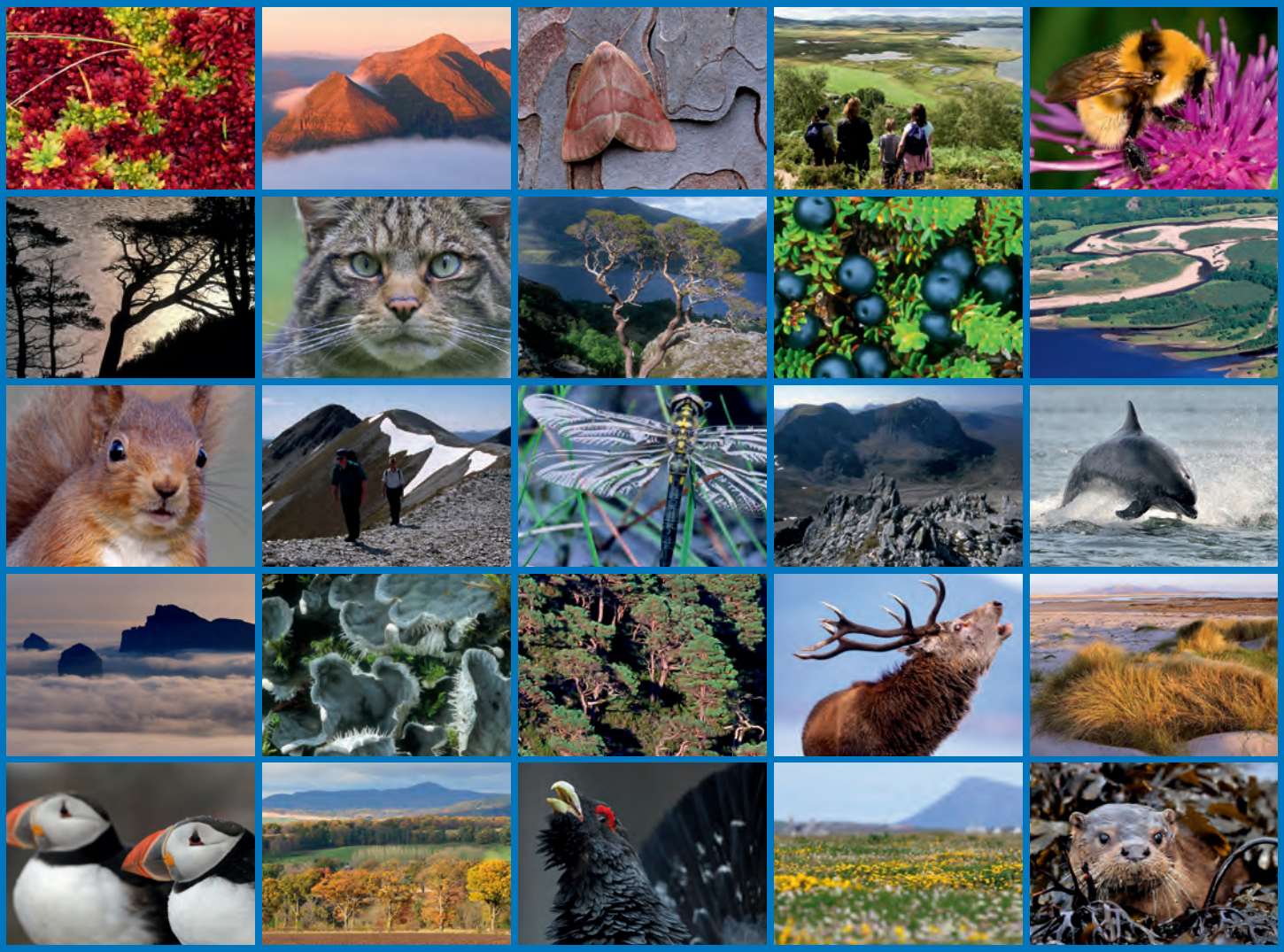
Scottish Natural Heritage
Commissioned Report No. 696

Aerial survey of northern gannet (*Morus bassanus*) colonies off NW Scotland 2013



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COMMISSIONED REPORT

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Aerial survey of northern gannet (*Morus bassanus*) colonies off NW Scotland 2013

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This report should be quoted as:

Wanless, S., Murray, S. & Harris, M.P. 2015. Aerial survey of northern gannet (*Morus bassanus*) colonies off NW Scotland 2013. *Scottish Natural Heritage Commissioned Report No. 696.*

COMMISSIONED REPORT

Summary

Aerial survey of northern gannet (*Morus bassanus*) colonies off NW Scotland 2013

Commissioned Report No. 696
Project No: 14641
Contractor: Centre for Ecology and Hydrology
Year of publication: 2015

Keywords

Northern gannet; Sula Sgeir; St Kilda; Flannan Islands; Sule Stack: Sule Skerry; gugas; population trends.

Background

Scottish Natural Heritage (SNH) commissioned an aerial survey of selected colonies of northern gannets (*Morus bassanus*) off the NW coast of Scotland in 2013. The principal aim was to assess the status of the population in this region, which holds some important, but infrequently counted colonies (St Kilda, Sula Sgeir, Sule Stack, Flannan Islands and Sule Skerry). In addition, an up-to-date assessment was required to review the basis for the licensed taking of young gannets (gugas) from the island of Sula

Main findings

- Aerial surveys of all five colonies were successfully carried out on 18 and 19 June 2013. Images were counted using standardized methods by at least two observers, to give colony totals broken down into sub-sections.
- Population estimates were: St Kilda (60,290 Apparently Occupied Sites (AOS), Sula Sgeir (11,230 AOS), Flannan Islands (5,280 AOS), Sule Stack (4,550 AOS) and Sule Skerry (1,870 AOS).
- Comparison of the 2013 counts with those in 2004 indicated that numbers had increased rapidly at Sule Skerry and the Flannan Islands (47.4% per annum (pa) and 7.5% p.a. respectively), but had changed little at Sule Stack and St Kilda. The harvested colony on Sula Sgeir increased by 2.2% p.a., reversing the trend over the previous 10 years when the population declined at 1.2% p.a.
- The NW of Scotland remains an extremely important region for northern gannets and still holds the largest colony in the E Atlantic (St Kilda). Conditions in the region currently appear highly favourable for northern gannets with the rapid growth of the recently founded colony on Sule Skerry, and potential colonization of another new colony on Barra Head.

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Acknowledgements

Thanks are due to pilot David Rutter for making the aerial surveys possible, Jill Harden for photographic support and Mike Harris for counting images. We are grateful to Paul Sharman, the National Trust for Scotland's ranger on St Kilda and Stornoway Coastguard for local weather reports.

1. INTRODUCTION

Scottish Natural Heritage (SNH) commissioned a survey of selected colonies of northern gannets (*Morus bassanus*) off the NW coast of Scotland in 2013. The principal aim was to assess the status of the population in this region which holds some important, but infrequently counted, colonies (St Kilda, Sula Sgeir, Sule Stack, Flannan Islands and Sule Skerry). In addition, an up-to-date assessment was required to review the basis for the licensed taking of young gannets (gugas) from the island of Sula Sgeir.

The main aim of the field work was to achieve 100% photographic coverage of each of the five colonies in the region. From this, high quality counts could be made of each colony and compared with counts made from similar images taken as part of the last Scottish gannet survey in 2004, thus allowing any changes in colony extent or size over the last nine years to be identified.

2. METHODS

2.1 Aerial surveys

An aerial survey of Scottish gannet colonies requires extensive preparation and planning by a coordinator with experience of the survey methodology and first-hand knowledge of all the colonies, a slow, twin-engine aircraft and an experienced and skilful pilot. A team of backup photographers preferably available at short notice, and with experience of aerial survey and a reasonable tolerance of air-sickness is also essential. If hand-held cameras are being used at least one, and preferably two, back-up photographers are normally required. Three photographers, including the coordinator, are the recommended minimum required to cover the colonies surveyed for this contract, and are absolutely essential for St Kilda. It is also important that at least one of the photographers is very familiar with the layout and configuration of the colony (or colonies) being surveyed and can thus assess whether coverage is complete from a rapid inspection of the images obtained.

The ideal time to conduct a survey is between mid-May and mid-June. There can, however, be logistic problems in achieving this. Constraints include weather conditions, other aircraft charter commitments and military activity, the latter being a particular problem at St Kilda, which is in the centre of a rocket testing range, and, to a lesser extent, Sule Stack which is at the edge of military firing ranges.

The main determinant of the success or failure of a survey flight is the weather. This is a particular issue for the colonies in NW Scotland that are well offshore. Local weather conditions can only reliably be assessed for St Kilda, which has a resident NTS summer warden. Weather at Sula Sgeir, Sule Stack and Sule Skerry can be assessed via Stornoway coastguard, who can contact ships in the vicinity for a weather report.

Aerial surveys obviously require good visibility and sea fog in summer can be highly localized and not apparent in a general area forecast. Wind speeds below 10-12 knots are also important, as turbulence quickly becomes a hazard over and near islands when flying at the survey height of around 350 m. For St Kilda, the cloud ceiling needs to be at least 800 m, twice the height of the island. Because of its height, this colony can often be cloud-capped when the surrounding area is in sunshine. It is therefore imperative to be certain of local weather conditions before a flight, and prudent to postpone it if there is any doubt.

The coordinator, or most experienced photographer, should sit next to, and be in headset contact with, the pilot. As well as taking photographs, this person has responsibility for minimizing disturbance to the colony by the aircraft whilst ensuring that all sections have been covered. Achieving both aims does require skill and experience.

In general, nesting gannets are unaffected by a low flying aircraft. Club and other non-breeding birds usually fly off however, and a survey should not commence until these birds have left. Gannets rarely fly higher than the summit of a cliff colony, and at the approach of an aircraft those that leave the colony do so by flying low over the water or settling on it.

Safety regulations dictate that only twin-engine aircraft can be used for flights over the sea. The aircraft used in gannet surveys up to 2004 was an eight-seat Islander while in 2013 the smaller six-seat Partenavia was chartered. The main advantage of both these aircraft is their ability to fly slowly, at speeds down to 85 knots, while accommodating up to four photographers in the rear seats. This ensures that colonies are photographed several times and from different angles with each circuit of the aircraft. Thus, maximum photographic coverage of the colony is obtained in the minimum time, thereby reducing disturbance to the colony.

On approach to any colony the method of operation is similar. The landing lights are switched on to make the aircraft as obvious as possible and the colony is circled at an altitude of about 1000 m. This allows the pilot to become familiar with the area and to ensure that club birds disperse. With the coordinator and photographers on the right hand side of the aircraft, the approach is made clockwise, spiralling down in tightening circles until a suitable survey height has been reached. These methods, or a variant of them, can be applied at all colonies, with the exception of Boreray (St Kilda) where gannets nest from sea level to the summit of the island at close to 400 m, on the south, east and west coasts. The rock architecture here is a complex mosaic of spires, buttresses and overhanging rock walls that require survey runs to be made parallel to the cliffs at different altitudes. Due to its height, the island is prone to turbulence in even light winds, and a close approach can be difficult. It is advisable that pilots or coordinators of any future surveys should gain experience of other colonies before attempting Boreray and its satellite stacks.

In 2013, despite the very short notice to arrange the flights and the limited time period in which to carry them out, all of these requirements were met. The surveys were successfully flown back-to-back on 18-19 June 2013, using a twin-engine, six-seat Partenavia aircraft chartered from RavenAir. In addition to the pilot there was a principal photographer, a back-up photographer and a third observer who was responsible for transferring camera card images to a laptop computer. Five cameras were carried, each with a 4GB memory card. Survey techniques followed those used at these colonies during the Scottish Gannet Survey in 2004.

A detailed breakdown of the survey flights flown in 2013 is given in Table 1.

Table 1. Details of survey flights of gannetries in 2013.

Date	Photographers	Airport / Colony	Landed / Arrived[1]	Departed[1]	Time in vicinity of colony (min)
18 June 2013	Stuart Murray Jill Harden Sarah Wanless	Inverness		10:50	
		Sule Skerry	11:30	11:39	9
		Sule Stack	11:43	11:49	6
		Sula Sgeir	12:25	12:50	25
		Flannan Isles	13:27	13:30	3
		Stornoway	13:50		
19 June 2013	Stuart Murray Jill Harden Sarah Wanless	Stornoway		13:05	
		Flannan Isles	13:25	13:38	13
		St Kilda	13:58	14:45	47
		Inverness	15:35		

On 18 June the sky was completely overcast, with no wind and a cloud ceiling of 600 m. Excellent coverage was obtained of Sule Skerry, Sule Stack and Sula Sgeir. The high, thick overcast conditions acting as a natural filter, dimming the glare that is reflected off close-packed gannets, thus decreasing the likelihood of overexposed photographs. Also, with no wind there was no turbulence to contend with, making it easier for both pilot and

[1] All times are in BST

photographers. Coverage of all three colonies was 100% and the overall standard of the photographs was extremely high, particularly for Sule Stack. A weather front was due to move west across the Hebrides in the late afternoon, bringing heavy continuous rain and a drop in the cloud base to 150 m. The pilot was initially hopeful that the Flannnan Islands could be surveyed before it arrived. Conditions deteriorated sooner than expected, however, so the attempt was abandoned and the aircraft returned to Stornoway.

On 19 June the bad weather was sitting firmly over the Hebrides but the forecast predicted a clear and cloudless afternoon before another front arrived in the evening. This forecast proved accurate and conditions improved as we arrived at the Flannan Islands. Coverage of the five sub-colonies making up the colony was 99% and the quality of the resultant images was very high.

The St Kilda archipelago was visible from the Flannan Islands and crucially the tops of Boreray and the stacks were cloud free, meaning that conditions were suitable for surveying. The combined colonies of Stac Li, Stac an Armin and Boreray present a formidable logistical challenge, with Boreray being particularly difficult to photograph from the air. For both Stac Li and Stac an Armin, 100% aerial coverage was achieved, with the overall standard of photographs for both being very high. As is often the case, there was considerable air turbulence at low altitudes along the cliffs on Boreray, but despite this coverage was virtually complete (96%). The missing areas were all covered using a combination of land and sea photographs taken by Stuart Murray in 2012 and 2013. The quality of some of the photographs was not as good as those for the other colonies but was still adequate to make counts and draw comparisons with 2004.

2.2 Camera systems

All three North East Atlantic Gannet Surveys (1984/85, 1994/95 & 2004; Murray & Wanless, 1986, 1997; Wanless *et al*., 2005; 2015) that aerially photographed gannetries in the UK and Ireland did so using hand-held SLR cameras loaded with K64 colour slide film. Film has since been superseded by digital cameras, which offer much greater flexibility and coverage, allowing hundreds of pictures to be taken rapidly and, if reloading is required, this can be done in seconds by removing and replacing the memory card. Hand-held cameras were proven to work well in previous surveys and being simple to use and reliable they were the preferred choice for the 2013 survey. Five cameras (Canon Eos 1100D) were carried, each loaded with a 4G memory card. All photographs were taken with a 55 mm standard lens, which gave high quality results and adequate resolution when images were enlarged for counting on the computer screen. A future improvement on the technique could be to use cameras with higher megapixel ratings, which would allow greater flexibility to manipulate and enlarge images without loss of definition at high magnification.

Fixed camera systems which are mounted externally below an aircraft's wing, or in a cradle in the floor of the fuselage pointing vertically downwards, are now widely used for various types of ornithological survey in the UK. To our knowledge, however, they have not yet been used to count any UK or Irish gannetry and their advantages or limitations in terms of the quality of images obtained, or comparability to results using the current method are not known at present. Clearly these aspects should be investigated with particular attention paid to difficult colonies like St Kilda.

2.3 Counts from images

Each colony should be photographed several times and from several angles to ensure complete coverage. The resulting overlapping, digital images should be fitted to form a mosaic of the colony (to prevent missing areas or double counting). For all colonies the

same count section boundaries, first defined in 1984/85 and used in subsequent censuses up to 2013 should be followed.

Unlike previous surveys where slide film was used, the initial sift of images in 2013 was done on a computer augmented by large-scale A3 colour prints that were helpful for orientation. This dual approach was used most extensively for Sula Sgeir as this colony was of particular significance and importance within the context of the 2013 survey.

The subset of images selected for counting were manipulated on a computer using appropriate software, e.g. Photoshop or Paint Shop Pro, to draw on the section boundaries used in previous surveys. This ensured that repeat counts of sections by the same or different observers were standardized with respect to sectional boundaries. In many cases however it was not possible to count a full section from one image and section totals were derived from sub-sections counted on different images. Thus while sections remain the same between surveys, thus ensuring comparability over time, sub-sections may vary since they depend on coverage quality at the time, e.g. in 2013 the eight Sula Sgeir sections were covered by 25 sub-sections.

Automated methods of counting are currently being developed by various organisations and could potentially be useful for gannet surveys, although the difficulties of counting gannet AOS, particularly in complex cliff areas, are far greater than, for instance, flamingos (Descamps *et al*., 2011). Comparisons of counts of gannet AOS obtained by conventional methods with those obtained using automated systems are thus urgently needed so that, if count methodology is changed in the future, the time series is not broken.

In total, just over 2,000 photographs were taken of the five colonies combined. The majority of these were not, however, of a high enough standard for counting or even as reference material. The initial sift of images was done largely on a computer augmented by large-scale A3 colour prints that were helpful to orientate in complex areas. This dual approach was used most extensively for Sula Sgeir, as this colony was of particular importance within the context of the survey. The filtering process identified 85 images suitable for detailed counting (c.4% of the total number taken) together these gave 99% coverage of the five colonies.

This subset of count images was then manipulated in Photoshop to draw on the section boundaries used in previous surveys. This ensured that repeat counts of sections by the same or different observers were standardized with respect to sectional boundaries. As in previous surveys the count unit used was the Apparently Occupied Site (AOS, defined as a site occupied by one or two gannets, irrespective of whether nest material is present). This unit does not provide an estimate of the number of breeding pairs, nor is it strictly correct to equate occupied sites with pairs, as some sites may be held by a single bird for at least a year (Nelson, 1978). For further methodological details see Walsh *et al*. (1995) and Gilbert *et al*. (1998).

In contrast to previous surveys where counts were either made using colour prints or from transparencies projected onto a screen, the 2013 images were counted off computer screens using either Photoshop or PaintShop Pro 7 software. This enabled images to be viewed at different magnifications and each AOS was blocked out with a dot using the paintbrush option. Dot colour was changed after every 100 AOS to facilitate keeping a rough tally of the total and a tally counter was used to keep an accurate running score. Counts by each observer were initially made blind removing any chance of subconsciously counting high or low because of prior information.

For most colonies the main counter (Stuart Murray) made more than one count. Average sectional values for these counts were calculated before combining with values from one (or occasionally two) additional counters to give overall mean section values. These mean

section values were then summed to give a mean colony total that was taken to be the best estimate of colony size in 2013. It should be noted that this method sometimes gives a slightly different colony total to the one obtained by taking the mean of the colony totals for each of the counters. Accordingly colony mean counts are given to the nearest 10 to allow for the rounding errors involved in the way they were calculated.

Images illustrating count sections were provided with the report on an accompanying CD.

2.4 Land and sea-based visits

Land and/or sea-based visits to colonies, ideally as close in time as possible to the aerial survey, can be very useful both for defining the status of non-breeders, if large numbers are present, or photographing areas known to have been missed or difficult to photograph from the air. In 2013 a post-aerial survey visit to St Kilda by sea was extremely helpful for counting the small area of Boreray that had been missed. Any photographs taken and incorporated into aerial surveys should use the Apparently Occupied Site as the count unit.

2.5 Quality assurance

Each colony was counted by at least two highly experienced people. Sula Sgeir received the greatest attention being counted three times by the principal observer and once by two other people. After the counts had been made, any sections where totals either within or between observers differed substantially, were recounted to check for errors. In most cases this resulted in the revised counts showing much greater agreement. To quantify the level of inter-observer variation at each colony, differences (%) were calculated as:

$$\frac{\text{mean difference between the counts (usually two, occasionally three) x 100}}{\text{mean count}}$$

Given that inter-observer effects were apparent (see results), to estimate colony totals we first derived a mean value where an observer had made replicate counts and then combined this value with single counts from one or two additional observers to obtain an overall mean value. In practice, this usually meant taking the average of repeat counts by Stuart Murray and then using this value with single counts from Mike Harris and/or Sarah Wanless to give a mean value for the colony.

2.6 North west Scotland gannetries, colony histories

Given below are brief histories of each of the five gannet colonies included in this contract (seven if Boreray, Stac Li and Stac an Armin of St Kilda are considered as separate colonies). Each colony has been divided into sections and the majority of these into sub-sections, giving 100% coverage of each colony. Sections have remained the same between surveys since the first of this series in 1985 (Murray & Wanless, 1986), thus ensuring comparability over time, but sub-sections may vary, since they depend on coverage quality at the time. For example in 2013 the eight Sula Sgeir sections were covered by 25 sub-sections made from a mosaic of 27 photographs.

Sections and sub-sections are each fully illustrated in the accompanying image file. Each file opens with a series of overview photographs showing the position of each section within the colony and the boundaries between each section. These are followed by the close-up photographs used to make both the section and sub-section counts. Colony sections, listed by either name or number are given in Tables 2 to 8 in the main report and in Appendix 1.

2.6.1 Sule Skerry

Location:	59º05´N 04º24´W, HX621244, 60km west of the Orkney Islands.
Colony establishment:	2003 (Blackburn & Budworth, 2004).
Conservation status:	SPA.
Colony sections:	First defined 2013 (this study), currently two named sections.

The nascent colony was simply named Sule Skerry at the time of the 2004 survey. Since then the colony has greatly expanded and currently occupies two discreet blocks on either side of Stack Geo, so were named East and West Stack Geo respectively. These may eventually connect up at the north end of the geo and require a defined boundary line between them.

2.6.2 Sule Stack

Location:	59º02´N 04º30´W, HX565177, 64km west of the Orkney Islands.
Colony establishment:	Prior to 1710 (Fisher & Vevers, 1943)
Conservation status:	SPA / SSSI
Colony sections:	First defined 24 May 1939 (Fisher & Vevers 1943). Redefined 1994 (Murray & Wanless, 1997). Eight named sections in 2013.

The 1939 map was drawn from photographs and sketches made from a boat lying off the rock: eleven sections were defined based on natural features. By contrast the 1985 survey photographs were of moderate standard and the rock could only be divided into four sections, broadly following Fisher & Vevers. However, the 1994 survey produced very high quality images, which allowed detailed scrutiny of the rock and eight named sections were defined. Subsequent surveys in 2004 and 2013 have produced images of outstanding quality, allowing the 1994 boundaries to be followed meticulously.

2.6.3 Sula Sgeir

Location:	59º06´N 06º09´W, HW620305, 64km north of Lewis in the Western Isles.
Colony establishment:	Prior to 1549 (Fisher & Vevers, 1943).
Conservation status:	SSSI / SPA.
Colony sections:	First defined 1985 (Murray & Wanless, 1986). Eight numbered sections in 2013.

The 1985 images were of a high standard and the seven colony sections and boundaries defined that year have since been largely adhered too. The only adjustments to boundaries were made in 1994 when Section 4 was divided into 4a and 4b, so giving eight instead of seven colony sections. All four surveys, in 1985, 1994, 2004 and 2013 have delivered high quality photographs, resulting in near identically drawn section boundaries between all of them.

2.6.4 Flannan Islands

Location:	58º18´N 07º36´W, NA690465, 27km west of Lewis in the Western Isles.
Colony establishment:	Found 1969 (Cramp *et al*., 1974).
Conservation status:	SSSI / SPA.
Colony sections:	First defined 1985 (Murray & Wanless, 1986). Six named sections in 2013.

The colony was first established on a small stack tenuously connected to the main island of Roareim. By 1994 colony expansion had spread onto three other nearby stacks and increased on Roareim itself, which was then divided into three sections, Main, South and East. These sections were adhered to in 2004 but redefined in 2013, as the colony had greatly expanded. Roareim is currently divided into South and East sections only, with the South section counted in four sub-divisions in 2013.

2.6.5 St Kilda (Boreray, Stac Li and Stac an Armin)

Location;	57°53´N 08°30´W, NA155050, 66km west of North Uist in the Western Isles.
Colony establishment:	Prior to 1549 (Fisher & Vevers, 1943).
Conservation status:	SSSI / SPA / World Heritage Site.
Colony sections:	First broadly defined 31 August 1941 (Fisher & Vevers, 1943), redefined in detail 13 May 1959 (Boyd 1961), then again in 1985 (Murray & Wanless, 1986). In 2013 Boreray had 23 numbered sections and Stac Li and Stac an Armin had five named sections each.

The 1941 survey was made from aerial photographs taken by the RAF. Very broad colony sections were defined, with 15 in total covering all of Boreray and the stacks. Fisher coined the phrase 'Top Table' for Stac Li summit, which has been used in all subsequent counts. The first detailed and comprehensive survey was based on aerial photographs, again taken by the RAF, in May 1959. Using these photographs Boyd sub-divided Boreray and the stacks into 116 sections, but the lack of defined boundaries made some of these sections difficult to identify. For the 1985 survey the Boreray sections were amalgamated to 26 (23 in 2013 only) and the numbering system dropped for Stac Li and Stac an Armin, with the sections redefined and renamed. The 1994, 2004 and 2013 surveys adhered to these boundaries.

3. RESULTS

3.1 Colony totals and colony extent in 2013 compared to 2004

3.1.1 St Kilda (sub-colonies combined)

Colony status: 60,290 AOS in 2013, 59,622 in 2004; population probably stable. Some very small increases confirmed by comparing photographs taken in 2004 and 2013 but variation in the quality of count photographs between years is the most likely explanation for count differences.

3.1.2 Boreray

Colony status: 32,240 AOS in 2013, 32,333 in 2004; population probably stable (Table 2).

Detailed comparison of 2013 images with the 2004 photographs failed to detect any major change in colony extent. Where very small increases have been noted in the past (between 1985 and 2004), they have been on cliff top edges and have involved small numbers of AOS and barely discernible changes in colony extent. The only exception to this has been on the upper east face of Section 83-88 sub-section B, which has noticeably expanded. On the steeper, largely inaccessible cliff faces there are no clear areas of change, with neither obvious increases nor decreases noted. Neither have changes in numbers of nests been found on the densely occupied ledges close to sea level in Section 16-41. Overall, there is no evidence for any major change in numbers or distribution of gannets on Boreray since 2004.

Table 2. Counts of gannet AOS on Boreray. Counters were Stuart Murray (SM) and Mike Harris (MPH). The sections used follow those for the 2004 survey but sub-sections are based on the 'best fit' images for each section in 2013. JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG No.	From	Section	SM	MPH	Mean
DSC_0244	air	1	29	30	30
DSC_0244	air	2	59	59	59
IMG_3152	air	3 to 12 A	1,099	1,138	1,119
IMG_6150	land	3 to 12 B	572	575	574
IMG_0453	air	3 to 12 C	31	32	32
IMG_3122	air	13 to15 A	991	946	969
IMG_3124	air	13 to15 B	903	957	930
IMG_0504_2	air	16 to 41 A	1,982	2,101	2,042
IMG_0504	air	16 to 41 B	2,864	3,042	2,953
IMG_3149	air	16 to 41 C	614	696	655
IMG_2561	sea	16 to 41 D	135	138	137
IMG_2560	sea	16 to 41 E	50	56	53
IMG_2559	sea	16 to 41 F	65	67	66
DSC_0234	air	42-43 A	994	1,081	1,038
DSC_0215	air	42-43 B	359	376	368
IMG_9986	land	42-43 C	42	39	41
DSC_0234_2	air	44	67	61	64
IMG_3138	air	45	425	424	425
DSC_0236	air	46 A	381	376	379
IMG_6146	land	46 B	151	160	156
IMG_0099	sea	46 C	46	63	55
DSC_0237	air	47	775	635	705

DSC_0219	air	48	666	816	741
IMG_0501	air	49	1,117	1,165	1,141
IMG_0499_2	air	50	31	33	32
IMG_0499	air	51 to 57	3,807	3,606	3,707
IMG_0343	air	58 to 63	2,051	2,305	2,178
IMG_3056	air	64 to 66 B	192	187	190
IMG_0347	air	64 to 66 A	1,268	1,191	1,230
DSC_0209	air	67 to 72 A	792	707	750
IMG_0370	air	67 to 72 B	962	1,057	1,010
IMG_0285	air	73	339	221	280
IMG_3070	air	74 to 78	1,730	1,777	1,754
DSC_0206	air	79	668	685	677
IMG_5945	land	80 to 82 A	75	72	74
IMG_0367	air	80 to 82 B	1,009	991	1,000
IMG_0283	air	80 to 82 C	500	373	437
IMG_3050	air	80 to 82 D	433	277	355
IMG_0529	air	83 to 88 A	147	114	131
IMG_0529	air	83 to 88 B	531	589	560
IMG_0523	air	83 to 88 C	496	270	383
IMG_0365	air	83 to 88 D	2,127	2,154	2,141
IMG_0520	air	83 to 88 E	22	20	21
IMG_3094	air	89	565	637	601
Boreray		**Total**	**32,162**	**32,299**	**32,240**

3.1.3 Stac Li

Colony status: 14,990 AOS in 2013, 13,369 in 2004; population probably mainly stable, possibly slight increase (Table 3).

Detailed inspection of the 2013 images did not indicate any obvious changes over 2004. Apparently suitable breeding ledges on the South Face close to the bothy and a prominent ledge cutting diagonally across the North Face, first identified in 1979, have both remained unused. Similarly, small broad ledges below the Casting Point would appear to offer space for more AOS. If there has been an increase since 2004 it has not been possible to find evidence of it, but incremental increases distributed throughout the rock would be extremely difficult to detect photographically.

Table 3. Counts of gannet AOS on Stack Li. Counters were Stuart Murray (SM), Sarah Wanless (SW)) and Mike Harris (MPH). The sections used follow those for the 2004 survey but sub-sections are based on the 'best fit' images for each section in 2013. JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG no.	Section	SM	SW	MPH	Mean
IMG_2961	Top Table East	2,133	2,408	2,168	2,236
IMG_2965_2	Top Table West	5,408	5,935	5,906	5,750
IMG_2965	Bothy Face A	1,090	999	1,082	1,057
IMG_2987	Bothy Face B	384	383	346	371
IMG_2977	Casting Point A	1,179	1,453	1,259	1,297
IMG_2984	Casting Point B	1,310	1,526	1,377	1,404
IMG_2975	Casting Point C	44	46	47	46
IMG_2953	North Face A	1,070	990	957	1,006
IMG_2968_2	North Face B	881	747	819	816

IMG_2968	North Face C	618	491	537	549
IMG_3001	North Face D	448	459	462	456
Stac Li	**Total**	**14,565**	**15,437**	**14,960**	**14,990**

3.1.4 Stac an Armin

Colony status: 13,060 AOS in 2013, 13,921 AOS in 2004. Population probably mainly stable but one area of increase identified (Table 4).

Areas of increase identified between 1994 and 2004 were in the South Centre section and on the East Face. Counts of these areas in 2013 indicated that there has been no further increase or change to colony extent in the former, but a clearly identifiable increase is continuing in the latter. Although there appears to be ample space for the colony to expand into, colony limits have remained largely unchanged since at least 1979 and there is no evidence for changes in nesting density within the present section limits.

Table 4. Counts of gannet AOS on Stac an Armin. Counters were Stuart Murray (SM) and Mike Harris (MPH). The sections used follow those for the 2004 survey but sub-sections are based on the 'best fit' images for each section in 2013. JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG No.	Section	SM	MPH	Mean
IMG_0183	Summit & East Face A	706	734	720
IMG_0182	East Face B	1,559	1,576	1,568
IMG_0181	East Face C	2,718	2,757	2,738
IMG_0184	East Face D	1,809	1,633	1,721
IMG_0178	East Face E	1,531	1,353	1,442
IMG_2912	East Face F	380	326	353
IMG_2946	East Face G	209	178	194
IMG_0179	Low East ledge A	1,383	1,386	1,385
IMG_2916_2	Low East ledge B	79	84	82
IMG_2916	Low East ledge C	66	67	67
IMG_2930	West Face A	623	478	551
IMG_2927	West Face B	466	409	438
IMG_2931	West Face C	131	114	123
IMG_2944	West Face D	17	11	14
IMG_2927_2	South Centre	1,537	1,547	1,542
IMG_0202	Low South ledge	126	124	125
Stac an Armin	**Total**	**13,340**	**12,777**	**13,060**

3.1.5 Sula Sgeir

Colony status: 11,230 AOS in 2013 9,225 AOS in 2004; population increasing after decline (Table 5).

There has been a clear and identifiable increase on the summit ridge of the colony, both in breeding density and colony extent, particularly in Sections 3, 4a, 4b and 6. Elsewhere Section 7 has increased; Section 1 possibly has, but only by a very small number; only Section 2 is unchanged, counts between years being nearly identical. Both colony and section limits are unchanged and there would appear to be ample space for colony expansion; most notably on the lower ledges of Section 3 and the so far wholly unoccupied Section 5. Both these sections hold long established club sites and in 1985 so many were

present in Section 5 it was unclear if the area was used for breeding. Subsequent land and sea visits have shown that it has remained free of breeding, clearly confirmed by the 2013 aerial photographs which show it to be completely gannet free.

Table 5. Counts of gannet AOS on Sula Sgeir. Counters were Stuart Murray (SM), Sarah Wanless (SW)) and Mike Harris (MPH). The sections used follow those for the 2004 survey but sub-sections are based on the 'best fit' images for each section in 2013. JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG No.	Section /sub-section	SM/1	SM/2	SM/3	SM/ mean	MPH	SW	Overall mean
DSC_0065	1/A	65	67	81		74	81	
DSC_0079	1/B	206	204	224		226	229	
DSC_0064	1/C	238	245	242		200	241	
DSC_0105	1/D	124	120	133		130	139	
	1/total	633	636	680	650	630	690	657
IMG_2857	2/A	227	221	229		244	247	
IMG_2857	2/B	111	95	111		112	122	
DSC_0104	2/C	0	0	0		0	0	
	2/total	338	316	340	331	356	369	352
IMG_9941	3/A	413	386	392		401	409	
IMG_9864	3/B	796	878	904		962	906	
IMG_9864	3/C	1,754	1,569	1,551		1,703	1,593	
	3/total	2,963	2,833	2,847	2,881	3,066	2,908	2,952
IMG_9843	4a/A	124	114	110		137	126	
IMG_2858	4a/B	184	153	171		191	186	
IMG_9841	4a/C	1,000	877	969		1,016	980	
IMG-9841	4a/D	1,083	1,064	1,003		1,067	1,103	
	4a/total	2,391	2,208	2,253	2,284	2,411	2,395	2,363
IMG_9996	4b/A	503	426	466		486	492	
IMG_9996	4b/B	614	576	627		834	596	
DSC_0136	4b/C	242	216	283		312	318	
DSC_0134	4b/D	89	78	89		85	98	
	4b/total	1,448	1,296	1,465	1,403	1,717	1,504	1,541
IMG_9974	5	0	0	0	0	0	0	0
IMG_0090	6/A	29	26	32		31	27	
IMG_0041	6/B	241	211	215		181	241	
IMG_9851	6/C	583	527	551		518	593	
IMG_9851	6/D	738	652	696		509	711	
	6/total	1,591	1,416	1,494	1,500	1,239	1,572	1,437
IMG_9988	7/A	1,055	1,006	1,002		1,056	1,003	
IMG_9988	7/B	840	709	702		707	797	
IMG_9893	7/C	170	152	155		128	155	
	7/total	2,065	1,867	1,859	1,930	1,891	1,955	1,925
DSC_0066	Helipad	0	0	0	0	0	0	
Sula Sgeir	**Total**	**11,429**	**10,572**	**10,938**	**10,980**	**11,380**	**11,393**	**11,230**

3.1.6 Sule Stack

Colony status: 4,550 AOS in 2013, 4,618 AOS in 2004; population stable (Table 6).

There have been no changes in numbers or colony extent since at least 1994, which would suggest that the rock is fully occupied. There are unoccupied areas in the North-east, North-west and South sections, but for some unknown reason gannets seem to be unwilling to nest here. Comparison with 2004 photographs show nests were dispersed almost identically in 2013 with the same open areas between them.

Table 6. Counts of gannet AOS on Sule Stack. Counters were Stuart Murray (SM) and Mike Harris (MPH). The sections used follow those for the 2004 survey but sub-sections are based on the 'best fit' images for each section in 2013. JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG No.	Section	SM/1	SM/2	SM/mean	MPH	Overall mean
IMG_2821	South rock	94	86	90	102	96
IMG_2804	Top	1,741	1,566	1,654	1,598	1,626
IMG_2802	Centre	627	569	598	555	577
IMG_2802_2	East	332	311	322	342	332
IMG_2800	South east	632	585	609	585	597
IMG_2780	North east	574	523	549	697	623
IMG_0052	North west A	379	358	369	493	431
IMG_0061	North west B	247	260	254	283	268
IMG_2845	North rock	0	0	0	0	0
Sule Stack	**Total**	**4,626**	**4,258**	**4,442**	**4,655**	**4,550**

3.1.7 Flannan Islands

Colony status: 5,280 AOS in 2013, 2,760 AOS in 2004. Population is increasing rapidly (Table 7).

In 2013 the same sections on Roareim were used for breeding as in 2004, but gannets have not colonized nearby Eilean a Gobha, where displaying pairs were first seen in 1988 and last recorded in 1992. The largest increase and greatest change has been to the sub-colony Roareim South, to differentiate it from the separate Roareim East, where breeding has been suspected but never confirmed. In 2004 and 2013 this section appeared to be occupied entirely by non-breeders, which left the ground on the approach of the aircraft. Aside from having the largest number of AOS, Roareim South has the largest number of non-breeders, which surround the breeding nucleus on all sides. Most of these birds left the ground but not those in sub-section D. Here there are a small number of birds on nests, but most appear to be site holding or paired pre-breeders. There is ample room for colony expansion on the island and at the present rate of increase there will be no point in designating separate South and East sections. The next largest increase has been on Sgeir an Eoin, with a near doubling of numbers since 2004. There appears to be only limited space for further expansion here, similarly on the much smaller West Stack. Main and Arch Stack are clearly full.

Table 7. Counts of gannet AOS on the Flannan Islands. Counters were Stuart Murray (SM) and Mike Harris (MPH). The sections used follow those for the 2004 survey but sub-sections are based on the 'best fit' images for each section in 2013. JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG No.	Section	SM/1	SM/2	SM/mean	MPH	Overall mean
IMG_2874	Roareim South /A	31	26	29	37	33
IMG_2859	Roareim South/ B	227	214	221	262	241
IMG_2857	Roareim South/ C	2,060	1,995	2,028	2,004	2,016
IMG_2875	Roareim South/ D	293	271	282	338	310
IMG_2864	Roareim East	0	0	0	0	0
	Roareim total	2,611	2,506	2,559	2,641	2,600
IMG_0171	West stack	108	113	111	107	109
IMG_2854	Arch stack	148	151	150	172	161
IMG_2818	Sgeir an Eoin	875	901	888	1,073	981
IMG_2808	Main stack A	1,468	1,373	1,421	1,385	1,403
IMG_2859_2	Main stack B	24	24	24	27	26
Flannans	**Total**	**5,234**	**5,068**	**5,151**	**5,405**	**5,280**

3.1.8 Sule Skerry

Colony status: 1,870 AOS in 2013, 55-60 in 2004; population increasing very rapidly (Table 8).

In 2004 the colony held between 55-60 AOS in a tightly structured group on the west side of Stack Geo, and that area now holds in excess of 1000 AOS. The remaining smaller numbers of AOS are on the east side of the geo, separate from the west group. If the colony continues to grow it seems likely that the east and west groups will soon meet up to form a continuous colony around the shoreline of the geo.

Table 8. Counts of gannet AOS on Sule Skerry. Counters were Stuart Murray (SM), Sarah Wanless (SW)) and Mike Harris (MPH). JPEG identifiers for the images used are also shown. Mean section values were combined to give an estimate for the whole colony. The colony mean count is rounded to the nearest 10.

JPEG No.	Section	SM	SW	MPH	Mean
DSC_0024	East	518	510	599	542
DSC_0024_2	West A	654	842	798	765
IMG_9776	West B	433	668	593	565
Sule Skerry	**Total**	**1,605**	**2,020**	**1,990**	**1,870**

3.2 Inter-observer differences

Inter-observer differences for all the colonies except Sule Skerry were less than 10%. Individual colony values were 2.5% for Sula Sgeir (3 counters), 4.7% for Sule Stack (2 counters), 4.8% for the Flannan Islands (2 counters), 0.4% for Boreray (2 counters), 3.7% for Stac Li (3 counters) and 4.3% for Stac an Armin (2 counters). These values were lower than those recorded in the 2004 aerial survey of the same colonies with the same counters, which ranged 3.7 – 14.5% (mean 8.9%) and similar to the mean of 4.0% (range 3.2 – 5.3%) for the three St Kildan sub-colonies in 1994 (Murray & Wanless, 1986, 1997; Wanless, 1987, Wanless *et al*., 2015).

The situation was, however, rather different on Sule Skerry where subtle differences in the criteria used by the three observers to classify AOS resulted in their totals varying according to whether sites along the landward boundaries were classified as AOS or prospecting birds. Inter-observer difference was estimated at 14.8% markedly higher than any of the other colonies despite the quality of images for Sule Skerry being extremely high. Inspection of individual totals revealed that Stuart Murray was consistently more conservative in what constituted an AOS compared to Mike Harris (MPH) and particularly Sarah Wanless (SW). Resolving these uncertainties appears impossible unless all counters count simultaneously and agree the status of each site. In the absence of a land-visit to the colony to ground-truth the aerial count, knowing which of the three counters most closely approximated the true total is unknown. We emphasize that the issue is only acute at colonies such as Sule Skerry that are increasing very rapidly and where the ratio of prospecting to site-holding birds is very high. Well-established colonies typically have many fewer 'edge' birds and thus problems of classifying AOS are much less. 2013 was the first time that Sule Skerry had been surveyed from the air; the 2004 total was derived from a single land-based count where it would have been easier to assess site status.

These results are in line with previous studies that have shown that even when photographs are of high standard and counters are experienced, there can be considerable variation in counts made by different observers, such that totals can vary by up to 13% of the mean (Harris & Lloyd, 1977)

4. DISCUSSION

4.1 Changes in numbers

While numbers of gannets at most British and Irish gannetries have increased in the long-term, strong density dependent effects have been apparent with rates of increase at large, long-established colonies markedly lower than those at smaller, more recently founded ones (Lewis *et al*., 2001; Davies *et al*., 2013). Accordingly, comparing the 2013 counts with those from 2004 indicated that numbers had increased rapidly at the two smallest colonies (Sule Skerry and the Flannan Islands) but had changed little at the largest colony (St Kilda) (Table 9). Although the colony on Sule Stack is relatively small, the count in 2013 indicated little or no overall change in numbers. The medium-sized colony on Sula Sgeir increased by 2.2 % p.a, reversing the change over the previous 10 years when the population declined at 1.2 % p.a.

Table 9. Counts and rates of change of AOS at gannetries in NW Scotland, 2004-13. Details of changes within sections of colonies are presented in Appendix 4.

Colony		**2004**	**2013**	**Change %**	**per annum**
St Kilda	Boreray	32,333	32,240	-0.3	0
St Kilda	Stac Li	13,369	14,990	+12.1	+1.3
St Kilda	Stac an Armin	13,921	13,060	-6.2	-0.7
St Kilda	Total	59,622	60,290	+1.1	+0.1
Sula Sgeir		9,225	11,230	+21.5	+2.2
Flannans		2,760	5,280	+91.3	+7.5
Sule Stack		4,618	4,550	-1.5	-0.2
Sule Skerry		57	1,870	+3200	+47.4
Total		**76,282**	**83,220**	**+9.1**	**+1.0**

Setting the 2013 counts in a longer term context further highlights the rapid increases in numbers at the Flannan Islands and Sule Skerry (Figure 1). Both of these sites appear to have plenty of unused but suitable nesting habitat for gannets and thus have considerable potential for further expansion. The lack of change in numbers on Sule Stack is consistent with the situation over the last 80 years with gannets apparently occupying all the suitable breeding areas so that the colony is probably at maximum capacity. It is possible that the recent colonization and rapid increase of the colony on nearby Sule Skerry, is partly due to the lack of space on Sule Stack.

Although St Kilda poses formidable counting problems it seems clear that a major increase occurred in the 20-40 years after the cessation of harvesting by the St Kildans in 1930, but that since then numbers have been fairly stable (Figure 2), even though there would appear to be plenty of spare nesting habitat on Boreray and Stac an Armin.

Numbers of gannets on Sula Sgeir have also been relatively stable over the last 30 years (Figure 2). This colony continues to be harvested by the Men of Ness. There would appear to be some, although not extensive, unused breeding habitat on Sula Sgeir suggesting that the population may not be at maximum carrying capacity with respect to nest sites. The 2013 count does indicate that numbers of AOS increased over the last 9 years despite continued harvesting. Given that the current harvesting license is for 2000 well-grown chicks per year (equivalent to at least 17% of annual chick production) the capacity for Sula Sgeir to increase from its own production would appear to be relatively limited. The colony may, however, be a sink population with recruits originating from St Kilda and Sule Stack fuelling the increase.

In conclusion, the 2013 survey of NW Scotland gannet colonies confirmed the importance of this region for gannets. St Kilda remains the largest colony in the E Atlantic, although the Bass Rock was also predicted to hold *c.*60,000 AOS around 2012 and thus rival St Kilda in size (Murray, 2011). Conditions in the region also seem favourable for the formation of new colonies with numbers at the newly colonized site on Sule Skerry increasing rapidly and an embryonic colony recorded on Barra Head in 2009. Gannets are also periodically recorded breeding on Rockall although it seems impossible that a colony could be established here given that in stormy conditions waves break right over the rock.

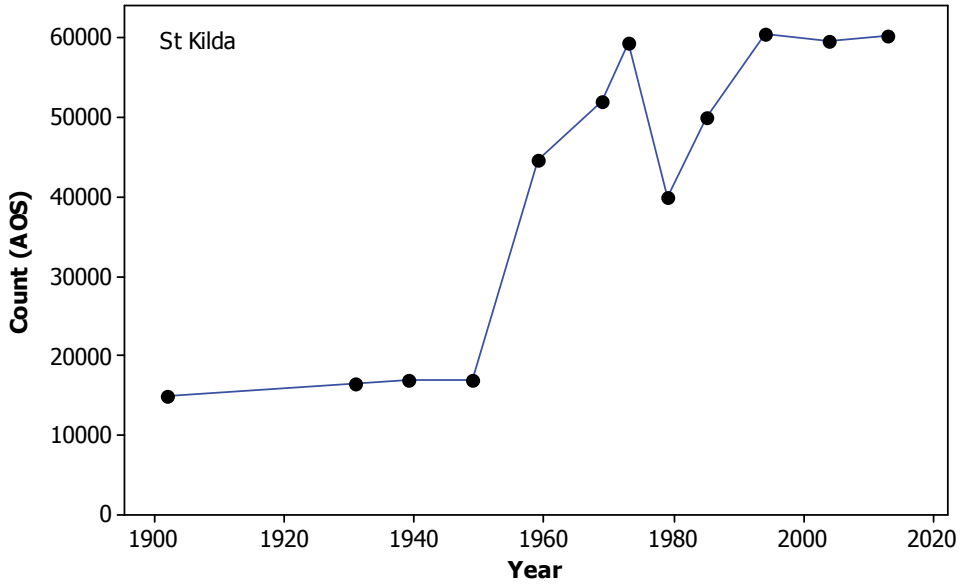

Figure 1. Time series of counts (AOS) of gannets on St Kilda.

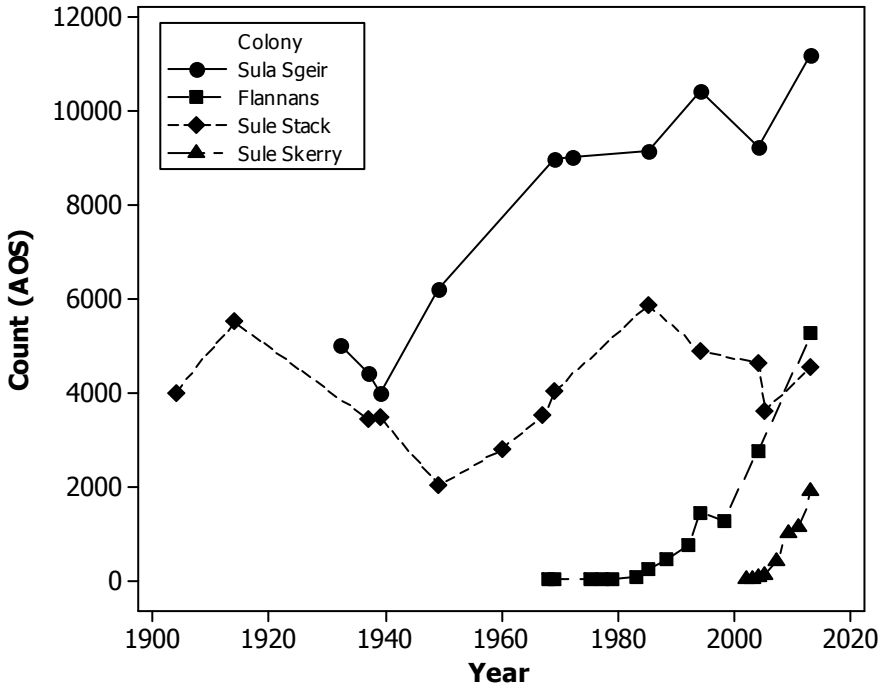

Figure 2. Time series of counts (AOS) of gannets on Sula Sgeir, Flannan Islands, Sule Stack and Sule Skerry.

4.2 Methodological considerations

Methods for aerial surveys of birds at sea, and rookery and haul-out sites of seals, are continuously developing in line with new technology. Thus improved camera systems may well be available for subsequent surveys of gannetries, further improving the quality of images available for counting. It is important however to recognize that methodological advances do not negate the need for detailed knowledge of the structure and layout of the colonies in order to obtain, and crucially to interpret, changes in colony size and extent. For example, if surveys were conducted from higher altitudes than currently, some preliminary lower circuits might still be necessary to disturb non-breeders sufficiently for them to leave the club areas, otherwise distinguishing between AOS and prospectors might become a much more serious and widespread issue.

Methods for counting images are also developing and starting to utilize automated systems. In contrast to previous gannet surveys we used digital cameras in 2013 and images were assessed, manipulated and counted using standard software (Photoshop and Paint Shop Pro 7). This was definitely an improvement from the previous method using high quality A3 prints and/or projected transparencies and was particularly useful for difficult images where the magnification could be varied. Having the completed count sections was also very useful for reference purposes, comparisons between counters and resolving inter-observer inconsistencies. However, there was probably little saving in time compared to the previous method.

During this survey we were approached by Dr David Grémillet who, in collaboration with colleagues at CNRS Montpellier, has been developing an automated method of counting gannet AOS. They have carried out trials for the colony of Rouzic in the Sept Isles off Brittany and provisionally concluded that the method is potentially feasible. Dr Grémillet's group is keen to test the technique with other colonies and we have agreed to send them a sample of images of differing quality that can be compared with our direct counts. It was hoped that results of these comparisons would be available for this report but unfortunately there have been delays compounded by staffing issues at CNRS, so this has not been possible. Clearly in the fullness of time results of these tests will be invaluable for assessing whether an automated counting method is potentially feasible for at least some Scottish gannetries.

In conclusion, while future gannet surveys will probably use at least some of these emerging methods it is essential that work is carried out to compare results from new approaches with current ones and any systematic biases quantified. Without this information it will be impossible to determine whether differences between surveys are due to changes in colony size or methodological differences for example in the definition of the AOS count unit between observer-based and automated methods. Given that the pace and magnitude of environmental change is likely to increase in Scottish waters over the next decade, e.g. as a result of the imminent ban on fishery discards and development of major offshore renewable energy schemes, maintaining the time series of gannet counts will be essential for assessing any impacts on this species.

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APPENDIX 1: SECTION COUNTS IN 2004 AND 2013

(a) Counts (AOS) for St Kilda in 2004 & 2013

Sub-colony	Count Section	Counts (AOS)		Change %	per annum
		2004	2013		
Boreray	1	30	30		
Boreray	2	58	59		
Boreray	3 to 12	1,720	1,724		
Boreray	13 to 15	1,557	1,898		
Boreray	16 to 41	5,505	5,905		
Boreray	42 to 43	1,410	1,445		
Boreray	44	65	64		
Boreray	45	592	425		
Boreray	46	610	588		
Boreray	47	683	705		
Boreray	48	853	741		
Boreray	49	1,043	1,141		
Boreray	50	25	32		
Boreray	51 to 57	4,246	3,707		
Boreray	58 to 63	2,408	2,178		
Boreray	64 to 66	1,342	1,419		
Boreray	67 to 72	1,795	1,759		
Boreray	73	322	280		
Boreray	74 to 78	2,371	1,754		
Boreray	79	542	676		
Boreray	80 to 82	1,919	1,865		
Boreray	83 to 88	2,875	3,235		
Boreray	89	362	601		
Boreray	**Total**	**32,333**	**32,240**	**- 0.3**	**0**
Stac Li	Top Table	7,247	7,986		
Stac Li	Bothy Face	1,273	1,428		
Stac Li	Casting Point	2,242	2,747		
Stac Li	North Face	2,607	2,826		
Stac Li	**Total**	**13,369**	**14,990**	**+ 12.1**	**+ 1.3**
Stac an Armin	South Summit/East Face	9,830	8,734		
Stac an Armin	Lower East Face	1,436	1,533		
Stac an Armin	West Face	1,155	1,125		
Stac an Armin	South Centre	1,431	1,542		
Stac an Armin	Lower South ledge	69	125		
Stac an Armin	**Total**	**13,921**	**13,060**	**- 6.2**	**- 0.7**
St Kilda	**Total**	**59,622**	**60,290**	**+ 1.1**	**+ 0.1**

(b) Counts (AOS) for Sula Sgeir in 2004 & 2013

Count Section	Counts (AOS)		Change %	Per annum
	2004	2013		
1	546	657		
2	337	352		
3	2,350	2,952		
4a	1,944	2,363		
4b	1,121	1,541		
5	0	0		
6	1,339	1,437		
7	1,589	1,925		
Helipad	0	0		
Total	**9,225**	**11,227**	**+ 21.5**	**+ 2.2**

(c) Counts (AOS) for Sule Stack in 2004 & 2013

Count Section	Counts (AOS)		Change %	Per annum
	2004	2013		
South	122	96		
Top	1,582	1,626		
Centre	633	576		
East	351	332		
South East	569	597		
North West	748	699		
North East	615	623		
North	0	0		
Total	**4,618**	**4,549**	**- 1.5**	**- 0.2**

(d) Counts (AOS) for the Flannan Isles in 2004 & 2013

Count Section	Counts (AOS)		Change %	Per annum
	2004	2013		
Roareim East	0	0		
Roareim South	637	2,600		
Main Stack	1,302	1,429		
Arch Stack	145	161		
Sgeir an Eoin	625	981		
West Stack	51	109		
Total	**2,760**	**5,280**	**+ 91.3**	**+ 7.5**

(e) Counts (AOS) for Sule Skerry in 2004 & 2013

Count Section	Counts (AOS)		Change %	per annum
	2004	2013		
East	0	542		
West	57	1,330		
Total	**57**	**1,872**	**+ 3,200**	**+ 47.4**

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ISBN: 978-1-78391-092-2

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All of nature for all of Scotland
Nàdar air fad airson Alba air fad