A survey of Leach's *Oceanodroma leucorhoa* and European Storm-petrel *Hydrobates pelagicus* populations on North Rona and Sula Sgeir, Western Isles, Scotland

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Abstract
Leach's Storm-petrel *Oceanodroma leucorhoa* was first recorded breeding on North Rona in 1883 and on Sula Sgeir in 1939. European Storm-petrel *Hydrobates pelagicus* was first recorded on North Rona in 1885 and on Sula Sgeir in 1958. Since then, there have been attempts to estimate the population size of both species on North Rona but there is little information about their current status on Sula Sgeir. In 2001, systematic surveys of both species using tape playback were conducted for the first time on both islands. North Rona held 1,133 Apparently Occupied Sites (AOS) of Leach's Storm-petrel but only 371 AOS of European Storm-petrel; numbers on Sula Sgeir were five and eight AOS respectively. The combined population of both North Rona and Sula Sgeir of Leach's Storm-petrel and European Storm-petrel, comprise 2.3% and 1.4% respectively, of the total number of each species breeding in Great Britain.

Introduction
North Rona (area = 128 ha, highest point = 108 m), uninhabited since 1844, lies about 70 km north of the Butt of Lewis in the Western Isles at 59°08'N 5°50'W. Leach's Storm-petrel *Oceanodroma leucorhoa* and European Storm-petrel *Hydrobates pelagicus* were first discovered there in the 1880s (Swinburne 1885; Harvie-Brown 1888), but there has never been an accurate census of either species. Both are difficult to survey, since they nest in burrows or in rock crevices and are nocturnal. However, the recently developed tape playback technique (Ratcliffe *et al*. 1998) enabled this study to obtain an accurate count of Apparently Occupied Sites (AOS) of both species for the first time.

Sula Sgeir (20 ha, 70 m) lies about 17 km west of North Rona, at 59°06'N 6°09'W. It is no more than 1 km in length and just 200 m across at its widest point. It is sparsely vegetated due to lack of soil, and is subject to heavy erosive pressure from breeding seabirds and sea-spray. It has rarely been visited by ornithologists and 'stormy petrels', species uncertain, were first confirmed present in 1930 (Dougal 1937). North Rona holds extensive evidence of past human occupation, most prominently a ruined village, graveyard and chapel enclosed by pronounced cultivation ridges. Sula Sgeir,

although never permanently occupied has been visited annually for centuries by the men of Ness in Lewis, who have built dry stone bothies on the rock. The structures on both islands are an important component of the available breeding habitat for both petrel species. North Rona and Sula Sgeir are designated as a Special Protection Area (SPA) under Article 4.1 of the EC Birds Directive (79/409/EEC) for supporting more than 1% of the Great Britain breeding populations of Leach's and European Storm-petrel, which are both listed in Annex 1 of the Directive (Stroud *et al*. 2001). The islands also qualify for SPA designation under Article 4.2 of the Directive by supporting more than 1% of the relevant bio-geographic breeding populations of Northern Gannet *Morus bassanus* and Common Guillemot *Uria aalge* (Stroud *et al*. 2001).

Leach's and European Storm-petrel were cited as qualifying species for the North Rona and Sula Sgeir SPA based on estimates of colony size and Great Britain population size given in Lloyd *et al*. (1991). These estimates were derived before tape playback was developed and most were expressed as orders of magnitude of the number of birds present at colonies during the night. The aim of the present study was to use tape playback to accurately census both species of storm-petrel and, combined with the latest Great Britain population estimates (also derived using tape playback) (Mitchell 2004; Mitchell & Newton 2004), assess their conservation status and validate the islands' SPA designation with respect to these species.

Methods

Colony census methods: The playback method entails playing recordings of the chatter call of a male Leach's Storm-petrel and the purr call of European Storm-petrel in suitable habitat during the incubation period, in order to elicit a reply from an incubating adult within a burrow. A hand-held dictaphone with integral speakers was used. All accessible areas on both islands, including the highest sea cliffs on North Rona, were systematically surveyed using the tape playback technique (Gilbert *et al*. 1998) and responses were counted and mapped. The main drawback with the tape playback method is that not all individuals will respond to the taped calls (Ratcliffe *et al*. 1998), so a count of responses will underestimate the total number of AOS at a colony. Furthermore, Leach's Storm-petrel will only respond to taped chatter calls of the same sex (Taoka *et al*. 1989), therefore it is necessary to measure what proportion of birds present in burrows are responding to the taped calls. This was achieved by setting up a calibration plot for each species, which entails repeatedly visiting a delimited section of the colony on successive days and each time marking new responding AOS. Calibration plots were set up on the North Rona storm beach for European Storm-petrel and along the village graveyard wall for Leach's Storm-petrel. On the first visit to each plot, 20 AOS were located and their positions marked with flagged canes. Both plots were visited on a total of six days between 26 June and 1 July 2001. The total number of AOS on each island was then estimated by multiplying counts of responding birds by the response rate derived from the calibration plots (Equation 1).

Equation 1: Number of AOS = no. responses x (1 / response rate)
where response rate is estimated as shown in Equation 2.

North Rona: The island was subdivided into 16 sections (A to P, Figure 1), using clearly defined natural or man-made boundaries, and each was searched systematically for both species. To ensure full coverage of each section only one species was searched for at a time by three surveyors. This ensured that each section received the same level of effort. In some areas, mainly Fianuis (section L) and the storm beach (section M), ropes and canes were used to subdivide the ground into strips several metres wide in order to aid coverage. Island coverage was close to 100% and the only site possibly holding breeding petrels that was not surveyed was the lower, inaccessible half of Geo Mairi, between sections O and P.

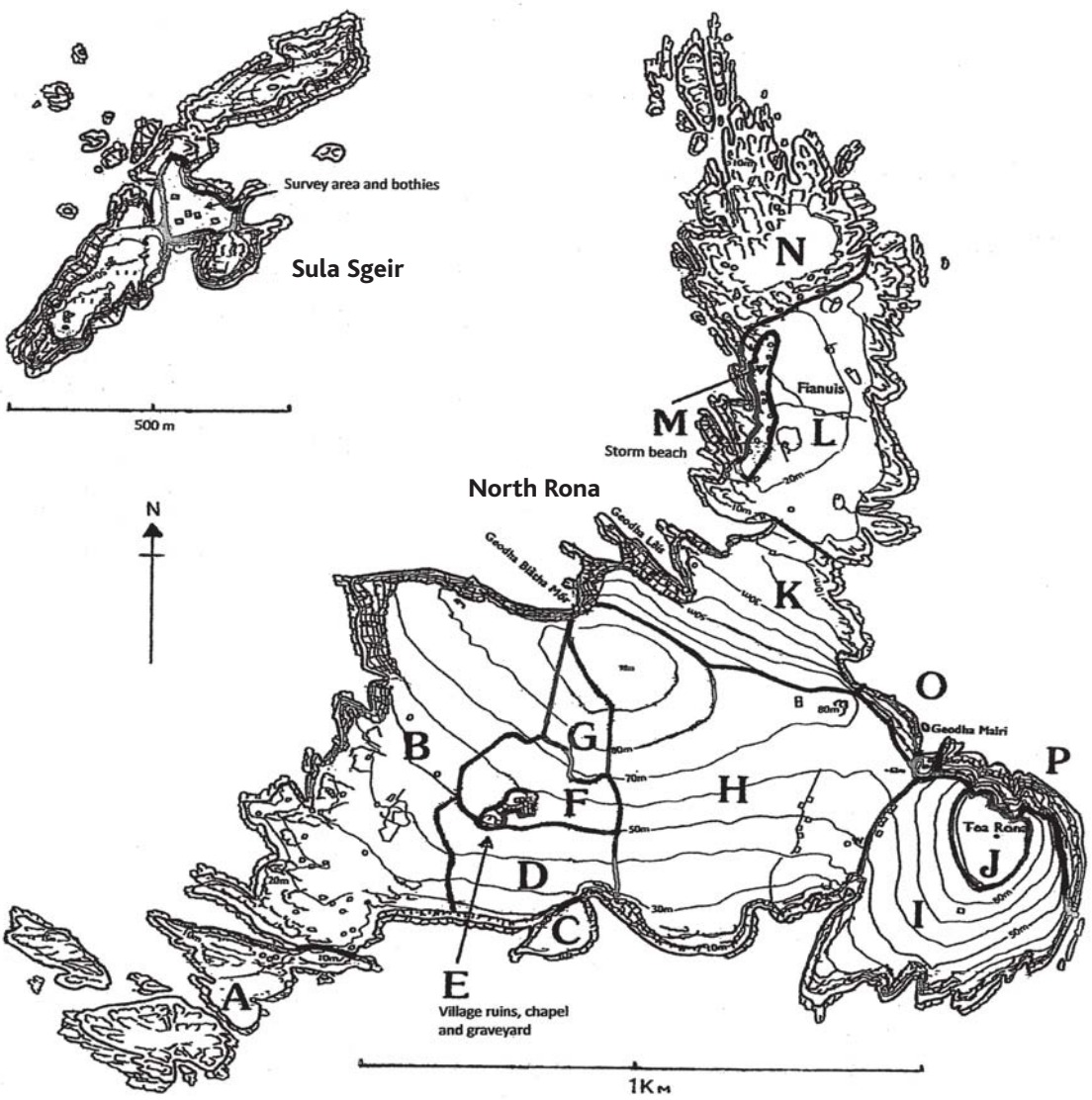

Figure 1. North Rona showing survey sections A to P, and place names given in the text. Sula Sgeir, showing the survey area and location of the bothies.

Figure 2. Aerial photograph of North Rona © *J. A. Love*.

The Toa Rona cliffs (section P) were difficult to access, held large numbers of Northern Fulmars *Fulmarus glacialis* and Atlantic Puffins *Fratercula arctica* and vegetation was unstable over shallow soil. Therefore, to lessen risks to surveyors and to minimise disturbance to the colonies, the area was surveyed by a single surveyor only. Overall, the slope was delimited by steep rock walls, narrow gullies and sharply defined vegetation boundaries, which simplified surveying.

European Storm-petrels were surveyed between 26 June and 2 July and Leach's Storm-petrels between 2 and 8 July, (except for the village ruins (section E), which were surveyed on 29 June 2001).

Sula Sgeir: Sula Sgeir was surveyed on 24 June 2001. To minimise disturbance to the dense assemblage of breeding seabirds on the flat top of the rock, only the five bothies, set in a small area of eroded soil edged by boulders, were surveyed (Figure 1).

Estimating response rate: There are two methods for estimating the response rate of a storm-petrel population from calibration plot data:
1. Simple arithmetic (Equation 2)

Equation 2: response rate = total number of responses / (total AOS x number of visits).

Confidence limits were calculated using a Generalised Linear Model, with the number of responses from each AOS as the dependent variable and the number of visits made to each AOS as the independent variable. However, this method is sensitive to birds becoming habituated to the taped calls, so that progressively fewer previously located AOS responded on successive days. Using this method in a habituated plot will tend to underestimate the response rate of a population not yet exposed to the taped calls. Furthermore, if not all AOS in the plot had been found by the time of last visit, response rate will be overestimated.

2. Iterative regression. The advantage of this method over the simple arithmetic method is that not all AOS in a plot need to be found; this is useful if a surveyor can only make a limited number of visits to the plot, which is often the case on remote islands that are difficult and costly to visit. For each calibration plot, an asymptotic regression model was fitted to the cumulative number of AOS that had been found following each visit (see Mayhew *et al*. 2000). The model took the form of Equation 3 and the parameters *a* and *b* were predicted using the iterative regression function of S-Plus® 2000 (Mathsoft Inc., Seattle, Washington).

Equation 3: where y = number of AOS detected on a given visit (x); b = the exponential (e) proportional rate of increase to the asymptote (a).

Thus, the coefficient *a* is an estimate of the total number of AOS present in the study plot. The response rate was calculated by substituting the values of the coefficients for *b* into Equation 4.

Equation 4: response rate =

The upper and lower 95% confidence limits of the response rate were determined from the Equations 5 and 6 respectively.

Equation 5: 95% UCL response rate = $1 - e^{-b-(se \times 1.96)}$

Equation 6: 95% LCL response rate = $1 - e^{-b+(se \times 1.96)}$ where *se* is the standard error of the estimate of the coefficient *b*.

Results

North Rona: *European Storm-petrel response rate;* The results from the European Storm-petrel calibration plot are shown in Table 1 and the cumulative number of AOS found following on each successive visit are plotted in Figure 3. Table 1 shows a clear reduction in total responses following the first visit, with only six birds responding on day six. This would suggest that some degree of habituation to the taped calls was taking place. Hence, the use of the simple arithmetic technique to calculate response rate was inadvisable in this case. Instead an iterative regression was applied to the plot

Table 1. European Storm-petrel *Hydrobates pelagicus* calibration plot results.

Visit no.	**1**	**2**	**3**	**4**	**5**	**6**
No. of new burrows found per visit	20	9	7	3	4	2
Cumulative total of burrows	20	29	36	39	43	45
No. of responses per visit	20	13	11	13	16	6

Table 2. Parameters of the iterative regression of the cumulative number of European Storm-petrel *Hydrobates pelagicus* Apparently Occupied Sites (AOS) on successive visits to the calibration plot. The resultant correction factor was multiplied by the total counts of responses to estimate the total number of AOS. Figures in parentheses are 95% CLs.

a	*b*	Response rate (1/response rate)	Correction factor
46.3	0.509	0.400	2.5
(44.1–48.6)	(0.035 s.e.)	(0.356–0.439)	(2.28–2.81)
t_5 = 40.329	t_5 = 14.385		

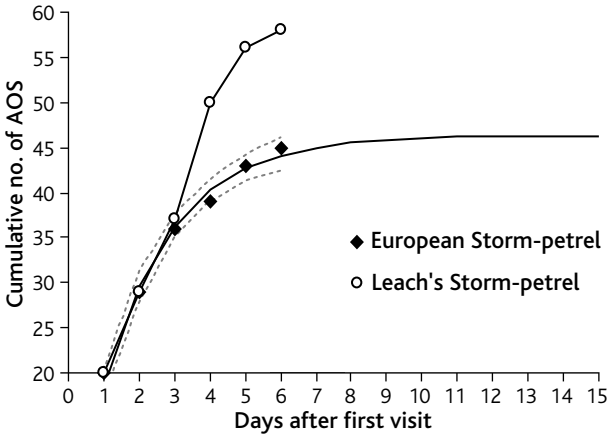

Figure 3. Change in cumulative number of new AOS found using diurnal playback on successive visits to the calibration plots for European Storm-petrel *Hydrobates pelagicus* and Leach's Storm-petrel *Oceanodroma leucorhoa* on North Rona. The curve was fitted to the European Storm-petrel data using iterative regression, dotted lines indicate 95% confidence limits. where a = 46.3 (44.1–48.6 s.e.) and b = 0.509 (0.035 s.e.)

and the results are shown in Table 2. The extrapolation of the response curve (Figure 3) estimated that 46 AOS were present in the plot, just one more than the number actually found after six visits. The response rate predicted from the slope of the curve was 0.40, giving a correction factor of 2.5 (i.e. 1 / response rate, see Equation 1).

European Storm-petrel population estimates; One hundred and forty-seven birds responded to the taped calls at 18 sites, in 11 out of 16 colony sections (Tables 3 & 4, Figure 1), representing an estimated 371 AOS (95% CL 335– 413). The largest concentration of 203 AOS was found in the storm beach (section M). The remainder were thinly scattered across the island, with man-made structures, e.g. the chapel ruins, Fianuis bothies, walls, cairns and enclosures forming an important component of the breeding habitat, accounting for 25% of all AOS (Table 3). None were found in the large, apparently suitable area of rock scree on the south side of Geodha Lèis (section K), but there were five AOS bordering the area. On the Toa Rona cliffs (section P), eight AOS were found along the cliff top, but none elsewhere. Both areas were densely occupied by breeding Atlantic Puffins and Geodha Lèis by Razorbills *Alca torda* also.

Leach's Storm-petrel response rates; There was no evidence of habituation by Leach's Storm-petrel to the taped calls, and the number of responses from the plot actually increased over the last three visits (Table 5). However, the iterative regression was not used to estimate response rate because, with hindsight, too few visits were made to

Table 3. Habitat selection and estimated AOS of European Storm-petrels *Hydrobates pelagicus* on North Rona.

Habitat type	No. of sites	No. of responses	% of total responses	AOS	(95% CL)
Storm beach	1	81	55	203	(185–228)
Other natural sites	8	29	20	74	(66–81)
Man-made structures	9	37	25	94	(84–104)
Total	18	147	100	371	(335–413)

Table 4. Number of AOS of Leach's Storm-petrel *Oceanodroma leucorhoa* and European Storm-petrel *Hydrobates pelagicus* on North Rona. See Figure 1 for map of sections A to P.

Section	Leach's Storm-petrel	European Storm-petrel	Section	Leach's Storm-petrel	European Storm-petrel
A	0	3	I	85	10
B	65	23	J	97	8
C	0	0	K	159	33
D	12	0	L	185	30
E	328	20	M	28	203
F	5	0	N	51	0
G	23	0	O	21	30
H	30	3	P	44	8
Total AOS				**1,133**	**371**

Table 5. Leach's Storm-petrel *Oceanodroma leucorhoa* calibration plot results.

Visit no.	1	2	3	4	5	6	Total
No. of new burrows found per visit	20	9	8	13	6	2	58
Cumulative total of burrows	20	29	37	50	56	58	58
No. of responses per visit	20	16	19	34	35	27	151

Table 6. Habitat selection and estimated AOS of Leach's Storm-petrels *Oceanodroma leucorhoa* on North Rona.

Habitat type	No. of responses	% of total responses	AOS	(95% CL)
Storm beach	12	2%	28	(26–29)
Other natural sites	306	62%	708	(673–745)
Man made structures	172	35%	397	(374–422)
Total	490	100%	1,133	(1,065–1,202)

the plot and consequently, produced too limited a range of *x*-values to enable Equation 3 to be meaningfully applied (see Figure 3). The simple arithmetic technique (Equation 2) was applied instead. The mean response rate across the six visits was 0.434, with 95% CL of 0.408–0.460 (GLM, t_{56} = 17.82, P < 0.001). The correction factor for Leach's Storm-petrel was therefore, 1/0.434 = 2.31 (95% CL 2.173–2.453).

Leach's Storm-petrel population estimates; Four hundred and ninety birds responded to the taped calls, representing 1,133 AOS (95% CL 1065–1202) (Table 4 & 6, Figure 1). The largest and densest subcolony on the island was found in the village ruins (section E), which held 328 AOS, 29% of the island total. A further 69 AOS (6%) were found in other man-made structures, including the low turf dyke demarcating section J on Toa Rona, which held 97 AOS in the second densest subcolony on the island.

Overall, 708 AOS (62%) were found in natural sites, widely distributed across the island, with the exception of sections A and C where none were found. Nests were situated in stone piles, under embedded boulders, along cliff edges and in well drained turf, but not in the old cultivation ridges of section F, or in the deep, waterlogged soils of sections D and H. None were found in the largest Atlantic Puffin colony on Toa Rona (section P), although they were present in small numbers along the cliff tops. Similarly, at other, smaller puffin subcolonies, e.g. Geodha Lèis and Geodha Blatha Mor (both in section K), Leach's Storm-petrel nests were found in abandoned puffin burrows on the edge of the colonies, but none were found in areas of densely occupied puffin burrows.

Sula Sgeir: Leach's and European Storm-petrels were found only in the walls of the bothies, but not in any of the cairns or other man-made structures that were surveyed. Around the bothies the ground was badly eroded and occupied by a high density of nesting Northern Fulmars. Potentially suitable storm-petrel habitat in boulders around the margins of the survey area (Figure 1) held nesting Atlantic Puffins and Common Guillemots, and probably as a result, did not appear to be occupied by either storm-petrel species. In total, only two responses from Leach's Storm-petrel and three from European Storm-petrel were elicited during the survey of Sula Sgeir. Using the response rates estimated on North Rona (Tables 2 & 5), these responses equated to five AOS and eight AOS respectively.

Discussion

European Storm-petrel on North Rona: The estimate of 371 AOS of European Storm-petrel is the lowest made of the North Rona population to date. However, the distribution of AOS found during the current study is broadly similar to earlier accounts. For example, the storm beach (section M) was considered by Bagenal & Baird (1959) to hold the largest concentration of burrows on the island and Love (1978) considered the storm beach to hold many more pairs than the village. In 2001, the storm beach also held the largest subcolony, with 55% of the total number of AOS on the island. By contrast, low numbers have consistently been noted in the village ruins (section E), with nests found only in the chapel and in a nearby boulder pile. In 2001, 20 AOS were found there, which was identical to the number of pairs estimated to be breeding there in 1936 by Ainslie & Atkinson (1937a). Despite conducting additional searches of the village during the night in 2001, none were found breeding in any structure other than the chapel. Likewise, Robson (1968) found a few nests in the chapel, but none elsewhere, and Love (1978) noted that 72% of his mist net captures of European Storm-petrels in the village were made close to the chapel. Elsewhere on the island, AOS were thinly distributed and in low numbers.

The mean response rate of European Storm-petrels on North Rona was very similar to other colonies in northwest Scotland (Mitchell & Newton 2004). The calibration and simultaneous census of North Rona were conducted early in the incubation period expected of European Storm-petrels at Scottish colonies (i.e. late June and most of July), so response rate may have been expected to increase if not all of the birds had commenced incubation by the start of the study (Ratcliffe *et al*. 1998). However, daily response rate in the calibration plot at least stayed fairly constant apart from on the day of the last visit when it was considerably lower. Furthermore, detailed daily searches of AOS in the village did not find any more than were there on the first day of searching. Therefore, the mean response rate estimated in the plot appeared to have accurately reflected the response rate across the rest of the colony when the census was conducted.

Leach's Storm-petrel on North Rona: On North Rona it is difficult to make any assessment of change prior to this study, since no systematic survey of Leach's Storm-petrel numbers, using comparable methods, has been conducted previously. Our count of 328 AOS in the village ruins is almost identical to the 327 occupied burrows found there in 1936 by Ainslie & Atkinson (1937b). They estimated only 50 burrows for the rest of the island, giving a total population of 380 pairs. In 1958, a study using ringing and recapture, estimated the village population to be around ten times larger, i.e. 2–3,000 pairs, with a total island population of about 5,000 pairs (Bagenal & Baird 1959). However, estimates of population size derived from mist-netting and mark-recapture include non-breeding birds as well as breeders, so will be greater than concurrent estimates derived from counts of occupied nest sites. Bagenal & Baird's (1959) estimate was also far greater than subsequent assessments of colony size, with both Robson (1968) and Love (1978) considering the village population to be little different in size compared to Ainslie & Atkinson's (1937b) estimate in 1936. Outside the village, calling birds have been heard at many different sites, but only in small numbers. P. G. H. Evans in 1972, cited in Lloyd *et al*. (1991) estimated the entire population, including that of the village, at 500 pairs. Our estimate in 2001 of 1,133 AOS of Leach's Storm-petrel on North Rona makes this the third largest colony, after St Kilda and the Flannan Isles, of only eight known colonies in Britain and Ireland (Mitchell 2004).

The response rate measured in the calibration plot on North Rona was probably a slight overestimate because not all the AOS in the plot were found, though visual inspection of the calibration plot data in Figure 3 would suggest that only 2–3 AOS were missed. Therefore, the 1,133 AOS is probably only a slight underestimate of the size of the colony on North Rona. A further inaccuracy may have resulted if the birds had responded differently during the census on 2–8 July, than they had done a week earlier when the response calibration was conducted (Ellis *et al*. 1998). The greatest determinant of response rate is the level of diurnal occupancy of burrows by the adults. At least one adult should be present in the burrow during the day throughout incubation and up to five days post-hatching. There are no published data on the phenology of Leach's Storm-petrels on North Rona, but recent observations on St Kilda have shown hatching to start during the second and third week in July (Money *et al*. 2008). It is reasonable to assume that breeding phenology is similar in both colonies, since they most probably use the same feeding grounds (Mitchell 2004).

Therefore it is unlikely that the Leach's Storm-petrel on North Rona were responding to the taped calls differently during the calibration and the census. Furthermore, the response rate estimated in the current study was very similar to that recorded during 4–10 July 2003 on St Kilda, using the same method (Newson *et al*. 2008).

European Storm-petrel on Sula Sgeir: European Storm-petrels have been rarely recorded breeding on Sula Sgeir. Although they may have been present in 1930 (Dougal 1937), they were not noted by either Stewart (1932), Atkinson & Ainslie (1940) or McGeoch (1954a,b). Bagenal & Baird (1959) caught one and heard others calling in June 1958 and this appears to be the first confirmed record. None were heard in 1980 but they were noted in 1986 (Benn *et al*. 1989) and the eight AOS in 2001 were all found within bothy walls.

Leach's Storm-petrel on Sula Sgeir: On Sula Sgeir Leach's Storm-petrels were probably the 'stormy petrels' observed in 1930 by Dougal (1937) and in 1932 by Stewart (1934), as being present in bothy walls. Breeding was proven in 1939 by Atkinson & Ainslie (1940) who found both young and incubating adults. They carried out an overnight survey of the rock, starting from the bothies and surveying southwards to the summit cairn. They found birds calling from underground near the bothies and along the length of the summit ridge (Figure 3). They considered that they were at least as numerous as the population on Rona and estimated that 400 pairs were breeding there. The subsequent loss of soil and vegetation around the bothies, caused largely by the increase in nesting Northern Fulmars, and on the plateau by the expansion of the gannetry, probably reduced the available breeding habitat. As a

Figure 4. Leach's Storm-petrel *Oceanodroma leucorhoa*, Merseyside, 23 September 2004 © *Sue Tranter*.

consequence, in 1954, McGeoch (1954a,b) found only a dozen birds, although he searched for several nights up to the edge of the gannetry. Bagenal & Baird (1959) caught 18 in mist nets set overnight between the bothies in June 1958, and a few were heard in bothy walls, but nowhere else, during an overnight stay in June 1980 (S. Murray pers. obs.). Since then there have been further increases in both Northern Gannet and Northern Fulmar numbers (Mitchell *et al*. 2004) and in 2001, only five AOS of Leach's Storm-petrel were found, all in the walls of bothies.

Conclusions

Although the European Storm-petrel appears never to have bred in large numbers on Sula Sgeir, numbers of the Leach's Storm-petrel have declined substantially since 1939, probably caused by habitat loss due to soil erosion and through competition for space from the larger and more aggressive Northern Gannets and Northern Fulmars. In 2001, three fresh and unmarked European Storm-petrel corpses were found lining a Northern Fulmar nest. We speculated that all had been killed by the incubating fulmar, as they made their way in or out of the adjacent bothy wall. Whatever the case, it illustrates the vulnerability of small petrels at this site.

It is unclear from previous records whether or not numbers of Leach's and European Storm-petrel breeding on North Rona have changed significantly during the last century. However, future surveys of either species on the island should use the results of the 2001 survey (shown in Tables 3, 4, & 6; Figure 1) as a baseline for assessing changes in breeding numbers and distribution. The precision of the 2001 estimates of colony size (see 95% CL in Tables 3 & 6) should enable future surveys to detect changes in breeding numbers of both species. Changes will have to be greater than 9% for European Storm-petrel and 6% for Leach's Storm-petrel in order to be statistically significant.

The combined population of both North Rona and Sula Sgeir of Leach's Storm-petrel and European Storm-petrel, comprise 2.3% and 1.4% respectively, of the total number of each species breeding in Great Britain (Mitchell 2004). Therefore, North Rona and Sula Sgeir qualify as an SPA under the EC Birds Directive for their importance as a breeding site for both Annex 1 listed species of storm-petrels.

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