

The recovery of seabird populations on Ramsey Island, Pembrokeshire, Wales, following the 1999/2000 rat eradication

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Abstract Ramsey Island, 259 ha, is ca. 1 km off the Pembrokeshire coast, south-west Wales. The eradication of brown rats (*Rattus norvegicus*) was successfully completed in the winter 1999/2000 using a ground-based bait station operation. The pre-eradication survey using tape playback estimated the Manx shearwater (*Puffinus puffinus*) population to be 849 pairs. These surveys were repeated in 2007, 2012 and 2016. Each survey showed the Manx shearwater population had increased, reaching 4,796 pairs in 2016 with birds spreading from previously known breeding locations. European storm petrels (*Hydrobates pelagicus*) were first recorded breeding on Ramsey Island in 2008 with up to 12 pairs in 2016 (a minimum estimate based on accessible survey areas). Other species have also shown improvements to population estimates and range since the rat eradication. This evidence shows that there can be little doubt that the presence of brown rats on Ramsey played a significant role in suppressing breeding numbers and limiting the breeding range of seabirds on the island and the positive results following the successful eradication are now being seen.

Keywords: brown rat, European storm petrel, *Hydrobates pelagicus*, Manx shearwater, *Puffinus puffinus*, *Rattus norvegicus*, survey

INTRODUCTION

Rats are known to have devastating effects on seabird and land bird populations by predation of eggs, chicks and adults which reduces breeding success, recruitment, population size and distribution. They have caused extinctions of birds on numerous islands throughout the world (Moors & Atkinson, 1984; Atkinson, 1985; Towns, et al., 2006; Jones, et al., 2008). Smaller burrowing seabirds are recognised as the species most affected by invasive rats (Jones, et al., 2008; Towns, et al., 2011). The eradication of rats from seabird islands is recognised as one of the most important tools in avian conservation in recent times, with significant long-term restoration benefits such as increased productivity and populations sizes and establishment of new, or return of previously locally extinct, seabird species being achieved (Atkinson, 1985; Moors, et al., 1992; Lock, 2006; Ratcliffe, et al., 2009; Booker & Price, 2010; Bourgeois, et al., 2013; Le Corre, et al., 2015). 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., 2017). Over 400 islands around the world have been successfully cleared of rats, including twelve in the United Kingdom, with a subsequent increase in bird populations (Thomas & Taylor, 2002; Towns & Broome, 2003; Jones, et al., 2008; Howald, et al., 2007, DIISE, 2015, Thomas, et al., 2017).

A feasibility study of eradicating brown rats (*Rattus norvegicus*) from Ramsey Island was completed in 1998 and led to the ground-based eradication in autumn 1999. Documenting the recovery of bird species on islands that have had invasive mammals removed is becoming increasingly important. RSPB has been monitoring bird populations on Ramsey Island since 1992. Due to difficulty in accessing natural burrows, between 2013 and 2016, RSPB constructed a man-made seabird habitat using artificial burrows with the aim to establish a Manx shearwater (*Puffinus puffinus*) colony that could be used to monitor productivity, recruitment and adult survival. This paper details the changes to the Manx shearwater population on Ramsey Island, including within the man-made habitat, and the subsequent colonisation of the island by European storm petrel (*Hydrobates pelagicus*) following the eradication of brown rats.

STUDY AREA AND METHODS

Study site

Ramsey Island, 259 ha (5°20'W, 51°51'N), is located about 1 km off the Pembrokeshire coast, south-west Wales (Fig. 1). It is a nature reserve owned and managed by the RSPB. Ramsey Island is approximately 3.2 km long and 1.6 km across at its widest point and is surrounded by coastal cliffs which are particularly high and steep on the western side of the island. There is also a number of small islets (including a chain of islets from the southern end) and caves around the coastline. The coastline of the island is made up of exposed rocky shores with a small number of sandy coves. The top of the island is gently rolling and is dominated by two prominent peaks (Carn Ysgubor 101 m and Carn Llundian 136 m). The island supports three main habitats; acid grassland, bracken-dominated grassland and coastal heathland (Doncaster, 1981; Hurford & Evans, 2006; CCW, 2008). The heathland and maritime grassland communities are of conservation importance in Wales (JNCC, 2001; Hurford & Evans, 2006; CCW, 2008). The rush-pasture fields are grazed by rabbits (*Oryctolagus cuniculus*), ponies (*Equus caballus*) and sheep (*Ovis aries*) as part of the management to support wildlife, particularly choughs (*Pyrhacorax pyrrhacorax*) (Doncaster, 1981; Long, 2003). The bank vole (*Myodes glareolus*) and common shrew (*Sorex araneus*) are also present on the island.

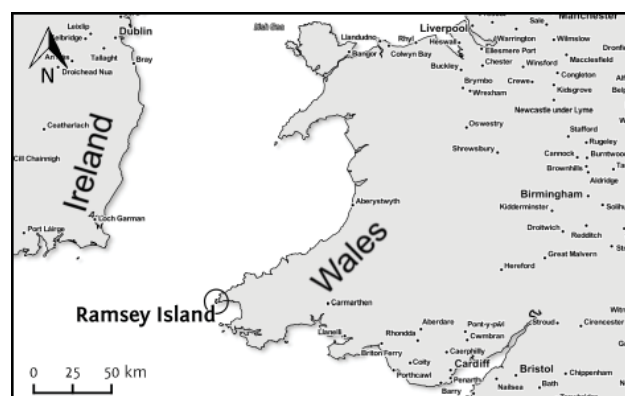


Fig. 1 Location of Ramsey Island, Wales.

The island is part of the Pembrokeshire Coast National Park and has a range of designations including as a Site of Special Scientific Interest (SSSI), National Nature Reserve (NNR), Important Bird Area (IBA), Special Protection Area (SPA) and Marine Special Area of Conservation (MSAC) (JNCC, 2001; CCW, 2008; Hayhow, et al., 2016). Ramsey holds important breeding populations of razorbill (*Alca torda*), guillemot (*Uria aalge*), kittiwake (*Rissa tridactyla*), Manx shearwater, chough and wheatear (*Oenanthe oenanthe*) (JNCC, 2001; Johnstone, et al., 2011). Ramsey Island is also an important breeding site for Atlantic grey seals (*Halichoerus grypus*).

The island is popular with visitors who are interested in the seabirds, land birds, flora and history. These visitors travel to the island on small passenger vessels from St David's between April and October. There is a jetty and several buildings on the island, including the warden's home and information shelter.

Manx shearwaters have been recorded on Ramsey Island since the 18th century (Mathew, 1894; Holloway, 2010; Lovegrove, et al., 2010). Historical reports and more recent seabird monitoring on Ramsey recorded declines in Manx shearwaters and other seabirds (Mathew, 1894; Humpridge & Bullock, 1999; Lovegrove, et al., 2010). These declines were attributed in part to the presence of brown rats and predation on eggs and chicks (Humpridge & Bullock, 1999; Lovegrove, et al., 2010).

It is not known when brown rats became established on Ramsey Island; but this was likely to have occurred more than two hundred years ago from an early shipwreck.

Brown rat eradication

The eradication of brown rats was completed as a ground-based operation using rodenticide cereal blocks in protective bait stations to reduce risk to non-target species. A 50 m × 50 m grid was established in autumn 1999. Bait stations were made from 500 mm lengths of corrugated plastic drainage pipe staked into position using wire. A total of 1,260 stations were placed on the main island and offshore stacks. The poisoning operation ran from 11 January 2000 to 10 March 2000. Two 24 g blocks of cereal-based rodenticide bait (NeosorexTM, active ingredient 0.005% difenacoum, manufactured by Sorex Ltd) were placed in each station on the main island and ten blocks on the offshore stack throughout the poisoning programme and replaced as required when eaten by rats, non-target species and/or damaged by weather.

The stations on the main island were checked daily, but stations on the offshore stacks were checked when sea conditions allowed. Bait take was recorded by bait station number and the species believed to have consumed or removed the bait.

From 1 March to 15 March 2000, monitoring stations were established around the island next to and in-between the bait stations. Chew sticks, chocolate blocks and small pieces of candle were used. Sand and mud areas on the island were checked for rat foot prints and burrows and rat runs were checked for fresh activity. All monitoring points were individually numbered and any evidence of activity (i.e. teeth marks or foot prints) was recorded by station number and the species believed to have consumed or marked the monitoring item. Each monitoring site was checked regularly, either separately or together with the poisoning bait station grid. Any rat and non-target species sign found on detection devices was recorded.

Manx shearwater breeding population survey

Earlier surveys on Ramsey Island had shown that Manx shearwaters only occur in a narrow strip around the coast

of the island on hills Carn Llundain and Carn Ysgubor (I.D. Bullock, unpublished data; Perkins, et al., 2017). For burrow counting and sampling purposes, Ramsey Island was divided into 42 sub-areas by topographical features. A full count of suitable burrows (i.e. more than 0.7 m in length and not doubling back to the surface) in these 42 sub-areas was completed in 1999, 2007, 2012 and 2016.

Estimation of the numbers of Manx shearwaters on Ramsey Island was based on playback of recorded calls (Brooke, 1978; Smith, et al, 2001; Perkins, et al., 2017). This method relies on the fact that if a male Manx shearwater call is played down a sample of burrows during the incubation period, most incubating males, but no incubating females will respond to that call (Smith, et al., 2001). For a given number of breeding pairs, it is then possible to establish the number of males that respond to recorded calls. From this, using the following formula it is possible to estimate the number of breeding pairs in the burrows on the island.

$$\text{Breeding pair} = \text{No. of burrows} \times \frac{\text{No. Responding}}{\text{No. Sampled}} \times \frac{1}{\text{Response Rate}}$$

The response rate for Manx shearwaters was calculated by Bullock in 1999 (0.409) and was based on a study set of 13 burrows (Humpridge & Bullock 1999). Alternative response rates were available from Skomer (0.43, Smith, et al., 2001) and Skokholm (0.505, Brooke, 1978) or the seabird monitoring handbook (0.505, Walsh, et al., 1995). The Ramsey response rate of 0.409 was used in 2007 as it allows direct comparison to the earlier survey on the island. The response rates were recalculated for the 2012 survey (to 0.4625) using methods developed by Murray, et al. (2003), Newton, et al. (2004) and Perrins, et al. (2012). The response rates were recalculated for the 2016 survey (to 0.845) which used dual-sex calls which had been shown to give a more reliable correction factor (Perkins, et al., 2017).

A recording of male Manx shearwater calls was played down 20% of burrows in each sub-area during the main incubation period unless the sub-area contained fewer than 50 burrows up to 2016 and then duetting male and female calls were used for 2016 (Perkins, et al., 2017). In those cases, the recording was played in all burrows. Recordings were played at natural volumes ('normal' Manx shearwater call volumes as heard from the burrows that were set 'by ear' before 2016 and by a decibel reader in 2016) within 30 cm of the burrow entrance for up to 25 seconds. Playback of calls was carried out in the day and responses, or lack thereof, were recorded. Playback was undertaken between the end of May and mid-June at a time when all eggs laid should be being incubated by one adult (Brooke, 1990).

Between 2013 and 2016 nearly 100 artificial nest boxes were established on the island. These burrows are the same design as those developed in New Zealand for fluttering shearwaters (*Puffinus gavia*) by Bell (1995) and recommended for burrow-nesting petrel and shearwater species (Gummer, et al., 2014). These artificial burrows were put in place to provide easily accessible study burrows for tracking studies and to determine productivity and population parameters such as survival and recruitment (Morgan, 2012; Kirk, et al., 2013).

European storm petrel breeding population survey

Surveys of suitable storm petrel habitat (i.e. stone walls, rock tumbles and scree) on Ramsey Island were undertaken using playback in 2008, 2010, 2012 and 2016. A recording of a male European storm petrel was played close to a suspected site and a reply listened for (Ratcliffe, et al., 1998; Gilbert, et al., 1999; Mayhew, et al., 2000). Burrow entrances that had responses were mapped using GPS.

RESULTS

Brown rat eradication

Bait acceptance was good, with rats accounting for 165 kg of bait consumed. As the LD_{50} for a 250-g brown rat is 9 g and the mean (\pm SE) bait take by rats was 81.6 ± 0.7 g (3.4 ± 0.02 blocks, range 0–30 blocks) the rat population on Ramsey Island was estimated to be between 1,850 and 5,400 rats). The bait take pattern was typical of other rat eradication operations; very high in the immediate five to ten days after original baiting and dropping to a relatively low level 21 days after original baiting. Bait take dropped to zero by day 41 after the original baiting (Fig. 2). The rats were widely distributed across the island, but the density was not even, as shown by the distribution of bait take (Fig. 3). Rats were present in all coastal areas and in highest numbers within the central and northern areas of the island.

Rabbits interfered with the bait stations between days 12 and 26 of the operation, with a number of carcasses being collected. Bait stations were modified by halving the entrance size to prevent access by rabbits and this greatly reduced their interference levels. Carrion crows (*Corvus corone*), ravens (*Corvus corax*) and herring gulls (*Larus argentatus*) also interfered with the stations from day 25 after the birds had learnt to reach into the stations to get access to the bait. Eight crows and three raven carcasses were located but no herring gull deaths were recorded. The bait stations were further modified by extending the length from 500 mm to 750 mm which reduced crow, raven and gull interference to almost nil. Crows were observed working in pairs to remove wires; one pulling the wire out while the other stood on top of the station to hold it in place, to get access to the bait. Access to the bait by the bank voles could not be prevented and 30 dead voles were found. A small captive population was maintained during the eradication as a precaution and was released after the poison had been removed. Voles and vole sign on monitoring tools were recorded throughout the eradication.

Monitoring for rat presence continued for two years after the end of the poisoning operation. No rats or sign were detected. The rat-free status for Ramsey Island was declared in March 2002.

Manx shearwater breeding population survey

The number of Manx shearwater burrows on Ramsey Island totalled 13,800 burrows in 1999, 14,970 burrows in 2007, 12,302 burrows in 2012 and 12,319 in 2016 (Humpridge & Bullock, 1999; Morgan & Morgan, 2008; Morgan & Morgan, 2013; Morgan & Morgan, 2017).

The Manx shearwater breeding population size increased 3-fold and 5-fold, 8 and 17 years after the rat eradication respectively (Table 1).

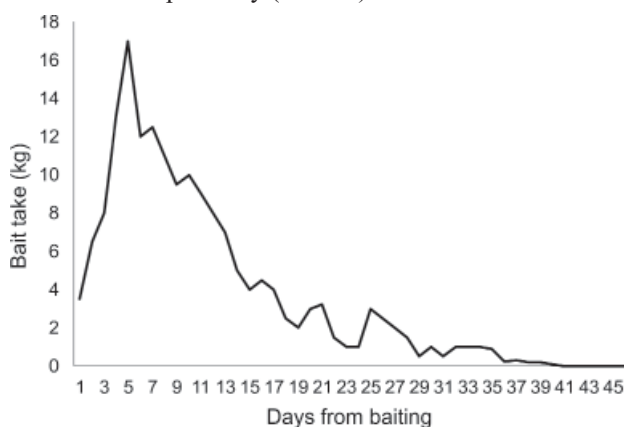


Fig. 2 Bait take by rats during the brown rat (*Rattus norvegicus*) eradication on Ramsey Island, Wales, 1999/2000.

The distribution of Manx shearwaters remained largely unchanged between 1999 and 2007 censuses, but the range spread between the 2007, 2012 and 2016 censuses (Fig. 4). There have also been significant increases in the population within the distribution with new areas recorded in 2007, 2102 and 2016 that previously had no responses recorded in 1999 (Fig. 4).

Burrow density is greatest along the west, north and north-east coasts and on the hills (Fig. 4). Interestingly in a section at the northern end of Ramsey Island there was no response to the recordings despite a high number of suitable burrows available for Manx shearwaters ($n = 2,247$) in 1999 or 2007. This area showed a low level of response in 2012 and higher in 2016.

A prospecting pair of Manx shearwaters was recorded in one of the artificial burrows in 2015. Two pairs nested successfully in the artificial burrows in 2016 and seven pairs were recorded incubating eggs in April 2017.



Fig. 3 Distribution of bait take during the brown rat (*Rattus norvegicus*) eradication on Ramsey Island, Wales, 1999/2000.

Table 1 The total number of burrows, response rate used, total number of burrows sampled using playback, total number of responses and total number of breeding pairs of Manx shearwater *Puffinus puffinus* on Ramsey Island between 1999 and 2016.

Year	Total number of burrows	Response rate used	Total number sampled using playback	Total number of responses	Total number of breeding pairs
1999	13,800	0.409	2,760	74	905
2007	14,970	0.409	3,190	208	2,387
2012	12,302	0.4625	2,788	402	3,835
2016	12,319	0.845	2,860	941	4,796

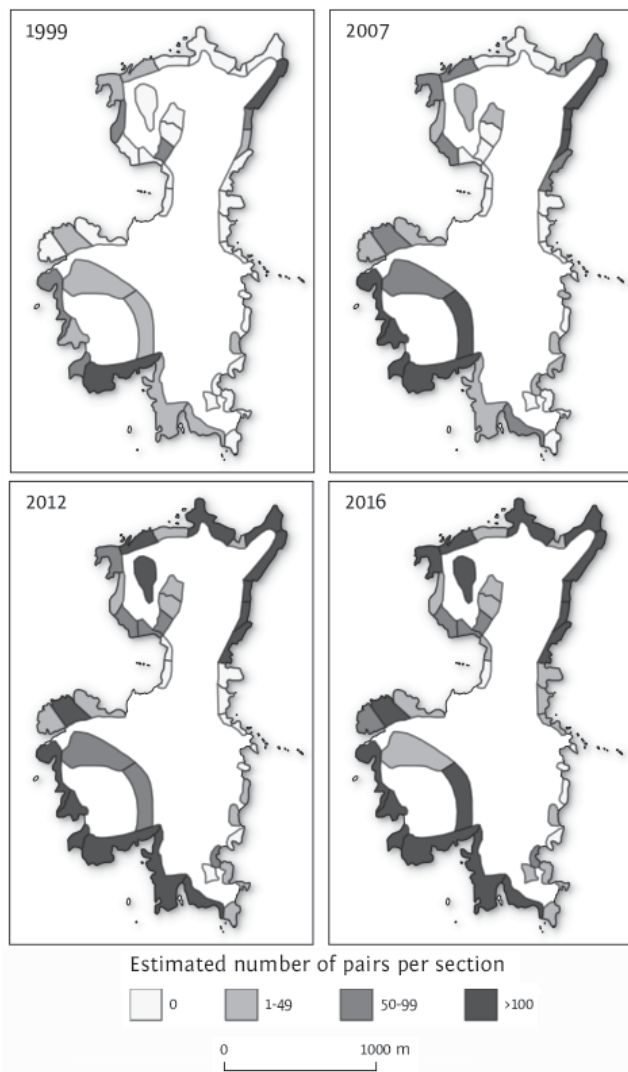


Fig. 4 Distribution and density of Manx shearwaters (*Puffinus puffinus*) from the full surveys in 1999, 2007, 2012 and 2016 on Ramsey Island, Wales.

European storm petrel breeding population survey

The first storm petrel breeding burrows were detected in 2008 (4 pairs). By 2016, the numbers had increased to 12 breeding burrows (Table 2).

DISCUSSION

The Ramsey Island brown rat eradication was one of the first eradications undertaken by the RSPB and a number of important lessons were learnt that helped with the planning and implementation of later eradications on Lundy Island, St Agnes and Gugh, Isles of Scilly and the Shiant Isles.

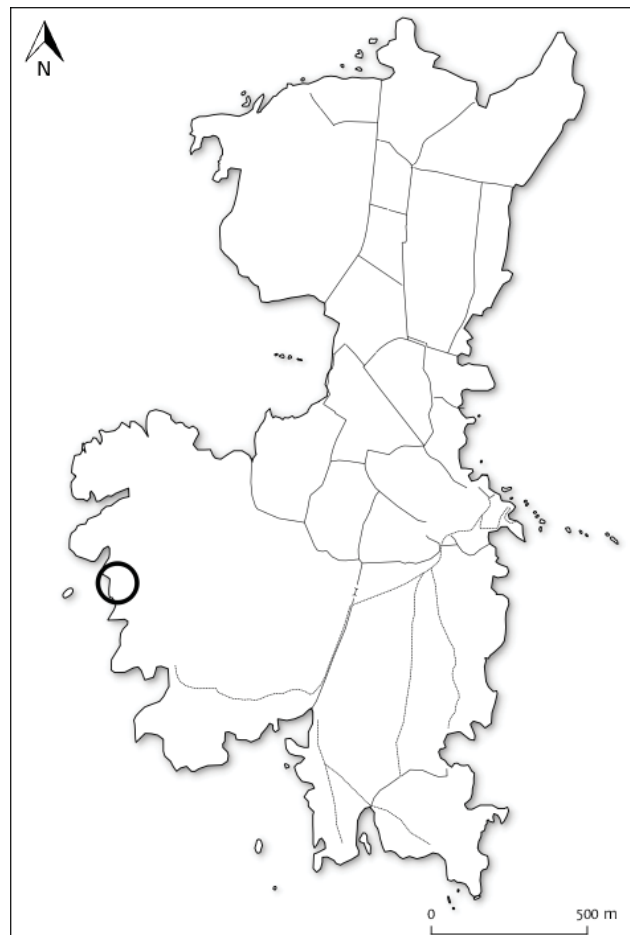


Fig. 5 Location of European storm petrel breeding sites (in black circle) on Ramsey Island, Wales, 2016.

Bait station design was adapted to suit local conditions and local non-target species.

The Ramsey Island operation was the first island-wide eradication that used a rodenticide containing the active ingredient difenacoum proving that this rodenticide could be used to successfully target all brown rats on an island. This toxin has since been used on a number of island eradication operations in the UK and around the world (Howald, et al., 2007; Jones, et al., 2008). Since the eradication of rats, there have been biosecurity protocols put in place to prevent a re-incursion on Ramsey Island and to outline how to respond if rats are ever detected on the island. It is important that these measures are maintained indefinitely.

Ramsey Island has seen dramatic changes since the removal of brown rats, not least the increase in the distribution and density of Manx shearwaters. The number of Manx shearwaters has multiplied by five times between

Table 2 The number of burrows of European storm petrels *Hydrobates pelagicus* on Ramsey Island between 2008 and 2016.

Year	Number of breeding burrows
2008	4
2009	Not surveyed
2010	6
2011	Not surveyed
2012	5
2013	5
2014	5
2015	8
2016	12

1998 and 2016 to almost 5,000 breeding pairs, representing a 560% increase. This proves that the brown rats were having a significant role in suppressing the number of breeding pairs on the island and their range across the island and provides more evidence that invasive rats have significant impacts on seabird populations on islands (Atkinson & Moors, 1984; Atkinson, 1985; Towns, et al., 2006; Jones, et al., 2008). A similar pattern was observed on Lundy Island following the rat eradication operation in 2004 (Brown, et al., 2011). It is suspected that although increased productivity will have occurred on Ramsey Island, given that the Manx shearwater does not breed until five or six years of age (Brooke, 1990), much of this increase may be due to immigration from the extremely large neighbouring colonies on Skomer and Skokholm. This theory was confirmed by the capture of an adult that had been ringed as a chick on Skomer in 1993 which was on its way to feed a chick on Ramsey Island in 2017 (GM, pers. obs.).

The greatest increases have occurred within the existing sub-colonies, but there has also been expansion into new areas. Nine sections that showed nil response in 1999 and 2007 contained breeding birds in 2012 and a further five new sections were occupied in 2016. There is limited habitat available on Ramsey Island away from the coastal areas. However, restoration of drystone walls, former rabbit warrens and artificial burrows have all provided more nest-sites. However, the presence of rabbits may affect the distribution of Manx shearwaters on Ramsey Island. Competition for burrows with a small number of birds may account for restricted range and densities in specific locations on the island. The development of an artificial study colony on Ramsey Island has proved successful with up to seven birds nesting in the man-made burrows in 2017, of which five successfully fledged chicks.

European storm petrels have also started breeding on the island for the first time since records began. Although storm petrels are known to breed on two offshore islands, the Bishops and Clerks (163 apparent occupied sites in 2017; G.M., pers. obs.), it was not until 2008 that they were confirmed on Ramsey Island itself. Six birds were recorded breeding in 2012 and this increased to 12 pairs in 2016. It is important to note that these estimates are the minimum number of storm petrels present on the island as not all adults may respond to the recorded calls. This has been shown to be the case in a number of other studies (Insley, et al., 2002; Brown, 2006; Hounscome, et al., 2006) and, as these studies have also shown that correction factors for storm petrels are known to be highly variable between sites and even between years, the use of recorded calls and corrections have not been used to estimate the

current Ramsey Island storm petrel population. As the population increases, an island-specific correction factor will be calculated for Ramsey Island and used to estimate the population size in the future. Currently, the minimum estimate is used (i.e. the known response to taped calls).

However, the basic playback-response method is widely used, standardised and is comparable between years and across sites. It is also a low-impact method, completed during the day, and provides spatial information on breeding burrows. The storm petrel population on Ramsey Island is likely to increase into a range of available habitat including drystone walls, rabbit burrows and rock tumbles.

The success on Ramsey Island provided valuable information and techniques for later eradication operations in the UK, particularly those with important non-target species. It also showed that ground-based eradication techniques developed in New Zealand could be adapted and used on islands in the UK, and Ramsey Island serves as a good example of the significant long-term benefits that can be achieved through short-term investment.

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REFERENCES

- Atkinson, I.A.E. (1985). 'The Spread of Commensal Species of *Rattus* to Oceanic Islands and their Effects on Island Avifaunas'. In: P.J. Moors (ed.) *Conservation of Island Birds*, pp. 35–81. ICBP Technical Publication 3. Cambridge, UK: International Council for Bird Preservation (ICBP).
- Bell, B. (1995). 'Translocation of Fluttering Shearwaters: Developing a Method to Re-establish Seabird Populations'. In: M. Serena (ed.) *Reintroduction Biology of Australian and New Zealand Fauna*, pp. 143–156. Australia: Surrey Beatty and Sons.
- Booker, H. and Price, D. (2010). 'Manx shearwaters on Lundy: A study of population and distribution change from 2001 to 2008'. *Journal of the Lundy Field Society* 2: 105–112.
- Bourgeois, K., Ouni, R., Pascal, M., Dromzée, S., Fourcy, D., and Abiad, A. (2013). 'Dramatic increase in the Zembretta Yelkouan shearwater breeding population following ship rat eradication spurs interest in managing a 1500-year old invasion'. *Biological Invasions* 15: 475–482.
- Brooke, M. (1978). 'Sexual differences in the voice and individual vocal recognition in the Manx shearwater (*Puffinus puffinus*)'. *Animal Behaviour* 26: 622–629.
- Brooke, M. (1990). *The Manx Shearwater*. London: Poyser.
- Brooke, M., Hilton, G. and Martins, T. (2007). 'Prioritising the world's islands for vertebrate-eradication programmes'. *Animal Conservation* 10: 380–390.
- Brown, A., Price, D., Slader, P., Booker, H., Lock, L. and Deveney, D. (2011). 'Seabirds on Lundy: their current status, recent history and prospects for the restoration of a once important bird area'. *British Birds* 104: 139–158.
- Brown, J. (2006). 'Census of European storm-petrels *Hydrobates pelagicus* on Skomer Island'. *Atlantic Seabirds* 8: 21–30.
- CCW (Countryside Council for Wales). (2008). *Core Management Plan Including Conservation Objectives for St David's Special Area of Conservation*. Bangor, UK: Countryside Council for Wales.
- DIISE. (2015). 'The Database of Island Invasive Species Eradications, developed by Island Conservation, Coastal Conservation Action Laboratory UCSC, IUCN SSC Invasive Species Specialist Group, University of Auckland and Landcare Research New Zealand'. <<http://diise.islandconservation.org>>.
- Dawson, J., Oppel, S., Cuthbert, R., Homes, N., Bird, J., Butchart, S., Spatz, D. and Tershey, B. (2015). 'Prioritizing islands for the eradication of invasive vertebrates in the United Kingdom overseas territories'. *Conservation Biology* 29: 143–153.

- Doncaster, C. (1981). 'The spatial distribution of ants' nests on Ramsey Island, South Wales'. *Journal of Animal Ecology* 50: 195–218.
- Gilbert, G., Gibbons, D. and Evans, J. (1999). *Bird Monitoring Methods B: A Manual of Techniques for Key UK Species*. Sandy, Bedfordshire, UK: RSPB, BTO, JNCC, ITE & The Seabird Group.
- Gummer, H., Taylor, G. and Collen, R. (2014). *Field Guidelines for Burrow-nesting Petrel and Shearwater Translocations—a Companion Guide to the Seabird Translocation Best Practice Documents*. Wellington: Department of Conservation.
- Hayhow, D., Burns, F., Eaton, M., Al Fulaij, N., August, T., Babey, L., Bacon, L., Bingham, C., Boswell, J., Boughey, K., Brereton, T., Brookman, E., Brooks, D., Bullock, D., Burke, O., Collis, M., Corbet, L., Cornish, N., De Massimi, S., Densham, J., Dunn, E., Elliott, S., Gent, T., Godber, J., Hamilton, S., Havery, S., Hawkins, S., Henney, J., Holmes, K., Hutchinson, N., Isaac, N., Johns, D., Macadam, C., Matthews, F., Nicolet, P., Noble, D., Outhwaite, C., Powney, G., Richardson, P., Roy, D., Sims, D., Smart, S., Stevenson, K., Stroud, R., Walker, K., Webb, J., Webb, T., Wynde, R. and Gregory, R. (2016). *State of Nature 2016*. UK: The State of Nature partnership.
- Holloway, S. (2010). *The Historical Atlas of Breeding Birds in Britain and Ireland 1875–1900*. London, UK: Poyser Series, A&C Black.
- Hounsomes, M., Insley, H., Elliott, S., Graham, K. and Mayhew, P. (2006). 'Monitoring European storm-petrels *Hydrobates pelagicus*: a comparison of the results provided by mark/recapture and tape response methods'. *Atlantic Seabirds* 8: 5–20.
- Howald, G., Donlan, C., Galvan, J., Russell, J., Parkes, J., Samaniego, A., Wang, Y., Veitch, D., Genovesi, P., Pascal, M., Saunders, A. and Tershey, B. (2007). 'Invasive rodent eradication on islands'. *Conservation Biology* 21: 1258–1268.
- Humpridge, R. and Bullock, I. (1999). 'Estimation of the breeding Manx shearwater population on Ramsey Island'. *RSPB Ramsey Island Annual Report 1999–2000*. St Davids, Pembrokeshire, UK: RSPB.
- Hurdford, C. and Evans, S. (2006). 'Monitoring Coastal Heaths at St David's'. In: C. Hurdford and M. Schieder (eds.) *Monitoring Nature Conservation in Cultural Habitats: A Practical Guide and Case Studies*, pp. 157–168. Netherlands: Springer.
- Insley, H., Hounsomes, M., Mayhew, P. and Chisholm, K. (2002). 'A preliminary comparison of population estimation by tape response and mark/recapture methods for storm petrels *Hydrobates pelagicus* in two contrasting Scottish colonies'. *Ringing & Migration* 21: 75–79.
- JNCC (Joint Nature Conservation Committee). (2001). *Ramsey and St David's Peninsula Coast: SPA Description. Special Protection Areas under the EC Birds Directive*. <<http://jncc.defra.gov.uk/default.aspx?page=2063>>. Accessed 16 June 2017.
- Johnstone, I., Thorpe, R. and Noble, D. (2011). *The State of Birds in Wales 2011*. Cardiff, Wales: RSPB Cymru.
- Jones, H., Tershey, B., Zavaleta, E., Croll, D., Keitt, B., Finkelstein, M. and Howard, G. (2008). 'Review of the global severity of the effects of invasive rats on seabirds'. *Biological Conservation* 22: 16–26.
- Kirk, H., Morgan, G. and Guilford, T. (2013). 'Ramsey Island Manx shearwater geolocation study: Field report 2012'. *Birds in Wales* 10: 42–47.
- Le Corre, M., Danckwerts, D.K., Ringler, D., Bastien, M., Orlowski, S., Morey Rubio, C., Pinaud, D. and Micol, T. (2015). 'Seabird recovery and vegetation dynamics after Norway rat eradication at Tromelin Island, western Indian Ocean'. *Biological Conservation* 185: 85–94.
- Lock, J. (2006). 'Eradication of brown rats *Rattus norvegicus* and black rats *Rattus rattus* to restore breeding seabird populations on Lundy Island, Devon, England'. *Conservation Evidence* 3: 111–113.
- Long, J. (2003). *Introduced Mammals of the World: their History, Distribution and Influence*. Wallingford, UK: CABI.
- Lovegrove, R., Williams, I. and Williams, G. (2010). *Birds in Wales*. London, UK: Bloomsbury Publishing.
- Mathew, M. (1894). *The Birds of Pembrokeshire and its Islands*. London: R.H. Porter.
- Mayhew, P., Chisholm, K., Insley, H. and Ratcliffe, N. (2000). 'A survey of storm petrels on Priest Island in 1999'. *Scottish Birds* 21: 78–84.
- Moors, P.J. and Atkinson, I.A.E. (1984). 'Predation on Seabirds by Introduced Animals and Factors Affecting its Severity'. In: J.P. Croxall, P.G.H. Evans and R.W. Schreiber (eds.) *Status and Conservation of the World's Seabirds*, pp. 667–690. ICBP Technical Publication 2. Cambridge, UK: International Council for Bird Preservation (ICBP).
- Moors, P., Atkinson, I. and Sherley, G. (1992). 'Reducing the rat threat to island birds'. *Bird Conservation International* 2: 93–114.
- Morgan, G. and Morgan, L. (2008). 'A census of the Manx shearwater *Puffinus puffinus* on Ramsey Island RSPB Nature Reserve, Pembrokeshire in 2007'. *RSPB Ramsey Island Annual Report 2007–2008*. St Davids, Pembrokeshire, UK: RSPB.
- Morgan, G. (2012). 'The bird populations of Ramsey and Grassholm'. *British Birds* 105: 716–732.
- Morgan, G. and Morgan, L. (2013). 'A census of the Manx shearwater *Puffinus puffinus* on Ramsey Island RSPB Nature Reserve, Pembrokeshire in 2012'. *RSPB Ramsey Island Annual Report 2012–2013*. St Davids, Pembrokeshire, UK: RSPB.
- Morgan, G. and Morgan, L. (2017). 'A census of the Manx shearwater *Puffinus puffinus* on Ramsey Island RSPB Nature Reserve, Pembrokeshire in 2016'. *RSPB Ramsey Island Annual Report 2016–2017*. St Davids, Pembrokeshire, UK: RSPB.
- Murray, S., Shewry, M., Mudge, G. and Spray, S. (2003). 'A survey of Manx shearwaters *Puffinus puffinus* on Rum, Inner Hebrides in 2001'. *Atlantic Seabirds* 5: 89–100.
- Newton, S., Thompson, K. and Mitchell, P. (2004). 'Manx Shearwater *Puffinus puffinus*'. In: P. Mitchell, S. Newton, N. Ratcliffe and T. Dunn, (eds.) *Seabird Populations of Britain and Ireland*, pp. 63–80. London: T & AD Poyser.
- Perkins, A., Douse, A., Morgan, G., Cooper, A. and Bolton, M. (2017). 'Using dual-sex call improves the playback census method for a nocturnal burrow-nesting seabird, the Manx shearwater *Puffinus puffinus*'. *Bird Study* 64: 146–158.
- Perrins, C., Wood, M., Garroway, C., Boyle, D., Oakes, N., Revera, R., Collins, P. and Taylor, C. (2012). 'A whole-island census of the Manx shearwater *Puffinus puffinus* breeding on Skomer Island in 2011'. *Seabird* 25: 1–13.
- Ratcliffe, N., Vaughan, D., Whyte, C. and Shepherd, M. (1998). 'Development of playback census methods for storm petrels *Hydrobates pelagicus*'. *Bird Study* 45: 302–312.
- Ratcliffe, N., Mitchell, I., Varnham, K., Verboven, N. and Higson, P. (2009). 'How to prioritize rat management for the benefit of petrels: a case study of the UK, Channel Islands and Isle of Man'. *Ibis* 151: 699–708.
- Smith, S., Thompson, G. and Perrins, C. (2001). 'A census of the Manx shearwater (*Puffinus puffinus*) on Skomer, Skokholm and Middleholm, west Wales'. *Bird Study* 48: 330–340.
- Thomas, B. and Taylor, R. (2002). 'A history of ground-based rodent eradication techniques developed in New Zealand, 1959–1993'. In: C.R. Veitch and M.N. Clout (eds.) *Turning the tide: the eradication of invasive species*, pp. 301–310. Occasional Paper SSC no. 28. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.
- Thomas, S., Brown, A., Bullock, D., Lock, L., Luxmoore, R., Roy, S., Stanbury, A. and Varnham, K. (2017). 'Island restoration in the UK – past present and future'. *British Wildlife* 28: 231–242.
- Towns, D. and Broome, K. (2003). 'From small Maria to massive Campbell: Forty years of rat eradications from New Zealand islands'. *New Zealand Journal of Zoology* 30: 377–398.
- Towns, D., Atkinson, I. and Daugherty, C. (2006). 'Have the harmful effects of introduced rats on islands been exaggerated?'. *Biological Invasions* 8: 863–891.
- Towns, D., Byrd, G., Jones, H., Rauzon, M., Russell, J. and Wilcox, C. (2011). 'Impacts of Introduced Predators on Seabirds'. In: C. Mulder, W. Anderson, D. Towns and P. Bellingham (eds.) *Seabird Islands: Ecology, Invasions and Restoration*, pp. 56–90. New York: Oxford University Press.
- Walsh, P., Halley, D., Harris, M., del Nevo, A., Sim, I., and Tasker, M. (1995). *Seabird Monitoring Handbook for Britain and Ireland*. Peterborough: Joint Nature Conservation Committee, Royal Society for the Protection of Birds, Institute of Terrestrial Ecology and Seabird Group.