Count of Northern Gannets on the Bass Rock in July 2025

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Summary

Following the major Highly Pathogenic Avian Influenza (HPAI) outbreak in 2022 which decimated the Northern gannet colony on the Bass Rock, annual surveys have been carried out to document the population recovery. A drone survey on 3 July 2025 achieved approximately 100% coverage of the colony, the first time that full coverage of Bass Rock has been achieved using a drone.

The total population in 2025 was estimated at 52,459 Apparently Occupied Sites (AOS). The close agreement between the surveys in 2023 and 2025, which were conducted at a similar time in the breeding season, suggests the colony may now be relatively stable following the sharp decline in 2022. The population in 2025 remains approximately 30% lower (22,800 fewer AOS) than the last complete pre-HPAI count in 2014, with declines across most count areas and no evidence of a major population recovery.

Building on analyses undertaken in 2024, replicate counts in two count areas confirmed very low inter-observer variability, including among new counters. As a result, most areas in 2025 were counted by a single observer, improving efficiency while maintaining confidence in the results.

Introduction

Seabirds are among the most threatened groups of birds globally, with many species experiencing long-term population declines driven by multiple interacting pressures, including climate change, fisheries interactions, habitat degradation and extreme weather events (Dias et al. 2019). In recent years, disease has emerged as an increasingly significant threat. The outbreak of Highly Pathogenic Avian Influenza (HPAI) during 2022 had unprecedented impacts on wild bird populations across Europe, with colonial seabirds particularly affected due to high breeding densities and close social contact (Klaassen & Wille 2023). Northern gannets (*Morus bassanus*; hereafter 'gannets') were among the most severely impacted species, with rapid spread of infection between colonies and widespread adult mortality resulting in marked demographic consequences (Lane et al. 2023).

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Evidence from subsequent breeding seasons suggests that the effects of HPAI may extend beyond initial mortality, with reduced breeding success recorded at the colony (Lewis et al. 2025).

Bass Rock supports one of the largest known breeding colonies of gannets, making it a critically important site for monitoring population trends in this species. Long-term census data have documented sustained growth in breeding numbers over many decades (Wanless et al. 2023). However, the 2022 HPAI outbreak caused an abrupt and dramatic reduction in adult survival and colony size, fundamentally altering population trajectories and necessitating new approaches to assess population change.

In response to the 2022 HPAI outbreak, drone-based surveys were initiated, supported by the University of Edinburgh's Airborne Research and Innovation Facility (www.ed.ac.uk/airborne), to provide high-resolution spatial data of the Bass Rock gannet colony. The first of these post-outbreak counts was conducted on 27 June 2023 and covered approximately 85% of the colony. Full coverage was not achieved due to challenges with maintaining line of sight with the drone, meaning that count areas 4, 5, 6, and 7 were not fully imaged. The total number of Apparently Occupied Sites (AOS) then was estimated to be 51,844. Comparison of the 2023 count with equivalent count areas surveyed in 2014 indicated a decrease in AOS of 31% (Harris et al. 2023).

A further drone survey was carried out on 29 July 2024, extending coverage to approximately 97% of the colony. The total Bass Rock population in 2024 was estimated to be 46,045 AOS (Burton et al. 2024). Comparison of areas counted in both 2023 and 2024 indicated a further decline of 6.7% in AOS, while comparison of estimated total population size suggested a decrease of around 11%. Inter-observer consistency was also assessed using high-resolution imagery to evaluate differences between counters. Encouragingly, there was no statistical evidence that counters differed in how they recorded AOS across areas varying in size and aspect.

Building on the experience gained during these previous surveys, this report documents the methods and results of the drone survey conducted on Bass Rock in early July 2025. In addition to the standardised count, inter-observer consistency is further examined, building on earlier analyses and examining potential differences between experienced and less experienced counters. By documenting changes in AOS following the HPAI outbreak, this work contributes essential evidence for understanding post-disease population trajectories and the capacity for recovery at one of the world's most important gannet colonies.

Methods

The University of Edinburgh's Airborne Research and Innovation group carried out a survey of the Bass Rock on 3 July 2025. A DJI Matrice 300 RTK UAV (drone) carrying a Zenmuse P1 45MP camera with 50mm lens was flown at 110m in terrain following mode, at a speed of 5 ms-1 (70% side lap, 80% end lap), and took approximately 15 minutes to cover the whole Bass Rock. Additional coverage of the steeper cliff faces around the island, and the steeper slopes at the northern end of the island, was provided by manually flying the aircraft, maintaining ~110m from the terrain and visual line of sight at all times, with the camera on a 1s intervalometer. This process required approximately 10 minutes of additional flight time and was completed mostly during a second flight. This additional

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flight time, along with increasing familiarity with the terrain and local line of sight considerations, facilitated the increased coverage of ~ 100%, compared to 85% in 2023, and 97% in 2024. The resulting high resolution, geo-referenced orthomosaic vertical image (Figure 1) with a pixel resolution (or ground sampling distance GSD) of 0.97cm was generated. This is slightly higher resolution than previous years, when a 35mm lens was used on the same camera, resulting in a 1.36cm resolution. The Scottish Seabird Centre (SSC) then overlaid the boundaries of the 14 count areas used in previous counts of the colony (Figure 2).

Figure 1: Orthomosaic vertical image of Bass Rock taken on 3 July 2025, used to make the count of Northern gannets in 2025. Image © University of Edinburgh.

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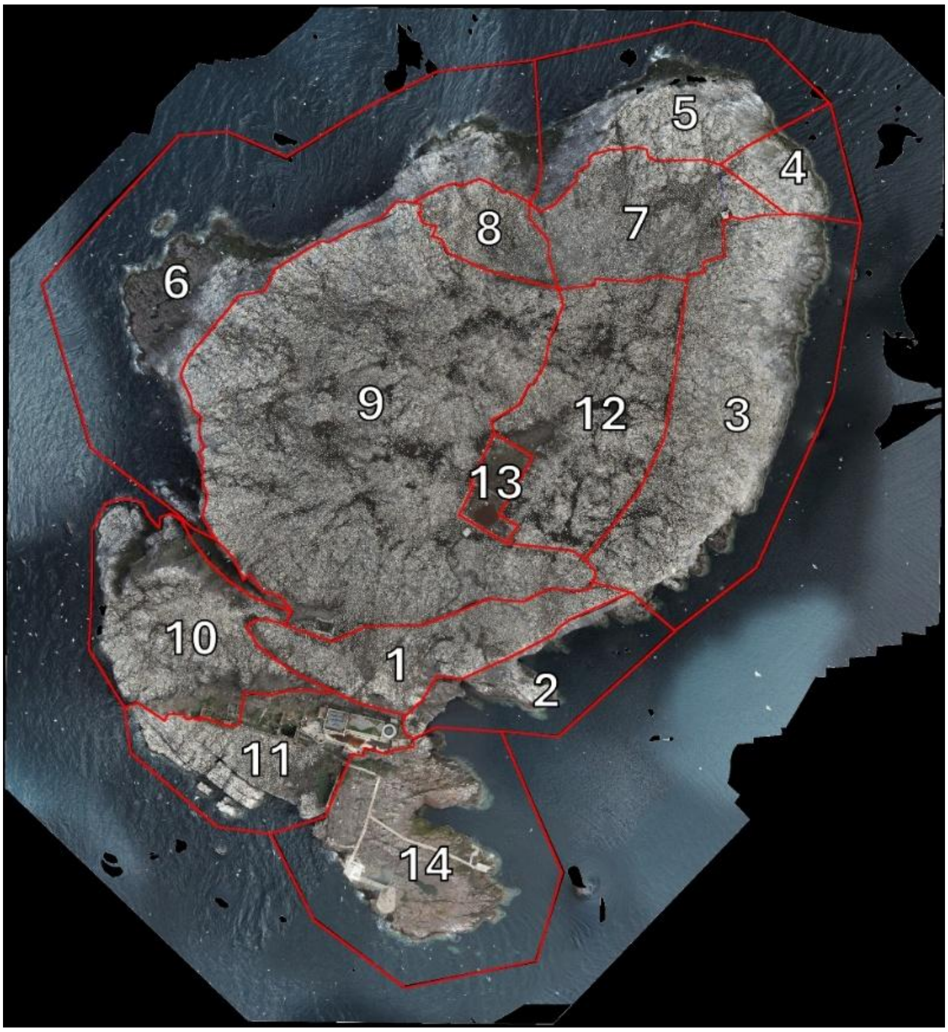

Figure 2: The orthomosaic vertical image of Bass Rock taken on 3 July 2025, demarcated into the 14 'count areas' used in previous counts. Image © University of Edinburgh.

The overall quality of the image was very clear, making site classification straightforward for most of the count areas. However, there were some limited areas of reduced resolution or blurring in Areas 3 and 4, and a larger blurred area on the seaward edge of Area 5, where a small patch of coverage was missing. However, there were no count areas where image quality was insufficient for reliable interpretation, or where coverage was significantly incomplete, and therefore no count areas were excluded from direct counting.

The images were analysed by authors EB, SL, and SW, all of whom were experienced counters and had taken part in previous Bass Rock counts, most recently in 2024. Analysis of inter-observer differences conducted during the 2024 Bass Rock survey demonstrated that counts of AOS derived from high-resolution drone imagery showed no systematic bias between observers and low overall variability (Burton *et al.* 2024). These findings indicated that observer-related differences were substantially reduced compared with earlier surveys, which relied on lower-resolution imagery. In light of this result, the 2025 survey adopted a streamlined counting approach, with each area

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predominantly counted by a single observer. However, to further assess the consistency of our approach, independent counts were completed by all three counters in Areas 5 and 7, and the mean of these results was used to determine the total AOS for each of these areas. These two areas were chosen as they contained differing topography, including relatively level ground in Area 7 and steeper, cliffy ground in Area 5. To assess inter-observer differences with inexperienced counters, two further counters with limited prior counting experience (authors EM and BM) also counted Areas 5 and 7.

As in the previous counts in 2023 and 2024, counters used the software DotDotGoose (Ersts, 2023) to assess 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). In most areas, counters recorded the presence of chicks where visible at sites (distinguished from adults by their size and white, downy plumage), but this was not required for a site to be classified as an AOS. All counters also counted 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).

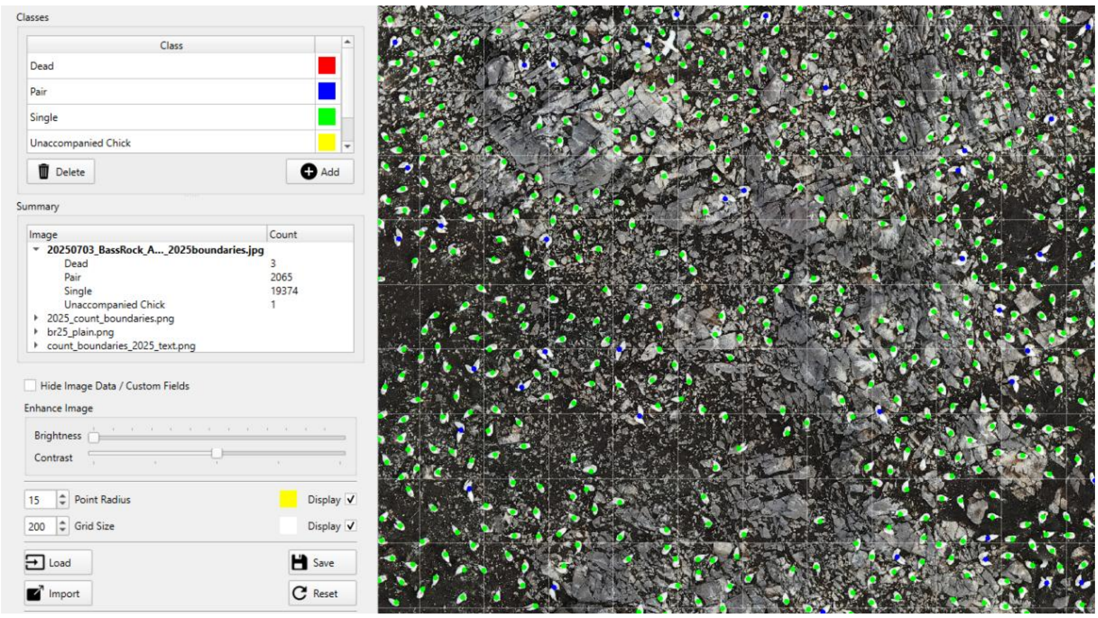

Figure 3: The orthomosaic vertical image (© Edinburgh University) open in DotDotGoose (Erst 2023). Two of the four classification categories are present. Green dots have been added to single birds (defined in the text), and blue dots have been added to pairs of birds (defined in the text).

For each of the 14 count areas, totals of singles, pairs and unattended chicks were summed to give estimates of AOS, enabling comparisons with previous counts to be made. Single birds with distinguishable immature plumage were counted in some areas. However, these were not deducted from the overall count of AOS, as their identification was somewhat subjective and very low numbers were recorded. Birds in flight were not counted at all.

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Inter-observer variation was assessed using Generalized Linear Mixed Models (GLMMs) fitted with the glmmTMB package in R. Models were specified with a Poisson error distribution and log link function to analyse count data. Counts of AOS from two count areas (Areas 5 and 7) were modelled as a function of observer (counter).

Analyses were first conducted using the three experienced counters (1 = EB, 2 = SW, 3 = SL), and then repeated including two additional, less experienced counters (4 = EM, 5 = BM). Count area was included as a random intercept to account for variability between areas (e.g. differences in size or habitat). Model structure was:

AOS ~ counter + (1 | count area)

Equivalent models were fitted for counts of single birds and pairs:

Single ~ counter + (1 | count area)

Pair ~ counter + (1 | count area)

In all models, coefficients for counter represent differences in expected counts on the log scale, relative to the reference observer (EB, counter 1). All analyses were conducted in R (version 4.5.2).

Results

The total Bass Rock population in 2025 was estimated to be **52,459 AOS** (Table 1). Areas 5 and 7 were independently assessed by three counters (authors EB, SL and SW). The means of these areas were combined with the AOS recorded in the remaining count areas, which were each assessed by a single counter. Similar to counts in 2023 and 2024, very few dead birds were recorded in each area (total sum across all areas was 10) and there was similarly little evidence of chicks being left unattended (total sum across all areas was 2).

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Table 1: Total counts from the orthomosaic image of Bass Rock obtained from a drone survey on 3 July 2025. Areas 5 and 7 were counted independently by three counters, and the mean of these counts is shown below. The remaining count areas were counted by a single counter. The counting areas are delimited in Figure 2, and the counting units are defined in the text.

Area	Counter	AOS
1	SL	3505
2	SW	119
3	SL	5606
4	SW	493
5	Mean (EB,SL,SW)	1902
6	SL	945
7	Mean (EB,SL,SW)	4013
8	SW	1713
9	EB	21440
10	SW	3559
11	SL	1810
12	SW	7194
13	SL	160
Total AOS		52459

Coverage

For the first time, drone imagery covered approximately 100% of the colony. A visual assessment of the small gaps in coverage was made with a video rendered from a 3D model of the island, which was generated as part of the same Structure-From-Motion process that created the orthomosaic used in the counts. Using lower-quality images taken from a boat on 17 July, it was possible to confidently identify the missing areas using geological features and confirm that a maximum of 50 AOS were present in total in the uncovered areas (Figure 4). This accounts for less than 0.1% of the total estimated AOS for the colony. This low number of AOS present is not surprising, as it was apparent from the photographs that the missing areas were mostly very sheer or overhanging sections of the cliffs which are unsuitable breeding habitat for gannets.

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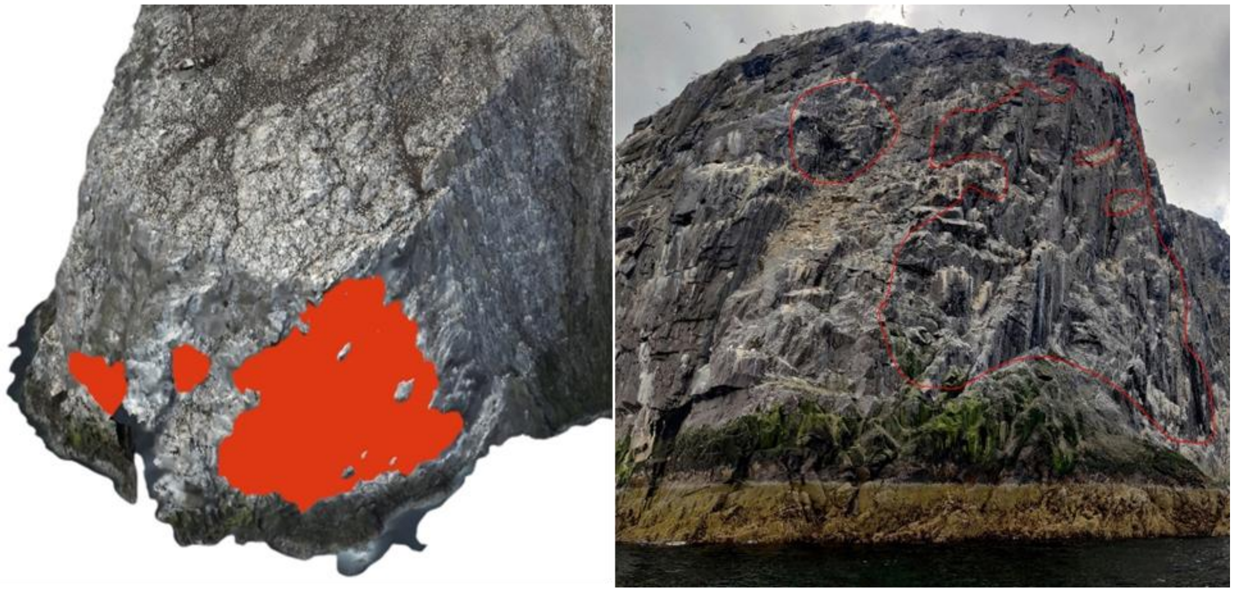

Figure 4: Gaps in coverage were identified on a 3D video produced using the 2025 orthomosaic model (left). Image © University of Edinburgh. These were matched against photographs taken of the cliffs from a boat on 17 July (right), which were uploaded into DotDotGoose to estimate AOS.

While it is probable that a small number of AOS may also be missing or potentially wrongly categorised due to blurring or image distortion in Areas 3, 4, and 5, it is thought that these uncertainties are likely to have very little impact on the overall estimate of AOS.

Timing of the 2025 survey

The 2025 drone survey was carried out on 3 July, more than 3 weeks earlier than the 2024 count (29 July) but within one week of the survey in 2023 (27 June). Some chicks were visible in 2025, but far fewer than had been evident in 2024, when the breeding season was more advanced.

Separate categorisation of pairs or single birds with visible chicks was undertaken in some areas, but these assessments are 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 2025 count with previous counts

The Bass Rock gannet colony increased significantly between 1985 and 2021, before the population sharply decreased due to the outbreak of HPAI in 2022 (Figure 5). The 2025 count achieved approximately 100% colony coverage. It therefore provides the first opportunity to make a direct comparison of all count areas in 2025 with the last full colony count prior to HPAI, which was carried out in 2014 (Table 2). Some care should be taken comparing these results, as the data collection methods differ (photographs from a fixed-wing aircraft *cf.* photographs from a drone). Different

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counting software was also used (Paintshop Pro *cf.* DotDotGoose), but AOS was the count unit for both surveys. Comparison of the two counts shows a total population decrease of 30% between 2014 and 2025, representing a reduction of 22,800 AOS. The majority of count areas decreased, in most cases between 20% and 40%. In contrast, two of the smaller count areas have increased since 2014, with Area 5 showing a dramatic increase of 235%, from 567 to 1902 AOS (Figure 6).

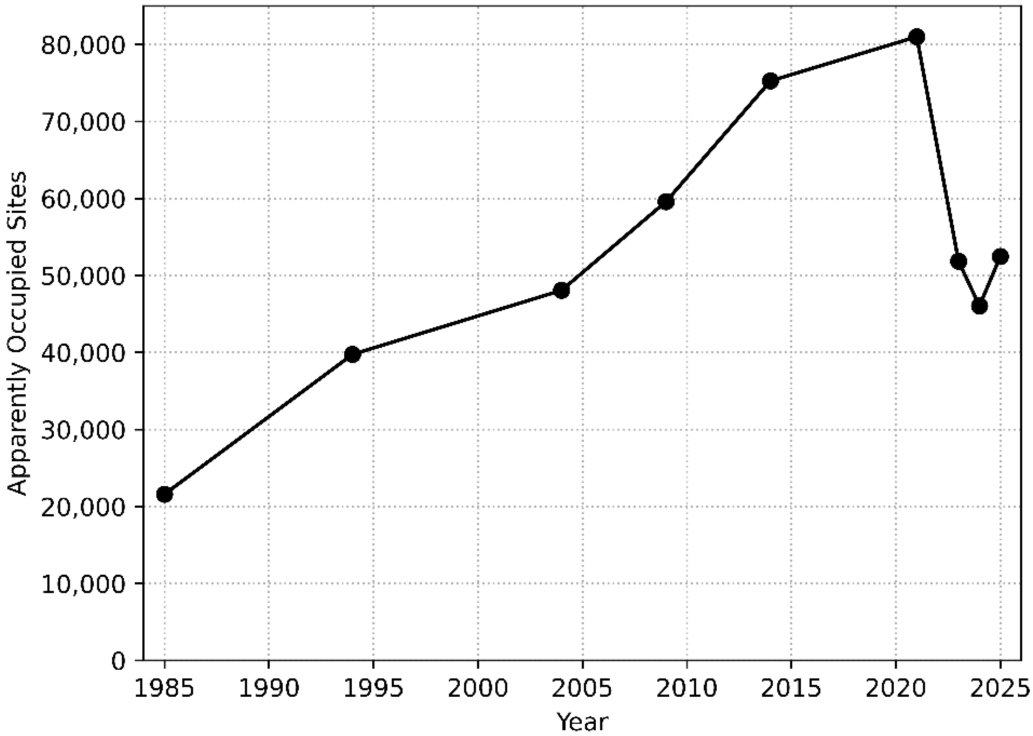

Figure 5: Changes in the numbers of AOS on the Bass Rock between 1985 and 2025. Note that the total for 2021 is a derived estimate based on previous population trajectories. Data from Murray & Wanless (1997), Murray et al. (2015), Wanless et al. (2023), Harris et al. (2023), and Burton et al. (2024).

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Table 2: Counts of AOS in the Bass Rock gannetry in 2014, 2023, 2024 and 2025. n/c: no count or incomplete count. Complete coverage of the colony was achieved in 2014 (Murray et al. 2015) and 2025. Coverages in 2023 and 2024 were 85% and 97% respectively and the results of the 2014 count were used to correct the unadjusted totals to estimate the total counts for each year (Harris et al. 2023).

Area	2014	2023	2024	2025	Change 2014 → 2025	Change 2023 → 2025	Change 2024 → 2025
1	5149	3381	3302	3505	-32%	4%	6%
2	294	124	117	119	-60%	-4%	2%
3	8134	5242	5240	5606	-31%	7%	7%
4	612	n/c	n/c	493	-19%		
5	567	n/c	n/c	1902	235%		
6	1433	n/c	n/c	945	-34%		
7	9013	n/c	3511	4013	-55%		14%
8+9	33321	22764	20599	23153	-31%	2%	12%
10	4714	3419	3234	3559	-25%	4%	10%
11	1643	1701	1576	1810	10%	6%	15%
12	9932	6981	6715	7194	-28%	3%	7%
13	447	248	151	160	-64%	-35%	6%
Unadjusted total	75259	43860	44447	52459	-30%		
Corrected total	75259	51844	46045	52459	-30%	1%	14%

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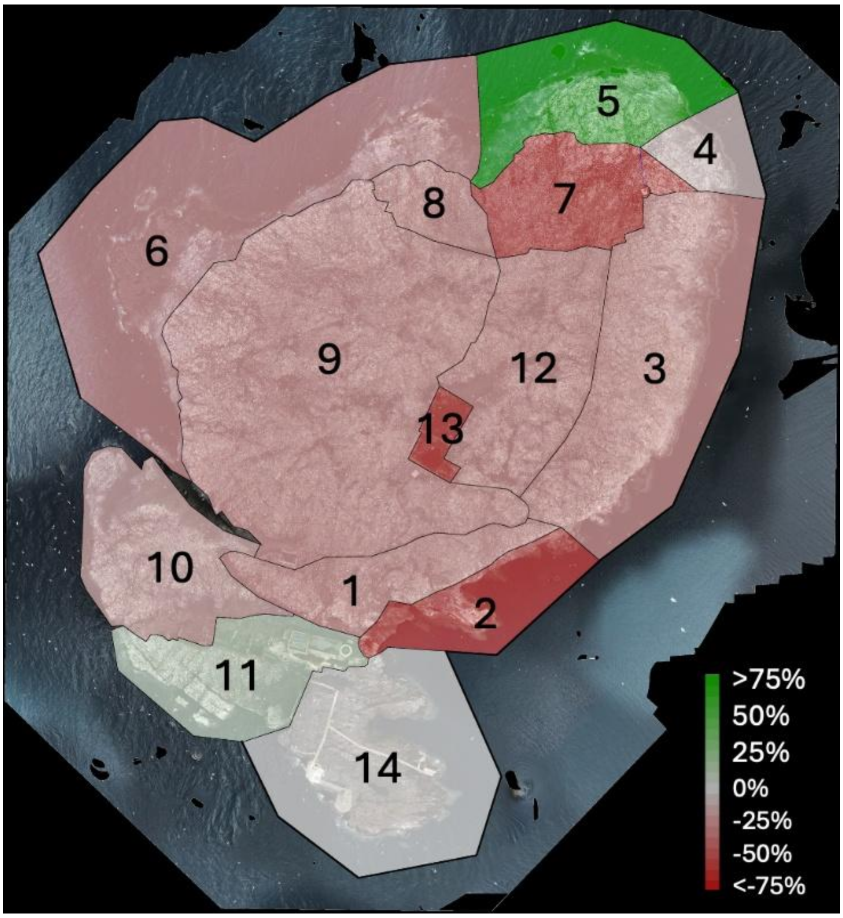

Figure 6: Percentage change of gannet population by count area between 2014 and 2025 (see Table 2).

By 2014, the colony had little capacity for further expansion and, using comparisons of subsequent imagery and field observations, Wanless *et al.* (2023) suggested that the population was likely to have reached around 81,000 AOS by 2021. If this figure accurately reflects colony size immediately prior to the HPAI outbreak in 2022, then the 2025 colony count suggests that AOS may have declined by approximately 35%, equating to a loss of more than 28,500 AOS from the colony.

Areas counted in 2025 increased against the same areas counted in 2024, showing changes between 2% and 15% (Table 2). However, it is important to note that the later survey date in 2024 (29 July) may have impacted count results.

Inter-observer differences

AOS in most count areas were conducted by a single observer. To verify consistency, AOS in Areas 5 and 7 were assessed independently by all three experienced counters participating in the 2025 count (EB, SL, and SW). In the GLMM, estimated coefficients for counter represent differences in expected counts on the log scale, relative to EB (counter 1). There were no statistically significant differences among the experienced counters: compared to EB, the estimated log-scale difference for SW (counter 2) was -0.0025 (SE = 0.0184, z = -0.138, p = 0.890), and for SL (counter 3) it was 0.0030 (SE =

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0.0184, z = 0.165, p = 0.869). These extremely small effect sizes (close to zero) indicate that counts were effectively identical among the experienced observers.

Two additional counters with very limited prior experience also assessed these areas. Including all five counters in the model, estimated differences relative to EB remained very small (all within ±0.02 on the log scale) and none were statistically significant. For example, the estimated differences were -0.0056 for EM (counter 4; SE = 0.0184, z = -0.304, p = 0.761) and -0.0147 for BM (counter 5; SE = 0.0185, z = -0.794, p = 0.427), indicating that counts recorded by all five observers were effectively equivalent in Areas 5 and 7 (Figure 7).

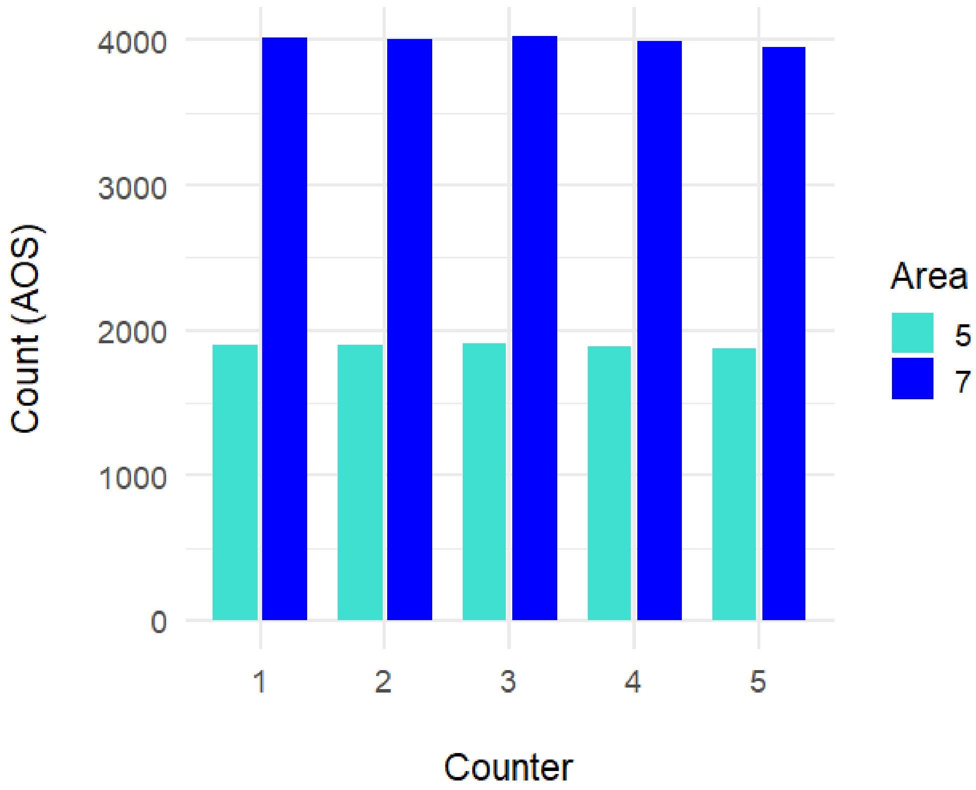

Figure 7: AOS for each of the five counters (counters 4 and 5 with no prior experience) in Areas 5 and 7, shown to illustrate negligible inter-observer differences.

Differences between counts of single birds and pairs among all five observers in Areas 5 and 7 were also examined (Table 3). The GLMM for single birds showed no statistically significant differences among observers. Relative to EB (counter 1), estimated log-scale differences were -0.0043 for SW (counter 2; SE = 0.0193, z = -0.222, p = 0.824), -0.0024 for SL (counter 3; SE = 0.0193, z = -0.125, p = 0.900), -0.0154 for EM (counter 4; SE = 0.0194, z = -0.794, p = 0.427), and -0.0310 for BM (counter 5; SE = 0.0194, z = -1.593, p = 0.111).

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Table 3: Counts of single adult gannets, pairs of gannets, and resulting AOS recorded independently by five counters (EB, SW, SL, EM, BM) in Areas 5 and 7 of the colony. These areas were used to assess inter-observer variability in AOS estimates. No unattended chicks were recorded by any of the counters in these areas. The lines highlighted in grey are the counts made by the main counters (EB, SL, SW), which were used to establish the AOS for Areas 5 and 7.

Area	Single	Pair	AOS	Counter
5	1694	204	1898	EB
5	1695	202	1897	SW
5	1698	212	1910	SL
5	1668	218	1886	EM
5	1653	222	1875	BM
7	3686	330	4016	EB
7	3662	340	4002	SW
7	3669	353	4022	SL
7	3630	365	3995	EM
7	3563	390	3953	BM

The GLMM for counts of pairs showed no statistically significant differences for four of the five observers. Relative to EB (counter 1), estimated log-scale differences were 0.0149 for SW (counter 2; SE = 0.0610, z = 0.244, p = 0.807), 0.0564 for SL (counter 3; SE = 0.0604, z = 0.935, p = 0.350), and 0.0878 for EM (counter 4; SE = 0.0599, z = 1.466, p = 0.143). However, there was a statistically significant difference between EB and BM (counter 5), with an estimated log-scale difference of 0.1363 (SE = 0.0592, z = 2.302, p = 0.021), indicating slightly higher counts recorded by BM.

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Discussion

The 2025 drone survey provides the first approximately 100% coverage of the breeding population of gannet on Bass Rock since before the outbreak of HPAI in 2022. This marks an important milestone, firstly because drone-based surveys are now directly comparable to previous surveys using fixed wing aircraft and handheld digital cameras and secondly, in understanding the trajectory of population recovery at this internationally significant gannet colony. The estimate of 52,459 AOS indicates an increase relative to the estimated totals derived from the post-outbreak surveys in 2023 and 2024. In particular, when compared with the 2024 estimate of 46,045 AOS, the colony appears to have increased by roughly 14% (Table 2).

However, the apparent increase between 2024 and 2025 should also be interpreted in the context of survey timing. The 2025 survey, undertaken on 3 July, was more than three weeks earlier than the late-July survey in 2024. The recent Bass Rock surveys discussed in this report (conducted in 2023, 2024, and 2025) were completed within the accepted survey window for breeding gannets of June or July (Walsh et al. 1995). However, ideally counts should take place during the peak of the breeding season, typically in the first three weeks of June. Counts made later in the season may be influenced by breeding failure and non-attendance of unsuccessful adults, which can reduce the number of AOS recorded. Although AOS methodology is designed to minimise this issue, phenological differences can still affect the detectability of sites in the colony.

The closer alignment in timing between the 2025 and 2023 surveys and results, which were conducted within one week of each other and indicate a difference of just 1.2% (51,844 AOS in 2023 and 52,459 AOS in 2025), lends support to the view that there is little evidence of any recovery in the Bass Rock gannet population since the HPAI outbreak .

The longer-term comparison with the last complete pre-HPAI census in 2014 suggest that the colony remains substantially reduced. The 2025 total is around 30% lower than in 2014, equivalent to a loss >22,000 AOS. This significant drop in population means that St Kilda has now overtaken Bass Rock as the world's largest colony of Northern gannets, with a population of approximately 59,205 AOS counted in 2023 (Nisbet et al*.* 2025).

Most count areas on Bass Rock show declines of between one-fifth and two-fifths, indicating that the reduction has been widespread rather than concentrated in a small part of the rock. Two small areas (Area 2, -60% and Area 13, -64%) and one larger area (Area 7, -55%) show the most significant declines since 2014. These areas cover both relatively level ground and steeper, cliff areas, suggesting that declines were not only concentrated in flatter areas. The few localised increases, most notably in Area 5, may be somewhat influenced by the redistribution of birds into sections of suitable habitat vacated after the mortality event, rather than genuine expansion. It is also possible that some area specific comparisons could be influenced by slight changes to count area boundaries between 2014 and 2025.

The principal methodological change to be considered when comparing results between 2014 and 2025 was the move from fixed-wing aircraft to drone-based image capture, together with the removal of any controlled disturbance to flush non-breeding birds before the images were captured. These changes in method, combined with the uncertainty created by changes in colony dynamics

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since HPAI, mean that producing robust productivity data for the Bass Rock colony is of increased priority. This data will allow us to better assess and understand how breeding success and site occupancy at plots across the colony interacts with count results.

Only small numbers of dead birds were visible in the 2025 imagery, and there was little evidence of widespread site abandonment at the time of the survey. While this cannot be taken as a direct measure of adult survival or breeding success, it is consistent with field observations that high mortality associated with HPAI has not occurred since 2022.

Methodologically, the 2025 survey demonstrates the continued improvement of the drone-based approach, compared with the surveys in 2023 and 2024. Almost full colony coverage was achieved in two short flights, and independent replicate counts in the test areas again showed no statistical differences between observers AOS counts. These findings reinforce the conclusions of the 2024 assessment that high-resolution orthomosaic images from drones substantially reduce observer counting error and bias, and thus that appreciable time savings can be achieved because replicate counts of areas are no longer required.

Further inter-observer analyses showed that AOS estimates produced by observers with little or no prior counting experience were comparable with those of experienced counters. Across Areas 5 and 7, differences in total AOS among all five observers were extremely small and none were statistically significant, indicating a high level of consistency in site classification from the drone imagery.

However, some differences emerged when examining the underlying components of these counts. While the numbers of single birds recorded did not differ significantly among observers, the counts of pairs showed a small but statistically significant difference between the reference observer (EB) and one of the less experienced counters (BM). This suggests that, although overall AOS estimates remain highly consistent, identification of pairs is more subjective and may be more sensitive to observer experience. This should be taken into account when using counts from less experienced observers for more detailed analyses, such as developing or validating machine-learning approaches or other studies that rely on finer-scale classification within the imagery.

The very small number of AOS inferred to lie within gaps or blurred sections of imagery (<0.1% of the colony) is unlikely to affect conclusions at the colony scale. Further improvements in survey methodology will hopefully mean that high-resolution coverage is achieved for the whole colony in future. However, it is recommended that high resolution images of the cliffs should be captured from a boat on the same day as the drone survey is completed, allowing these to be analysed where gaps are identified in the drone coverage.

Taken together, the results from the 2023, 2024 and 2025 surveys suggest that the Bass Rock population, while still far below its pre-HPAI size, is currently stable (Figure 5). Thus, detecting signs of a population recovery will require further surveys over the coming years, ideally at standardised times in the breeding season and using the now-established analytical framework. Given the global importance of Bass Rock for gannets, maintaining this continuity will be critical for interpreting the long-term consequences of HPAI and for placing local trends in a wider North Atlantic context.

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