Monitoring the breeding success of Common Guillemots *Uria aalge*: the value of multiple plots

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Abstract

Results from seabird monitoring programmes are increasingly being used to assess the state of the marine environment, but data are time consuming to collect. We used monitoring data from a colony of Common Guillemots *Uria* aalge in the North Sea to determine whether temporal changes in breeding success over a 34-year period were reflected in six consistently monitored plots and if individual plots showed significant differences in breeding success. Annual mean breeding success showed a four-fold difference over the study period varying from 0.261 to 0.848 young fledging per pair laying. Although the annual pattern of change was broadly reflected in all six monitoring plots there were significant differences in annual breeding success and changes in breeding success over time among the plots. Monitoring any single plot thus gave an approximate indication of the overall patterns of change over time, including periods when breeding success was reduced. However, significant among plot differences indicated that at least at this colony, robustness of colony level estimates of breeding success and changes over time were improved by monitoring multiple plots.

Introduction

The Seabird Monitoring Programme (SMP) was established in 1986 with the aim of ensuring that sample data on breeding numbers and breeding success of the 25 species of seabird that regularly breed in Britain and Ireland are collected to enable their regional and national conservation status to be assessed. The SMP is led and coordinated by the UK Joint Nature Conservation Committee (JNCC) in partnership with other organizations (http://jncc.defra.gov.uk). Monitoring the status of the Common Guillemot (henceforth Guillemot) *Uria aalge* is a high priority since the species is widespread around the coasts of Britain and Ireland and is known to be at risk from multiple anthropogenic threats such as oiling, drowning in fishing gear, accumulation of toxic chemicals and heavy metals, as well as extreme storm events resulting in wrecks (Bourne 1976; Mitchell *et al*. 2004). Considerable effort has been invested in developing appropriate protocols for monitoring the numbers of this species in terms of the timing and numbers of counts and the number of sample plots needed to allow changes over time to be assessed statistically (Birkhead & Nettleship 1980; Anker-Nilssen *et al*. 1996; Sims *et al*. 2006, 2007). However, no comparable evaluation has been carried out on protocols for monitoring breeding success.

Figure 1. Part of Plot 2 used for monitoring the breeding success of Common Guillemots *Uria aalge* on the Isle of May, 8 May 2015. This plot consists of broken cliff and large stones. © *Mike P. Harris*.

Figure 2. Part of Plot 3 used for monitoring the breeding success of Common Guillemots *Uria aalge* on the Isle of May, 7 May 2017. On this wide ledge, more than 60% of incubating birds were touching at least two neighbours. This year, 91 pairs bred in the area covered by the photograph. Documenting breeding success in such groups is only possible when the birds can be viewed from above. © *Mike P. Harris*.

The current recommendations for monitoring the breeding success of the Guillemot given in the *The Seabird Monitoring Handbook for Britain and Ireland* suggest following five or more plots of about 50 breeding pairs selected randomly or otherwise dispersed through the colony to include a range of different breeding habitats, with checks made every 1–2 days (Walsh *et al*. 1995). To our knowledge, no assessment of whether this level of replication of the number of study plots is adequate to provide a robust estimate of changes of breeding success at a colony level has been made. From a practical point of view, such an assessment is needed because monitoring breeding success of Guillemots is time consuming. For instance, Birkhead & Nettleship (1980) considered that it took 3 hours per day to follow a sample plot of 80 pairs. Since in Britain and Ireland breeding at any colony spans about three months it is not surprising that few studies have monitored more than 2–3 plots and some rely on estimates from a single plot.

The Isle of May, Firth of Forth, southeast Scotland is one of the four key UK SMP sites (the others being Fair Isle, Shetland, Skomer, southwest Wales, and Handa/Canna, northwest Scotland), where detailed monitoring of seabird numbers and breeding success are undertaken under contract to JNCC. On the Isle of May, breeding success of Guillemots has been monitored by checks of six plots several times a day throughout the entire breeding season since 1984. Results of this work have been used extensively to investigate the effects of changing conditions in the North Sea and to construct integrated population models of this Guillemot population (Kokko *et al*. 2004; Ashbrook *et al*. 2010; Newell *et al*. 2015; Lahoz-Monfort *et al*. 2017). Here we use individual monitoring plot data to assess whether overall temporal patterns of change were similar and whether there was evidence of significant differences in mean breeding success among the plots.

Methods

We followed the breeding success of all pairs of Guillemots breeding within six clearly defined study plots dispersed along c.100 m of cliff on the Isle of May, Firth of Forth, Scotland (56°11'N, 2°34'W) between 1984 and 2017. These plots have held breeding Guillemots since at least 1973, and probably much longer, and at the start of the study all had room for an increase in the numbers of pairs. The plots were chosen to cover a range of cliff types and bird densities (Table 1). All but one (Plot 3; see Figure 2) extended from above the cliff top down to sea level. Examples of plot topography are given in Figures 1 & 2. These plots covered a mean (± SD) of 5.6 ± 0.5% of the Isle of May breeding population each season. The methodology remained constant throughout the study with visual checks made from permanent hides located 10–30 m from the birds following protocols described by Birkhead & Nettleship (1980).

Breeding sites were numbered on large photographs taken from the hides (Figure 3) and each was checked 2–5 times daily by an experienced observer from before the first egg was recorded until the last chick had fledged from the plots (Harris & Wanless 1988). This intensity of observations was possible since we were resident on the island and the plots were located within 200 m of our accommodation. Most

Table 1. Details of study plots used to measure breeding success on the Isle of May 1984–2017.

Plot	Mean ± SD no. of pairs	Density score[1]	Cliff structure
1	235 ± 23	24	Narrow ledges, broken cliff-top
2	196 ± 48	21	Broken cliff and large stones
3	272 ± 24	64	Wide, flat ledge
4	62 ± 8	11	Broken cliff and small ledges
5	44 ± 5	17	Broken cliff and small ledges
6	29 ± 7	46	Narrow ledges
Total	838 ± 93	35	

[1] Percentage of incubating birds that were in contact with two or more other incubating birds at the start of the study or when a new site was first bred at.

Table 2. Breeding success (young fledged per pair laying) of Common Guillemots *Uria aalge* in six study plots on the Isle of May 1984–2017. Also shown are the number of years in which that plot had the highest or lowest success in a year. Plots 5 and 6 were joint lowest in one year.

Plot	Years	Mean success ± SD	Lowest	Highest	Highest in year	Lowest in year
1	34	0.6962 ± 0.1313	0.2432	0.8472	2	4
2	34	0.7497 ± 0.1123	0.3877	0.8968	13	0
3	34	0.7329 ± 0.1364	0.2519	0.9023	4	1
4	34	0.7117 ± 0.1560	0.1724	0.9231	6	9
5	34	0.6900 ± 0.1536	0.1905	0.8889	4	9
6	34	0.6846 ± 0.1201	0.3226	0.8333	5	12
Annual mean	34	0.7109 ± 0.1235	0.2614	0.8480		

young Guillemots 'fledge' i.e. are taken to sea by the male parent, in the late afternoon or evening to complete their growth at sea (Figure 4). Breeding was taken to have been successful if a chick aged ≥ 15 days old was absent during the check the following morning. Each year, breeding success of a plot was expressed as the number of young fledged divided by the number of pairs that laid in the plot and an annual measure of success for the colony was estimated as the mean of the six plots. Estimates of colony level breeding success obtained from pooling data across plots gave very similar annual estimates to values derived from plot means (pairwise correlations: $r = 0.99$; $P < 0.001$, $n = 34$ years), suggesting that the variation in sample size among plots did not have a large impact on breeding success. However, to test formally whether plots differed in breeding success, we fitted a generalized linear mixed model (GLMMs) in Genstat with a binomial error structure. We fitted plot, linear year, quadratic year, a plot by linear year interaction and a plot by quadratic year interaction as fixed effects, and year as a categorical random effect.

Results

Annual breeding success of Guillemots on the Isle of May was high during the 1980s and 1990s, then declined to a low in 2007 before recovering to a high level again during the 2010s (Figure 5a). The mean (± SD) breeding success over the 34 years was 0.711 ± 0.123 chicks fledged/pair that laid but varied greatly being

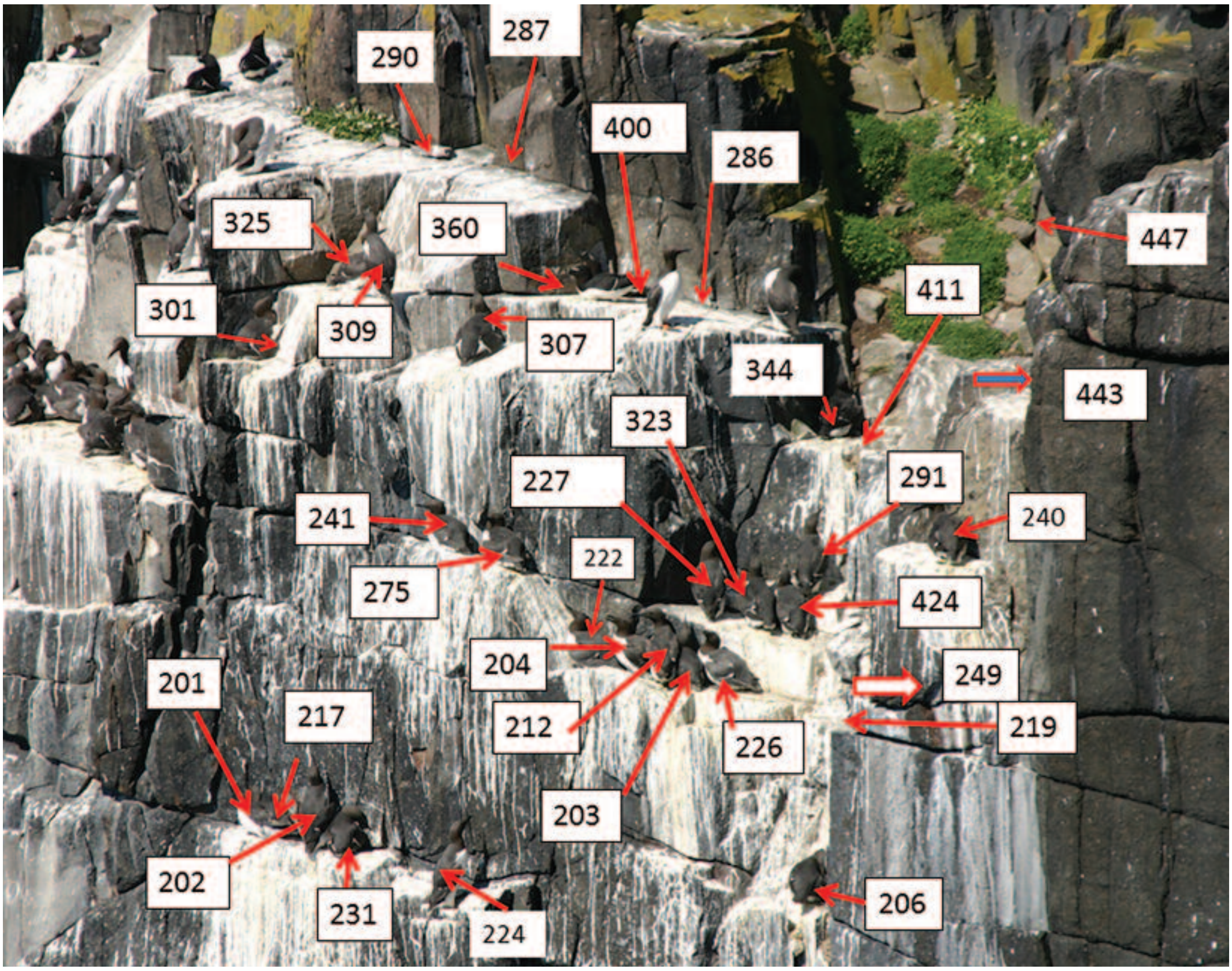

Figure 3. Part of Plot 1 with breeding sites labelled. Many pairs in this plot breed on narrow ledges.

Figure 4. Young Common Guillemot *Uria aalge* 'fledging' from Plot 3 on 8 July 2013 watched by the male parent who then immediately followed it down to the sea. The two then reunited and immediately swam away from the island. © *Mike P. Harris*.

highest (0.848) in 1988 and lowest (0.261) in 2007 (Table 2). The same general pattern was evident in all six plots and thus values from any one plot reflected the general long-term pattern of change and highlighted the poor success in the mid 2000s (Figure 5b). However, plot had a significant effect on breeding success, such that the overall difference between the highest and lowest mean plot breeding success was 0.068 chicks, equivalent to 9.8% (Table 2; Figure 5b). Furthermore, a significant interaction between plot and year showed that the decline in breeding success varied among the plots, in particular was less marked in Plot 6 (GLMM: plot: $F_{5,155.1} = 6.30$, $P < 0.001$; linear year: $F_{1,31.3} = 5.99$, $P = 0.02$; quadratic year: $F_{1,31.0} = 4.71$, $P = 0.04$; linear year by plot interaction: $F_{5,155.1} = 2.84$, $P = 0.02$; quadratic year by plot interaction: $F_{5,155.1} = 1.02$, $P = 0.41$; estimated effects of interaction between plot and year; values on logit scale: Plot 1: 0.000; Plot 2: 0.000; Plot 3: 0.006; Plot 4: 0.007; Plot 5: 0.008; Plot 6: 0.025).

Discussion

During the 34 years of the study, breeding conditions for Guillemots on the Isle of May varied markedly with the mean success varying from 0.261 to 0.848 young fledging per pair laying. These changes were reflected in all six plots indicating that this level of replication was unnecessary to track the broad observed pattern of change (Figure 5b). However, there were significant differences both in overall breeding success and in changes over time among the six plots indicating spatial heterogeneity in breeding performances across the colony. Although the among-plot variation was numerically small, our results nevertheless highlight that having multiple plots improved the robustness of annual estimates and trends over time for Guillemot breeding success on the Isle of May.

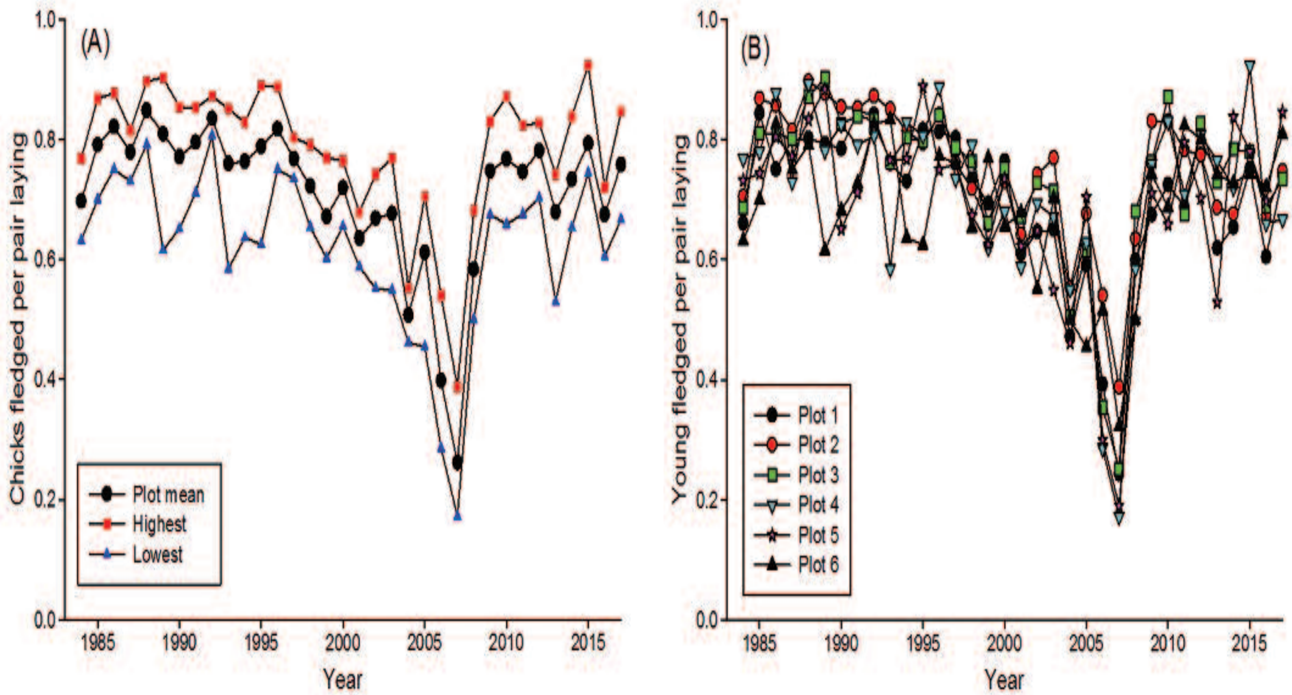

Figure 5. Annual estimates of breeding success of Common Guillemots *Uria aalge* in six study plots. (A) Mean, highest and lowest plot values for each year. (B) All plot values each year.

The main aim of this study was not to attribute causes of among plot differences but rather to determine whether they occurred. However, a possible reason for among plot variation was breeding density because breeding success in Guillemots tends to be negatively correlated with breeding density (Birkhead 1977; Harris *et al*. 1997). However, Plot 3, with by far the highest density in terms of the proportion of sites where birds were in physical contact with multiple neighbours, was not consistently more successful than others where density scores were lower (Table 1). Plot 3 was also the one that did not include sites at the bottom of the cliff which are most vulnerable during storms (Newell *et al*. 2015). The differences in both overall breeding success and changes over time between plots could well not be attributable to general features but rather to the quality of individual sites within each plot (Gaston & Nettleship 1981).

Comparison of our findings with the limited numbers of studies that have previously looked at inter-plot variation is equivocal. Murphy and Schauer (1996) found no significant difference in hatching success among seven plots of Guillemots that they followed for five years in Alaska and a significant among-plot difference in chick success in only one of the five years. In contrast, Gaston and Nettleship (1981) found significant differences between breeding success among seven plots over three years in the closely related Brünnich's Guillemot *Uria lomvia* at Prince Leopold Island, eastern Canadian Arctic. Clearly, assessing among plot variability across a larger sample of colonies is desirable.

Any monitoring scheme assumes that the sample plots being followed are representative of the population of interest. Ideally, plots should be chosen randomly with a stratified selection if conditions within the population vary markedly. For example, in Guillemots breeding habitat e.g. distance above sea level or below cliff top, nesting density or aspect, varies greatly throughout the colony and these characteristics are known to be associated with variation in breeding success (Birkhead 1977; Harris *et al*. 1997; Newell *et al*. 2015). However, in most cases a large proportion of the variation remains unexplained. Furthermore, given that in most situations only a small proportion of Guillemots breed in situations where the individual pairs can be seen clearly enough to determine success, e.g. the birds must be viewed from at least slightly above and from sufficiently close to provide a clear view of each bird (Birkhead & Nettleship 1980), at most colonies only a very small proportion of pairs can be monitored. Estimates based on such samples assume that viewable sites are not systematically different to non-viewable ones. There is no obvious way to test this assumption.

Generalizing from results for the Isle of May to other Guillemot colonies is not straightforward because spatial heterogeneity in breeding success may be colony-specific. However, a precautionary approach would suggest, particularly if the proportion of the colony that can be viewed is small and if breeding habitat is heterogeneous, that annual estimates of colony success and estimates of changes over time will be more robust if they are based on results from multiple plots to allow for spatial variation in success.

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References

Anker-Nilssen, T., Erikstad, K. E. & Lorentsen, S.-H. 1996. Aims and effort in seabird monitoring: an assessment based on Norwegian data. *Wildlife Biology* 2: 17–26.

Ashbrook, K., Wanless, S., Harris, M. P. & Hamer, K. C. 2010. Impacts of poor food availability on positive density dependence in a highly colonial seabird. *Proceedings of the Royal Society B: Biological Sciences* 277: 2355–2360.

Birkhead, T. R. 1977. The effect of habitat and density on breeding success in the common guillemot *Uria aalge*. *Journal of Animal Ecology* 46: 751–764.

Birkhead, T. R. & Nettleship, D. N. 1980. Census methods for murres *Uria* species - a unified approach. *Canadian Wildlife Service Occasional Paper* 43: 1–25.

Bourne, W. R. P. 1976. Seabirds and pollution. In: Johnson, R. (ed.), *Marine Pollution*: 403–502. Academic Press, London.

Gaston, A. J. & Nettleship, D. N. 1981. The Thick-billed Murres of Prince Leopold Island. *Canadian Wildlife Service Monograph* No. 6. Canadian Wildlife Service, Ottawa.

Harris, M. P. & Wanless, S. 1988. The breeding biology of guillemots *Uria aalge* on the Isle of May over a six-year period. *Ibis* 130: 172–192.

Harris, M. P., Wanless, S., Barton, T. R. & Elston, D. A. 1997. Nest site characteristics, duration of use and breeding success in the Guillemot *Uria aalge*. *Ibis* 139: 468–476.

Kokko, H., Harris, M. P. & Wanless, S. 2004. Competition for breeding sites and site-dependent population regulation in a highly colonial seabird, the common guillemot *Uria aalge*. *Journal of Animal Ecology* 73: 367–376.

Lahoz-Monfort, J. J., Harris, M. P., Wanless, S., Freeman, S. N. & Morgan, B. J. T. 2017. Bringing it all together: multi-species integrated population modelling of a breeding community. *Journal of Agricultural, Biological and Environmental Statistics* 22: 140–160.

Mitchell, P. I., Newton, S. F., Ratcliffe, N. & Dunn, T. E. 2004. *Seabird populations of Britain and Ireland*. T. & A.D. Poyser, London.

Murphy, E. C. & Schauer, J. H. 1996. Synchrony in egg-laying and reproductive success of neighboring common murres, *Uria aalge*. *Behavioral Ecology and Sociobiology* 39: 245–258.

Newell, M., Wanless, S., Harris, M. P. & Daunt, F. 2015. Effects of an extreme weather event on seabird breeding success at a North Sea colony. *Marine Ecology Progress Series* 532: 257–268.

Reynolds, T. J., King, R., Harwood, J., Frederiksen, M., Harris, M. P. & Wanless, S. 2009. Integrated data analysis in the presence of emigration and mark loss. *Journal of Agricultural, Biological and Environmental Statistics* 14: 411–431.

Sims, M., Elston, D. A., Harris, M. P. & Wanless, S. 2007. Incorporating variance uncertainty into a power analysis of monitoring designs. *Journal of Agricultural, Biological and Environmental Statistics* 12: 236–249.

Sims, M., Wanless, S., Harris, M. P., Mitchell, P. I. & Elston, D. A. 2006. Evaluating the power of monitoring plot designs for detecting long-term trends in the numbers of common guillemots. *Journal of Applied* Ecology 43: 537–546.

Walsh, P. M., Halley, D. J., Harris, M. P., del Nevo, A., Sim, I. M. W. & Tasker, M. L. 1995. *Seabird monitoring handbook for Britain and Ireland: a compilation of methods for survey and monitoring of breeding seabirds*. Joint Nature Conservation Committee, Peterborough.