# FIVE ESTUARIES OFFSHORE WIND FARM

## ENVIRONMENTAL STATEMENT

## VOLUME 6, PART 5, ANNEX 4.11: DESIGN BASED BOOTSTRAP VARIANCE ESTIMATES

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# Five Estuaries Offshore Windfarm

# Ornithology Technical Annex 4.11
# Design based bootstrap variance estimates:

# Comparison of transect level results with auto-correlation based time-series method


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## Contents

## 1 INTRODUCTION

The Five Estuaries Offshore Windfarm (VE) baseline ornithology densities and abundances have been estimated using design-based analysis of digital aerial survey data collected as continuous transects. Measures of variance for the point estimates (standard deviation, 95% confidence intervals) were calculated using a time-series bootstrap method which incorporates a blocking structure to control for auto-correlation between adjacent sampling units (500m segments along the transects). The appropriate length of block (i.e. the number of segments) required for each species and site was found using an autocorrelation (AC) test. The block length, to be used for subsequent bootstrap resampling, was derived as the length over which significant autocorrelations were detected. Thus, if a species exhibited no spatial auto-correlation then there would be no significant correlations detected and the block size would be one. At the opposite end of the scale, if significant autocorrelation is detected along the full length of the transect then the entire transect itself is treated as the sampling unit.

This method is an alternative to that suggested by Natural England which treats each transect as an independent sample for bootstrapping. The motivation for the method's development was to use the survey data to determine the appropriate sampling unit size, rather than assuming that the survey transect, which is an arbitrary length reflecting the study site rather than statistical considerations, is the appropriate unit to use in all cases.

Natural England, in their response to the Five Estuaries PEIR made this comment with respect to the bootstrap method:

> *Natural England are broadly supportive of the novel approach taken to calculating design-based estimates. However, we reiterate our request that a comparison is presented against data derived from a standard design-based approach (i.e. using the entire transect as the smallest independent unit for resampling). This would evidence the claimed improvement in precision, increase confidence that suitable estimates have been generated, and allow SNCBs to properly consider more general application of the method at other appropriate projects. Note this was requested by NE at an ETG on 20/05/22.*

This report provides the requested comparison between the AC method and the transect method.

## 2 METHODS

The survey data for each species in each site (North and South) were processed as follows to obtain a dataset for estimating autocorrelations:

1. Each transect was subdivided into 500m long segments;
2. The number of observations in each segment on each transect and each survey was summed. For example, a sequence of: 010030020202210 would represent 15 sequential segments with no birds in the first, 1 in the second, none in the third and fourth, 3 in the fifth, none in the sixth and seventh etc.;
3. A long list of all observations for each species was created by appending the segment data for all of the transects and surveys (i.e., survey 1, transect 1 all segments, survey 1, transect 2 all segments… survey 24, transect 9 all segments), with 30 'NA' values inserted as padding

between the data for each transect in order to prevent the auto-correlation analysis treating data from consecutive transects as continuous.

An autocorrelation function was fitted to the segment data, with a maximum lag set as 25 segments (i.e., with 500m long segment this equates to 12.5km) on the basis that any apparent correlations beyond this length would be spurious. An empirical confidence interval was estimated as the 95% quantiles (2.5%-97.5%) for the maximum lag (25) divided by the square-root of the sample size for each lag distance[1]. It was necessary to derive empirical confidence intervals because the AC function ('acf') calculates the sample size including the NA values used to separate each transect, resulting in an overestimated sample size and hence tighter confidence intervals.

# 3 RESULTS

## 3.1 Autocorrelation test

The AC outputs for 11 species from the north site is provided in Figure 1. The strength of AC at each segment separation (lag) is shown in the vertical bars. If the line is higher than the upper 95% confidence interval (the red-dashed line) then this indicates a significant correlation at that distance. For example, there was evidence that gannet observations were significantly positively correlated at up to 20 segments, and for guillemot almost for the complete distance tested (24 segments). In contrast, for fulmar significant results were only obtained up to three segments apart and for lesser black-backed gulls at up to four segments.

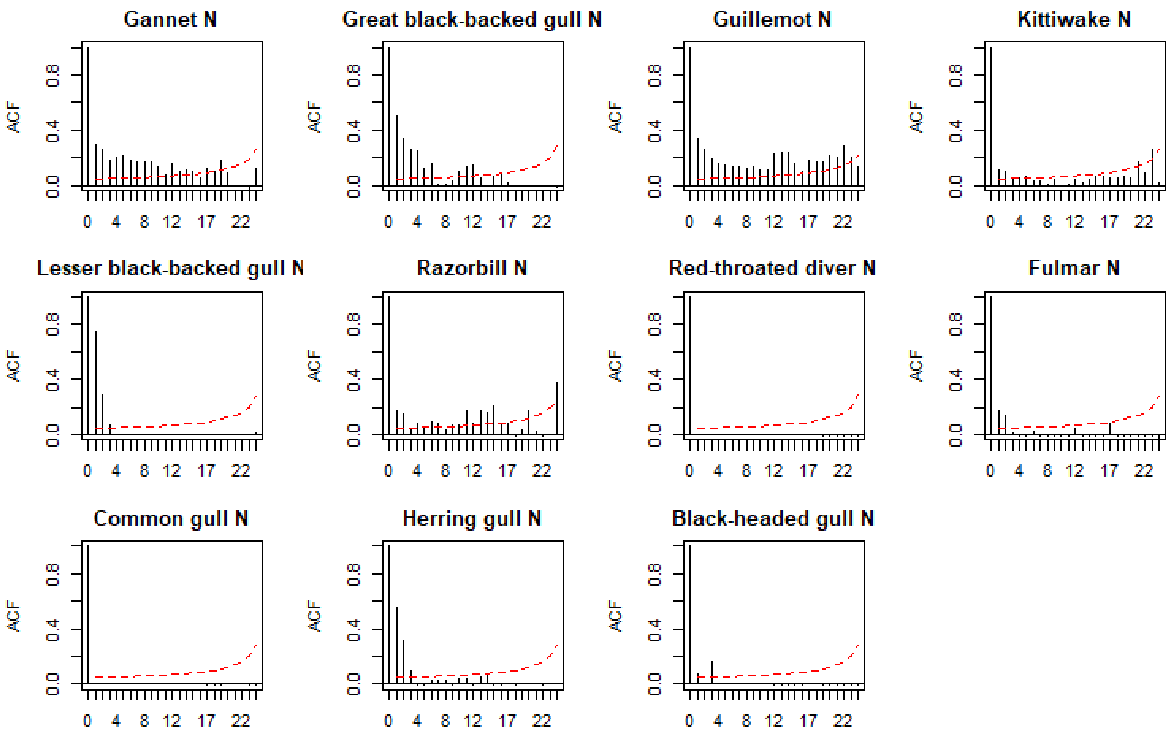


**Figure 1. Example autocorrelation plots for species recorded in the north site. Lag distances in segments on the x-axis, strength of positive correlation on the y-axis. The empirical upper confidence limit is shown with the red dashed line.**

[1]https://sakai.unc.edu/access/content/group/2842013b-58f5-4453-aa8d-3e01bacbfc3d/public/Ecol562_Spring2012/docs/lectures/lecture17.htm#testing

The same analysis was conducted for the south site. The number of segments at which a significant result was obtained for each species are provided in Table 3-1.

**Table 3-1. Length of significant autocorrelations (in number of 500m segments) for each species on the north and south sites.**

| Species | No. of significant segments | |
|---|---|---|
| | North | South |
| Gannet | 20 | 6 |
| Great black-backed gull | 17 | 25 |
| Guillemot | 24 | 26 |
| Kittiwake | 24 | 15 |
| Lesser black-backed gull | 4 | 2 |
| Razorbill | 25 | 13 |
| Red-throated diver | 1 | 11 |
| Fulmar | 3 | 2 |
| Common gull | 1 | 18 |
| Herring gull | 4 | 2 |
| Black-headed gull | 4 | 15 |

## 3.2 Bootstrap comparison

The number of significant segments was treated as the block length in a call to a time-series bootstrap function (package 'boot', function 'tsboot'). Thus, if no significant autocorrelation was detected (e.g. red-throated diver in the north site) then each segment was treated as an independent sample, while for guillemot the block would be 24 segments long (north) or 26 (south). The larger the number of estimated independent samples (i.e. the shorter the length of significant autocorrelation) the smaller the variance around the mean is expected to be.

To estimate how much the precision was improved using this method, the bootstrap was run a second time, but with the transect set as the smallest independent unit for resampling for all species.

To illustrate the improvements in precision the results of the bootstrap analysis from the AC approach have been plotted alongside those from the transect level sampling for a selection of species. As can be seen in Figure 2 to Figure 8, in most cases the AC corrected bootstrap abundance estimates have smaller confidence intervals than those derived from the transect level bootstrap. In general, the improvement in precision was greater for more abundant species. This can also be seen from comparison of the coefficients of variation for the survey data (Table 3-2 and Table 3-3), where the AC bootstrap estimates also tend to have higher precision. It should be noted that the transect level bootstrap results did not always have lower precision, however typically when the transect bootstrap results gave better precision the improvement compared with the AC results was small.

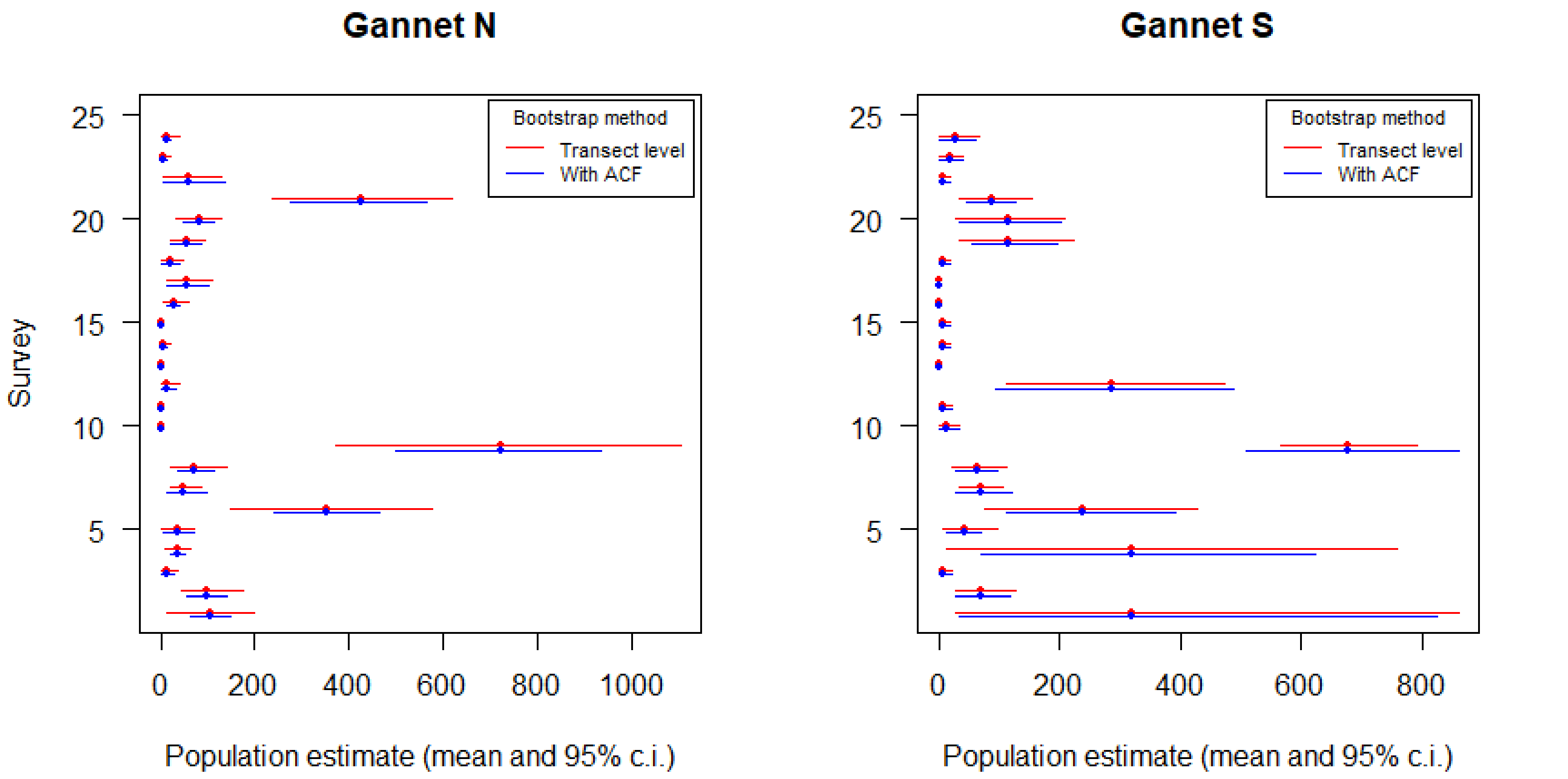


Figure 2. Gannet measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.

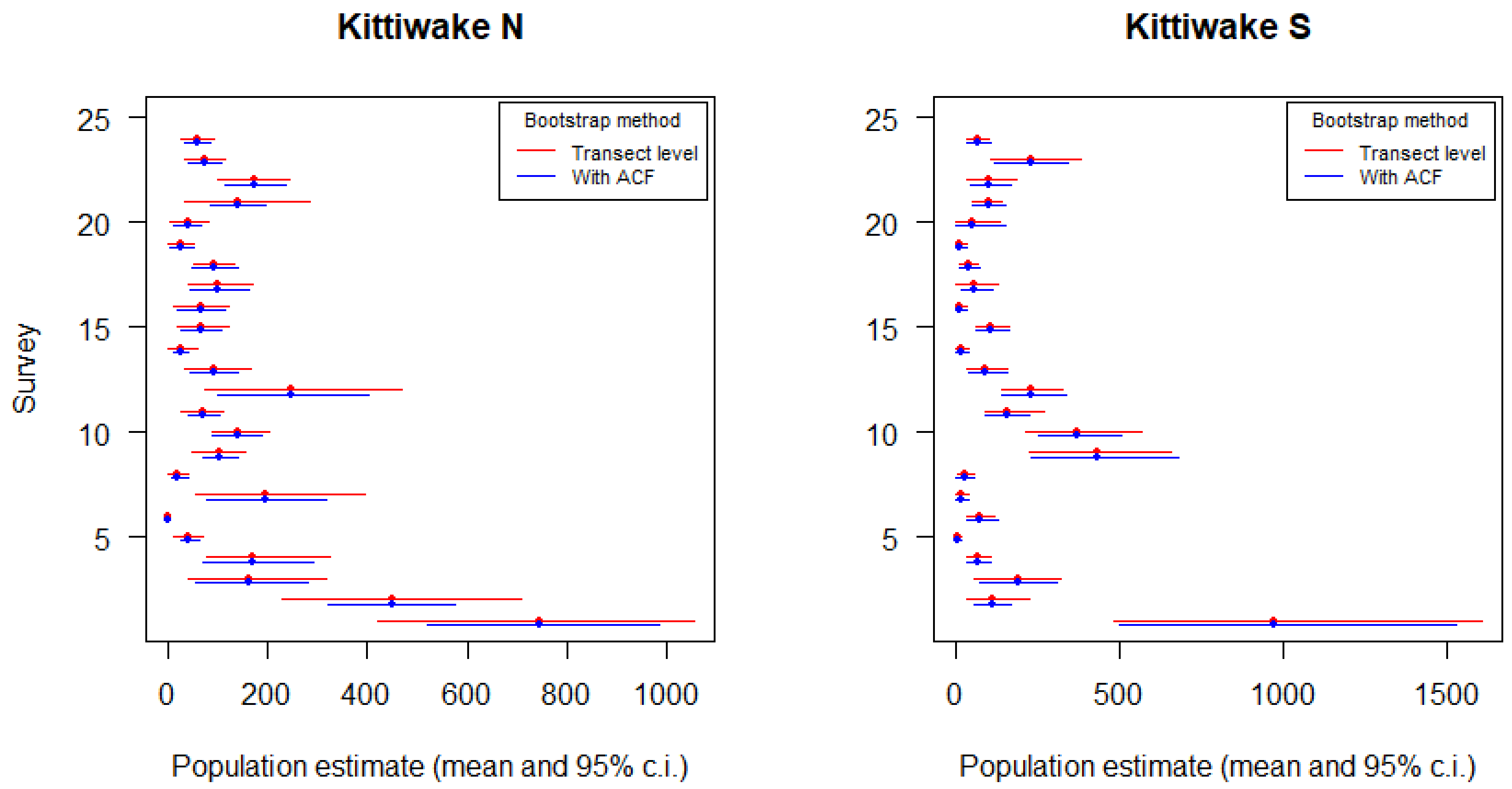


Figure 3. Kittiwake measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.

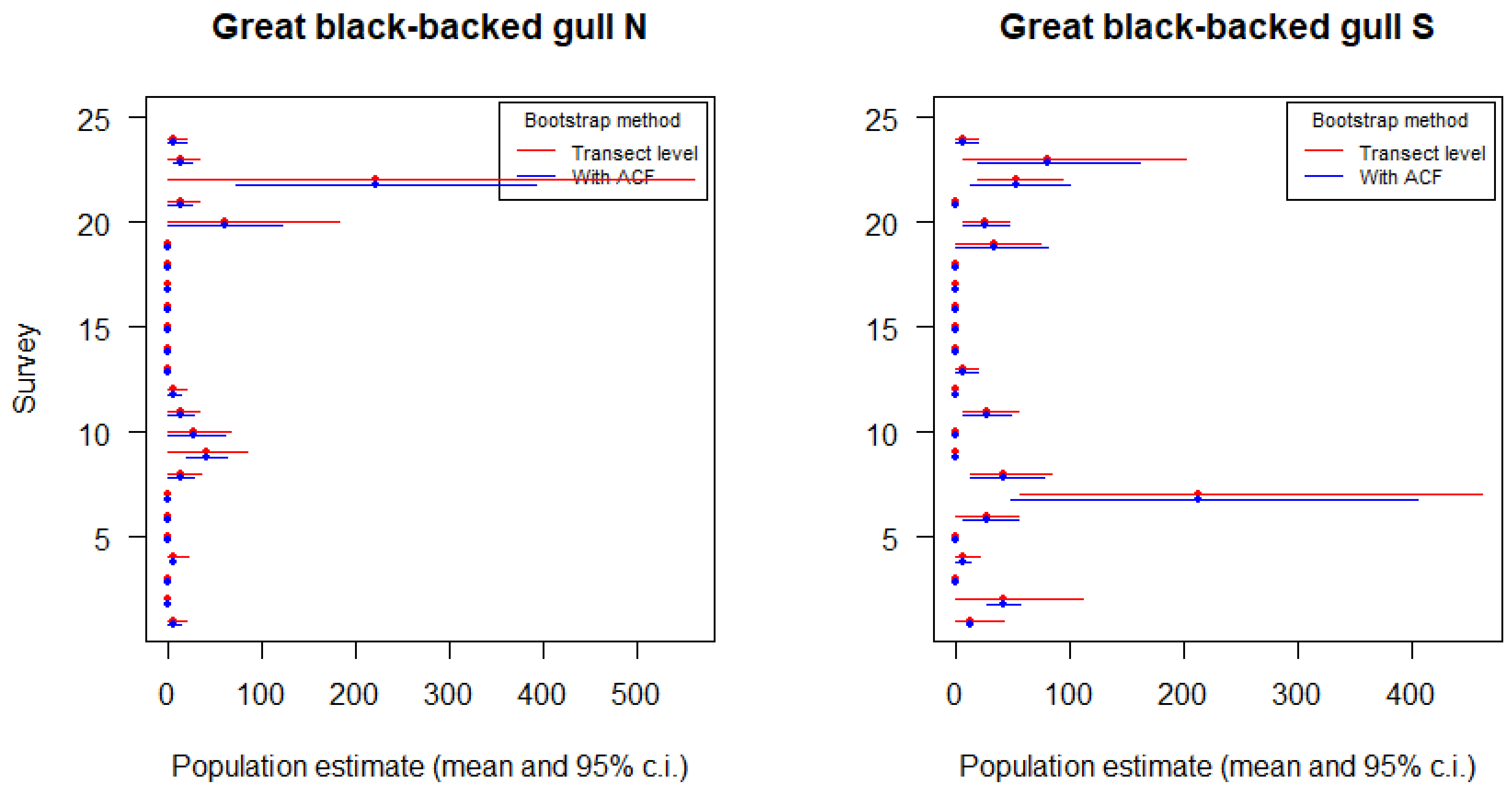


**Figure 4. Great black-backed gull measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.**

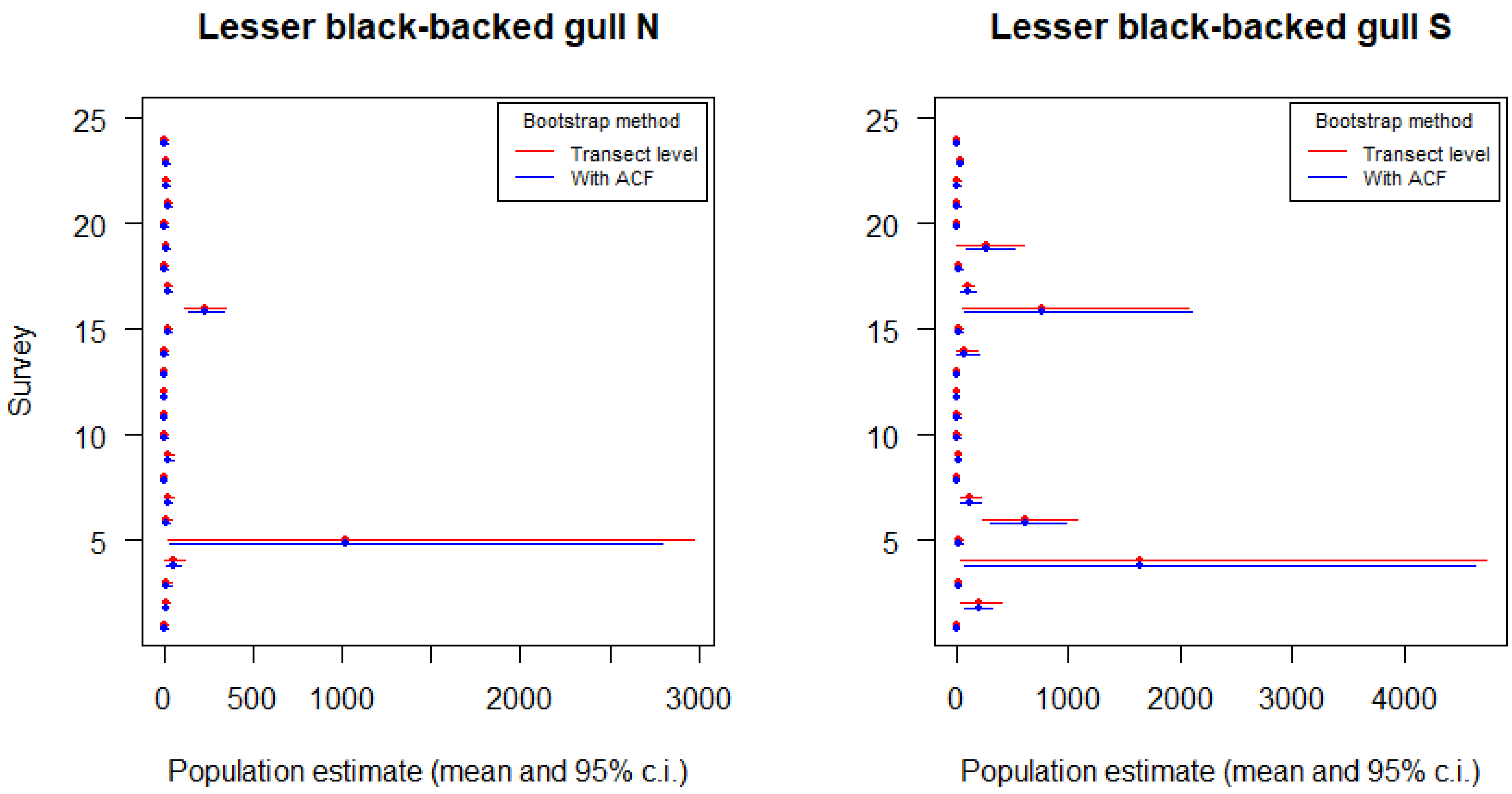


**Figure 5. Lesser black-backed gull measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.**

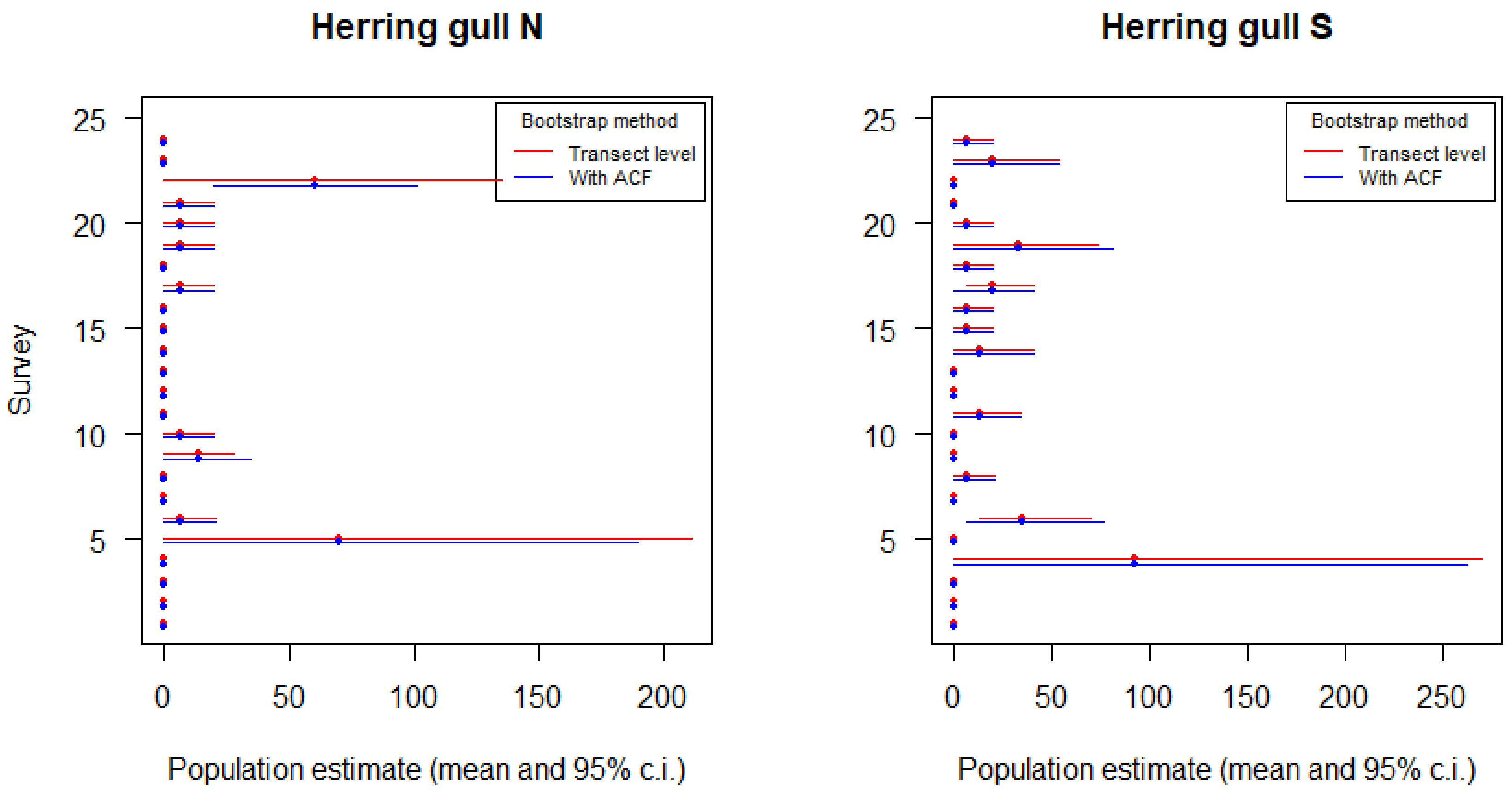


Figure 6. Herring gull measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.

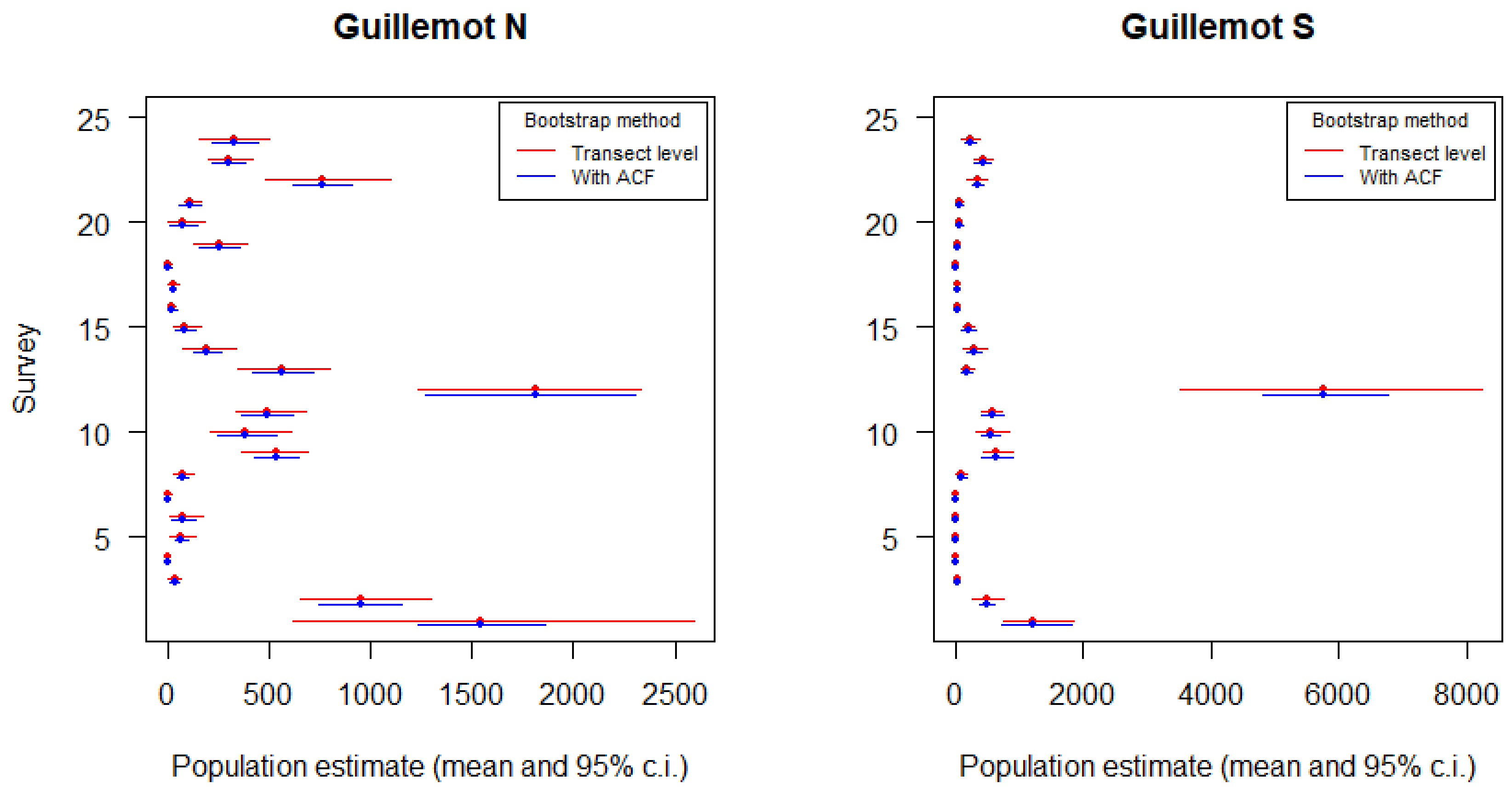


Figure 7. Guillemot measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.

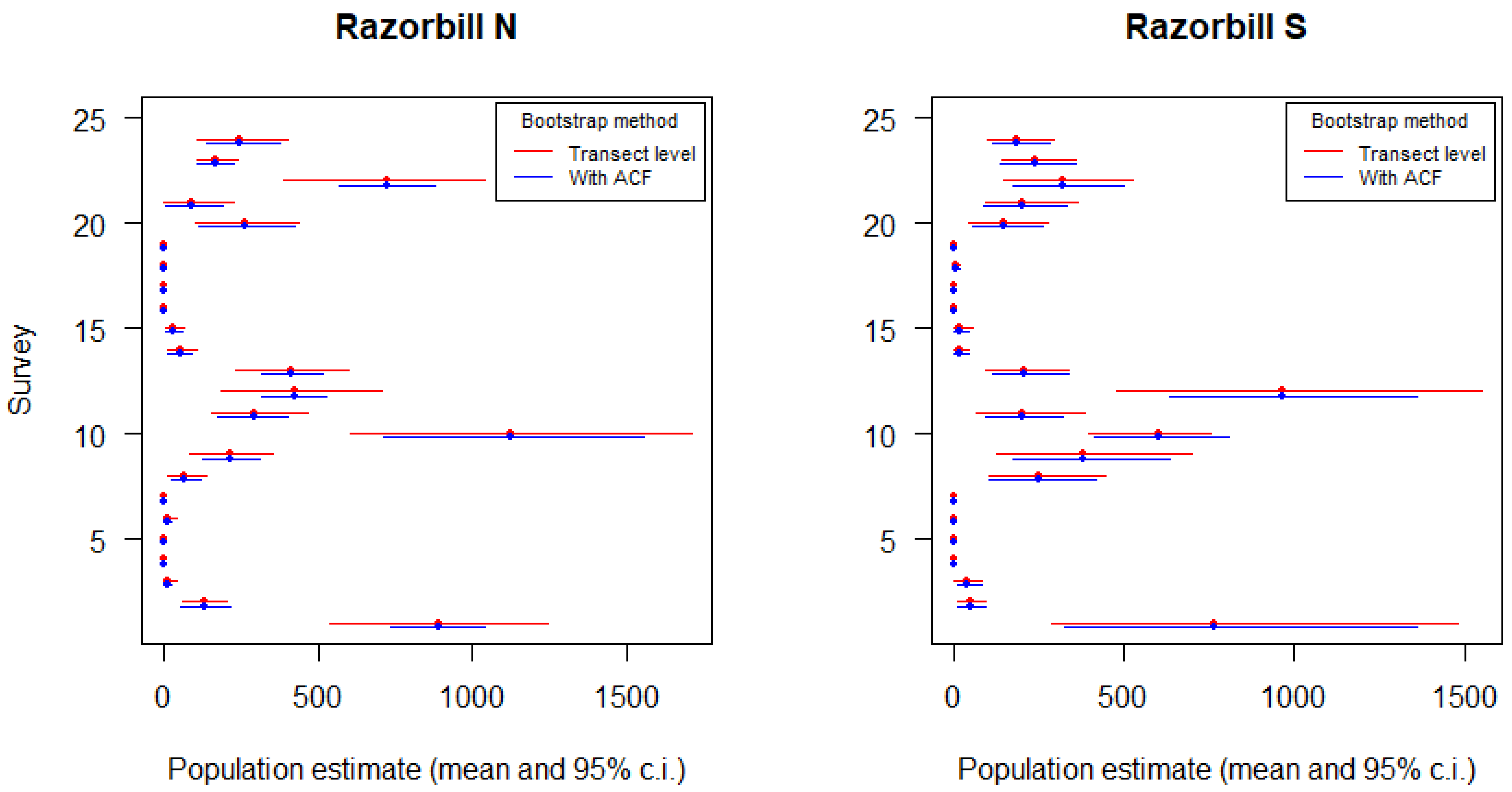


Figure 8. Razorbill measures of precision. Dots indicate mean abundance, lines the 95% confidence range for the transect level bootstrap (red lines) and the autocorrelation corrected bootstrap (blue lines) for the North and South sites across all 24 surveys.

**Table 3-2. Coefficients of variation of bootstrap abundance estimates for each survey (and averaged) for the north and south sites, estimated with transect as the smallest sampling unit (Ex. ACF) and using the smallest non-correlated block of segments (Inc. ACF).**

| Survey no. | Fulmar | | | | Gannet | | | | Guillemot | | | | Razorbill | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North | | South | | North | | South | | North | | South | | North | | South | |
| | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF |
| 1 | 0.42 | 0.38 | 0.38 | 0.31 | 0.44 | 0.21 | 0.78 | 0.69 | 0.32 | 0.10 | 0.25 | 0.24 | 0.21 | 0.09 | 0.42 | 0.37 |
| 2 | 0.64 | 0.67 | 0.62 | 0.72 | 0.34 | 0.22 | 0.37 | 0.33 | 0.17 | 0.11 | 0.25 | 0.13 | 0.28 | 0.30 | 0.40 | 0.45 |
| 3 | 0.34 | 0.40 | 0.49 | 0.38 | 0.63 | 0.49 | 0.98 | 0.91 | 0.49 | 0.34 | 0.33 | 0.37 | 0.94 | 0.80 | 0.47 | 0.44 |
| 4 | 0.65 | 0.70 | 0.51 | 0.39 | 0.43 | 0.24 | 0.65 | 0.46 | NA | NA | NA | NA | NA | NA | NA | NA |
| 5 | 0.99 | 0.73 | 0.91 | 0.98 | 0.50 | 0.55 | 0.61 | 0.36 | 0.48 | 0.27 | NA | NA | NA | NA | NA | NA |
| 6 | 0.63 | 0.63 | 0.39 | 0.42 | 0.30 | 0.16 | 0.39 | 0.32 | 0.58 | 0.41 | 0.94 | 0.89 | 0.94 | 0.79 | NA | NA |
| 7 | 1.00 | 0.94 | 0.54 | 0.49 | 0.34 | 0.46 | 0.26 | 0.31 | 0.95 | 0.72 | 0.62 | 0.60 | NA | NA | NA | NA |
| 8 | 0.94 | 0.94 | 0.93 | 0.91 | 0.47 | 0.29 | 0.35 | 0.30 | 0.33 | 0.19 | 0.42 | 0.39 | 0.47 | 0.35 | 0.34 | 0.32 |
| 9 | 0.95 | 0.95 | 0.90 | 0.97 | 0.27 | 0.16 | 0.09 | 0.13 | 0.15 | 0.11 | 0.19 | 0.19 | 0.31 | 0.22 | 0.39 | 0.33 |
| 10 | NA | NA | NA | NA | NA | NA | 0.62 | 0.61 | 0.27 | 0.19 | 0.24 | 0.14 | 0.26 | 0.19 | 0.16 | 0.17 |
| 11 | 0.46 | 0.54 | 0.62 | 0.66 | NA | NA | 0.91 | 0.77 | 0.18 | 0.13 | 0.13 | 0.15 | 0.27 | 0.19 | 0.41 | 0.31 |
| 12 | NA | NA | NA | NA | 0.93 | 0.71 | 0.31 | 0.38 | 0.16 | 0.15 | 0.21 | 0.09 | 0.31 | 0.13 | 0.30 | 0.20 |
| 13 | 0.61 | 0.65 | NA | NA | NA | NA | NA | NA | 0.20 | 0.14 | 0.28 | 0.22 | 0.22 | 0.12 | 0.30 | 0.27 |
| 14 | NA | NA | NA | NA | 0.94 | 0.69 | 0.95 | 0.87 | 0.37 | 0.19 | 0.32 | 0.18 | 0.48 | 0.39 | 0.68 | 0.69 |
| 15 | 0.91 | 0.90 | 0.48 | 0.50 | NA | NA | 0.93 | 0.83 | 0.38 | 0.30 | 0.22 | 0.26 | 0.49 | 0.41 | 0.65 | 0.67 |
| 16 | 0.66 | 0.63 | NA | NA | 0.50 | 0.30 | NA | NA | 0.47 | 0.59 | 0.51 | 0.46 | NA | NA | NA | NA |
| 17 | 0.95 | 0.61 | 0.51 | 0.57 | 0.46 | 0.46 | NA | NA | 0.52 | 0.29 | 0.37 | 0.43 | NA | NA | NA | NA |
| 18 | NA | NA | 0.91 | 0.96 | 0.66 | 0.51 | 0.93 | 0.86 | 0.96 | 0.76 | NA | NA | NA | NA | 0.91 | 0.93 |
| 19 | 0.91 | 0.90 | 0.98 | 0.98 | 0.37 | 0.31 | 0.42 | 0.32 | 0.26 | 0.19 | 0.41 | 0.39 | NA | NA | NA | NA |
| 20 | NA | NA | NA | NA | 0.30 | 0.22 | 0.39 | 0.38 | 0.70 | 0.49 | 0.47 | 0.52 | 0.33 | 0.30 | 0.42 | 0.36 |
| 21 | NA | NA | NA | NA | 0.23 | 0.17 | 0.37 | 0.25 | 0.18 | 0.24 | 0.26 | 0.26 | 0.68 | 0.55 | 0.35 | 0.31 |
| 22 | NA | NA | NA | NA | 0.49 | 0.59 | 0.95 | 0.92 | 0.20 | 0.09 | 0.23 | 0.13 | 0.24 | 0.11 | 0.30 | 0.25 |
| 23 | 0.93 | 0.91 | NA | NA | 0.95 | 0.79 | 0.47 | 0.48 | 0.18 | 0.14 | 0.18 | 0.16 | 0.21 | 0.18 | 0.23 | 0.25 |
| 24 | NA | NA | 0.94 | 0.94 | 0.94 | 0.33 | 0.71 | 0.58 | 0.27 | 0.19 | 0.32 | 0.21 | 0.32 | 0.24 | 0.26 | 0.24 |
| **Mean** | **0.75** | **0.72** | **0.67** | **0.68** | **0.52** | **0.39** | **0.59** | **0.53** | **0.38** | **0.27** | **0.34** | **0.31** | **0.41** | **0.32** | **0.41** | **0.39** |

**Table 3-3. Coefficients of variation of bootstrap abundance estimates for each survey (and averaged) for the north and south sites, estimated with transect as the smallest sampling unit (Ex. ACF) and using the smallest non-correlated block of segments (Inc. ACF).**

| Survey no. | Great black-backed gull | | | | Herring gull | | | | Lesser black-backed gull | | | | Kittiwake | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North | | South | | North | | South | | North | | South | | North | | South | |
| | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF | Ex. ACF | Inc. ACF |
| 1 | 0.95 | 0.74 | 0.95 | 0.00 | NA | NA | NA | NA | 0.99 | 0.83 | NA | NA | 0.22 | 0.16 | 0.30 | 0.28 |
| 2 | NA | NA | 0.68 | 0.21 | NA | NA | NA | NA | 0.60 | 0.62 | 0.48 | 0.34 | 0.28 | 0.15 | 0.44 | 0.25 |
| 3 | NA | NA | NA | NA | NA | NA | NA | NA | 0.93 | 0.97 | 0.61 | 0.66 | 0.45 | 0.35 | 0.35 | 0.30 |
| 4 | 0.96 | 0.00 | 0.93 | 0.68 | NA | NA | 0.86 | 0.83 | 0.52 | 0.39 | 0.88 | 0.84 | 0.41 | 0.36 | 0.27 | 0.28 |
| 5 | NA | NA | NA | NA | 0.90 | 0.75 | NA | NA | 0.86 | 0.74 | 0.51 | 0.49 | 0.33 | 0.22 | 0.95 | 0.94 |
| 6 | NA | NA | 0.54 | 0.47 | 0.92 | 0.94 | 0.41 | 0.51 | 1.00 | 0.77 | 0.34 | 0.28 | NA | NA | 0.28 | 0.34 |
| 7 | NA | NA | 0.54 | 0.48 | NA | NA | NA | NA | 0.52 | 0.41 | 0.40 | 0.39 | 0.44 | 0.34 | 0.47 | 0.50 |
| 8 | 0.58 | 0.52 | 0.47 | 0.38 | NA | NA | 0.93 | 0.96 | NA | NA | 0.93 | 0.95 | 0.46 | 0.44 | 0.52 | 0.52 |
| 9 | 0.54 | 0.27 | NA | NA | 0.62 | 0.63 | NA | NA | 0.66 | 0.68 | 0.94 | 0.90 | 0.25 | 0.18 | 0.25 | 0.27 |
| 10 | 0.72 | 0.59 | NA | NA | 0.98 | 0.93 | NA | NA | 0.97 | 0.91 | 0.64 | 0.69 | 0.21 | 0.18 | 0.25 | 0.18 |
| 11 | 0.66 | 0.53 | 0.51 | 0.40 | NA | NA | 0.61 | 0.68 | NA | NA | 0.93 | 0.92 | 0.30 | 0.24 | 0.31 | 0.23 |
| 12 | 0.96 | 0.70 | NA | NA | NA | NA | NA | NA | NA | NA | 0.94 | 0.99 | 0.41 | 0.31 | 0.21 | 0.23 |
| 13 | NA | NA | 0.98 | 0.81 | NA | NA | NA | NA | NA | NA | 0.93 | 0.90 | 0.38 | 0.25 | 0.35 | 0.32 |
| 14 | NA | NA | NA | NA | NA | NA | 0.97 | 0.94 | 0.93 | 0.90 | 0.74 | 0.79 | 0.51 | 0.31 | 0.47 | 0.51 |
| 15 | NA | NA | NA | NA | NA | NA | 1.00 | 0.84 | 0.66 | 0.66 | 0.70 | 0.58 | 0.38 | 0.30 | 0.23 | 0.25 |
| 16 | NA | NA | NA | NA | NA | NA | 0.94 | 0.89 | 0.26 | 0.22 | 0.79 | 0.81 | 0.41 | 0.39 | 0.61 | 0.65 |
| 17 | NA | NA | NA | NA | 0.93 | 0.92 | 0.48 | 0.55 | 0.48 | 0.53 | 0.28 | 0.35 | 0.32 | 0.30 | 0.57 | 0.43 |
| 18 | NA | NA | NA | NA | NA | NA | 0.90 | 0.98 | 0.94 | 0.89 | 0.46 | 0.54 | 0.23 | 0.25 | 0.33 | 0.39 |
| 19 | NA | NA | 0.57 | 0.60 | 0.95 | 0.87 | 0.63 | 0.62 | 0.63 | 0.65 | 0.56 | 0.40 | 0.51 | 0.48 | 0.60 | 0.65 |
| 20 | 0.93 | 0.55 | 0.36 | 0.39 | 0.92 | 0.87 | 0.96 | 0.84 | 0.98 | 0.91 | 0.95 | 0.96 | 0.48 | 0.36 | 0.71 | 0.79 |
| 21 | 0.63 | 0.48 | NA | NA | 0.93 | 0.91 | NA | NA | 0.47 | 0.54 | 0.63 | 0.67 | 0.45 | 0.21 | 0.23 | 0.27 |
| 22 | 0.70 | 0.42 | 0.36 | 0.39 | 0.55 | 0.35 | NA | NA | 0.64 | 0.64 | 0.63 | 0.65 | 0.21 | 0.18 | 0.40 | 0.31 |
| 23 | 0.62 | 0.42 | 0.66 | 0.45 | NA | NA | 0.69 | 0.69 | 0.61 | 0.61 | 0.41 | 0.40 | 0.28 | 0.24 | 0.32 | 0.26 |
| 24 | 0.96 | 0.81 | 0.97 | 0.86 | NA | NA | 0.95 | 0.94 | 0.88 | 0.91 | NA | NA | 0.28 | 0.24 | 0.27 | 0.27 |
| **Mean** | **0.77** | **0.50** | **0.66** | **0.47** | **0.86** | **0.80** | **0.79** | **0.79** | **0.73** | **0.69** | **0.67** | **0.66** | **0.36** | **0.28** | **0.40** | **0.39** |

# 4 CONCLUSION

This note has provided a summary of the methods and results for design based bootstrap resampling of the ornithology survey collected at the Five Estuaries wind farm. The standard method for bootstrap resampling as advised by Natural England is to resample at the level of the transect, on the basis that variance estimates obtained from such an analysis are robust since it is assumed that transects are independent samples. However, depending on the survey design, such an approach may be an inefficient use of the data, for example if the number of transects is small, resulting in unnecessarily low precision. Here we have provided details about the bootstrap methods used for the Five Estuaries wind farm site characterisation which employed a combination of an AC test to determine a block size for each species over which significant AC was detected, together with a time-series bootstrap method which uses the block size to resample data whilst controlling for AC. This method ensures maximal use of the survey data, whilst also defaulting to the transect level approach for highly correlated species distributions.

It is important to acknowledge that the AC method does not always return higher precision outputs, but it rarely yielded much lower precision and more often than not gave improved precision (i.e. it is usually a better method than the transect level approach, but sometimes is slightly worse). Thus, on balance these results indicate this method offers an improvement in terms of reducing uncertainty.

It is also worth noting that survey design will affect the comparison of these two methods, since a survey with fewer, longer transects would be expected to give much better precision with the autocorrelation approach, while comparison of the bootstrap results for a survey with more, shorter transects (like that at Five Estuaries) would be expected to have slightly less definitive results. Thus, the fact that the Five Estuaries analysis has demonstrated the benefits of this approach lends further support to its value as an analytical method.

FIVE ESTUARIES OFFSHORE WIND FARM

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