

Population surveys of burrow-nesting seabirds on the St Kilda archipelago: results and insights from the 2019 Seabirds Count census

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Abstract

Populations of burrow-nesting seabirds were surveyed on the St Kilda archipelago, off the northwest coast of Scotland, in June and July 2019 as a contribution to the national Seabirds Count census. This paper details the results for Atlantic Puffin *Fratercula arctica*, European Storm-petrel *Hydrobates pelagicus* and Manx Shearwater *Puffinus puffinus*. Puffins were surveyed via counts of Apparently Occupied Burrows, while the other two species population sizes were assessed by call-playback. The surveys of Boreray and Soay were the first to have been carried out since the Seabird 2000 survey (1999–2000), with surveys of Dùn and Hirta building on more recent surveys. Comparison with the Seabird 2000 survey showed that Puffin numbers have remained relatively stable on all islands. There appears to have been a decline in European Storm-petrel populations on Hirta, confirming the results shown by the long-term monitoring programme on St Kilda. Manx Shearwater numbers have remained more stable, though we have found evidence of redistribution of the largest colony on the archipelago from the Carn Mòr boulder field on Hirta to the higher slopes. St Kilda is the largest colony of seabirds in the British Isles and it is therefore of critical importance that it continues to be monitored at regular intervals. While population trends can be deduced from monitoring easily accessible plots, whole-colony counts are needed to detect changes in the extent of sub-colonies.

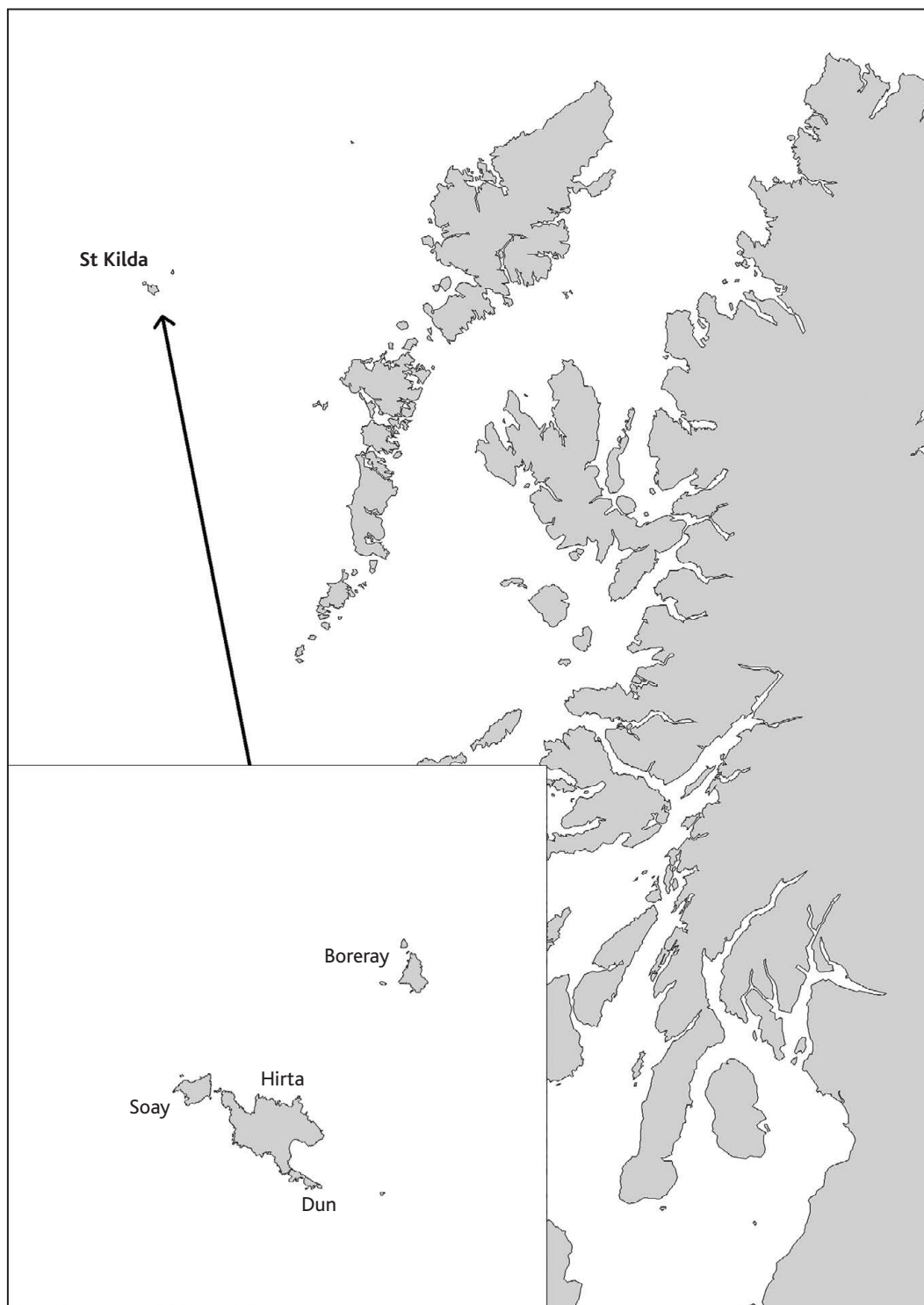


Figure 1. The location of St Kilda, showing the major islands of the archipelago.

Introduction

St Kilda, a small archipelago to the northwest of Scotland, 64 km west of North Uist (Figure 1), is the site of the largest seabird colony in the UK (Mitchell *et al.* 2004). It is internationally important for a range of burrow-nesting seabirds, notably Atlantic Puffin *Fratercula arctica* (hereafter 'Puffin'), Leach's Storm-petrel *Hydrobates leucorhous*, European Storm-petrel *H. pelagicus*, and Manx Shearwater *Puffinus puffinus*. Difficulty of access, particularly to the uninhabited islands, has restricted the ability of researchers to carry out comprehensive seabird surveys of the archipelago. The last full survey of the archipelago's burrow-nesting seabirds was carried out in 1999–2000 as part of the Seabird 2000 census of Britain and Ireland's breeding seabirds (Mitchell *et al.* 2000), but some sub-colonies have been surveyed more recently. Surveys of Leach's Storm-petrel were carried out on the island of Dùn in 2003 and 2006 (Newson *et al.* 2008), and there is regular monitoring of sub-colonies of Manx Shearwaters and European Storm-petrels on Hirta (Lawrence 2019). A survey of Puffins on the islands of Dùn and Hirta was carried out in 2018 (Luxmoore *et al.* 2019), but weather conditions prevented access to the islands of Boreray and Soay. Here, we describe a follow-up survey conducted in 2019, designed to complete the survey of the Puffin colonies on Boreray and Soay, and to survey the storm-petrels and shearwaters on all the islands as part of the national Seabirds Count census (Burnell *et al.* 2023). Additional observations were made of Puffins on Dùn and Hirta to augment the results of the 2018 survey. The survey of Leach's Storm-petrels is described separately in Deakin *et al.* (2021). Here, we report on the surveys of the remaining three species.

Methods

Timing of surveys

The surveys were carried out from 18 June to 5 July 2019. Surveying during these dates enabled the four species to be surveyed simultaneously, and minimised the logistical difficulties of landing on the outlying islands. The timing is later than is recommended for Puffin surveys (generally early- to mid-May, corresponding with the incubation period), but Walsh *et al.* (1995) state that "acceptable counts can be made at any time from late April to early August". The Seabird Monitoring Programme recommends that surveys for Manx Shearwater are conducted from early May to early June (the early incubation period), although Walsh *et al.* (1995) extend this to between early May and early July. European Storm-petrels are best surveyed in early July (peak incubation period; Walsh *et al.* 1995). It is important that call-playback surveys for Manx Shearwaters and European Storm-petrels are conducted during the incubation period as this is the only period of the breeding season when an adult is usually present in each active burrow at all times of day and night. Following hatching and a short brood-guarding stage, chicks (which do not tend to respond to playback) are usually left alone in the nest site, with adults making only brief provisioning visits at night.

Surveying for all burrow-nesting species was undertaken by six people on 18–21 June on Boreray, and by six people on 23 June on Soay. Puffin surveys were undertaken on Hirta by a two-person rope-access team on some of the less

accessible slopes to the south of Carn Mòr on 25 June, and by two people in the large Carn Mòr boulder colony on 2 July. Manx Shearwaters and European Storm-petrels were surveyed alongside Leach's Storm-petrels by four people at Carn Mòr on 25 June, by four people at Gleann Mòr on 30 June, and by two people in Village Bay on 1 July. Storm-petrel and shearwater surveys were carried out by four to six people on Dùn on 27–29 June, and 3 and 5 July. An additional survey of Puffins was undertaken in some of the higher density zones on Dùn on 27 June.

Atlantic Puffin burrow surveys

To allow comparison with previous surveys, 3 m wide linear transects were established by running a rope down the slope, perpendicular to the contour, at approximately 30 m intervals in high density zones. Fewer transects were counted in the low-density zones. Apparently Occupied Burrows (AOB) of Puffins were counted within 1.5 m either side of the rope by pairs of surveyors moving uphill. AOBs were recognised by wear in the vegetation or soil around the entrance or by the presence of faeces. No attempt was made to probe the burrows. There are no European Rabbits *Oryctolagus cuniculus* on St Kilda and so there was no danger of misidentifying these burrows. Note that Manx Shearwaters and European storm-petrels also nest in burrows so there is potential for confusion, but the Puffin survey was accompanied by call-playback for the other species, which should have minimised misidentifications. Most of the Puffins nest in turf burrows in steep (c. 30–45°) grassy slopes with short sward where burrows are easy to spot, except on Dùn, which has no Sheep *Ovis aries* and so has longer, ungrazed vegetation. Also, in some areas, notably Carn Mòr on Hirta and Tigh Dugan on Soay, Puffins nest amongst and under huge boulders (Figure A4, see online Supplementary Materials). The methods for surveying these areas are specified and discussed below. For other zones, the transect rope was divided into 10 m sections, giving individual quadrats of 30 m², the position of which was recorded with a hand-held GPS. Rope-access techniques were used to access some of the steeper slopes on Boreray, Soay and Hirta. The rest of the transects were counted by pairs of surveyors on foot.

As far as possible, the transects were related to the survey zones established on Boreray and Soay during Seabird 2000 (Mitchell *et al.* 2000), but the quality of the maps available (photocopies of black and white aerial photographs) was poor enough that it was difficult to relate some of the boundaries to features on the ground. These boundaries were reinterpreted on detailed aerial photographs taken by Historic Environment Scotland as part of a LIDAR survey in 2012. As far as possible, the outer edges of each zone were drawn around vegetation patches likely to contain Puffin burrows (i.e. excluding solid rock areas). The LIDAR survey produced a digital elevation model, accurate to 1 m, which permitted the surface area of each zone to be calculated by GIS. The locations of each survey quadrat were overlaid with the boundaries of each zone and used to assign each quadrat to a zone.

Confidence intervals were determined by bootstrapping using the 'boot' function in the R statistical software (version 4.0.3; R Core Team 2020). This involved taking the density estimate of AOB in each quadrat within each zone, resampling the data

points with replacement, and taking the mean of the resampled data. This process was repeated 1,000 times to produce 1,000 estimates of the mean AOB density for each zone. For each zone, the 2.5th and 97.5th percentiles of the resampled means were taken as the 95% confidence limits of the mean density of AOB in the sample of transects. Density estimates were multiplied by the total slope-corrected area of the zone (i.e. area of available habitat) to give population estimates. Detailed descriptions and maps of the surveys on each island are given in the online Supplementary Materials.

The majority of Puffins on Hirta nest in the Carn Mòr boulder field where some of the rocks are as large as houses. Previous attempts to survey this area have been made by counting birds on the ground, flying above the island, or rafting close offshore. In the present study we delineated square quadrats (9.47 m x 9.47 m) with ropes and two observers searched each quadrat to identify the probable number of burrows present. Each observer recorded the minimum number of AOB (burrow entrances visible) and the likely total number (including estimates for the number of burrows obscured beneath boulders where there were signs of Puffin footprints or faeces around the boulders). The average of the two observers' counts was used as an estimate of AOB. Ten adjacent quadrats were counted in a transect running downhill through the centre of the boulder field, with the centre of each quadrat determined with GPS (Figures A4, A5 & A7, see online Supplementary Materials).

Playback surveys for European Storm-petrel and Manx Shearwater

European Storm-petrels and Manx Shearwaters nest in turf burrows, under boulders or amongst piles of stones, including ruined structures. On Dùn, the only surveyed island not grazed by Sheep, the 'burrows' were often on the surface of the soil, underneath the thick vegetation.

Both species were surveyed using call-playback in which the number of birds responding from nest sites is recorded. The calls of European Storm-petrels and Manx Shearwaters were played at the top and bottom of each Puffin survey quadrat, following playback for Leach's Storm-petrels. Playback was always performed in the order: Leach's Storm-petrel, European Storm-petrel, Manx Shearwater. Not all birds present will vocalise in response to playback, so the number of responses detected is an underestimate of population size which must be corrected for (see online Supplementary Materials 1.2).

The National Trust for Scotland (NTS) Seabird Ranger undertakes regular monitoring of four Manx Shearwater study plots in zone 20a on Hirta (Figure A4, see online Supplementary Materials), but it is not clear how this relates to the overall size of the colony. Accordingly, the entire zone was surveyed by a four-person team on 27 June 2022, using the same method employed in the main 2019 survey.

Further details of the playback surveys and their analysis are given in the online Supplementary Materials (section 1.2), along with the playback recordings used.

Results

Atlantic Puffin burrow counts

The overall numbers of Puffin AOB on the different islands of St Kilda are given in Table 1, with a total population estimate of 121,291 AOB.

Table 1. Counts and population estimates (total Apparently Occupied Burrows, AOB) for Atlantic Puffins *Fratercula arctica* on different islands in St Kilda in 2019 and 2018. 95% CLs = bootstrapped 95% confidence intervals. Totals from the Seabird 2000 survey of 1999/2000 (Mitchell *et al.* 2000) are given for comparison. Seabird 2000 ranges are range estimates, not confidence limits.

Island	Area	Apparently	95% CLs Occupied Burrows	Seabird 2000
Boreray		44,230	30,977–60,033	50,999
Soay	Sectors surveyed 2019	15,186	7,751–24,105	13,501
	Unsurveyed, estimated	8,003	4,208–12,373	14,013
	Whole island	23,189	11,959–36,478	27,514
Hirta	Sectors resurveyed 2019	18,253	13,090–23,734	5,070–10,100*
	Sectors surveyed 2018	866		2,060–2,890
	Whole island	19,119	13,956–24,600	7,670–12,990*
Dùn	Surveyed 2018	34,753	26,961–41,614	38,095†
Total		121,291	83,853–162,725	124,278–129,598*

* Includes an estimate of 5,000–10,000 for Carn Mòr boulder field.

† Recalculated for same area as 2018.

Boreray

Thirty-six transects (total 5.02 km) were surveyed on Boreray (Figure A1, see online Supplementary Materials), for a total of 502 Puffin quadrats (30 m² each) and a total survey area of 1.506 ha. Within these quadrats, 2,816 AOB were found, for an average density of 0.187 AOB/m². The overall population estimate for surveyed zones on Boreray is 44,230 (95% CLs: 30,977–60,033; Table A1, see online Supplementary Materials).

Soay

Twelve transects were sampled on Soay, covering eight zones, with a total length of 1.06 km for 106 30 m² quadrats and a total area of 3,180 m² (Figure A2, see online Supplementary Materials). In all, 566 Puffin AOB were counted in these quadrats, for an average density of 0.178 AOB/m². The highest density was in SOY8a (0.4854 AOB/m²), but as it was based on only two quadrats, it was excluded from the total AOB and an estimate was made instead (Table A2, see online Supplementary Materials, also described below).

Given that we did not manage to survey all the sectors in 2019, we made estimates of unsurveyed sectors from the density of burrows in neighbouring sectors that were surveyed. Thus, the density in zone SOY4 was assumed to be the same as SOY3, in SOY8a the same as SOY9a, and in SOY8b the same as SOY9b. We made a conservative estimate of 2,000 AOB for the remaining zones (SOY1, SOY2, SOY5, SOY11, SOY13, SOY14), giving a total estimate for the island of 23,189 AOB (Table A2, see online Supplementary Materials).

Dùn

In 2019, five transects were sampled on Dùn, in the southeast part of the island where the 2018 survey identified the highest densities of Puffin burrows (Figure A4, see online Supplementary Materials). A total of 51 quadrats were counted, yielding 1,076 AOB, and an average density of 0.7303 AOB/m² (Table A3, see online Supplementary Materials).

Hirta

On Hirta, three transects were sampled using rope-access techniques on the steep, grassy slopes to the southeast of Carn Mòr (Figure A4, see online Supplementary Materials). In zone 19, 16 quadrats (480 m²) were counted, yielding 25 Puffin AOB. This gives an average density of 0.0514 AOB/m². Extrapolated to the whole area of the zone (67,783 m²), this gives a total of 3,481 AOB (95% CL: 989–6,494). The wide confidence intervals are due to the small number of quadrats. Moreover, the transects were not randomly selected and represent only 0.7% of the total area.

In zone 20, all Puffin burrows were at the bottom 30 m of the zone around the lip of the cliffs (Figure 4A, see online Supplementary Materials). Puffins observed standing on the surface confirmed that almost all burrows were confined to the marginal strip. The average density in the transect was 0.101 AOB/m², for an estimated population of 835 AOB (95% CLs: 89–1,990) for the whole area of the zone (8,268 m²). Taking the length of the marginal strip (70 m) and assuming it has the same density as the 3 m wide transect (which held 27 AOB) gives a total of 630 AOB (= 27 x 70/3), instead.

Within the Carn Mòr boulder field, ten contiguous square quadrats were assessed by two observers (each 89.7 m²; see online Supplementary Materials and Figure A4). There was a strong correlation between the total number of Puffin AOB estimated by these observers within each quadrat (Figure A7, see online Supplementary Materials). The average number of AOB counted per quadrat was 29.7 (95% CL: 26.1–33.4) for an estimated burrow density of 0.331 AOB/m². Applied to the whole area of the boulder field (41,951 m²), this gives an estimated total of 13,937 AOB (95% CL: 12,012–15,250).

European Storm-petrel counts

Table A4 (see online Supplementary Materials) gives the results of the distance sampling playback survey for European Storm-petrels. On Boreray, European Storm-petrel responses were detected only in the cleitean (small, drystone storage structures). On Hirta, one response was detected in the Carn Mòr boulder field (Figure A4, see online Supplementary Materials) and none were detected on the grassy slopes to the south (zones H19 and H20; Figure A4, see online Supplementary Materials). The survey of Gleann Mòr and the Glen Bay gullies resulted in six responses (Figure A6, see online Supplementary Materials), although weather conditions were suboptimal for playback, with very strong winds. An additional three responses were detected above the head dyke in Village Bay. The NTS Seabird Ranger's survey resulted in 23 responses in a calibration plot just outside the head

Table 2. Estimated numbers of Apparently Occupied Sites (AOS) for European Storm-petrels *Hydrobates pelagicus* on each island of the St Kilda archipelago. Totals from the Seabird 2000 survey of 1999/2000 (Mitchell *et al.* 2000) are given for comparison.

Island	Apparently Occupied Sites in this study (95% CLs)	Apparently Occupied Sites in Seabird 2000 (95% CLs)
Boreray	51 (40–71)	84 (62–171)
Dùn	0	0
Soay	791 (621–1,094)	529 (387–1,071)
Hirta	110 (67–118)	508 (366–1,000)
Total	952 (728–1,283)	1,121 (825–2,242)

Table 3. Estimated number of Apparently Occupied Sites (AOS) for Manx Shearwaters *Puffinus puffinus* on all islands of the St Kilda archipelago. Totals from the Seabird 2000 survey of 1999/2000 (Mitchell *et al.* 2000) are given for comparison.

Island	Apparently Occupied Sites in this study (95% CLs)	Apparently Occupied Sites in Seabird 2000 (95% CLs)
Boreray	0	0
Dùn	983 (762–1,268)	222*
Soay	598 (323–1,104)	Few, not surveyed
Hirta	2,150 (1,651–2,816)	4,581 (3,371–5,687)
Total	3,731 (2,736–5,188)	4,803 (3,593–5,909)

*The estimate of 222 AOS for Dùn represented only the northwestern portion of the island, based on just five playback responses. Mitchell *et al.* (2000) thought it “unlikely there were more than double this number on the whole island”.

dyke in Village Bay, and ten responses in the survey area within the head dyke (Lawrence 2019). On Soay, 14 responses were detected, with all but one of these in the Tigh Dugan boulder field (SOY7, Figure A2, see online Supplementary Materials). No European Storm-petrels were detected on Dùn. The total population estimate for the archipelago was 952 Apparently Occupied Sites (AOS; 95% CLs: 728–1,283; Table 2).

Manx Shearwater counts

The distance sampling surveys for Manx Shearwaters resulted in 320 detected responses from 2,092 playback occasions (Table A5, see online Supplementary Materials). The additional surveys of Gleann Mòr and the Glen Bay gullies elicited 50 responses (Figure A6 and Table A5, online Supplementary Materials). No Manx Shearwaters were detected in the Village Bay survey and, as with the Seabird 2000 survey, no Manx Shearwaters were detected on Boreray. The total population estimate for the archipelago was 3,731 AOS (95% CL: 2,736–5,188; AOS, Table 3).

Discussion

This survey, together with the survey of Puffins in 2018 (Luxmoore *et al.* 2019) and Leach’s Storm-petrels in 2019 (Deakin *et al.* 2021), produced an updated estimate of all the burrow nesting species on the main islands of the St Kilda

archipelago. As far as possible, to facilitate comparable estimates of population trends over the past 20 years, survey methods replicated those used in Seabird 2000 (Mitchell *et al.* 2004). Here, we summarise our results in the context of previous surveys. Further discussion of the changes on and within each island can be found in the online Supplementary Materials, which might prove useful for those conducting future surveys.

The number of Puffins estimated on St Kilda in 2019 (121,291 AOB; Table 1) was lower than the 135,000 AOB reported by Mitchell *et al.* (2000), although the large confidence limits of these estimates does not allow us to draw a firm conclusion about population change. For example, our estimate of population density for Dùn was similar to previous surveys (Luxmoore *et al.* 2019; Mitchell *et al.* 2000). Boreray still holds the majority of the St Kilda Puffin population (Brooke 1972; Duncan *et al.* 1982; Tasker *et al.* 1988; Mitchell *et al.* 2000), and the population on the slopes of Carn Mòr appears to have been underestimated recently (Luxmoore *et al.* 2019). Paradoxically, results from Soay, though the least-surveyed major island in the archipelago, show the strongest evidence of a population decline between 1989 and 2000.

Our total population estimate for European Storm-petrels is lower than that from Seabird 2000, but falls within the Seabird 2000 survey confidence intervals (Mitchell *et al.* 2000; Table 2). The main difference is in the estimates for Hirta, where resources limited the extent and timing of the 2019 survey and thus limited its usefulness. More regular surveys of European Storm-petrels in Village Bay detected a substantial decline in the population between 1999 and 2004 (Lawrence 2019).

Our total population estimate for Manx Shearwaters is also lower than that from Seabird 2000, although it is within the Seabird 2000 survey's confidence limits (Mitchell *et al.* 2000). Carn Mòr was the largest colony in the archipelago in Seabird 2000 at 3,443 AOS (95% CLs: 2,233–4,549), falling to 414 AOS (95% CLs: 277–619) in our survey. However, annual monitoring plots on the slopes above Carn Mòr showed a 99% increase in AOS between 2010 and 2022 (Table A9, see online Supplementary Materials; Nisbet 2022), which may indicate birds relocating from the Carn Mòr boulder field colony. Future work should continue to survey apparently unoccupied areas (e.g. Boreray) to identify the relocation of any sub-colonies within and between islands. Walsh *et al.* (1995) recommend that shearwater surveys take place between late May and early June, but peak burrow occupancy occurs later at St Kilda and Hatsell (2018) recommended that surveys are conducted in early June (see also Perrins *et al.* 2019).

The St Kilda archipelago is the largest seabird colony in Britain and Ireland and therefore it is of critical importance that it should be regularly monitored. However, its remoteness and the inaccessibility of several of the islands means that it is difficult, expensive and time-consuming to survey it completely. The burrow-nesting species of seabirds pose particular problems, often requiring differing techniques at different times of year. This survey has demonstrated that they can be successfully surveyed with a single, carefully planned visit, using a combined survey technique.

While surveys of accessible sample plots or sub-colonies may be able to identify long-term changes in populations, they cannot identify when sub-colonies expand, contract or relocate to new areas. Examples of this identified during the 2019 survey include the possible contraction of the Puffin colony on the southern slopes of Boreray, the movement of Manx Shearwaters from Carn Mòr to the grass slopes above it and, at an earlier date, the loss of the Puffin colony on the northeastern slopes of Hirta. It is, therefore, important to survey the whole archipelago at intervals: the repeated survey of breeding seabirds in the UK and Ireland aspires to do this every decade (Mitchel *et al.* 2004; Burnell *et al.* 2023). Whilst it will not be possible to access all potential nesting areas (such as the northern portion of Boreray, the northern and western slopes of Soay, the northern cliffs of Hirta, and the southwestern side of Dùn) detailed surveys of the remaining parts of the archipelago are possible and should be continued.

Estimates of population size calculated from the product of burrow density and colony area are strongly affected by small differences in the boundaries of the colony, the delineation of which inevitably involves subjectivity. It is therefore important to carry out periodic surveys of the wider area to check for changes to colony boundaries. This is especially true for cryptic burrow-nesting species, such as storm-petrels and shearwaters, where there may be few visual signs that a colony is active.

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Supplementary Materials

The Supplementary Materials for this article are available online at:

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