technical advice on eradication methodology as well as an eradication project management framework to enable greater confidence in achieving island restoration goals in invasive rodent management projects in the UK (Thomas, et al., 2017b).

THE ROLE OF COMMUNITIES

The majority of eradications around the world have occurred on uninhabited islands and it is thought that islands with significant human populations, unreceptive communities or occurrence of livestock and domestic animals are unlikely to be feasible for rat eradication (Campbell, et al., 2015). However, because invasive species are also a problem on inhabited islands, such eradications must be considered. A lack of public awareness about invasive species impacts and misunderstanding of eradication techniques from island communities are thought to have been responsible for the opposition of proposed eradications on inhabited islands around the world (Bryce, et al., 2011). The importance of the engagement and inclusion of local communities has been highlighted in a number of recent eradication and research projects, especially in regard to risk and benefit analysis and to ensure a suitable environment for eradication projects to proceed can occur (Bryce, et al., 2011; Eason, et al., 2008). Respect for the attitudes, and safety, of local communities needs to be a priority in any eradication planned for inhabited islands. The support and agreement by the community to proceed with an eradication is vital for any project on an inhabited island. This is particularly important as access into all properties is vital to effectively carry out an eradication. Involving the residents in the concept, planning, implementation and on-going biosecurity of the island was recognised as the only way such an eradication could have occurred on the islands in the UK.

Considerations to how the community view the environment, how they think the proposed eradication will affect them and other social science considerations need to be assessed for eradications planned for inhabited islands. Most importantly, all aspects of the eradication should be discussed with the community in the early stages of the proposal. Unlike eradication operators, most members of the public do not have any knowledge of the principles and techniques of eradication, particularly in regard to rodenticide choice and operational procedures. It is important that each community member understands these aspects and how they will personally be affected by the day-to-day operational requirements.

As there were staff or small communities present at four of the five previously mentioned UK eradications, almost all recent operations undertaken in the UK have had to work closely within these communities and have had to adapt to the issues and technical challenges the presence of people has on the eradications. During each of these eradications, WMIL and the local project partner worked closely with the landowner, staff and residents to understand and address concerns and questions about the operations. Where the operation occurred on staffed islands, the decision to complete an eradication had already been made by the main project partner concerned and much of the consultation with staff on the islands had already been completed by the management prior to the operation. Resident staff were generally supportive of the eradication and often viewed the eradication operational team as temporary, but separate, staff members. In comparison to those islands with resident staff, WMIL and RSPB recognised the importance of the engagement of the 85-person resident community on St Agnes and Gugh in the Isles of Scilly and started this engagement process early for the eradication of brown rats (Bell, et al., this issue a, Pearson, et al., 2019). The success of the St Agnes and Gugh eradication (Isles of Scilly Seabird Recovery Project, IOSSRP) showed how the community-based approach that was designed to develop local networks and use existing community structures to build support for the project worked extremely well. The vision and benefits of the project were shared by the community and the residents were part of the decision-making process and management of the project.

An open and transparent operating system has worked well in all these five previously mentioned eradications in the UK. Information covering details on rodenticide type, bait station design, anticoagulant poisoning symptoms and treatment, contact numbers and project management was provided to all residents, stakeholders and interested parties. The project team was permanently present on each of the islands throughout the eradication to implement the operation, answer any questions and deal with any issues. Project updates were provided to the community and stakeholders each week, which gave the residents the opportunity to observe the operational procedures and results as the eradication proceeded. Real-time bait-take maps were provided as part of this process. A 24-hour contact telephone number was provided for immediate response to any issues that a resident may have.

BIOSECURITY

With the eradication of rats from islands, the priority is to ensure that they do not become re-established. Biosecurity is a critical aspect of any eradication and should be designed, implemented and tested prior to the completion of the eradication and departure of the eradication team. Prevention of an accidental rat reintroduction should be the primary aim. Precautions need to be taken not only in obvious situations such as with visitors or boat movements, or when high-risk items like stock feed or hay are being delivered to the island, but also when the risk may be mistakenly thought to be negligible.

The long-term legacy of these five UK eradication projects was important to the implementing agencies involved as well as the communities and agency staff on the island. As such, practical biosecurity strategies were established for the community and supporting agencies; measures that have been designed to reduce the risk of rats being reintroduced to a minimum, without being a hindrance to the daily lives of the staff, community or visitors to the island. A range of biosecurity strategies were proposed to the residents or agency staff on each island and, following discussions about the protocols of each strategy, suitable measures for each island were selected and implemented. Public awareness and education leaflets have been developed for every eradication to ensure that the public are aware of the rat-free status of each island and ways they can assist in keeping the islands rat-free. Residents and staff members from the project partners have been trained in all relevant biosecurity measures and they will maintain regular monitoring checks on the islands in perpetuity. Funding for on-going biosecurity has been provided by partner agencies and completed by staff or in the case of St Agnes and Gugh, funds will be provided by the community through fundraising and grants (Pearson, et al., 2019). In some instances, such as on St Agnes and Gugh, community coordinators will maintain liaison between the residents and the supporting partner agencies (Pearson, et al., 2019).

DISCUSSION

Rat eradications have been undertaken on islands around the world for the past 65 years and in the UK for the past 50 years. International rat eradication projects over this time have used a range of methods but most recently focused on the aerial application of rodenticides. However, due to legislative limitations upon the outdoor-use of rodenticides and application methods, and although derogations can be issued to allow aerial operations, ground-based methods are likely to remain the predominant rat eradication technique in the UK (and other European counties). Developments from five eradications in the UK have streamlined operating procedures and eradication techniques for the next eradication. Using plastic corrugated drainage pipe as the main bait station type has enabled the design to be adapted to exclude large or problematic non-target species such as rabbits and crows. The positioning of bait stations using GPS and GIS-linked systems has streamlined recording bait take by rats and non-target species and enabled this to be monitored in real time. Constant monitoring throughout the operations starting with the bait take and progressing through to using a range of monitoring devices, such as flavoured wax, allowed for each operation to adapt to deal with high risk areas or 'fussy' rats to maximise the likelihood of eradication success. This intensive level of monitoring allows any issues that may arise with bait to be addressed directly with the manufacturers and rectified early in the operational timeframe.

Ground-based eradications have been completed on islands ranging in size from <1 ha to 3,100 ha (Taylor, et al., 2000; DIISE, 2015). Although an island's size and terrain may prevent a ground-based bait station operation being completed, it would be perfectly feasible to eradicate rats from even larger inhabited and uninhabited islands assuming there were enough resources (including staff and funding) and commitment and support from all involved. The feasibility assessment for any proposed eradication needs to investigate the costs and benefits of all possible methods before deciding on the final operational techniques. In many cases, a combination of aerial and ground-based operations may also be suitable or preferred by communities on large inhabited islands, as shown by recent eradication plans such as for Lord Howe Island (Wilkinson & Priddel, 2011; Walsh, 2019).

Over 85% of rat eradications around the world have been completed on uninhabited islands (n = 721 out of 820 eradications; DIISE, 2015). However, many are now either being investigated or planned for islands with resident communities (Oppel, et al., 2011; Russell & Broome, 2016; Stanbury, et al., 2017). Eradications on inhabited islands raise social, economic, conservation and technical challenges for the operation (Moon, et al., 2015). The experience in the UK shows that to ensure an island restoration project runs successfully the support and agreement from the community must be secured. The community must share the project's vision and feel that they are one of the beneficiaries. To do this, they will need to be included and play an integral role in the decision-making process, planning preparation and implementation and management of the project. In this way, the legacy of the project will be much stronger. Those proposing the eradication need to ensure that the community is aware of the effects of invasive rats on the native biodiversity of their island and how the proposed eradication can benefit those species as well as explaining the process of the eradication operation itself. However, project partners and eradication operators also need to realise that for a number of residents the biodiversity and environmental reasons to eradicate rats may be of no interest; as such, social and economic benefits should also be outlined during the planning stages as these may be more important to the communities themselves. It is important for operators to realise that communities may not have the same understanding of eradication processes and each aspect of the project may have to be explained.

The larger the community the longer, potentially, the project managers will need to ensure that the residents are all at the same position of understanding through the various stages of the project. Archipelagos or groups of islands bring additional stakeholders and interested parties that need to be engaged compared to single islands. From my experience, ten years is not an unreasonable timescale depending upon the starting point, the value placed upon seabirds by the community and the strength of the project partnership. In my view, and in agreement with others such as Moon et al. (2015), the ongoing consultation and communication with the local community and wider stakeholder groups during any eradication is essential.

As the need to prioritise islands for restoration has increased, the requirement of understanding and quantifying the costs of eradications has also increased (Martins, et al., 2006; Holmes, et al., 2015). Although general costs for eradications can be estimated if the size of the island and target species are known, and it appears that costs increase with the size of island, there are other costs from application method, permits, non-target mitigation, and biodiversity monitoring that need to be factored into an eradication operation (Martin, et al., 2006; Holmes, et al., 2015). This information is vital to be able to accurately determine the complete costs for future eradications and it is important that project costs are reported.

The defining factors underpinning the success of the eradication operations on inhabited UK islands were the professional management of the eradication, dedicated and passionate volunteer involvement, efficient and systematic monitoring, adapting to local conditions and ensuring a community-inclusive approach.

This model of consultation, engagement and community-involvement developed on these inhabited islands eradications in the UK can offer valuable information, advice and direction for eradication operations planned on islands with larger communities in the UK and

around the world. The eradication of brown rats from St Agnes and Gugh could be used as a valuable education tool to show other communities that it is possible to safely eradicate rats and implement suitable biosecurity measures to reduce the risk of reinvasion without impacting on the lives of the residents, as reported by Pearson, et al. (2019). This model, and future techniques developed during other eradications on inhabited islands, will be even more important if restrictions on application measures and outdoor-use of rodenticides expand to countries outside of the UK. It is important for eradication operators to realise that even if aerial application methods are possible at the location, the community on the island may not approve or permit that type of method. As such, the use of ground-based bait station techniques will have a vital part to play and this option should be assessed as part of any original feasibility assessment.

Island restoration on UK islands has led to the dramatic recovery of seabird populations. Manx shearwaters on Ramsey and Lundy Islands have increased nearly ten-fold in the ten to fifteen years since the eradication of brown and black rats and the recolonization of European storm petrels and other small burrowing species has been recorded after long absences (Brown, et al., 2011; Morgan, 2012; Booker & Price 2014; Bell, et al., 2019b). These types of results have helped develop a legacy for many of the projects, with the residents and agency personnel on the islands committing to and doing their part to maintain important biosecurity measures. These results can also be used to help explain the benefits of completing this type of eradication project on other islands, even those with larger communities or a complex of target species. Providing safe breeding habitat and creating and then maintaining rodent-free status at important island sites, will be an important part of the long-term legacy of protection for UK seabirds.

It is important that when eradication projects are being designed and assessed that operators and project partners factor in on-going biosecurity after the completion of the project, particularly in relation to equipment, capacity and long-term funding requirements. It is one of the most vital aspects of an eradication project and agencies must recognise the requirement that biosecurity is required *in perpetuity*. For eradications that occur on inhabited islands, this makes the engagement of, and commitment from, the communities to undertake biosecurity measures, even more important to ensure the legacy of any eradication project.

Detailed prioritisation exercises such as Brooke, et al. (2007), Ratcliffe, et al. (2009) and Stanbury, et al. (2017) have identified a number of UK and UK Overseas Territories' islands as being pre-eminent sites for rat eradication because of their importance to seabirds. Twenty of the 25 islands identified in the most recent prioritisation exercise have resident human populations which increases the challenges for any eradication proposed for those sites (Stanbury, et al., 2017). One of the most important lessons identified by completing eradication operations on inhabited islands is that the community needs to be engaged as early as possible, preferably in the concept and development process. As important, all stages of the eradication need to be completely open and transparent, with community members involved throughout the implementation of the project and into the future to ensure the sustainability of the on-going biosecurity for the island. The newly developed Best Practice for UK islands (Thomas, et al., 2017b) which has built on all the lessons learnt from these eradications that have occurred over the past 50 years in the UK should help make these future eradication operations more likely to succeed on both uninhabited and inhabited islands.

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