# Count of Northern Gannets on the Bass Rock in July 2024

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## Summary

A drone survey of Northern Gannets on the Bass Rock was carried out on 29 July 2024, following the protocol of the earlier surveys in 2023 and 2022. The resulting orthomosaic vertical image covered *c.*97% of the colony. Three independent counts of this area gave a mean count of 44,447 Apparently Occupied Sites (AOS) ± 192 standard deviation (SD). After scaling up this value to correct for the missing areas, the total Bass Rock population in 2024 was estimated to be 46,045 AOS. Comparison of the areas counted in both 2023 and 2024 indicated a 6.7% decline in AOS, while comparison of the estimated total population indicated a decrease of around 11%. Thus, there was no evidence of a population recovery after the high pathogenicity avian influenza (HPAI) outbreak in 2022. However, very few dead birds or unattended chicks were recorded indicating no recurrence of HPAI in 2024 and that foraging conditions for parents were favourable.

A detailed analysis of inter-observer variation in counts of AOS was also carried out. Due to the high resolution of the drone image, inter-observer variation is substantially reduced compared to previous surveys using lower quality images from fixed-wing aircraft. Crucially, there was no statistical support that counters differed in how they counted areas varying in size and aspect. Thus, appreciable savings in time and/or expense needed to obtain population counts of gannetries may be possible by reducing the need for replicate counts.

## Introduction

In 2023, a drone survey of the Bass Rock gannetry was carried out by the University of Edinburgh's Airborne Research and Innovation Facility to assess the feasibility of using images from drone surveys to monitor population changes in Northern gannets (*Morus bassanus,* hereafter gannet) following the severe outbreak of high pathogenicity avian influenza (HPAI) at this colony in 2022. The survey covered approximately 85% of the colony and produced a high-resolution orthomosaic vertical image. Three independent counts of Apparently Occupied Sites (AOS, defined as a site occupied by one or two gannets irrespective of whether nest material or a chick is present) in 10 areas previously used for surveys, recorded a mean count of 47,790 AOS, with no evidence of unusual mortality of breeding adults (Harris *et al.* 2023). Assuming the distribution of AOS in 2023 was unchanged since the last survey in 2014, the total Bass Rock population was estimated at 51,844 AOS, 31% lower than in 2014, with a much-reduced density of AOS (Harris *et al.* 2023).

Given the magnitude of the decrease in 2023, it was clearly important to continue monitoring the Bass Rock population as often as possible to 1) check for evidence of adult mortality at the colony that would indicate further HPAI outbreaks and 2) document changes in numbers and dispersion of AOS to provide a detailed description of population changes after the HPAI outbreak. Accordingly, the University of Edinburgh's Airborne Research and Innovation Facility carried out a further drone survey in 2024. This survey covered slightly more of the colony than in 2023 (*c.*97% *cf. c.*85%) and was made a month later (29 July *cf.* 27 June). This meant that well grown, white, downy chicks were visible at some sites as well as adult birds.

In addition to monitoring population changes, the 2024 survey provided the opportunity to assess inter-observer variation in counts of AOS. Results from 2023 indicated that the inter-observer variation associated with high resolution drone images was markedly reduced compared to previous surveys that used lower quality images taken from fixed-wing aircraft (Harris *et al.* 2023). Accordingly, a more detailed assessment of inter-observer variation was carried out in 2024 to determine whether appreciable savings in time and/or cost could be made by reducing the number of replicate counts.

## Methods

*Colony counts*

A photogrammetry survey of the Bass Rock on 29 July 2024 was carried out by the University of Edinburgh's Airborne Research and Innovation group A DJI Matrice 300 RTK UAV (drone) carrying a Zenmuse P1 45MP camera with 35mm lens was flown at 105m in terrain following mode, at a speed of 4ms-1 (70% side lap, 80% end lap), and took approximately 15 minutes to cover the whole Bass Rock. The resulting high resolution geo-referenced orthomosaic vertical image (Figure 1) with a pixel resolution (or ground sampling distance GSD) of 1.36cm was generated. The boundaries of the 14 counting areas used in previous counts of the colony overlaid by the Scottish Seabird Centre (SSC) (Figure 2).

All 14 count areas were counted independently by SL, SW and EB. SW has decades of experience of counting gannets from fixed-wing aircraft surveys and along with EB, took part in the count of the Bass Rock drone survey in 2023 (Harris *et al.* 2023). In contrast, SL had no previous experience of counting gannets although she has extensive experience of other aspects of gannet biology, including collecting behavioural and productivity data using images and footage from the SSC Bass Rock cameras.

All three counters used the software DotDotGoose (Ersts 2023) to mark and count the numbers of 1) pairs of gannets (two adult birds in close physical contact that were assumed to be members of a pair rather than neighbours) and 2) single adult gannets in the colony (Figure 3). Some pairs and single gannets were associated with chicks, which were distinguished from adults by their white, downy plumage. Sites where chicks were present were not counted separately because this separation was not always possible. All counters did however, mark and count numbers of 3) unattended chicks and 4) birds that appeared to be dead on the basis of their body posture (extended neck and outspread wings).

Although the overall quality of the image was extremely good, resolution at the seaward edges was markedly lower. Thus, in count areas 2, 3, 4, 5, 6 and 10, presumed gannets appeared blurred or streaky. This made it difficult to accurately classify some sites in these areas.

Birds in immature plumage were visible in the colony. However, the overall resolution of images was not sufficiently high to make a robust assessment of their numbers and distribution feasible. All counts relate to birds on the ground. Birds in flight, although identifiable by their apparently larger size and body posture, were not counted. For each of the 14 count areas, totals of pairs, singles, and unattended chicks were summed to give estimates of AOS, enabling comparisons with previous counts to be made.

*Inter-observer variation*

Inter-observer variation was investigated by fitting a Generalized Linear Mixed Model (GLMM)using the glmmTMB package in R, with a Poisson error distribution, to analyse the AOS from each count area in relation to counter (1 = EB; 2 = SW; 3 = SL). Count area was included as a random effect to account for variation attributed to count area effects, modelled as follows:

Model 1: AOS $\sim$ counter + (1|count area)

A more complex model was also fitted to investigate inter-observer differences, specifically whether the different counters counted the different count areas in a different way, by including an interaction between counter and count area in the model, as follows:

Model 2: AOS $\sim$ counter $*$ count area +(1|count area)

The two models were compared based on their Akaike Information Criterion (AIC) to determine which model best fitted the data: one with the interaction term or one without.

Counts from area 9 which held markedly more AOS than the other areas, were excluded from the above analysis to reduce overdispersion in the residuals.

All statistical analyses were performed using R version 4.4.2 (R Core Team, 2024).

**Figure 1.** The orthomosaic vertical image from the drone survey on 29 July 2024 used to make the count of Northern Gannets on the Bass Rock in 2024. Image © University of Edinburgh.

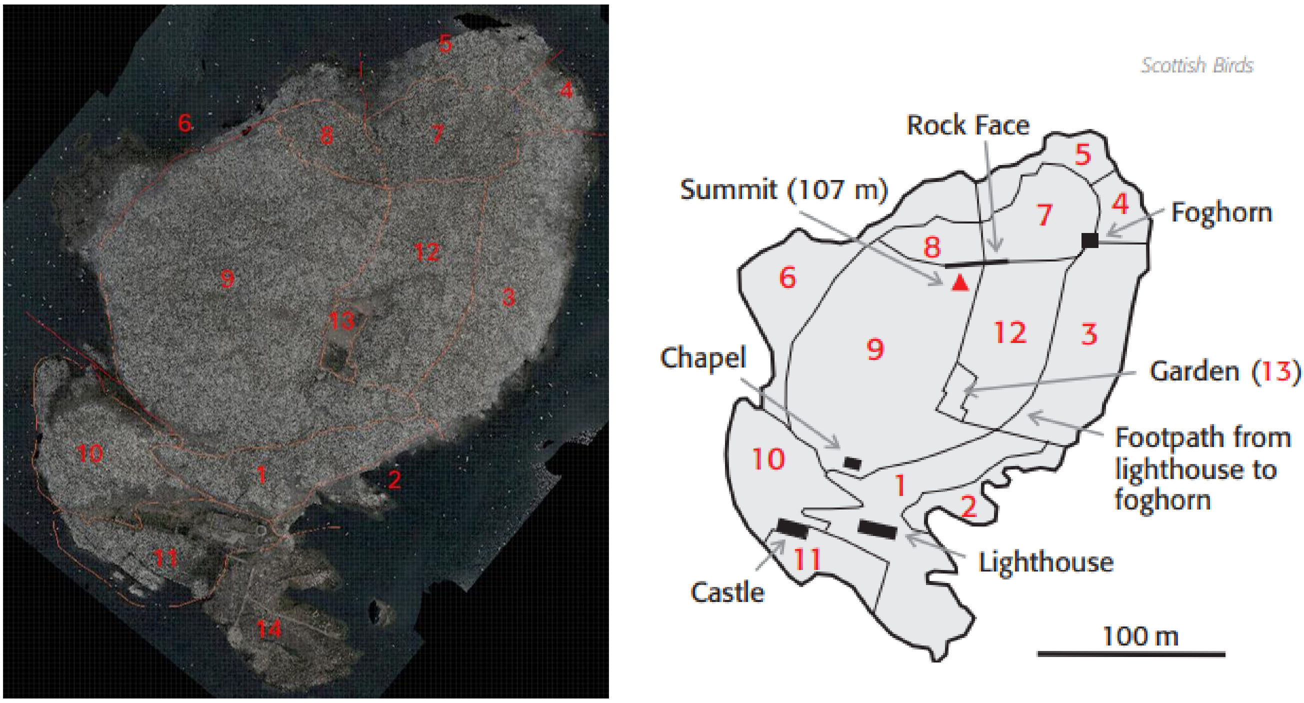


**Figure 2.** (Left) The orthomosaic vertical image from the drone survey on 29 July 2024, demarcated into 14 'count areas'. Image © University of Edinburgh. (Right) Schematic showing topographic features on the Bass Rock in relation to count areas. Courtesy of Scottish Ornithologists' Club.

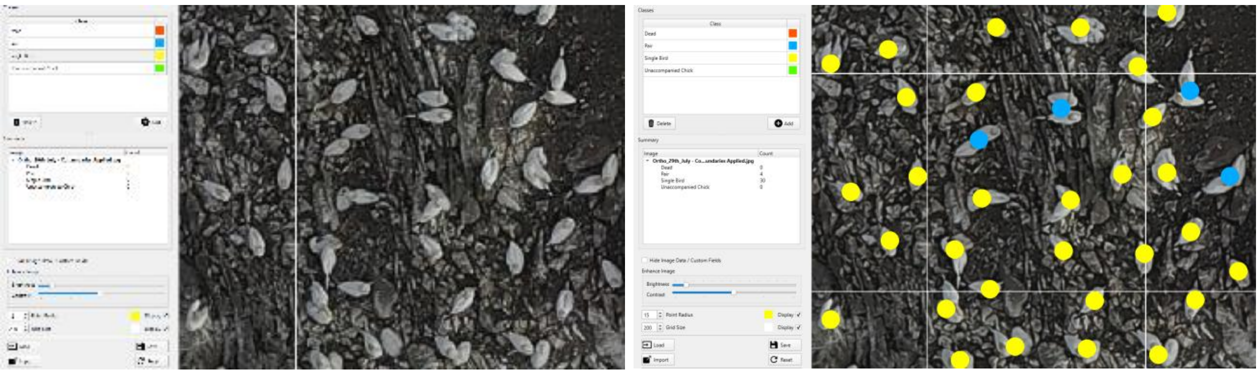

**Figure 3:** The orthomosaic vertical image (© Edinburgh University) open in DotDotGoose (Erst 2023). These two screenshots show the same area, before counting (left) and after counting (right). Two of the four classification categories are present. Yellow dots have been added to single birds (defined in the text), and blue dots have been added to pairs of birds (defined in the text). Many single birds in this image are accompanied by a chick.

## Results

*Coverage*

The 2024 survey covered approximately *c.*97% of the colony, compared to *c.*85% coverage in 2023. However, some areas of the cliffs, particularly areas 4, 5 and 6 (see Figure 4) were still only partially covered with the seaward edges distorted or blurred. These incomplete areas, which amounted to *c.*3% of the Bass Rock colony in 2014 (Murray *et al.* 2015), were excluded from the count, as assessing the exact area missing was deemed highly subjective. If the dispersion of sites remained the same as in the last complete count in 2014, the 2024 raw count of 44,447 AOS was assumed to account for *c.*97% of the total. Accordingly, the corrected total population in 2024 was estimated to be 46,045 AOS (Table 1).

Very few dead birds were recorded in each area (total sum across all areas for each observer was 9, 10 and 9, respectively; range in each area was 0 – 5) and there was similarly little evidence of chicks being left unattended (total sum across all areas for each observer was 56, 47, 27, respectively; range in each area was 0 – 29).

*Timing of the 2024 survey and implications for count units*

The 2024 survey occurred approximately one month later than in 2023 (29 July 2024 *cf.* 27 June 2023). Thus, the breeding season was more advanced, and at many sites white, downy chicks were visible.

In contrast to 2023 when sites were almost exclusively occupied by either one or two adults, in 2024 the situation was more complex and sites were occupied by one adult, two adults, one adult and one chick, or two adults and one chick. In a very few cases sites were occupied by a single unattended chick.

However, the presence of visible chicks could not be used to classify sites as 'breeding' because the adult could have been incubating an egg, brooding a small chick or might have already failed. In addition, counts of chicks, whilst possible for some areas, were not considered to provide robust biological information about breeding success (proportion of sites which fledged a chick in sample areas) or overall productivity (number of chicks fledged from the whole colony). Rather, they provided useful snapshots of the colony midway through the breeding season.

*Comparison of the 2024 count with the count in 2023*

Pairwise comparisons of the areas counted in 2023 and 2024 provided no support for the start of a recovery of the Bass Rock gannet population after the HPAI outbreak in 2022 (Table 1). All areas decreased, in most cases by between 5% and 10%. The biggest decrease (-39%) was in area 13, within the walled garden near the summit of the rock. This is a small area and was one of the last parts of the colony to be colonised. In areas fully counted in both 2023 and 2024, the decrease in AOS was 6.7%.

The corrected total population in 2024 was estimated to have decreased by 11% since 2023. However, it is important to note that this figure includes areas that were not counted (n/c) in 2023 and/or 2024 and have been estimated assuming the same distribution across the areas as the last complete count in 2014 (Harris *et al*. 2023). Crucially, this assumes no systematic among-area variation that may not be valid, and thus, this figure should be treated with caution.

*Inter-observer differences*

Counts of AOS by count area by the three counters and the summary statistics for each area are given in Table 2.

Figure 5 shows the mean ± SE of the unadjusted total count of AOS for each of the three counters from the count areas included in the analysis, highlighting the similarity in counts among observers.

Model 1 did not find any significant differences between counters in AOS (Figure 5). Specifically, the effect of counter2 (SW) was not statistically significant compared to counter1 (EB) (Estimate = 0.0106, SE = 0.0085, z = 1.259, p = 0.208), and similarly, the effect of counter3 (SL) was also not significant compared to counter1 (Estimate = 0.0087, SE = 0.0085, z = 1.027, p = 0.304).

Thus, counts for the three observers were extremely close such that counter 2 was only 0.011 x higher than counter 1 and counter 3 was only 0.009 x higher than counter 1.

The random effect of area had a variance of 6.692, with a standard deviation of 2.587, indicating substantial variation in AOS across areas.

Crucially, the interaction term in model 2 was not significant, providing no support for the counters differing in how they counted the count areas. Specifically, the interaction between counter 2 and area (Estimate = -0.0012, SE = 0.0022, z = -0.534, p = 0.593), and between counter 3 and area (Estimate = -0.0010, SE = 0.0022, z = -0.477, p = 0.633) were both non-significant.

The comparison of AIC values between the two models indicated that the simpler model without the interaction term, had a lower AIC (model 1 AIC: 367.3) compared to the more complex model (model 2 AIC: 371.2), suggesting that the simpler model provided a better fit for the data. Together, these results highlight the lack of evidence for any difference in counts between the counters.

**Table 1:** Counts of AOS in the Bass Rock gannetry in 2014, 2023 and 2024. n/c: no count or incomplete count. All areas of the colony were counted directly in 2014 (Murray *et al.* 2015). Coverages in 2023 and 2024 were 85% and 97% respectively and these values were used to correct the unadjusted totals to estimate the total counts for each year (Harris *et al.* 2023).

| Area | 2014 | 2023 | 2024 | Change 2023 → 2024 |
|---|---|---|---|---|
| 1 | 5149 | 3381 | 3302 | -2% |
| 2 | 294 | 124 | 117 | -5% |
| 3 | 8134 | 5242 | 5240 | 0% |
| 4 | 612 | n/c | n/c | |
| 5 | 567 | n/c | n/c | |
| 6 | 1433 | n/c | n/c | |
| 7 | 9013 | n/c | 3511 | |
| 8+9 | 33321 | 22764 | 20599 | -10% |
| 10 | 4714 | 3419 | 3234 | -5% |
| 11 | 1643 | 1701 | 1576 | -7% |
| 12 | 9932 | 6981 | 6715 | -4% |
| 13 | 447 | 248 | 151 | -39% |
| **Unadjusted total** | 75259 | 43860 | 44447 | |
| **Corrected total** | 75259 | 51844 | 46045 | -11% |

**Table 2:** Total unadjusted counts and summary statistics from the orthomosaic image of Bass Rock obtained from a drone survey on 29 July 2024. The image was counted independently by EB (counter 1), SW (counter 2) and SL (counter 3) and the values shown are the raw counts, mean and standard deviation for each count area. The counting areas are delimited in Figure 2 and the counting units are defined in the text. Numbers in italics indicate that an incomplete count was made in these areas. An estimated 97% of the colony was surveyed and the corrected population total is provided in Table 1.

| Count Area | Counter 1 | Counter 2 | Counter 3 | Mean AOS | SD |
|---|---|---|---|---|---|
| 1 | 3259 | 3311 | 3337 | 3302.33 | 39.72 |
| 2 | 118 | 117 | 117 | 117.33 | 0.58 |
| 3 | 5181 | 5290 | 5250 | 5240.33 | 55.14 |
| 4 | *423* | *439* | *442* | *434.67* | *10.21* |
| 5 | *1580* | *1606* | *1589* | *1591.67* | *13.2* |
| 6 | *655* | *676* | *664* | *665* | *10.54* |
| 7 | 3533 | 3502 | 3499 | 3511.33 | 18.82 |
| 8 | 1506 | 1518 | 1515 | 1513 | 6.24 |
| 9 | 19014 | 19078 | 19165 | 19085.67 | 75.79 |
| 10 | 3206 | 3271 | 3225 | 3234 | 33.42 |
| 11 | 1569 | 1576 | 1583 | 1576 | 7 |
| 12 | 6692 | 6712 | 6742 | 6715.33 | 25.17 |
| 13 | 150 | 152 | 152 | 151.33 | 1.15 |
| 14 | 0 | 0 | 0 | 0 | 0 |

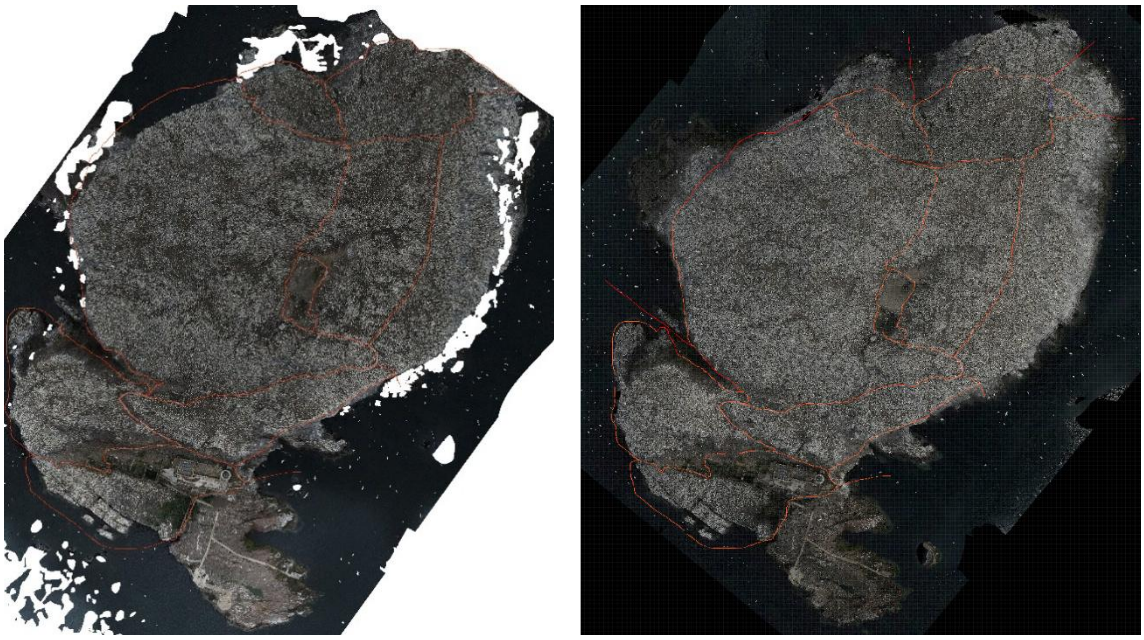

**Figure 4:** Survey coverage of Bass Rock in 2023 (left) covered *c.*85% of the colony. Coverage in 2024 (right) was markedly better (c.97%) except in areas on steep cliff faces around the edges of the rock, particularly areas 4, 5, and 6 (Figure 2), which were still missing. Orthomosaic images (© University of Edinburgh).

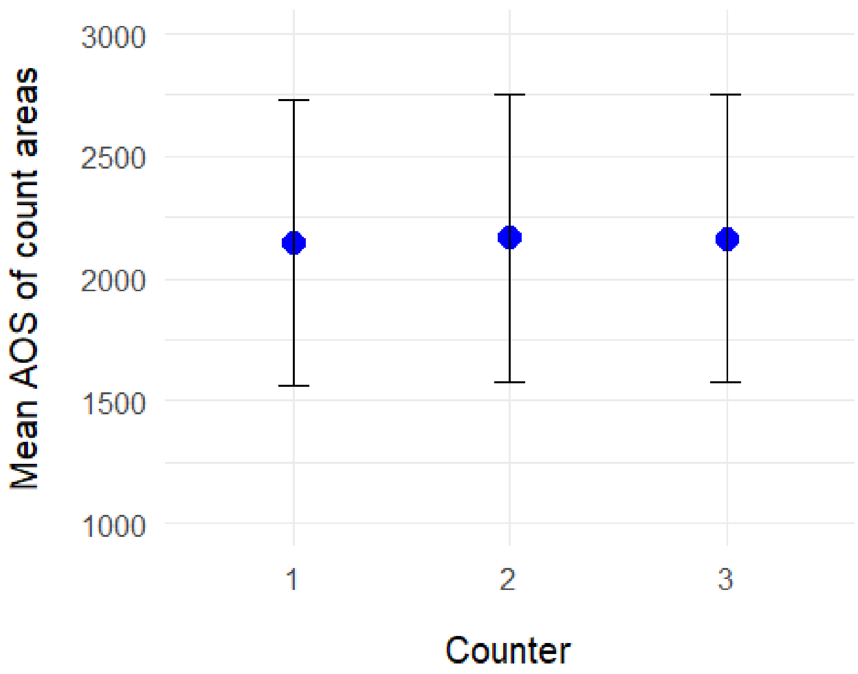


**Figure 5:** Mean ± SE of the unadjusted counts of AOS for each of the three counters from the different count areas used in the analysis of inter-observer differences.

## Discussion

Documenting changes in the population sizes of gannets in the aftermath of the HPAI outbreak in 2022 is a top conservation priority, and assessments are particularly critical for colonies such as the Bass Rock which were severely affected (Lane *et al.* 2024). Prior to the outbreak, Bass Rock was the largest Northern gannet population in the world, holding 75,259 AOS in 2014 and an estimated 81,000 AOS in 2021 (Murray *et al.* 2015; Wanless *et al*. 2023). However, the census in 2023 revealed a dramatic decline of 31% since 2014 and 36% since 2021, associated with a much-reduced density of AOS (Harris *et al*. 2023). The 2024 census was carried out using very similar methods to those in 2023 with two of the counters being common to both years, maximising the chances that any differences in totals could be attributed to demographic rather than methodological causes.

Although the quality of the image used for counting in 2023 was extremely high, coverage of the colony was incomplete (Harris *et al.* 2023). Coverage in 2024 was significantly improved enabling all of area 7 to be counted and partial counts to be made of the cliff areas 4, 5 and 6. Thus, assuming the same dispersion of AOS as in 2014, the proportion of the colony counted directly increased from *c.*85% in 2023 to *c.*97% in 2024. Further improvements in drone techniques will hopefully mean that complete counts of areas 4, 5 and 6 will soon be possible, removing the need for correction factors and enabling direct comparisons of changes in cliff and slope areas to be made (see below).

A notable feature of the 2023 census was the very low inter-observer variability which was attributed to the high quality of the image obtained using the drone (Harris *et al*. 2023). Inter-observer differences were explored in more detail in 2024 and analyses confirmed that there were no statistically significant differences, and crucially, that counters did not differ in how they counted areas varying in size and aspect. These effects were apparent even though counters varied in counting experience. Combined with the results obtained in 2023, there is now compelling evidence that appreciable savings in time and/or cost could be made by 1) reducing the number of replicate counts and/or 2) allocating different sections to different counters which would then be summed to give a population total. The large variation in AOS among area in the analysis was due to the difference in size of the different counting areas included in the analysis.

Pairwise comparisons of the areas counted in 2023 and 2024 indicated that there was no evidence of a colony-wide recovery. Indeed, counts for all areas were lower (Table 1). Overall, the population is similar in size to the mid-2000s (Figure 6). However, the dispersion of AOS is now dramatically different, with sites distributed across the rock at a much lower density compared to the previous high-density dispersion with a distinct colony edge.

Intriguingly, the partial counts of the cliff areas (4, 5 and 6), indicated that decreases from 2014 (the most recent available direct count), were markedly less than in the sloping parts of the colony. The quality of the seaward boundaries of the cliff images in 2024 were poor which means there is considerable uncertainty associated with the area boundaries and hence estimated changes. However, it is possible that gannets in cliff areas were less affected by HPAI because disease transmission was reduced compared to slope areas where the density of AOS was higher. This result further highlights the need to obtain high quality direct counts of cliff areas as soon as possible, in order to compare inter-area changes in AOS and investigate changes associated with breeding habitat. Area-specific changes in AOS also have important implications for scaling up the raw count to give a population total because estimates for slope areas could potentially be overestimated and cliff areas underestimated.

Area 7 was not counted in 2023 due to incomplete survey coverage, but a full count was made in 2024. This provided the first count for this area since the severe HPAI outbreak in 2022. It is noteworthy that, applying the method used to estimate uncounted areas (which relies on data from the last complete colony count in 2014), to area 7 in 2024, gives an estimate of 5798 AOS. Comparing this to the actual mean count for area 7 obtained in 2024 (3511 AOS, Table 1) suggests that the method substantially overestimated the number of AOS. The estimated count for area 7 in 2023 could therefore, also have been a substantial overestimate, which would lead not only to an overestimate of the total number of AOS in 2023, but also to an overestimate of the subsequent decrease in numbers of AOS from 2023 to 2024. This finding further supports the need for complete survey coverage of the colony in future, to eliminate the uncertainty associated with accounting for incomplete areas.

The 2024 drone survey, which was carried out using the same drone, camera and flight parameters, was conducted approximately one month later than in 2023, meaning that breeding was further advanced and white, downy chicks were visible at some sites. Whilst a snapshot survey is not sufficient to obtain a robust assessment of productivity, it was nevertheless very encouraging to confirm that breeding was occurring across the colony. Thus, assuming that post-fledging survival to breeding age is not depressed and that natal fidelity is high, the Bass Rock population could potentially start to show signs of recovery generated by its own output in three to five years time.

A major aim of the first drone survey of the Bass Rock in 2022, and again in 2023, was to identify and compare dead bird numbers to estimate mortality (Tyndall *et al*. 2024). Distinguishing between dead and displaying gannets can be challenging (Harris *et al.* 2023). However, very few dead birds were recorded in 2024 and thus, there was no evidence of major mortality as a result of a further HPAI outbreak. The high quality of the 2023 and 2024 images, which used an upgraded P1 camera (2022 using the L1 camera)  also meant that it was possible to identify unattended chicks. The reduction in population size will potentially have reduced conspecific feeding competition during the breeding season (Lewis *et al.* 2001). The very low number of unattended chicks at the time of the drone survey is consistent with this, indicating that foraging conditions for the parents were favourable.

An advantage of drone surveys over those from fixed-wing aircraft is that pre-breeders and off-duty birds are not disturbed and remain in the colony. Although some gannets in immature plumage were present, there was no evidence of any substantial clubs of immatures such as used to occur on the Bass Rock during the second half of the twentieth century when the colony was increasing (Nelson 1978). The structure of the Bass Rock gannetry after the HPAI outbreak is clearly very different to that in the 1960s to 1990s when gannets were absent from substantial parts of the rock. Thus, currently AOS are dispersed across the rock at a low density, meaning that there are no obvious gaps where clubs could form. Consequently, post-HPAI prospecting and recruitment could be very different processes that might potentially slow population recovery. Having a time series of images of the colony showing the distribution of the colony and the dispersion of AOS will be an invaluable tool for tracking spatial changes in the colony.

In the past, the Bass Rock gannetry was only censused approximately every 10 years. However, the catastrophic decline associated with the 2022 HPAI outbreak is unprecedented (Lane *et al.* 2023, Harris *et al.* 2023). Continuing to monitor the colony annually to obtain as much information as possible remains a high priority, both to add to our fundamental knowledge of gannet ecology and to contribute to effective conservation of gannets in general, and the Bass Rock population in particular.

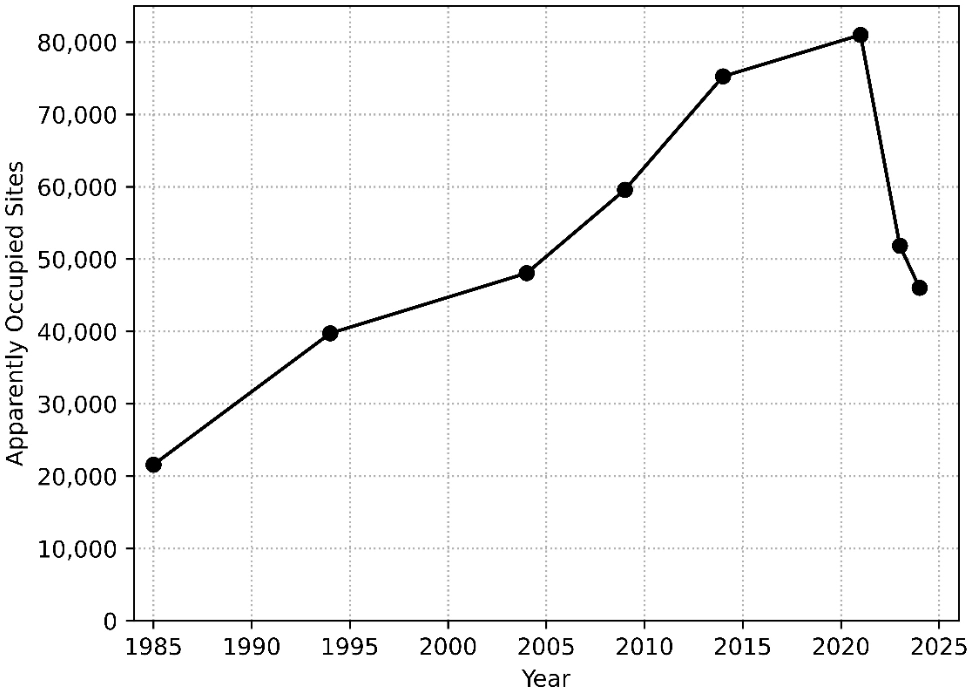


**Figure 6:** Changes in the numbers of AOS on the Bass Rock between 1985 and 2024. Note that the total for 2021 is a derived estimate based on previous population trajectories. Data from Murray & Wanless (1997), Murray *et al.* (2015), Wanless *et al.* (2023), and Harris *et al.* (2023).


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