A survey of Leach's *Oceanodroma leucorhoa* and European Storm-petrel *Hydrobates pelagicus* populations on North Rona and Sula Sgeir, Western Isles, Scotland, in 2009

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Abstract
In 2001, surveys of both Leach's *Oceanodroma leucorhoa* and European Storm-petrel *Hydrobates pelagicus* were made on North Rona and Sula Sgeir, Western Isles, Scotland, using tape playback for the first time. North Rona held 1,133 apparently occupied sites (AOS) of Leach's Storm-petrel (1,084 AOS after re-analysis of the 2001 data in 2009) and 371 AOS of European Storm-petrel; numbers on Sula Sgeir were five and eight AOS respectively. A repeat survey in 2009 using the same methods found 713 AOS of Leach's Storm-petrel on North Rona, a decline of about 34% since 2001, and none on Sula Sgeir. A partial survey of European Storm-petrel on North Rona found 313 AOS, suggesting no significant population change since 2001; limited time on Sula Sgeir prevented a survey there for this species. Great Skuas *Stercorarius skua* and Great Black-backed Gulls *Larus marinus* breed on North Rona and take an unknown number of storm-petrels each year, but it has yet to demonstrated whether either or both together have caused the decline in Leach's Storm-petrel. The timing of the decline in Leach's Storm-petrels can only be dated from 2001, because earlier population estimates are not comparable with the tape playback surveys of 2001 and 2009.

Introduction

Leach's Storm-petrel *Oceanodroma leucorhoa* breeds on both sides of the North Atlantic, with the largest known colony, on Baccalieu Island, Newfoundland, holding c. 3.4 million pairs (Sklepkovych & Montevecchi 1989) out of a global population of 9–10.6 million pairs (Mitchell *et al.* 2004). The northeast Atlantic colonies are much smaller, the largest, on the Westmann Islands, Iceland, holding 80–150,000 pairs (Icelandic Institute of Natural History 2000). In Britain and Ireland, the largest Leach's Storm-petrel colonies are in the Western Isles of Scotland, with an estimated 45,433 apparently occupied sites (AOS) on St Kilda

(94% of the total population) in 1999–2000, followed by 1,425 on the Flannan Isles, and 1,133 on North Rona; the remaining 11 colonies held a total of only 367 AOS in 2000–02 (Mitchell *et al*. 2004).

European Storm-petrel *Hydrobates pelagicus* breeds widely in the northeast Atlantic and Mediterranean, the largest colonies being in the Faeroe Islands. In Scotland, it is found from the Western Isles, north through Orkney to Shetland, co-occurring with Leach's Storm-petrel on St Kilda, the Flannan Isles, North Rona and Sula Sgeir, all of which are in the Western Isles and also Gruney in Shetland. All these populations are relatively small, with estimates for North Rona and Sula Sgeir of 379 AOS in 2001, or 1.4% of the Great Britain population; St Kilda held 1,121 AOS, the Flannans 7 AOS and Gruney 12 AOS (Mitchell *et al*. 2004).

Population trends of both species on these islands are poorly known. On St Kilda, numbers of Leach's Storm-petrels declined by 54% between 1999 and 2006 on Dun, the island holding the largest subcolony in the archipelago, but trends on the other three breeding islands are unknown (Newson *et al*. 2008). The cause of this decline remains unclear, but predation by Great Skuas *Stercorarius skua*, which also breed in small numbers on North Rona and the Flannan Isles, is thought to be mainly responsible (Phillips *et al*. 1999a). Anecdotal evidence suggests the European Storm-petrel has declined on St Kilda since the last survey in 2000 (Mitchell *et al*. 2004) but the exact status of the population is unknown at present. The Flannan Isles were last surveyed for both species in 2001 (Mitchell *et al*. 2004), while a partial survey on Gruney in 2004, for Leach's Storm-petrel only, found 10 AOS c.f. 20 in 2000 (Moncrieff 2005). The paucity of data from these remote colonies and the decline of Leach's Storm-petrel on Dun since 1999 motivated a repeat survey of both storm-petrel species on North Rona and Sula Sgeir in 2009 for any evidence of population change since 2001.

Methods

North Rona and Sula Sgeir lie about 70 km north of the Butt of Lewis in the Western Isles. For details of the islands' geography, relevant ornithological history and the survey and analytical methods used in 2001 see Murray *et al*. (2008).

Timing of visits: The survey was conducted on North Rona between 28 June and 9 July 2009, with the aim of carrying out the work as closely as possible to the hatching date for Leach's Storm-petrel, assumed to be similar to that of St Kilda, i.e. mid to late July (Money *et al*. 2008) and comparable in timing to the survey carried out between 24 June and 16 July 2001. Sula Sgeir was visited briefly on 5 July 2009 and 24 June 2001.

The timing of the survey was not ideal for European Storm-petrel and it is likely that an unknown, possibly substantial proportion of the population were only available to respond to the tape playback after 9 July, by which time we had left the island. At colonies such as North Rona where there is no precise data on laying date, the recommended time for playback surveys is early to mid July (Ratcliffe *et al*. 1998a; Cadiou 2001).

The species of most concern was Leach's Storm-petrel, and visits in both 2001 and 2009 were timed to give optimum results for a survey of this species. The two islands are remote, uninhabited, have no secure landing site or anchorages, and are difficult and costly to reach. A further complication can be weather, and the islands are frequently swept by gales, even in summer. In 2009, we chartered a vessel for 14 days as a precaution against bad weather, but landed on the planned date, 27 June, and were able to fully survey the island for Leach's Storm-petrel and run a 10-day calibration plot for the species. All accessible areas on both North Rona and Sula Sgeir were systematically surveyed for Leach's Storm-petrel using the tape playback technique (Gilbert *et al.* 1999) and responses were counted and mapped. A nearly complete survey was made of North Rona for European Storm-petrels, but limited time on Sula Sgeir meant we were unable to survey there for this species.

Figure 1. North Rona showing survey sections A to P, Great Skua *Stercorarius skua* apparently occupied territories (dots) and the core breeding areas of Great Black-backed Gulls *Larus marinus* (horizontal lines) in 2009.

Ground survey: In 2001 North Rona was divided into 16 sections, designated A to P (Figure 1), following clearly defined natural or man-made boundaries (Murray *et al*. 2008). All can be accessed safely by walking through them except sections O and P, where a combination of difficult access on steep ground close to cliff edges and high densities of Atlantic Puffin *Fratercula arctica* (hereafter 'Puffin') burrows requires careful footwork and in places rope protection. The ruined village (section E) comprises three distinct groups of structures, designated as subgroups A, B and C (Nisbet & Gailey 1962). If time is limited in a future survey, effort is best concentrated on these ruins, as changes here will be more easily detectable than in any other section. They comprise the smallest and most clearly defined section, holding c. 33% of the island total of Leach's Storm-petrel and was the only section surveyed between the 2001 and 2009 surveys, by A. Robinson in 2005.

To ensure full coverage of each section only one species was searched for at a time, by up to three surveyors using hand-held tape cassette players (Gilbert *et al*. 1999). Not all sections needed intensive searching in 2009, as large areas of ground were known from 2001 to hold little or no suitable breeding habitat. In 2001, all 16 sections were surveyed for both species, but in 2009 shortage of time left sections I, O and P unsurveyed for European Storm-petrel (Table 4).

On Sula Sgeir, 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 in both years. Due to lack of time in 2009 only Leach's Storm-petrel was surveyed.

Playback: The tape playback technique (Ratcliffe *et al*.1998a) used in 2001 and 2009 involves playing recordings of the chatter call of Leach's Storm-petrel, which only responds to chatter calls of the same sex (Taoka *et al*. 1989) or the purr call of European Storm-petrel, in order to elicit a reply from an incubating adult within a burrow. For both species, not all individuals respond to the taped calls at a given time, even during peak to late incubation, so a count of responses greatly underestimates the total number of AOS at a colony. Therefore it is necessary to measure what proportion of birds is present in burrows and responding to the taped calls. This was achieved by setting up a calibration plot for each species to calculate a colony-specific correction factor (Ellis *et al*. 1998), by repeatedly visiting a delimited section of the colony on successive days and each time marking new responding AOS.

Calibration plots: Calibration plots were set up on the North Rona storm beach for European Storm-petrel and along the village graveyard wall and adjacent ruins for Leach's Storm-petrel, both sites used in the 2001 survey. Sufficient burrows were included to ensure that at least 20 sites responded on the first visit, and on each day thereafter when new responding sites were located, they were marked and numbered with flagged canes. The Leach's Storm-petrel plot was visited on ten days and the European Storm-petrel plot on eight days. The total number of AOS was then estimated by dividing counts of responding birds by the response rate derived from the calibration plots (see below). Dividing the number of responses by the confidence intervals for the response rates also enables confidence intervals for the number of AOS to be calculated.

Response rate: Response rates were estimated using a method that depended on whether there was evidence that the birds at each burrow became habituated to the tape and so were less likely to respond on the days following the initial response. Data from the calibration plots used in the 2001 survey were also re-analysed in the same way as it was felt the methods used previously led to overly narrow confidence intervals when habituation was suspected.

If no habituation was suspected, the response rate was calculated using the 'simple arithmetic' method (see Murray *et al*. 2008), whereby:

response rate = total number of responses / total AOS in the plot x number of visits

This method is appropriate when one can be reasonably confident that all AOS within the plot have been located, and the likelihood of a response from each occupied burrow is reasonably constant over the period of the study. The 95% confidence intervals (CI) were estimated by bootstrapping the apparently occupied sites in the calibration plot (Efron 1979) and generating 9,999 re-samples with 2.5% and 97.5% percentiles.

A different method was required where habituation was suspected, as the arithmetic method risks grossly underestimating the response rate. An 'iterative regression' method was used for the 2001 survey, which fits a curve to the cumulative number of responses over each visit. This allows the total number of occupied sites and the response rate to be estimated. Whilst this approach produces a valid estimate of the response rate, valid confidence intervals are less straight-forward, as the cumulative counts used to fit the curve are not independent. This is a requirement for the calculation of parametric limits, so one approach would be to bootstrap the calibration sites and fit a curve to each bootstrap sample. However, a more intuitive method was developed which is also more straightforward to implement. If habituation is suspected, only the initial response at each occupied site can be relied upon to be representative of the underlying response rate. Thus, for each visit, the response rate can be estimated by:

- *the number of first responses / the number of occupied sites that have not yet responded*.

Rather than estimate this for each visit and combine the estimates, it is easier and more robust to estimate the overall response rate as:

- *sum of the number of first responses / sum of the number of potential first responses where the sum is over all the visits*.

Table 1. Leach's Storm-petrel *Oceanodroma leucorhoa* 2009 calibration plot results.

Dates in June & July	28	29	30	1	2	3	4	5	6	7	Total
Number of new AOS found per visit	20	15	17	8	4	8	0	1	1	0	74
Cumulative total of AOS	20	35	52	60	64	72	72	73	74	74	74
Number of responses per visit	20	25	28	23	27	34	34	28	22	22	263

Table 2. Estimates of response rates and AOS for Leach's Storm-petrel *Oceanodroma leucorhoa* in 2001 and 2009.

	2001		2009		Change	
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Response rate	0.452	0.402–0.503	0.355	0.320–0.391	-0.097	-0.159–-0.036
AOS	1,084	974–1,219	713	647–791	-371	-519–-237

Table 3. Number of Leach's Storm-petrel *Oceanodroma leucorhoa* AOS on North Rona in 2001 and 2009 and the percentage change between years.

Section	2001	2009	% change	Section	2001	2009	% change
A	0	0	0	I	81	48	-41
B	62	45	-27	J	93	45	-52
C	0	0	0	K	152	65	-57
D	12	8	-33	L	177	161	-9
E	314	235	-25	M	27	14	-48
F	5	8	+60	N	48	51	+6
G	22	11	-50	O	20	0	-100
H	29	22	-24	P	42	0	-100
Total					1,084[1]	713	-34

[1] 1,133 in Murray *et al.* 2008

Table 4. European Storm-petrel *Hydrobates pelagicus* 2009 calibration plot results.

Dates in June & July	29	30	1	2	3	4	5	6	Total
Number of new AOS found per visit	20	11	8	13	1	0	0	0	53
Cumulative total of AOS	20	31	39	52	53	53	53	53	53
Number of responses per visit	20	19	22	33	18	27	11	29	179

In practice the last visit was not included because the number of new sites was either zero or very small.

This 'first response' estimate still relies on knowing the total number of occupied sites in the plot. The iterative regression method was used for this purpose, with the number of sites taken as the rounded asymptote of the fitted curve. Confidence intervals were estimated by bootstrapping the occupied sites 9,999 times.

Estimating change between 2001 and 2009: The bootstrapping approach used to estimate confidence intervals for each estimate of AOS lends itself neatly to estimating whether a change has taken place between the two surveys. Bootstrap estimates for the number of AOS for each survey were calculated using each bootstrap estimate for the relevant response rate. The difference between these provides bootstrap estimates of change, which can then be used to estimate a confidence interval for change. Such intervals only take account of uncertainty in the response rate, but that due to other factors, such as differences in the completeness of the surveys for example, are harder to assess.

Results

Leach's Storm-petrel 2009 response rate on North Rona: A calibration plot was carried out on North Rona over 10 days between 28 June and the 7 July 2009 (Table 1). The arithmetic method was used to estimate the response rate, as the number of responses per visit gave no evidence of habituation. The mean response rate was 0.355, with 95% CI of 0.320–0.391.

In the whole island survey 253 birds responded to the taped calls. The population estimate in 2009, is therefore, 253 / 0.355 = 713 AOS (95% CI = 647–791) (Table 2).

Leach's Storm-petrel 2001 response rate: A re-analysis of the 2001 calibration data resulted in a slightly different response rate estimate of 0.452 (95% CI = 0.402–0.503), compared with the previously published figure of 0.434 (Murray *et al*. 2008). This was a result of a re-examination of the original calibration plot data, which indicated that there were two fewer responding burrows than previously thought, but with one additional response. The arithmetic method was used for the re-analysis as there was no evidence of habituation.

This results in slightly changed section totals, reducing the overall estimate for the number of AOS in 2001 from 1,133 to 1,084 (95% CI = 974–1,219) (Table 3).

Compared with 2001 there has been an overall population decline on North Rona of an estimated 34% between 2001 and 2009 ($P < 0.001$) (Table 2). This is despite a reduction of about 0.1 in the estimated response rate ($P < 0.01$). However, it is possible that not all AOS in the 2001 calibration plot had been found, resulting in the response rate being overestimated, and the population being underestimated.

All 16 sections were surveyed in 2009, with decreases in 12, small gains in two, and no responses in either year in two (Table 3). The greatest decreases were in O and P, where no responses were elicited. Both are steep cliff sites, densely burrowed by Puffins and difficult to survey, but in both years were searched by the same surveyor, in the same way and in good weather. There were no obviously different, external circumstances to account for the lack of responses. By contrast, section K is a shallow-angled, closely-cropped grass slope, where most responses came from the edge of Puffin colonies, and the decrease here (-57%) was the next greatest. Sections G and J also decreased by 50% or more, the breeding sites here being under old stone and turf dykes on the high grassy tops of the island. In the ruined village (section E), the largest and most densely concentrated sub-colony, the 2009 daytime survey found 83 responses, representing 235 AOS, compared with 142 responses and 314 AOS respectively for 2001, a decrease of 25%.

Sula Sgeir: The survey was confined to the five bothies and the boulders fringing the area of eroded soil in which they sit. No responses were elicited, compared with two in 2001.

European Storm-petrel 2009 response rate on North Rona: A calibration plot was carried out between 29 June and 6 July 2009 (Table 4). The arithmetic method was used to estimate the response rate, as the number of responses per visit provided no evidence of habituation. The mean response rate was 0.422, with 95% CI of 0.368–0.479 (Table 5).

In a partial island survey 132 birds responded to the taped calls. The (partial) population estimate in 2009, was therefore 132 / 0.422 = 313 AOS (95% CI = 276–359). The unsurveyed sections held a combined total of 19 responses in 2001. If a similar figure is assumed for 2009, then total island responses would be 151, giving 358 AOS (95% CI = 315–410) compared with 362 estimated for 2001 (Table 5).

European Storm-petrel 2001 response rate: The 2001 calibration plot showed clear signs of habituation, with a reduction in total responses following the first visit and only six birds responding by day six, the final visit (Murray *et al.* 2008). The data were therefore re-analysed using the new 'first response' method. The number of AOS in the plot was estimated from the fitted curve of cumulative responses against visit as 46 (46.3 was the unrounded estimate in Murray *et al.* (2008)). This gave a slightly lower estimate of AOS in 2001, 362 against 371, but with a somewhat wider 95% confidence interval of 294–448. For the comparable sections covered in 2009 the estimate for 2001 became 318 AOS (95% CI = 258–393). Thus, the partial island estimates for 2001 and 2009 are very similar and there is no evidence for change ($P > 0.05$). Indeed, even in the worst case scenario that the unsurveyed sections in 2009 held no AOS, there would still be no evidence for an island wide decline in overall numbers.

Thirteen of the 16 sections were surveyed in 2009, with no change in six, increases in four, and decreases in three (Table 6). The largest decrease was in section B, down from 22 AOS to five; section J showed a slight decline but numbers there are small, going from eight AOS to five. In section M, the largest sub-colony on the island, numbers were virtually unchanged, at 200 AOS in 2001 compared with 196 in 2009. The losses in these sections have been largely offset by increases elsewhere.

Detecting future changes: An approximate power analysis method was used to estimate the change that could be detected by future surveys of both species. This was achieved by simulating the results of 1,000 future surveys, where the population of AOS had fallen by a specified percentage, and calculating the proportion of these surveys that result in a significant change being detected ($P < 0.05$). For each future survey, the results of a calibration plot were simulated by assuming no habituation and for simplicity, that the expected response rate was unchanged from that estimated for the 2009 survey. This was combined with a simulated number of island survey responses to estimate the number of AOS for the survey. The same bootstrap method for detecting change between the 2001 and 2009 surveys was then used to examine whether a significant change would be detected. The percentage of simulated surveys, which result in a significant change, is an estimate of the power of the survey to detect a given level of change.

Power analysis indicated that future surveys with a similar number of responding burrows in the Leach's Storm-petrel calibration plot would have about an 80% chance of detecting an 18% reduction in the number of AOS, and for European Storm-petrel an 80% chance of detecting a reduction of about 22% in the number of AOS.

Table 5. Estimates of response rates and AOS for European Storm-petrel *Hydrobates pelagicus* in 2001 & 2009.

	2001		**2009**		**Change**	
	Estimate	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Response rate	0.406	0.328–0.500	0.422	0.368–0.479	0.016	-0.094–0.111
AOS (partial survey)[1]	318	258–393	313	276–359	-5	-86–72
AOS (whole island)[2]	362	294–448	358	315–410	-4	-97–83

[1] Total AOS for the comparable sections covered by the partial island survey in 2009.
[2] Total AOS for the whole island with the 2009 figures extrapolated using the responses from the 2001

Table 6. Number of European Storm-petrel *Hydrobates pelagicus* AOS on North Rona in 2001 and 2009 and percentage change between years.

Section	2001	2009	% change	Section	2001	2009	% change
A	3	3	0	**I**	10	NS	NS
B	22	5	-77	**J**	8	5	-37
C	0	0	0	**K**	32	38	19
D	0	0	0	**L**	30	40	33
E	20	21	5	**M**	200	196	-2
F	0	0	0	**N**	0	0	0
G	0	0	0	**O**	29	NS	NS
H	3	5	67	**P**	8	NS	NS
Partial total [1]					**318**	**313**	**-2**
Whole island total					**362 [2]**	**358 [3]**	**NC**

[1] For the sections covered in both surveys.
[2] 362 is the 2001 total after re-analysis in 2009.
[3] 358 is an extrapolated total for 2009.

NS = not surveyed in 2009.
NC = 2001 and 2009 totals not comparable, extrapolated whole island total given for 2009.

Figure 2. Overhead view of Rona village (section E) and cultivation ridges (section F), 26 May 2004. © *Stuart Murray*

Discussion

Before considering possible causes of the decline in the Leach's Storm-petrel population on North Rona, we should rule out possible methodological artifacts in the results, stemming from: a) interpretation of response rates; b) breeding phenology relative to the survey dates; and c) potential differences between the ground surveys.

Given that both the 2001 and 2009 surveys covered the entire island and were not samples, any methodological error in estimation would likely be that associated with the response rate calibration. During both surveys response rate calibrations were at the same times, between 09.00 and 11.00 and during the expected peak of incubation. Both rates were comparable to those in other studies (Mitchell *et al*. 2004). There are two possibilities remaining: a) that the 2001 survey overestimated the population, and/or b) that the 2009 survey underestimated the population.

For the former to be true the real response rate would have had to be greater than the 0.452 estimated, higher even than the highest known response rate for this species, of 0.518, recorded at dusk on Boreray, St Kilda in 2000 (Mitchell *et al*. 2004). If the response rate was as high as this in 2001, the population estimate would be 1 / 0.518 x 490 responses = 946 AOS. Even if this unlikely scenario were true, this is still 25% more AOS than the 713 estimated in 2009.

It is also possible that the 2009 response rate was overestimated, but for the resulting population estimate to equal the 'artificially reduced' estimate of 946 AOS for 2001, i.e. a scenario of no change between 2001 and 2009, the response rate in 2009 would have had to have been reduced to 0.267, which is significantly lower than any recorded response rate (Mitchell *et al.* 2004). Therefore, it seems extremely unlikely that the direction of population change estimated here is a methodological artifact.

Changes in phenology between years could account for the declines in Leach's Storm-petrel on North Rona, but with so little published data for the species in Scotland it is unclear how much year to year variability there is in laying dates. The most recent studies on St Kilda gave dates of first hatching of 9 July in 2003 (O'Brien *et al.* 2005) and hatching dates of mid to late July in 2007 (Money *et al.* 2008). The only other comparable study, on Gruney in Shetland (Ellis *et al.* 1998) found the first young on 6 July. These studies were all of small sample sizes, covering less than 30 occupied burrows, but used an endoscope to confirm burrow occupancy. From this, Ellis *et al.* (1998) were able to show that an occupied burrow had the highest probability of being attended by a breeding adult between mid June and mid July,

Figure 3. Playback survey for Leach's Storm-petrel on Fianuis (section L). Lighthouse and Toa Rona (section J) beyond, 30 June 2009. © *Stuart Murray*

after which attendance and responses to tape playback declined rapidly, presumably as hatching progressed and small chicks grew beyond the need to be brooded by an adult. There has been no similar work done recently on North Rona but an early study found first hatching to be around 9 July in 1936 (Ainslie & Atkinson 1937). On St Kilda the date of first hatching was slightly later than on Gruney, but all three studies on both islands, and on North Rona 70 years earlier, suggest little variability in mean laying date or in first hatch dates. Therefore, it seems reasonable to assume that hatch dates on North Rona in 2001 and 2009 were similar to St Kilda in 2003 and 2007 and that survey dates in both years were close to the optimum for this species.

There are no published data on the phenology of European Storm-petrels at North Rona, although in 1936 most were still incubating on 12 August (Ainslie & Atkinson 1937), so it is uncertain if the 2001 and 2009 surveys were carried out during the period of optimum colony attendance. In 2001, the survey was completed by 2 July and in 2009 the last colony section was surveyed on 7 July, which was closer to the recommended survey date for the species: early to mid July if no laying dates are known (Ratcliffe *et al*. 1998a; Cadiou 2001). The nearest colony to North Rona where a phenology study has been made is Mousa in Shetland, where nest attendance peaked at 85–90% in late June (Ratcliffe *et al*. 1998b). In Brittany, Cadiou (2001) found a wide variability in peak laying in a three year study (1996–1999) with the date by which 50% of eggs had been laid ranging from mid May to early July. Changes in phenology on North Rona could therefore lead to a large underestimate of colony size, and had there been a decline in the numbers found in 2009, then this could be attributed to a later mean laying date. However, while total numbers could have been underestimated, the survey results show no change between 2001 and 2009 (Table 5).

It is possible that the surveys could have been conducted differently between years, so accounting for at least some of the losses in Leach's Storm-petrel sub-colonies and survey sections. This could have come about if the survey team in 2009 had no prior experience of the island, or had rushed the ground survey for lack of time, or worked in bad weather and limited their search effectiveness as a result. None of these factors applied in 2009. The survey team was led by the same person in both years, the team of three being augmented for a week by a fourth surveyor, and we had two weeks to complete what had taken three surveyors three weeks in 2001. The experience gained in 2001 also meant a considerable time saving in 2009, and this coupled with exceptionally sunny and windless conditions made for efficient survey conditions. It therefore seems unlikely that qualitative differences between the surveys accounted for the observed losses in 2009.

There has been an island-wide decline in the Leach's Storm-petrel population on North Rona between 2001 and 2009, particularly in the dense village colony (section E), the only sub-colony where a similar survey to 2001 has been attempted in the interim (Robinson 2005). On 17 June 2005, a tape playback survey was made of most of the village ruins within the section, including the structures categorized as subgroups A, B and C by Nisbet & Gailey (1962). The number of responses in A (62) was similar to the 68 found in 2001 and C showed an increase to 50, from 37 in 2001. In total, including part of B, 122 responses were elicited in 2005 compared to 142 in 2001. This would suggest little or no change between 2001 and 2005, and whatever happened to cause the decline has possibly been sudden and recent. However, without a calculated response rate in 2005 to estimate total AOS and thus make valid comparisons between years, a more definite timing for the observed decline remains unclear. On Sula Sgeir, no responses were elicited in 2009, and only two in 2001. The number is too small to draw conclusions from and it could simply be that no males were present at the time of the survey.

The survey of European Storm-petrels on North Rona was incomplete but covered 13 of the 16 sections covering the island, which in 2001 held 87% of the population (Table 4). The largest sub-colony, in the storm beach, held 196 AOS c.f. 203 in 2001, and totals for the village and several other areas were similar or unchanged between years, suggesting little or no change in the population.

Two known predators of small petrels breed on North Rona, Great Skua and Great Black-backed Gull *Larus marinus* (Figure 1). The history of the Great Skua on North Rona has been well documented since the first two nests were found in 1965 (Eggeling 1965), but the colony has grown only slowly since then, with 14 breeding pairs in 1986 (Benn *et al*. 1989), 18 in 2001 (Murray 2001), 17 in 2005 (Robinson 2005), and 18–20 in 2009 (Murray 2009). Non-breeding 'clubs' are not a feature of the colony and total numbers present are rarely more than the aggregate of territorial pairs (SM pers. obs.). In 1972, there were 2,000 pairs of Great Black-backed Gulls breeding on North Rona (Evans 1975), since when numbers have slowly declined, to 733 pairs in 1986 (Benn *et al*. 1989), 551 in 2005 (Robinson 2005) and 3–400 in 2009 (this study).

There has been no study of Great Skua diet on North Rona, or their impact on storm-petrels or other seabirds. The only such study on Great Black-backed Gulls, in 1972 (when only three pairs of Great Skuas were present), recorded a wide range of avian prey taken, including both storm-petrels, but the bulk of the gulls' diet then was fish (Pisces) (Evans 1975).

The present situation regarding bird predation by Great Skuas is complicated by the still large population of Great Black-backed Gulls on North Rona, so it is uncertain which predator was responsible for the few storm-petrel kills found in 2009 (one freshly killed and 12 long-dead Leach's Storm-petrels, and three European Storm-petrels); in 1972 the remains of 42 storm-petrels were found, all considered gull kills (Evans 1975).

The concern that Great Skuas in particular are having a serious impact on storm-petrels on North Rona, as appears to be the case on St Kilda (Newson *et al*. 2008), was not investigated due to lack of time and personnel. A consumption model similar to that constructed by Votier *et al*. (2004) would be useful to provide an estimate of the numbers killed, combined with a population model to test whether skua predation alone would be sufficient to cause the observed decline. The same approach is required toward Great Black-backed Gulls, whose declining numbers and poor breeding success suggest they are regularly having difficulty in provisioning young. In 2009 the colony experienced near total breeding failure, with the few chicks present succumbing to starvation and cannibalism (Murray 2009). At present it is unclear whether one or both predators are increasingly switching to seabird prey, but numbers of Northern Fulmar *Fulmarus glacialis*, Black-legged Kittiwake *Rissa tridactyla* and Common Guillemot *Uria aalge* have shown large decreases at North Rona over the last ten years (Benn *et al*. 1989; Murray & Love 1994; Robinson 2005; Murray 2009), although Puffins, commonly taken by skuas and gulls, have shown no such decline (Murray 1995, 2001, 2009).

If Leach's and European Storm-petrel are equally at risk from predation, then the population decline should, to some extent, be evident in the latter species, but at present this is not the case. On St Kilda, both species are taken indiscriminately and in large numbers by Great Skuas (Phillips *et al*. 1999a,b), so if there are specialist skua or gull predators targeting storm-petrels on North Rona, they appear to be largely ignoring the smaller species at present. The larger size of Leach's Storm-petrel and the more extravagant display flights of non-breeders may expose them to a higher risk of predation. They are also the more abundant species and could be preferentially selected as a result, but these are speculations.

Predation may only be one driver of the decline, and wider ecological factors may be impacting Leach's but not European Storm-petrel. Although both species winter in the southeast Atlantic they utilise different niches in the breeding season (Mitchell *et al*. 2004), but what, if anything, could be having a negative effect during this period on one species but not the other is unknown. What is certain is that in the changed circumstances of this serious and possibly ongoing decline of Leach's Storm-petrel, predators will take an increasing percentage of the dwindling population, thereby accelerating the rate of colony decline.

North Rona remains the third largest UK Leach's Storm-petrel colony, after St Kilda and the Flannan Isles. Newson *et al*. (2008) found a 54% decline on Dun, St Kilda, between 1999 and 2006, the island holding the majority of the population in the archipelago, and there may be equally serious losses on the other islands in the group. The decline on North Rona, 34% over eight years or less, is not as severe but is happening to a much smaller population, so if losses continue at the present rate, the existence of the colony could be threatened. We do not know if the decline began before 2001, because earlier population estimates before the advent of tape playback are not comparable (Murray *et al*. 2008), but the survey of the ruined village in 2005 suggests it may be recent (Robinson 2005).

As this study has shown, the recent decline in Leach's Storm-petrel numbers is not restricted to St Kilda and may now be more widespread in the northeast Atlantic. In the light of this, a reassessment of the British and Irish population is overdue.

Figure 4. Jill Harden, Stuart Murray and Kathleen Jamie (left to right), outside the ruined village chapel on Rona, 10 July 2009. © *Stuart Murray*.

Acknowledgements

The North Rona expedition was a partnership project, with funding provided by the Seabird Group, Scottish National Heritage, the Scottish Ornithologists' Club, the Gibson Estate, the Royal Commission for Ancient and Historical Monuments of Scotland, Historic Scotland and the British Broadcasting Corporation. We thank Tim Dee for assistance with storm-petrel surveying, Dave Cowley for help with skuas, and Paddy Pomeroy for permission to use the SMRU hut. Thanks also to Bob Theakston, who did much more than we asked in delivering us to Rona and supporting us while we were there. Stuart Newson and Norman Ratcliffe improved the manuscript with their rigorous criticisms.

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