A SURVEY OF MANX SHEARWATERS *PUFFINUS PUFFINUS* ON RUM, INNER HEBRIDES IN 2001

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Murray S., Shewry M.C., Mudge G.P. & Spray S. 2003. A survey of Manx Shearwaters *Puffinus puffinus* on Rum, Inner Hebrides in 2001. Atlantic Seabirds 5(3): 89-100. *A sample survey of breeding numbers of Manx Shearwaters* Puffinus puffinus *was carried out on Rum in 2001, based on 658 circular quadrats randomly positioned throughout the colony. All burrows in the quadrats were checked for occupancy during the late incubation period by playing a tape of a male shearwater call at burrow entrances and recording any response. In order to account for non-responding occupants, the estimate of the total number of responding burrows was multiplied by a correction factor of 2.16, derived from a calibration study carried out in 2003. A total population estimate of 76,310 occupied burrows (61,160 - 95,740, 95% CL) resulted. Burrows were also checked visually for signs of occupancy and this suggested a higher total of 119,950 occupied burrows (106,730 - 133,550, 95% CL). Further study of the response rate at this colony is advisable in order to understand the discrepancy between these findings. The estimate based on visual signs of occupancy is comparable with earlier studies, and little evidence exists to indicate that the colony is decreasing, as was suggested in the 1990s.*

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INTRODUCTION

As a breeding species the nominate form of the Manx Shearwater *Puffinus puffinus* is confined mainly to north-western Europe, from Iceland to the Azores, with very small numbers breeding in Canada and the USA. Prior to recent surveys, the total population was estimated at between 260,000-330,000 pairs, with more than 90% being in Britain and Ireland (Lloyd *et al.* 1991). The largest breeding concentration is on the islands of Skomer, Skokholm and Middleholm in Wales, with a combined estimated total of 151,000 pairs in 1998 (Smith *et al.* 2001).

The island of Rum in the Inner Hebrides has been known as a breeding site of the Manx Shearwater since the 17th century (Martin 1716) but the first attempt to assess the size of the colony was made only in the 1960s (Wormell 1976). In contrast to the low-lying Welsh colonies, shearwaters on Rum breed in mountains, mainly above 457m and as high as 800m. The colonies are often

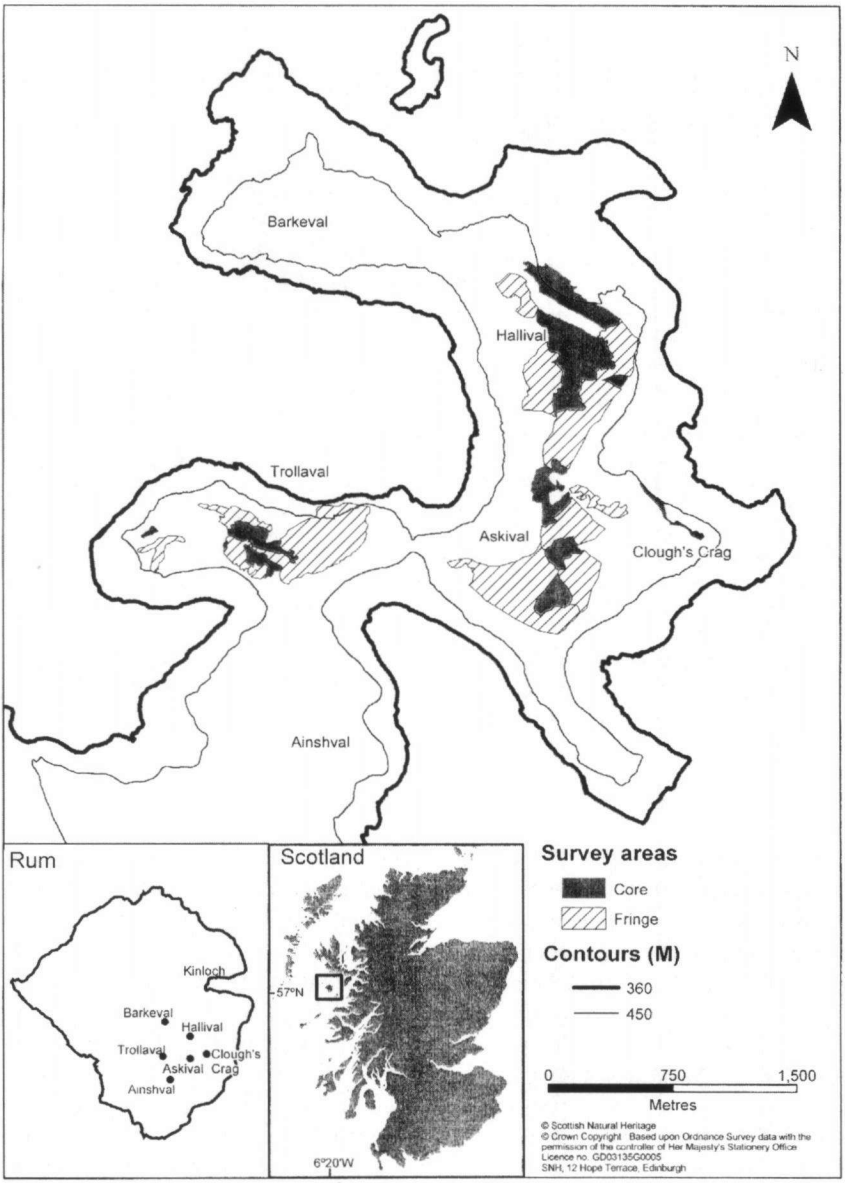


Figure 1. Main breeding areas of Manx Shearwaters on Rum, Inner Hebrides.
Figuur 1. Belangrijkste broedgebieden van Noordse Pijlstormvogel op Rum, Hebriden.

visually obvious as 'shearwater greens' due to the manuring effect of the birds droppings enriching the surrounding vegetation. The total extent of these greens was estimated by both Wormell (1976) and Earthwatch (in Furness 1990) to be *c.* 30 hectares. Wormell (1976) drew greens on overlays of aerial photographs, transferred the traces to a 1:10560 scale grid and measured their extent with a planimeter; he considered the resulting estimate of colony size to be very approximate. The Earthwatch teams attempted to locate greens by ground survey, but produced only a "crude map of doubtful accuracy" (Furness 1990). Population estimates were made between 1965 and 1969 (Wormell 1976), in 1978-1979 based on Wormell's map of the greens (Thompson & Thompson 1980) and in 1982, also based on Wormell's map (Philips 1982). Furness (1990, 1997) based his surveys on the greens as mapped by Earthwatch.

In 2000, we attempted to re-assess the size of the colony using new maps commissioned by Scottish Natural Heritage. However, once the field study began it became obvious that the maps were inadequate and that any sampling frame based on them would be flawed. Consequently, a different method was used in 2001, with all potentially suitable ground above the 457m contour defined as the colony. This paper reports on the survey work undertaken in 2000, a complete survey in 2001 (which avoided the need to pre-determine green locations) and fieldwork carried out in 2003 to calibrate population estimates based on responses to tape playback.

METHODS

In 2000 and 2001, two methods were used to estimate the numbers of shearwater burrows: visual estimation of 'apparently occupied burrows' (AOBs), and tape playback at burrow entrances.

Although AOBs are usually sufficiently deep to conceal an incubating bird, occupation may be indicated in several ways. There may be signs of recent digging activity, disturbed or recently flattened soil and vegetation, droppings, feathers or the smell of shearwaters. The number of AOBs were counted within circular $20m^2$ quadrats to allow for comparison with previous surveys. In addition, a taped call of a male (Rum) shearwater was played at the entrance of every burrow within the quadrat, whether or not there were signs of occupancy, and any responses noted (Walsh *et al.* 1995). AOBs could not be defined in the few quadrats that were covered with boulders, but the tape was played systematically across the quadrat and again responses noted. We assumed that males always respond to the taped call of another male and females do not (Brooke 1978; Walsh *et al.* 1995).

Herein, the term burrow is used solely for an apparently occupied burrow. There were no other burrowing birds or mammals in the shearwater

breeding areas, which prevented misidentification of burrows. Burrows with double entrances are not uncommon, so every burrow entrance within all quadrats was carefully checked to avoid double counting.

Survey work on Rum in 2000 In 2000, a map derived from aerial photography that attempted to differentiate greens and boulder fields was compiled, but it became clear from field survey that these features could not be distinguished accurately. However, data were obtained from 276 quadrats on greens that informed the sampling regime applied in the 2001 survey.

Boulder fields varied widely in area, composition and stability, with only small areas apparently suitable for breeding shearwaters. Typically, shearwater occupancy of these was low compared with greens; of a total of 159 quadrats sampled only 13 responses to the tape were obtained, so most of these areas were excluded from the 2001 survey.

Survey work on Rum in 2001 In 2001, we randomly placed quadrats throughout all ground in the main shearwater breeding areas. Most fieldwork was undertaken from 20 May-12 June, coinciding with the latter half of the incubation period and maximum diurnal burrow occupancy (Thompson 1987).

Quadrats were located using a hand held global positioning system, pre-programmed with 10 figure National Grid references. Over most of the colony, positioning was accurate to within 5 m, but where signals were poor, such as under cliff faces, readings could vary by up to 30 m. Such positional errors are unlikely to be systematically biased.

Previous surveys have indicated the potential for bias if sampling is based only on attempts to map shearwater greens. We used our field experience from the 2000 survey to draw boundaries that encompassed all the main shearwater breeding areas, which were above 457m. On each of the three main peaks Hallival, Askival and Trollaval, the ground within the boundaries was divided into a 'core' area of relatively high density (49.7 ha), surrounded by a 'fringe' area of low density (98.0 ha), a total breeding area of 148 ha. (Fig. 1). The core areas included most of the greens mapped on each mountain in previous studies (Wormell 1976; Furness 1990). Areas where burrow densities were so low that a disproportionate number of quadrats would have been required to obtain sufficient data to allow robust estimates to be calculated were excluded; such areas were Ainshval, Barkeval, west Trollaval, all ground between 366 m and 457 m, and hazardous cliff terraces on Askival and Clough's Crag (Fig. 1).

Data from tape playback in 2000 were used to determine the number of quadrats required to achieve a given level of precision for the 2001 population estimates for each habitat stratum. These data derived from a random sample of

the greens mapped in 2000; we assumed, therefore, a similar random sample pertained in 2001.

As no data were available on the area of unsuitable ground within strata, we estimated the proportion of quadrats likely to be on such ground. However, the expected precision of the population estimates is not particularly sensitive to variation in the proportion of unsuitable ground, so we assumed that responses would not be elicited in 50% of quadrats in the core areas or in 80% of the fringe areas. An appropriate number of zero counts was then added to each stratum's 'green' data from 2000 in order to simulate a random sample. This was used to determine the 'optimal' number of quadrats in each strata in order to minimise sampling error for a given sample size. On this basis, 400 quadrats were selected to give an expected coefficient of variation (CV) of 10%. Additional quadrats were generated, giving a total of 658 quadrats with an expected CV of about 8%. A disadvantage of this approach is that only a proportion of the defined area will contain burrows and many quadrats would be located in unsuitable ground; a balance was achieved that minimized the risk of excluding ground that may have contained significant numbers of shearwaters, and at the same time did not include too much unoccupied ground.

The total surface area of each stratum was estimated from a 10 m resolution contour digital terrain model (DTM) in ERDAS Imagine software. The use of surface area was justified as the DTM resolution is of the same order of magnitude as the size of a quadrat (5 m diameter).

Estimates for each stratum were calculated by computing the average number of responses and AOBs/m^2, multiplied by the area of the stratum. Estimates from the six strata were then summed to give an overall population estimate. Confidence intervals for the total number of burrows were calculated using bootstrapping (Efron 1979); 1000 bootstrapped estimates were generated, each estimate being calculated from a different sample of each stratum.

Calibration factor calculation in 2003 Population estimates based on responses to tape playback must be corrected for non-responding birds, mainly females and possibly non-breeders. In 2001, a calibration factor of 1.98 (see Walsh *et al.* 1995) was applied. However, it is advisable that a colony-specific correction factor be applied, ideally derived at the time of the survey (I.P. Mitchell *pers comm.*). We obtained such a correction factor for Rum between 21 and 31 May 2003. This period is late enough to include the peak of egg laying (Thompson 1987), and early enough to exclude most non-breeding birds, some of which may occupy burrows and respond to taped calls (Smith *et al.* 2001). This study was carried out in the core area on Hallival using the 2001 survey criteria for selecting AOBs, chosen as randomly as possible. The tape was played at each burrow entrance, and sufficient burrows were included to obtain

a minimum of 30 responses on the first day. The 85 selected burrows were marked with numbered flags, although one burrow later found to have a double entrance reduced the number checked to 84.

The correction factor was calculated as the mean response rate over 10 days for the 84 burrows. Bootstrapped estimates for the response data, from the 2001 survey, were generated in the same way as those for AOBs and then combined with bootstrapped correction factors generated from the 84 burrows to calculate confidence intervals for the corrected estimates.

Table 1. Numbers of quadrats (each 20m^2), with Manx Shearwater burrows, and number of burrows from which responses were obtained to tape playback in core and fringe areas on Rum in 2001.

Tebel 1. Aantal plots (elk 20m^2), met holen van Noordse Pijlstormvogel en het aantal holen waaruit positief werd gereageerd op het afspelen van de roep in het kerngebied en aan de randen van de kolonie.

Stratum	Site	Area (ha)	Total no. quadrats	No. quadrats with burrows (%)	No. burrows with response (%)
Core	Hallival	26.1	162	94 (58)	64 (40)
	Askival	15.9	70	54 (77)	33 (47)
	Trollaval	7.7	46	29 (63)	21 (46)
	All core	**49.7**	**278**	**177 (64)**	**118 (42)**
Fringe	Hallival	31.1	159	45 (28)	25 (16)
	Askival	36.3	111	35 (32)	21 (19)
	Trollaval	30.6	110	37 (34)	27 (25)
	All fringe	**98.0**	**380**	**117 (31)**	**73 (19)**
	All	**147.7**	**658**	**294 (45)**	**191 (29)**

RESULTS

All 658 quadrats were visited. In the core area, 36% of quadrats held no burrows, but in the fringe area 69% held none (Table 1); average burrow density in the former area was 0.140 AOB/m^2, and in the latter area 0.051 AOB/m^2 (Table 2). In the core area, no responses were elicited from 58% of quadrats, and in the fringe area none were elicited from 81%, close to the 50% and 80% predicted values (Table 1).

Table 2. Estimates and confidence limits for the number of apparently occupied burrows in the main Manx Shearwater colonies on Rum in 2001.
Tabel 2. Schattingen en betrouwbaarheidsintervallen van het aantal bezette holen van Noordse Pijlstormvogel in de belangrijkste kolonies op Rum in 2001.

Stratum	Site	Mean AOBs/m^2	Estimated no. of AOBs	95% confidence limits
Core	Hallival	0.141	36,760	29,960-44,480
	Askival	0.144	22,980	18,420-27,970
	Trollaval	0.129	9900	7,040-13,320
	All core	**0.140**	**69,640**	**60,070-78,870**
Fringe	Hallival	0.037	11,650	7,930-15,660
	Askival	0.059	21,260	14,400-28,050
	Trollaval	0.057	17,400	11,970-23,950
	All fringe	**0.051**	**50,310**	**40,850-60,420**
	All	**0.081**	**119,950**	**106,730-133,550**

Table 3. Estimates and confidence limits for the number of Manx Shearwater burrows based on responses to taped calls in the main colonies on Rum in 2001.
Tabel 3. Schattingen en betrouwbaarheidsintervallen van het aantal holen van Noordse Pijlstormvogel in de belangrijkste kolonies op Rum in 2001.

Stratum	Site	Mean responses/m^2	Estimated no. of burrows	95% confidence limits
Core	Hallival	0.075	21,370	16,230-26,950
	Askival	0.081	14,250	10,190-19,180
	Trollaval	0.079	6,650	4,140-9,470
	All core	**0.077**	**42,270**	**34,690-50,700**
Fringe	Hallival	0.018	6,130	3,600-8,760
	Askival	0.036	13,780	7,770-21,050
	Trollaval	0.042	14,130	8,570-21,030
	All fringe	**0.032**	**34,040**	**25,100-43,690**
	All	**0.048**	**76,310**	**61,160-95,740**

A correction factor of 2.16 (calculated from 2003 data) has been applied to the estimates. Confidence limits take account of uncertainty in the true value of the correction factor.

From the area of each stratum and the respective burrow densities, a total of *c.* 70,000 burrows (60,000-79,000, 95% CL) resulted for the core area, and *c.* 50,000 (41,000-60,000, 95% CL) for the fringe area, a colony total of *c.* 120,000 burrows (107,000-134,000, 95% CL; Table 2). Shearwaters also bred at low density outwith the mapped areas, but no attempt was made to assess numbers. However, based on the approximate area of available habitat elsewhere and applying the density measurement obtained in the fringe area, it is likely that 3,000-6,000 pairs bred elsewhere on Rum.

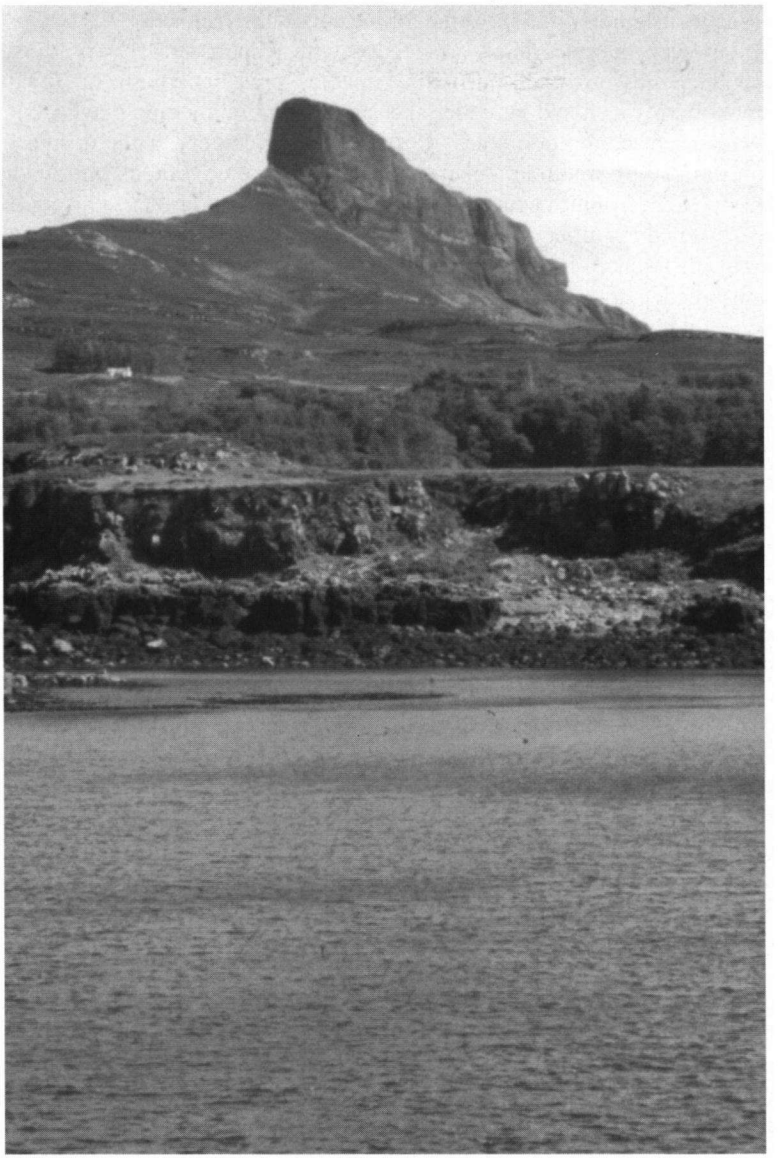
Population estimates and confidence limits for the number of burrows based on response to tape playback are presented in Table 3. The 2003 calibration study resulted in a correction factor for non-responding occupants of 2.16. The total coefficient of variation for the number of responses was 7.8%, close to the 8% predicted from the 2000 survey data. The estimated total number of burrows where a male responded to the tape was 35,000 (28,000-44,000, 95% CL). Application of the correction factor resulted in an estimate of *c.* 76,000 burrows.

DISCUSSION

Our survey suggested that there were about 120,000 (107,000-134,000, 95% CL) occupied Manx Shearwater burrows on Rum in 2001. However, the total number of burrows based on response rates was 76,000 (61,000-96,000, 95% CL), considerably fewer than the AOB estimate. This difference might be attributable to the presence of non-breeders prospecting burrows and who did not respond to tape playback. However, Smith *et al.* (2001) reported that unoccupied burrows on Skomer were visited only occasionally by responding, presumably non-breeding, birds; only 1% of responses were made by non-breeders. If a similar situation prevailed on Rum, and the survey period predated the expected arrival date of most non-breeders (James 1985), then non-breeders alone cannot account for non-responding burrows.

The colony-specific calibration factor, calculated in 2003, did not greatly reduced the discrepancy between the population estimates resulting from the two different methods; it is also unlikely that the numbers of non-breeders represent as much as 30-40% of the total population. A discrepancy between estimates obtained from responses to tape and the AOB method was also found on St Kilda, where a response was elicited from 36% of apparently occupied burrows (PI Mitchell *pers comm.*), and on Bardsey (30.5%; Leaper *et al.* in prep.). These figures are very similar to that on Rum (29%).

The reasons for the discrepancies are unknown. It might appear that the two methods measure different population parameters. Perhaps calibration factors vary not only between colonies but also interannually. Furthermore,



View of the breeding areas on Rum. Uitzicht op de broedgebieden op Rum. *(Steve Geelhoed)*

there are several ways in which data from the calibration can be analysed, each resulting in a slightly different value for the correction factor.

Given the uncertainty associated with response rates, we advise that where there are no other burrowing species present, counts of apparently occupied burrows should be undertaken in tandem with a tape playback survey and concurrent calibration study. Possible improvements to the design of the calibration study include ensuring wide spatial coverage, and using an endoscope to determine occupancy.

It is difficult comparing the results of our study with previous surveys given the differences in field methods, sampling strategies and timing in relation to non-breeder activity. However; the core area in 2001 (49.7 ha) broadly coincides with the mapped greens in previous studies (30-33 ha) and here the burrow counts (69,900) are within 12% of Philips (1982) estimate of 79,000 in 1982, and 10% of Furness (1997) estimate of 62,800 in 1995. Wormell's (1976) estimate of 116,000 in 1976 (32-46% higher than the later counts), and Thompson and Thompson's (1980) estimate in 1978-1979 of 124,000-146,000 pairs (at burrow densities 21% higher than in any other study), might appear anomalous. However, the degree to which surveys focus on the most densely populated greens probably greatly affects population estimates. Furness (1990) noted that the large variation in all areas rendered it difficult to demonstrate statistically significant changes over time; however, he considered that there may have been a slow decline in burrow densities from the 1960s through to 1990.

It appears to be widely accepted that the Rum shearwater colony is in slow decline (e.g. Smith *et al.* 2001), but the evidence for this rests mainly on the analysis by Furness (1997) of his fixed quadrat data from 1985, 1990 and 1995. A re-examination of Furness (1997) suggests that population decline between 1985 and 1995 had not been clearly established. Although the decline in used burrows within 105 permanent quadrats, grouped into larger plots in some major greens, was greater than that which could be attributed to observer error, the estimated decline remains subject to sampling error. If we assume that the quadrats, although non-random, are representative of change, then an appropriate statistical test may be used to examine whether the data indicate that actual population change has occurred. A paired t-test was applied by Furness (1997), but this provided no evidence for a statistically significant decline in used burrow density (Furness 1997) and we consider there is no compelling evidence of any substantial change in the size of the Rum shearwater colony since at least the 1980s, if not earlier.

The present population on Rum is somewhere between 61,000 (Table 3) and 134,000 pairs (Table 2), depending on the method used, compared with *c.* 102,000 pairs on Skomer (based on tape playback; Smith *et al.* 2001). Skomer,

therefore, is the world's largest single colony of Manx Shearwaters; Rum is certainly of a similar size.

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INVENTARISATIE VAN NOORDSE PIJLSTORMVOGELS OP RUM, HEBRIDEN, IN 2001

Op het eiland Rum werd in 2001 een steekproefsgewijze inventarisatie van broedende Noordse Pijlstormvogels uitgevoerd met behulp van 658 plots die *at random* verdeeld waren over de kolonie. Ieder hol in de plots werd laat in het broedseizoen gecontroleerd op de aanwezigheid van vogels door de roep van een mannetje af te spelen bij de ingang en de reactie te registreren. Om te corrigeren voor niet-roepende vogels werd het geschatte totaal vermenigvuldigd met een correctiefactor van 2,16, die in 2003 was verkregen tijdens een calibratiestudie op Rum. Het resultaat was een populatieschatting van 76.310 (95%-betrouwbaarheidsinterval 61.160-95.740, tabel 3). Een visuele controle van de holen leverde een hogere populatieschatting op, nl. 119.950 (95%: 106.730-133.550, tabel 2) schijnbaar bezette holen (AOB). Verder onderzoek naar de *response rate* in deze kolonie is nodig om het verschil tussen beide schattingen te begrijpen. De visuele schatting is vergelijkbaar met eerder behaalde resultaten. Er zijn geen aanwijzingen voor een afname, zoals in de jaren negentig werd gesuggereerd.

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