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Urban Breeding Gull Surveys: A Survey Design Simulation

Authors

Chris B. Thaxter, Cat Horswill, Kathryn E. Ross, Graham E. Austin, Dawn E. Balmer and Niall H.K. Burton

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EXECUTIVE SUMMARY

1. To support delivery of the latest census of the breeding seabird population of Britain and Ireland, a previous Natural England commissioned report (Ross *et al.* 2016) reviewed the survey methods in order to make recommendations for the most cost-effective survey design for quantifying (urban) gull abundance in UK and Ireland. Within that report, recommendations were made on the expected necessary coverage, with reference to previous analogous bird surveys across similar geographic scales. This report builds on Ross *et al.* (2016) using computer simulations to examine how survey coverage affects the precision of population estimates. This work will provide a first step towards improving the population estimates of urban gulls, assuming surveys go ahead in the future.

2. To deliver the population estimates for gulls required for the UK and Ireland, Ross *et al.* (2016) proposed a survey design using a paired key site and stratified sampling approach, the latter covering the entire spectrum of urbanisation. 'Non-urban' key sites would be covered by the wider national seabird census, such that population estimates derived from aerial surveying of urban key sites and sampling of the wider landscape could be combined with these counts to produce first complete and robust estimates for the UK and Ireland. The focus of this report is assessing the trade-off between sample coverage and the precision of population estimates.

3. Spatial data describing the distributions of Lesser Black-backed Gulls and Herring Gulls in the UK and Ireland were obtained from Timed Tetrad Visit data from Bird Atlas 2007-11 (Balmer *et al.* 2013). We used the possible, probable and confirmed breeding evidence from the 'Bird Atlas 2007-11' data to describe bird distribution (i.e. presence within a 10-km square) and calculated the mean number of sightings per hour for each tetrad.

4. Using this dataset, we examined the effect of varying coverage within sample 10-km squares and in the extent of sample 10-km coverage on the confidence intervals around population estimates of Lesser Black-backed Gulls and Herring Gulls through bootstrap simulations. Scenarios of sampling effort included 11 different levels of 10-km square coverage per region, as well as five levels of tetrad coverage within each square. We also examined whether the confidence intervals around population estimates of gulls in each region could be improved by weighting the survey coverage towards tetrads in coastal or urban strata.

5. The confidence intervals around population estimates of Lesser Black-backed Gulls and Herring Gulls reduced with increased coverage of both tetrads and 10-km grid squares. However, the improvement was most apparent through increased coverage of 10-km grid squares. This likely reflects that (within any one region), at low levels of coverage, there is likely to be greater variability in the relative abundance of gull populations between 10-km squares than within a given 10-km square.

6. Confidence intervals were greater for Herring Gull than for Lesser Black-backed Gull, although this was reflective of the relative size of the population estimates produced, Herring Gull being more numerous and widespread outside of protected sites and key sites excluded from this analysis.

7. Relationships varied between regions, in part reflecting the relative size of those regions. However, typically confidence intervals dropped sharply with an increase in coverage of 10-

km grid squares up to around 20-40 squares per region, but beyond this, the benefits of increased coverage were less.

8. Typically the proportion of grid squares in a 10-km square covered by Bird Atlas 2007–11 was less than 100% and as such the simulations of higher levels of coverage will have drawn from incomplete pools of available tetrads with such squares. In part, this is likely to explain why, while confidence intervals reduced with an increase from low to medium levels of coverage of tetrads within a 10-km square, there was less apparent benefit with further increases in coverage.

9. The effect of the urban weighting varied between species and between regions. The urban weighting was more effective at reducing the size of confidence intervals relative to increased coverage of 10-km grid squares for Lesser Black-backed Gull than Herring Gull, and principally in Wales, Scotland and Ireland.

10. The effect of the coastal weighting varied between species and between regions. The coastal weighting was more effective at reducing the size of confidence intervals relative to increased coverage of 10-km grid squares for Herring Gull than Lesser Black-backed Gull, and principally in Wales, Scotland and Ireland.

11. Given these relationships, a broad recommendation would be that there should be a minimum of 20 10-km squares covered per region (although potentially more or less for specific regions), with 50% coverage within these 10-km squares. Ostensibly, the 10-km squares selected within a region for a survey of Lesser Black-backed Gull should not need to differ to those selected for a survey of Herring Gull. However, it may be that for one species, the level of coverage of the region may need to be greater, while it is recommended that coverage be weighted, in some regions, towards the urban stratum for Lesser Black-backed Gull and towards the coastal stratum for Herring Gull. Options for rationalising required survey coverage in such instances are discussed.

1. INTRODUCTION

1.1 Background

There have been three complete censuses of the breeding seabird population of Britain and Ireland. Operation Seafarer was conducted from 1969-1970 by the Seabird Group. Operation Seafarer provided the first comprehensive, detailed account of the abundance and distribution of seabirds breeding around the coasts of Britain and Ireland (Cramp *et al.* 1974). The Seabird Colony Register (SCR) Census of breeding seabirds in Britain and Ireland was instigated by the Nature Conservancy Council (now Joint Nature Conservation Committee, JNCC) and the Seabird Group, and was conducted between 1985 and 1988 (Lloyd *et al.* 1991). Seabird 2000 was the third complete census of the breeding seabird population of Britain and Ireland, conducted between 1998 and 2002. It was co-ordinated by JNCC in partnership with other organisations (Mitchell *et al.* 2004), and included improved coverage of inland colonies of terns, gulls and cormorants.

Natural England is engaged with the other Statutory Nature Conservation Bodies (SNCBs), the JNCC, Royal Society for the Protection of Birds (RSPB), the Seabird Group and other project partners from the Seabird Monitoring Programme (SMP) to organise and deliver the next of these periodic censuses of the breeding seabirds of Britain and Ireland, currently under the working title '*Seabirds Count*'.

Seabirds Count would provide a number of outputs:

- National population estimates, that provide for EU Article 12 reporting and context to site-level population estimates, and which feed into conservation assessments at various geographic scale;
- Site-level population estimates that provide for Common Standards Monitoring of species interest features of protected sites (Special Protection Areas [SPAs], Sites of Special Scientific Interest [SSSIs], Ramsar sites) and inform case-work (e.g. in relation to general licences issued for gull species, and conflicts with urban gulls: Calladine *et al.* 2006). (Both national and site-level population estimates are also required to inform Habitat Regulations Assessments/Environmental Statements submitted in the consenting process);
- Trend data that provide verification and qualification of annual SMP trend data. The seabird census also provides the only available data on short and long-term trends for some species;
- Distribution data that can be combined with data from 'Bird Atlas 2007-11' (Balmer *et al.* 2013) to refine information on seabird range and range change;
- Data to inform research, e.g. aiming to understand the drivers of change in UK's internationally important seabird populations;
- Recruitment of census volunteers to the SMP in order to improve future annual seabird monitoring.

Each previous census has seen improvements in data collection methods that have resulted in new baseline population estimates for species. For *Seabirds Count*, there is a particular desire for improved survey methods and coverage for urban breeding gulls, predominantly Herring Gulls *Larus argentatus* and Lesser Black-backed Gulls *L. fuscus*, but also other species such as Common Gulls *L. canus* and Black-legged Kittiwakes *Rissa tridactyla*. Here, urban is taken to mean all man made (non-natural) habitats, including but not limited to buildings and other structures found in villages, towns, cities and industrial land.

While gulls nesting in urban environments have been surveyed by Seabird 2000 in 1998-2002 (Mitchell *et al.* 2004) and previously by Monaghan and Coulson (1977) and Raven and Coulson (1997), the spread in the species' distributions to urban habitats apparent from 'Bird Atlas 2007-11' (Balmer *et al.* 2013) and concerns regarding the accuracy and efficacy of some previous approaches (Coulson & Coulson 2015, Rock 2005) have highlighted the need for a robustly designed survey methodology.

An earlier Natural England commissioned report (Ross *et al.* 2016) reviewed the available and potential survey methods, in order to make recommendations for the most cost-effective survey design for quantifying (urban) gull abundance in UK and Ireland. Within that report, recommendations were made on the expected necessary coverage, with reference to previous analogous bird surveys across similar geographic scales. This report builds on Ross *et al.* (2016) using computer simulations to examine how survey coverage affects the precision of population estimates. This work will provide a first step towards improving the population estimates of urban gulls, assuming surveys go ahead in the future.

1.2 Project Aims

The primary aim of this work is to develop an understanding of the trade-off between survey coverage and the precision of derived population estimates. Population estimates for gulls are required for the UK and Ireland (including England, Scotland, Wales, Northern Ireland and the crown dependencies in the British Isles) with associated measures of uncertainty (e.g. 95% confidence intervals); informed by this work it is hoped to deliver surveys, with acceptable uncertainty, that are still affordable. In order to meet this aim, this work has the following objectives:

i. To run computer simulations, as per strata identified in Ross *et al.* (2016), to understand the effect of varying coverage on the precision of gull population estimates.

ii. Through the process of running simulations, to develop computer code to generate population estimates for gulls, assuming surveys will take place in future; and

iii. To clearly describe the trade-off between coverage and precision of population estimates, such that it is possible to either determine the number of samples it is desirable to collect, and / or what level of precision would be delivered by collecting a set number of samples. This should be at regional (defined in Ross *et al.* 2016) and national (devolved country) scales.

2. METHODS

2.1 Data

To deliver the population estimates for gulls required for the UK and Ireland, Ross *et al.* (2016) proposed a survey design using a paired key site and stratified sampling approach, the latter covering the entire spectrum of urbanisation. It was proposed that the survey would best be achieved by digital aerial survey and that the stratification should be based on gull abundance, region, percentage urban cover and whether the site was coastal or inland. 'Non-urban' key sites would be covered by the wider national seabird census, such that population estimates derived from aerial surveying of urban key sites and sampling of the wider landscape could be combined with these counts to produce first complete and robust estimates for the UK and Ireland.

Ross *et al.* (2016) identified seven potential key urban sites to be surveyed: London, Manchester, Birmingham, Edinburgh, Glasgow, Liverpool and Dublin. To generate the required population estimates, it was also proposed that digital aerial surveys be conducted in sample 10-km squares across 14 defined regions of the UK, and Ireland. In the absence of additional simulation, an approximate figure of 100 sample 10-km squares, in addition to the potential key sites, was proposed, reflecting coverage by other previous surveys (e.g. the 2003/04-2005/06 Winter Gull Roost Survey: Banks *et al.* 2009, Burton *et al.* 2013; and the Dispersed Waterbird Survey: Jackson *et al.* 2006). The focus of this report is assessing the trade-off between sample coverage and the precision of population estimates.

Spatial data describing the distributions of Lesser Black-backed Gulls and Herring Gulls in the UK and Ireland were obtained from Bird Atlas 2007-11 (Balmer *et al.* 2013). Timed Tetrad Visits (TTVs: https://www.bto.org/volunteer-surveys/birdatlas/methods/field-methods) (1 or 2 hours in length) were conducted during the breeding season (April-July) within each 10-km grid square of the British and Irish National Grids, although coverage varied between regions (Table 2.1). Ten-km squares were divided into 25 tetrads, 2 km x 2 km squares, and squares with less than eight tetrads covered were not considered in the analysis. Tetrads falling within the seven potential key urban sites identified by Ross *et al.* (2016) were also excluded. Further, because they are likely to receive dedicated survey coverage during the wider national seabird census, Special Protection Areas (SPAs) and potential SPAs (pSPAs) designated for breeding colonies of Lesser Black-backed Gull and Herring Gull (http://jncc.defra.gov.uk/page-1409; https://www.npws.ie/protected-sites) were also excluded. For the large Morecambe Bay and Duddon Estuary potential SPA, the excluded area was limited to the South Walney and Piel Channel Flats Site of Specific Scientific Interest (SSSI), which include the protected gull colonies. In addition, squares often did not contain the full 25 tetrads, i.e. due to being on the coast, bordering a neighbouring region or containing key sites. Such squares with a reduced number of tetrads were included in analyses if at least 8/25ths of the available tetrads were surveyed, thus matching the criteria of eight squares used above for squares containing a full 25 tetrads available.

Table 2.1 Coverage of Bird Atlas 2007-11 data for 12 regions within the UK and Republic of Ireland.

Region	Number of 10-km grid squares per region	Number of 10-km grid squares included in analyses	Max (mean) number of tetrads covered per grid square
Scotland NW	508	342	19 (9)
Scotland E	337	302	25 (12)
Scotland SW	310	234	24 (9)
England NW	160	137	25 (18)
England NE	296	273	25 (15)
Midlands	369	359	25 (18)
Wales	282	237	25 (12)
East Anglia	241	229	25 (15)
England SE	276	247	25 (18)
England SW	281	237	25 (17)
Northern Ireland	189	112	21 (8)
Republic Ireland	574	427	16 (8)

We used records of possible, probable or confirmed breeding from the 'Bird Atlas 2007-11' data to describe bird distribution and calculated the mean number of sightings per hour for each tetrad. This thus excluded other records of birds not thought to be breeding and was consistent with data presented in Bird Atlas 2007-11 on species' breeding distributions. While it should be noted that the inclusion of 'possible' breeding records might potentially inflate the apparent breeding estimates produced in this analysis, it is the relative size of the confidence intervals to the estimate that is of importance rather than the estimate itself (see below).

It should be noted that the counts from Bird Atlas 2007-11 are likely to underestimate the actual numbers of nesting pairs of Lesser Black-backed Gulls and Herring Gulls due to the difficulties of surveying roof-nesting birds from the ground – hence the recommendation that digital aerial surveys should be used as the basis of the proposed survey (Ross *et al.* 2016) – and as they are timed counts (1 or 2 hours) and thus do not provide comprehensive coverage of the tetrads. However, it is expected that the variation in counts between tetrads is likely to be proportionate to that in actual breeding numbers, and thus that the counts provide a suitably representative dataset to assess how varying coverage will affect the confidence intervals around population estimates, even if those population estimates in themselves are underestimated.

Each 10-km square was assigned to coastal vs. inland strata and urban vs. non-urban habitat strata. These two stratifications were not mutually exclusive, thus a four-level categorisation of individual squares was produced (i.e. 'inland urban', 'coastal urban', 'inland non-urban' and 'coastal non-urban'). Tetrads within squares that clipped a 1 km buffer around the coastline (including estuaries) were first classified as coastal and all others were considered as inland (Ross *et al.* 2016). Any 10-km grid squares containing coastal tetrads (and consequently all tetrads within those squares) were themselves then considered as coastal. The urban stratum was based on the Land Cover Map (LCM) 2007 dataset (http://www.ceh.ac.uk/services/land-cover-map-2007; Morton *et al.* 2011), with the exceptions of Northern Ireland and the Republic of Ireland, which was based on CORINE Land Cover data (http://land.copernicus.eu/pan-european/corine-land-cover). Both datasets offer urban coverage at a 1 km resolution. The thresholds for assigning 10-km squares to the urban stratum were 2% and 3.8% for the LCM and CORINE Land Cover data, respectively. Bird Atlas 2007-11 data indicated an increase in the proportion of squares with medium abundance of Lesser Black-backed Gulls between 0-2% urban and >2-5% urban categories (Ross *et al.* 2016), suggesting that 2% might be an appropriate threshold for the LCM dataset. Linear regression of the % urban cover of the LCM and CORINE datasets for Great Britain indicated that 2% urban cover in the LCM dataset roughly corresponds to 3.8% in the CORINE dataset. Given this close relationships between gull abundance and urban habitats, we did not consider further stratification based on gull abundance as previously suggested by Ross *et al.* (2016). Regions also follow those presented in Ross *et al.* (2016), although for the purposes of this simulation exercise, Wales was treated as a single region and the Isle of Man and Channel Islands was excluded (due to the limited size of the latter and of the south Wales region).

It was necessary to classify 10-km squares (and consequently all tetrads within those squares) to strata in order to be able to weight survey effort towards specific strata equally across all levels of survey coverage considered in the simulation. It should be noted that this inflates the variation within each strata in the simulation beyond that which will be expected from the survey itself, for which individual tetrads within 10-km squares would be independently assigned to strata. This would be expected to result in confidence intervals much reduced in magnitude.

2.2 Varying Sampling Effort

Using this dataset, we examined the effect of varying coverage within sample 10-km squares and in the extent of sample 10-km coverage on the confidence intervals (i.e. the interval between the upper and lower 95% confidence limits) around population estimates of Lesser Black-backed Gulls and Herring Gulls through bootstrap simulations.

We produced 119 bootstrap realisations of population estimates of the survey areas using data collected for Bird Atlas 2007–11, using resampling procedures carried out at both the 10-km grid square level and the 2x2 km tetrad level within each square. We selected 119 bootstraps (i.e. rather than higher numbers) as a trade-off of limitations in computing time of the sampling algorithm, and also to allow confidence intervals to be generated through selection of ordered bootstraps (see below).

At the 10-km grid square level, we used a stratified random sampling approach, resampling squares with replacement from those proportionally available within the four-level strata (i.e. 'inland urban', 'coastal urban', 'inland non-urban' and 'coastal non-urban') within each region. The effect of sample size (regional coverage) was estimated by varying the number of 10-km grid squares, thus simulating scenarios of surveying smaller subsets of the total available within the region. Each subset of 10-km squares was randomly sampled with replacement from those squares within each stratum for which tetrad samples were available (see Table 2.1). Thus, subsets of squares were sampled in relation to the proportion of available strata within each region. The subset of squares was then scaled up to the number of 10-km squares in the region allowing a regional population estimate to be determined. Scenarios of sampling effort included 11 different levels of 10-km square coverage (6, 8, 10, 15, 20, 30, 40, 50, 60, 80 and 100 squares per region). Note, the effect of increasing levels of 10-km square coverage (on confidence intervals) was expected to vary between regions, both because of inherent differences in the variation in counts between regions and because of the differences in the proportional coverage of each region that these levels represent. Thus, while we provide broad recommendations on the minimum number of 10-km squares that should be covered per region, specific requirements are likely to vary between regions.

To investigate the effect of proportional coverage within 10-km squares, a second stage of resampling based on tetrad coverage was simultaneously carried out. A subset of tetrads was randomly selected with replacement from those surveyed within each square, which were then extrapolated to the total number of tetrads within the square. However, the extrapolated number of tetrads was only 25 if the square was fully inland and did not border neighbouring regions, or key sites. Five levels of tetrad coverage within each square were considered (20%, 40%, 60%, 80% and 100% of available tetrads within a square). Percentage values rather than absolute numbers of squares were chosen to accommodate constraints on the numbers of tetrads noted above, which in turn better simulated potential coverage within a square by aerial surveys. It should be noted, however, that typically the proportion of grid squares in a 10-km square covered by Bird Atlas 2007–11 was less than 100% (although usually greater than 32%, i.e. 8 of 25 squares – see above), and as such the simulations of higher levels of coverage will have drawn from incomplete pools of available tetrads with such squares.

Following both stages of resampling above, carried out for 119 realisations, a population estimate for each strata for each region was then calculated. All strata estimates were aligned within the region for each un-ordered realisation and summed to give 119 estimates of the population in the region. Realisations were then ordered from smallest to largest and a median estimate with confidence intervals was derived for the number of gulls in the survey area (using 119 repetitions, the 60th, 3rd & 116th ordered values give estimates with 95% confidence intervals).

From this simulation, we plotted the magnitude of confidence intervals across the range of 10-km grid sample coverage and within-grid proportional coverage for each region (n = 12), thus investigating trade-offs of increasing surveying coverage within the region (number of 10-km grid square subsets), versus the percentage coverage within individual squares. Median population estimates were also plotted in relation to coverage. All plots were visually inspected for a suitable point in this 3D space where both confidence intervals and medians plateaued, with minimum confidence intervals ideally sought. It was anticipated that much larger within region coverage (i.e. up to 100 individual 10-km squares) would result in the lowest confidence intervals, thus we inspected plots for the point at which as similar error in estimates could be obtained with minimal within region and within square survey coverage.

As indicated above, it is the relative size of the confidence intervals to the estimate that is of importance rather than the estimate itself, the key assumption being that the variation observed during Bird Atlas 2007–11 will be representative of the variation expected during the proposed aerial survey. Although the acceptable size of the confidence intervals is a subjective decision, the proposed simulation will help guide that decision and allow us to seek an optimal balance between survey effort and level of refinement of the population estimates it will generate.

In addition to producing plots at the region level, we also produced combined plots for England, Scotland, Wales, Northern Ireland, Republic of Ireland, UK, Great Britain and Great Britain and Ireland (although note some regions were at the country level as originally specified). For such region-combined plots, all population estimates within strata and for each region were aligned for non-ordered bootstraps, thereafter a row-sum across for each 119 realisations was computed, prior to further ordering of realisations for calculation of medians and confidence intervals, as described above.

All data manipulation and resampling algorithms were computed using R version 3.3.2 (2016-10-31, ‘Sincere Pumpkin Patch’).

2.3 Weighting Survey Effort Towards Specific Strata

To examine whether the accuracy of estimating the relative abundance of gulls in each region could be improved by weighting the survey coverage towards tetrads in coastal or urban strata we repeated the simulation analysis under two scenarios: (1) resampling coastal tetrads and inland tetrads; and (2) resampling urban tetrads and non-urban tetrads. This analysis was limited to regions with 50 or more 10-km squares in coastal or urban strata.

A worked example explaining the weighting procedure is provided in Table 2.1 Weighted estimates were obtained using the same resampling algorithm as defined above, with procedures at the tetrad level in the second stage being identical. Weighting was applied at the first stage when drawing samples of 10-km squares within strata. The number of 10-km squares to be resampled within urban strata (inland urban, coastal urban) or coastal strata (coastal urban, coastal non-urban) was initially derived in the same way as the un-weighted version, i.e. in proportion to the number of squares of that stratum within the region. However, we then also weighted sampling, by initially doubling the numbers of urban or coastal squares to be resampled and then re-scaling the adjusted values so obtained to bring the total sample back down to the overall target level of sampling (6, 8, 10, 15, 20, 30, 40, 60, 80 or 100 squares per region).

Table 2.2 Example of the weighting procedure for one bootstrap for a single region, carried out when resampling numbers of 10-km squares. Here presented for a subset of 40 squares (range of 6 to 100 considered in the analysis – see methods) from a region containing 175 available squares. Stages are as follows: (1) the total number of squares falling into the four-tier urban/coastal inland/coastal strata are determined, and (2) the proportions of squares within strata are identified (e.g. 46% urban inland). Next, (3) the subset number of 40 squares are apportioned to strata; note, at this point, the algorithm has selected an un-weighted subset of squares (as used in un-weighted analyses). Weighting (4) is then carried out by in stage 1 doubling *only* the number of squares in the strata to be sampled from, in this example, urban (urban coastal and urban inland); this results in more than the 40 square regional total (i.e. now 64 squares), hence in stage 2, *all* squares are proportionally adjusted back to the subset number through a ratio correction (i.e. 40/64); these are then (5) rounded to an integer to provide the numbers of squares needing to be resampled.

PROCESS:	**---->**	**---->**	**---->**	**---->**	**---->**	
DESCRIPTION:	**(1) Total region coverage**	**(2) Strata proportions**	**(3) 10-km square subset**	**(4) Weighting**		**(5) Resampling**
Strata	Number of squares per strata per region	The proportion of each strata within the region	Subset proportions for regional coverage	Stage 1: doubling urban representation	Stage 2: re-scaling back to 10-km square region coverage	Rounded random no. squares picked per boot
Coastal urban	25	0.14	5.71	11.43	7.14	7
Inland urban	80	0.46	18.29	36.57	22.86	23
Coastal non-urban	50	0.29	11.43	11.43	7.14	7
Inland non-urban	20	0.11	4.57	4.57	2.86	3
Totals	**175**	**1.00**	**40**	**64**	**40**	**40**

3. RESULTS

3.1 Impact of Varying Sampling Effort

Confidence intervals around population estimates for Lesser Black-backed Gulls and Herring Gulls in regions and constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data (and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata) are shown in Figures 3.1 and 3.3 respectively.

The median population estimates themselves are shown in Figures 3.2 and 3.4 respectively. It should be noted that these are indicative only and should not be taken as true estimates of population size for the reasons stated in the methods. Further, it must be emphasised that the shapes of the relationships of the confidence intervals with increasing sample size are of more importance than the relative size of the confidence limits to the median population estimates for the same reasons (see methods/discussion).

Confidence intervals around population estimates of Lesser Black-backed Gulls and Herring Gulls reduced with increased coverage of tetrads and 10-km grid squares, albeit to a much greater extent with higher coverage of 10-km grid squares (Fig. 3.1; Fig. 3.3).

Relationships varied between regions, in part reflecting the relative size of those regions (Table 2.1). However, typically confidence intervals dropped sharply with an increase in coverage of 10-km grid squares up to around 20-40 squares per region, but beyond this, the benefits of increased coverage were less.

Benefits of increased coverage of tetrads within a 10-km square were also less apparent beyond 60% coverage. We note, however, that at smaller regional coverage numbers of squares, the confidence intervals increase across tetrad coverage, rather than decrease as would be predicted. Such a pattern is not unexpected as with smaller regional coverage the probability of selecting a large count is more stochastic but in turn is increased by greater within tetrad coverage.

Confidence intervals were greater for Herring Gull than for Lesser Black-backed Gull (Fig. 3.1; Fig. 3.3), although this was reflective of the relative size of the population estimates produced.

3.2 Impact of Weighting Survey Coverage Towards Specific Strata

3.2.1 Urban

Confidence intervals around population estimates for Lesser Black-backed Gulls and Herring Gulls in regions and constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares are shown in Appendices 1 and 5 respectively. The median population estimates themselves are shown in Appendices 2 and 6 respectively.

The effect of the urban weighting varied between species and between regions. The urban weighting was more effective at reducing the size of confidence intervals relative to increased coverage of 10-km grid squares for Lesser Black-backed Gull than Herring Gull, and principally in Wales, Scotland and Ireland.

3.2.2 Coastal

Confidence intervals around population estimates for Lesser Black-backed Gulls and Herring Gulls in regions and constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares are shown in Appendices 3 and 7 respectively. The median population estimates themselves are shown in Appendices 4 and 8 respectively.

The effect of the coastal weighting varied between species and between regions. The coastal weighting was more effective at reducing the size of confidence intervals relative to increased coverage of 10-km grid squares for Herring Gull than Lesser Black-backed Gull, and principally in Wales, Scotland and Ireland.

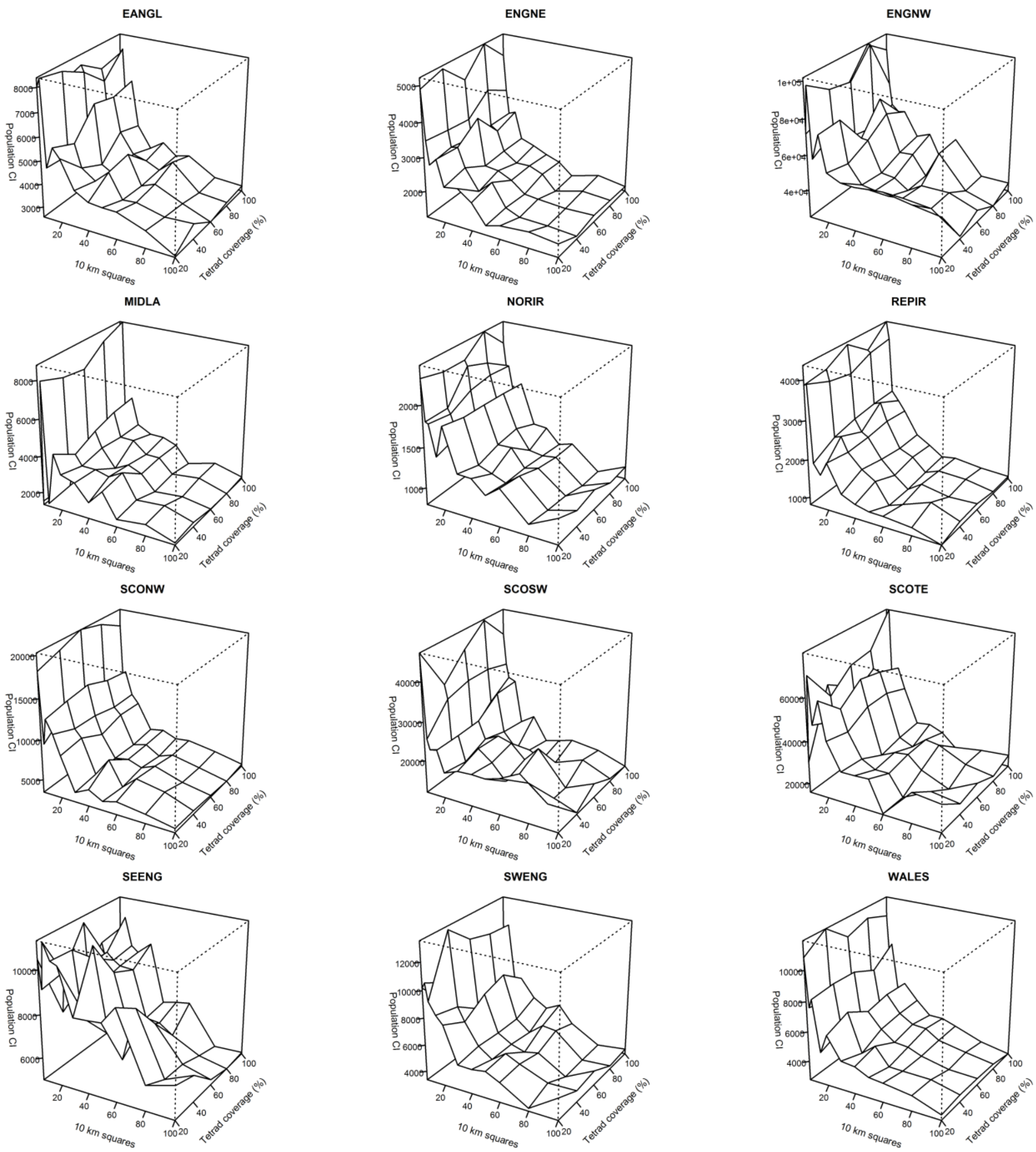

Figure 3.1a Confidence intervals around population estimates for Lesser Black-backed Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

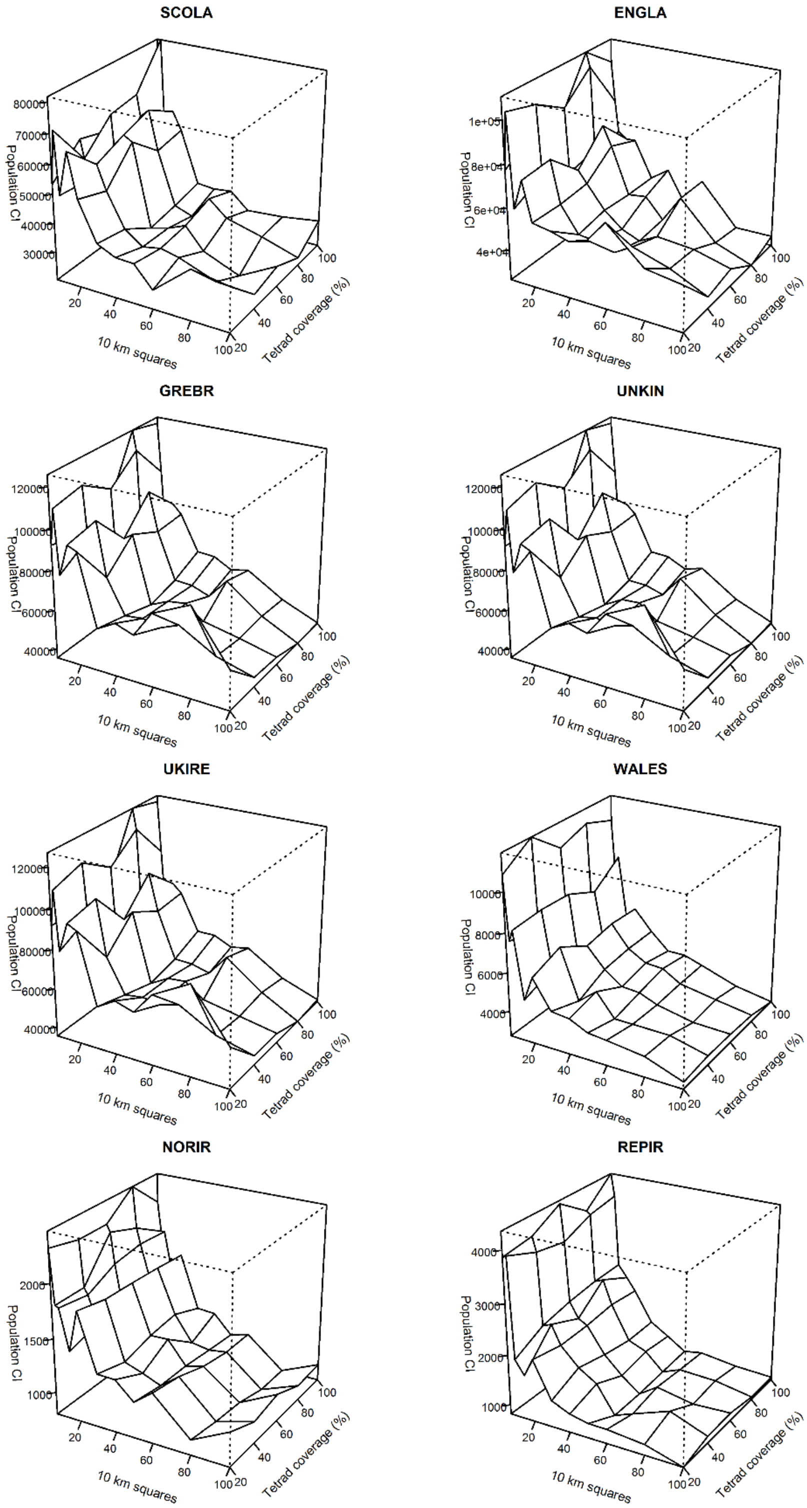

Figure 3.1b Confidence intervals around population estimates for Lesser Black-backed Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

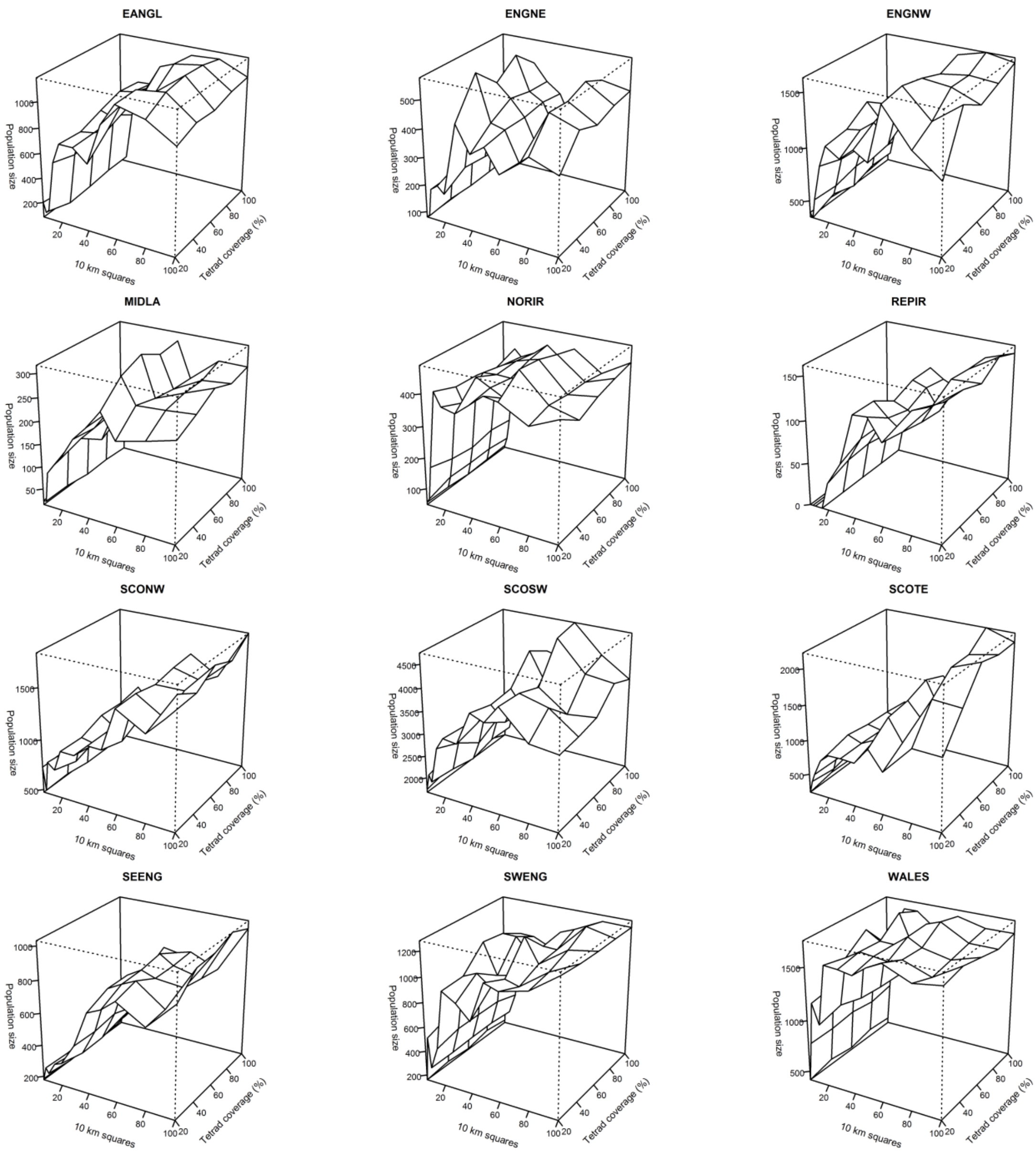

Figure 3.2a Median population estimates for Lesser Black-backed Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

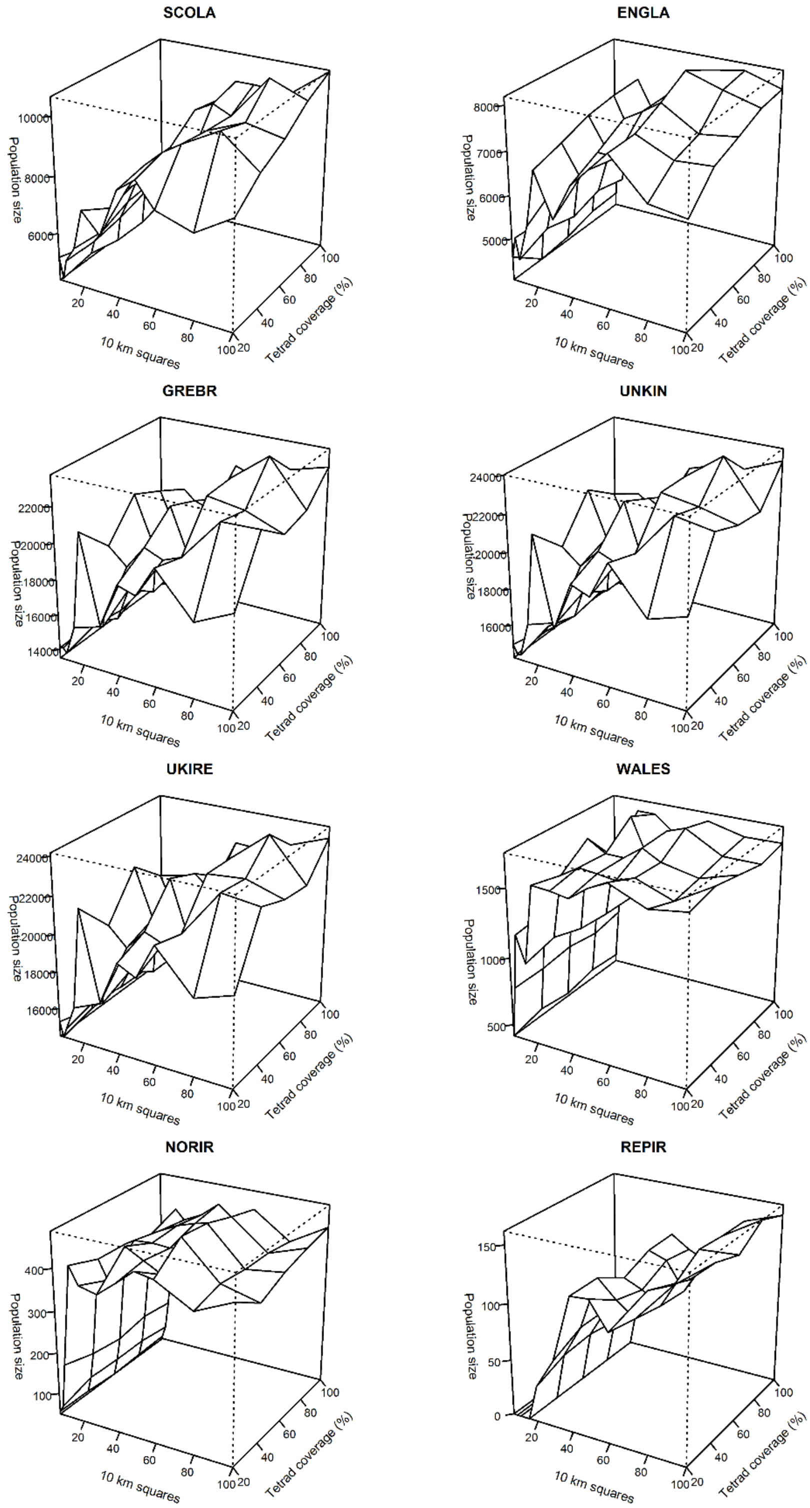

Figure 3.2b Median population estimates for Lesser Black-backed Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

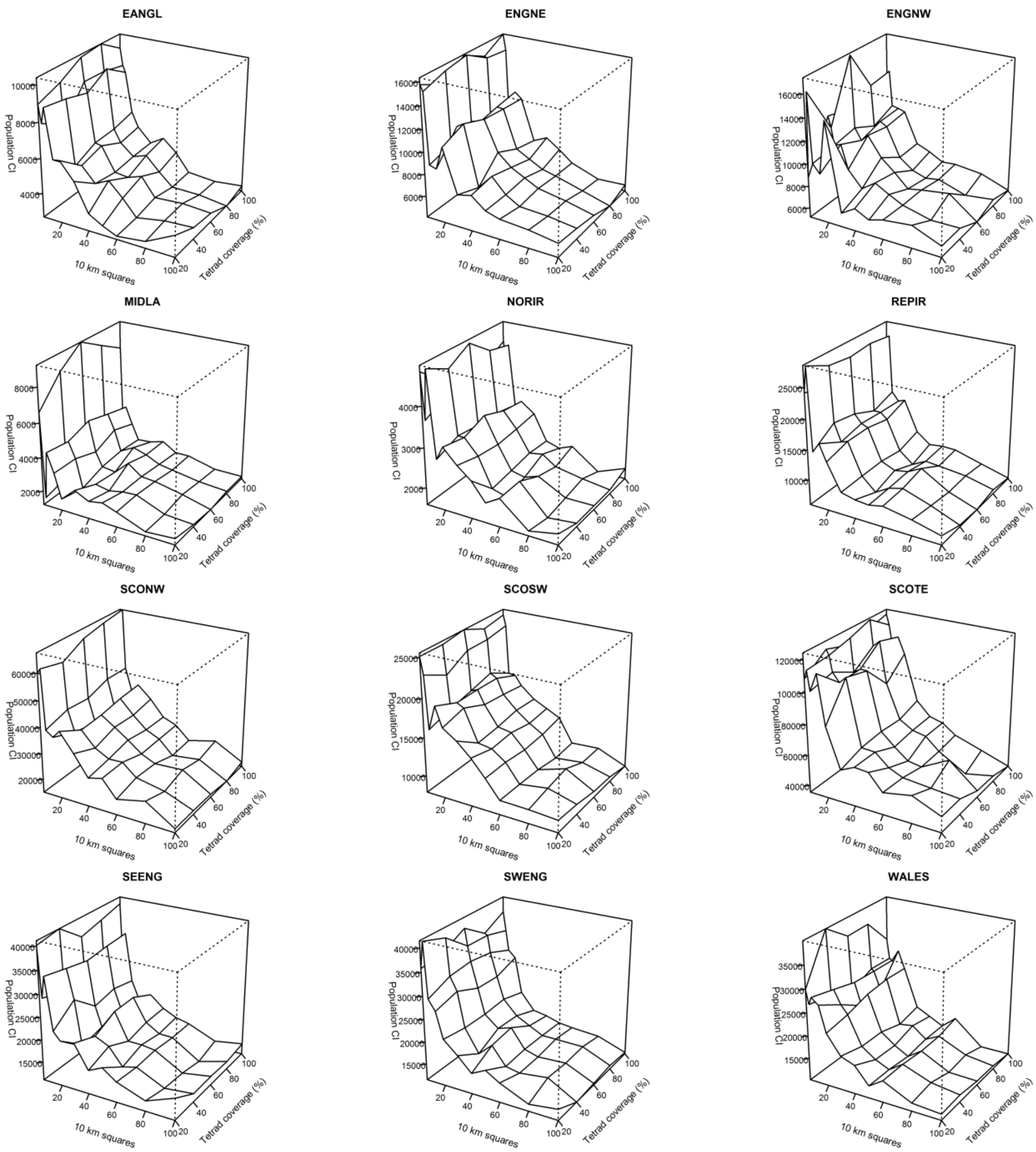

Figure 3.3a Confidence intervals around population estimates for Herring Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

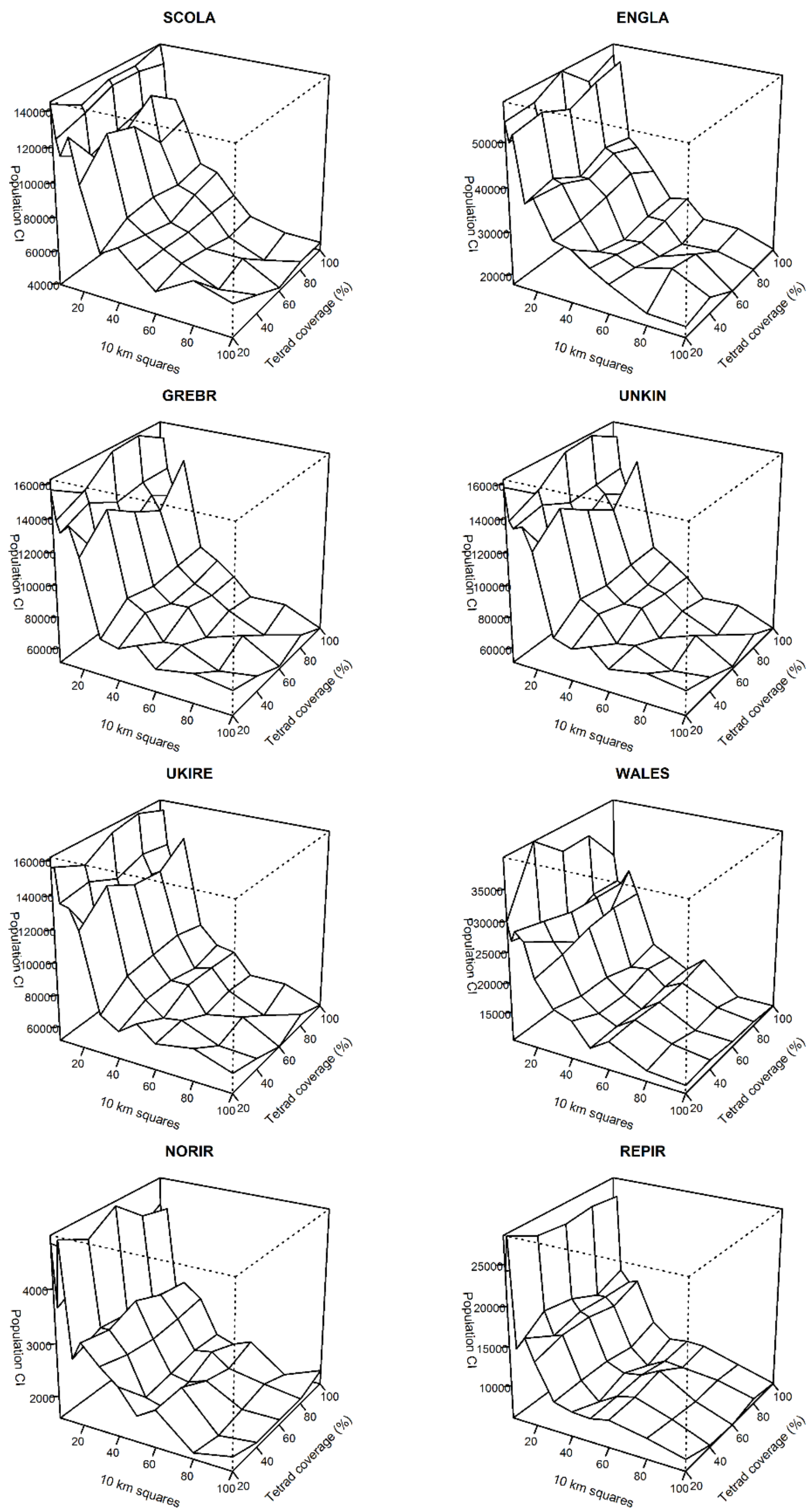

Figure 3.3b Confidence intervals around population estimates for Herring Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

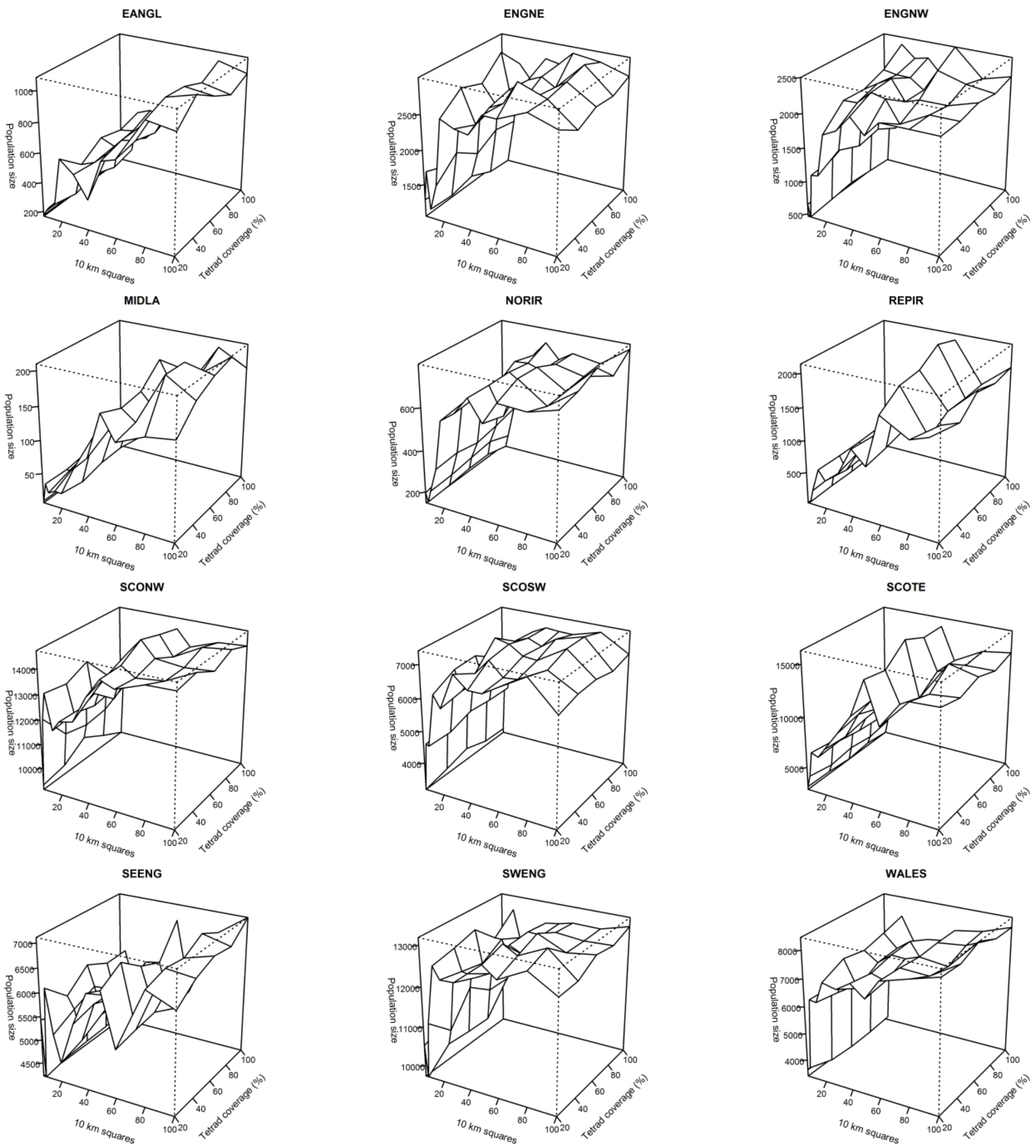

Figure 3.4a Median population estimates for Herring Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

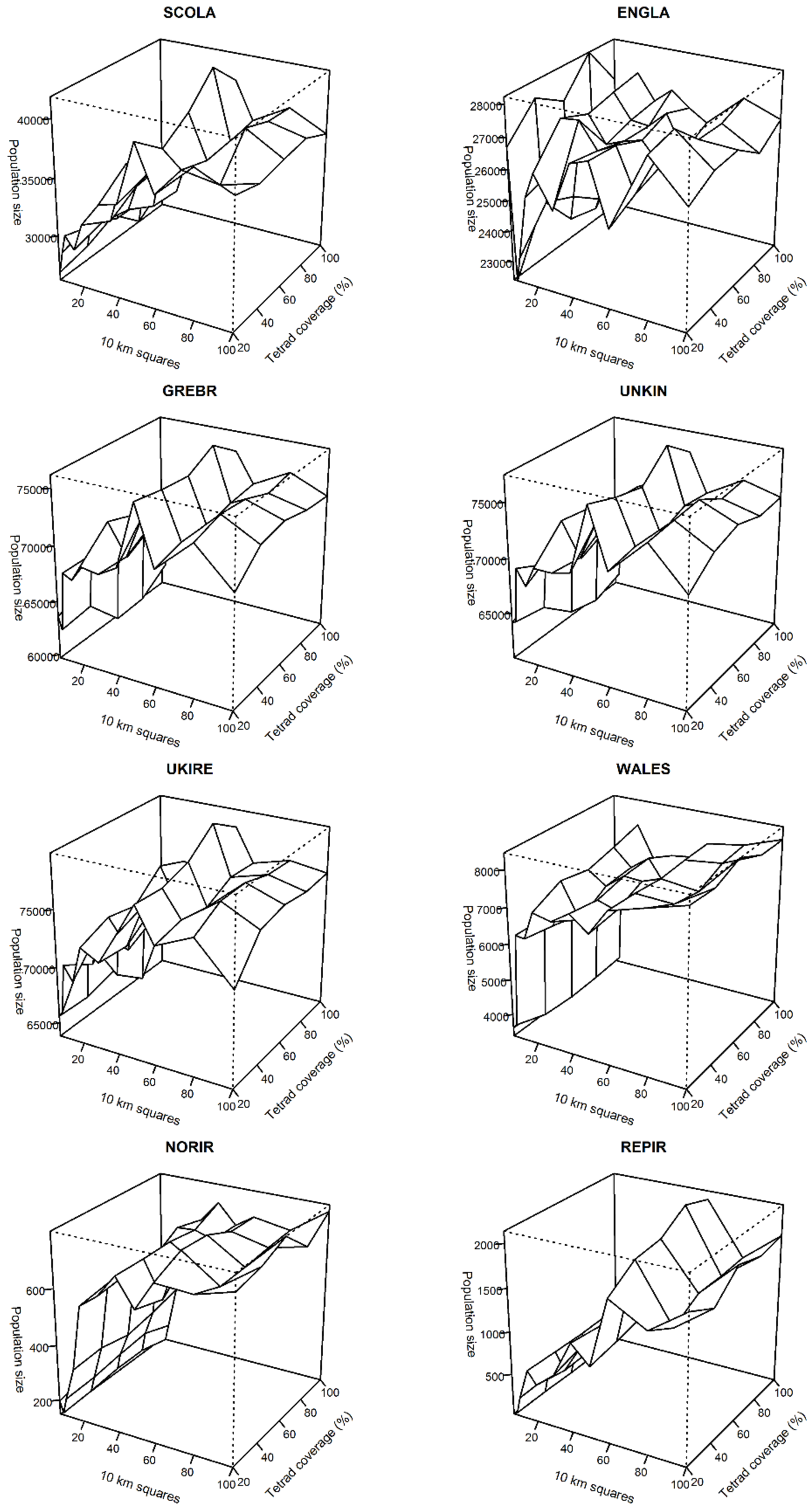

Figure 3.4b Median population estimates for Herring Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage un-weighted in relation to coastal/inland or urban/non-urban strata.

4. DISCUSSION AND RECOMMENDATIONS

To deliver the population estimates for Lesser Black-backed Gulls and Herring Gulls required for the UK and Ireland, Ross *et al.* (2016) proposed a survey design using a paired key site and stratified sampling approach, the latter covering the entire spectrum of urbanisation. It was proposed that the survey would best be achieved by digital aerial survey and that the stratification should be based on gull abundance, region, % urban cover and whether the site was coastal or inland. 'Non-urban' key sites would be covered by the wider national seabird census, such that population estimates derived from aerial surveying of urban key sites and sampling of the wider landscape could be combined with these counts to produce first complete and robust estimates for the UK and Ireland.

The principal aim of the present study was to examine the effect of varying coverage within sample 10-km squares and in the extent of sample 10-km coverage on the confidence intervals around population estimates of Lesser Black-backed Gulls and Herring Gulls outwith the provisional key sites identified by Ross *et al.* (2016), so as to provide guidance on the levels of coverage required by a future national survey.

It should be noted that it is the relative size of the confidence limits around the estimates, i.e. the precision of the estimates, rather than their accuracy that is of importance. As noted in the methods, the tetrad counts from Bird Atlas 2007-11 used in this study are likely to underestimate the actual numbers of nesting pairs of Lesser Black-backed Gulls and Herring Gulls due to the difficulties of surveying roof-nesting birds from the ground – hence the recommendation that digital aerial surveys should be used as the basis of the proposed survey (Ross *et al.* 2016) – and as they are timed counts (1 or 2 hours) and thus do not provide comprehensive coverage of the tetrads. Further, the relative size of the confidence limits to the median population estimates is likely to be much greater than would be expected from a bespoke survey, both for these reasons and also as it was necessary to classify 10-km squares (and consequently all tetrads within those squares) to strata in order to be able to weight survey effort towards specific strata equally across all levels of survey coverage considered in the simulation. For the purposes of the proposed survey itself, individual tetrads within 10-km squares would be independently assigned to strata and confidence intervals would consequently be much reduced in magnitude. It is nevertheless expected that the variation in counts between tetrads is likely to be proportionate to that in actual breeding numbers, and thus that the counts provide a suitably representative dataset to assess how varying coverage will affect the confidence intervals around population estimates.

The confidence intervals around population estimates of Lesser Black-backed Gulls and Herring Gulls improved with increased coverage of both tetrads and 10-km grid squares. However, the improvement was most apparent through increased coverage of 10-km grid squares. This likely reflects that (within any one region), at low levels of coverage, there is likely to be greater variability in the relative abundance of gull populations between 10-km squares than within a given 10-km square.

Confidence intervals were greater for Herring Gull than for Lesser Black-backed Gull (Fig. 3.1; Fig. 3.3), although this was reflective of the relative size of the population estimates produced, Herring Gull being more numerous and widespread outside of protected sites and key sites excluded from this analysis (Mitchell *et al.* 2004).

Relationships varied between regions, in part reflecting the relative size of those regions (Table 2.1). However, typically confidence intervals dropped sharply with an increase in coverage of 10-km grid squares up to around 20-40 squares per region, but beyond this, the benefits of increased coverage were less.

As noted in the methods, typically the proportion of grid squares in a 10 square covered by Bird Atlas 2007–11 was less than 100% (although usually greater than 32%, i.e. 8 of 25 squares – see above), and as such the simulations of higher levels of coverage will have drawn from incomplete pools of available tetrads with such squares. In part, this is likely to explain why, while confidence intervals reduced with an increase from low to medium levels of coverage of tetrads within a 10-km square, there was less apparent benefit with further increases in coverage.

Given these relationships, a broad recommendation would be that there should be a minimum of 20 10-km squares covered per region (although potentially more or less for specific regions), with 50% coverage within these 10-km squares.

This recommendation might be refined, for some regions, by weighting sampling effort. The urban weighting was more effective at reducing the size of confidence intervals relative to increased coverage of 10-km grid squares for Lesser Black-backed Gull than Herring Gull, and principally in Wales, Scotland and Ireland. Conversely, the coastal weighting was more effective at reducing the size of confidence intervals relative to increased coverage of 10-km grid squares for Herring Gull, and again principally in Wales, Scotland and Ireland. These relationships likely reflect that both species are less extensively distributed in these regions, with fewer occupied 10-km squares/tetrads away from the coast and major urban areas, reflecting the lower urban cover in these regions.

Ostensibly, the 10-km squares selected within a region for a survey of Lesser Black-backed Gull should not need to differ to those selected for a survey of Herring Gull. However, it may be that for one species, the level of coverage of the region may need to be greater or, as suggested above, that coverage could be weighted towards particular strata. As indicated above, in some regions, coverage might be weighted towards the urban stratum for Lesser Black-backed Gull and towards the coastal stratum for Herring Gull. In such a case, the same squares might be selected for the two species in the 'coastal urban' and 'inland non-urban' strata, but extra squares might be required for Lesser Black-backed Gull in the 'inland urban' stratum and for Herring Gull in the 'coastal non-urban' stratum. Alternatively, one might weight further towards the 'coastal urban' stratum. In some regions, one might also consider the relative expected populations of the species and whether weighting might be prioritised for one species over the other. It should also be noted that, as the proposed survey would aim to support delivery of the latest census of the breeding seabird population of Britain and Ireland, any sites that are covered by that wider census might be excluded from the area requiring sample coverage, these most likely occurring within the 'coastal non-urban' stratum.

Ross *et al.* (2016) provided indicative costs for both coverage of key sites and also an approximate figure of 100 sample 10-km squares across all regions, this figure reflecting coverage by other previous sample-based surveys (e.g. the 2003/04-2005/06 Winter Gull Roost Survey: Banks *et al.* 2009, Burton *et al.* 2013; and the Dispersed Waterbird Survey: Jackson *et al.* 2006). These costs included varying levels of coverage of the 10-km squares from 10 to 100%. The figure of 100 sample 10-km squares across all regions equated to around seven squares per region – less than the suggested figure of 20 that the analyses presented here would suggest is required. However, relative costs would be reduced by the lower level of coverage needed within those 10-km squares and could be further reduced by surveying more than one 10-km square per flight, reducing transit costs.

Acknowledgements

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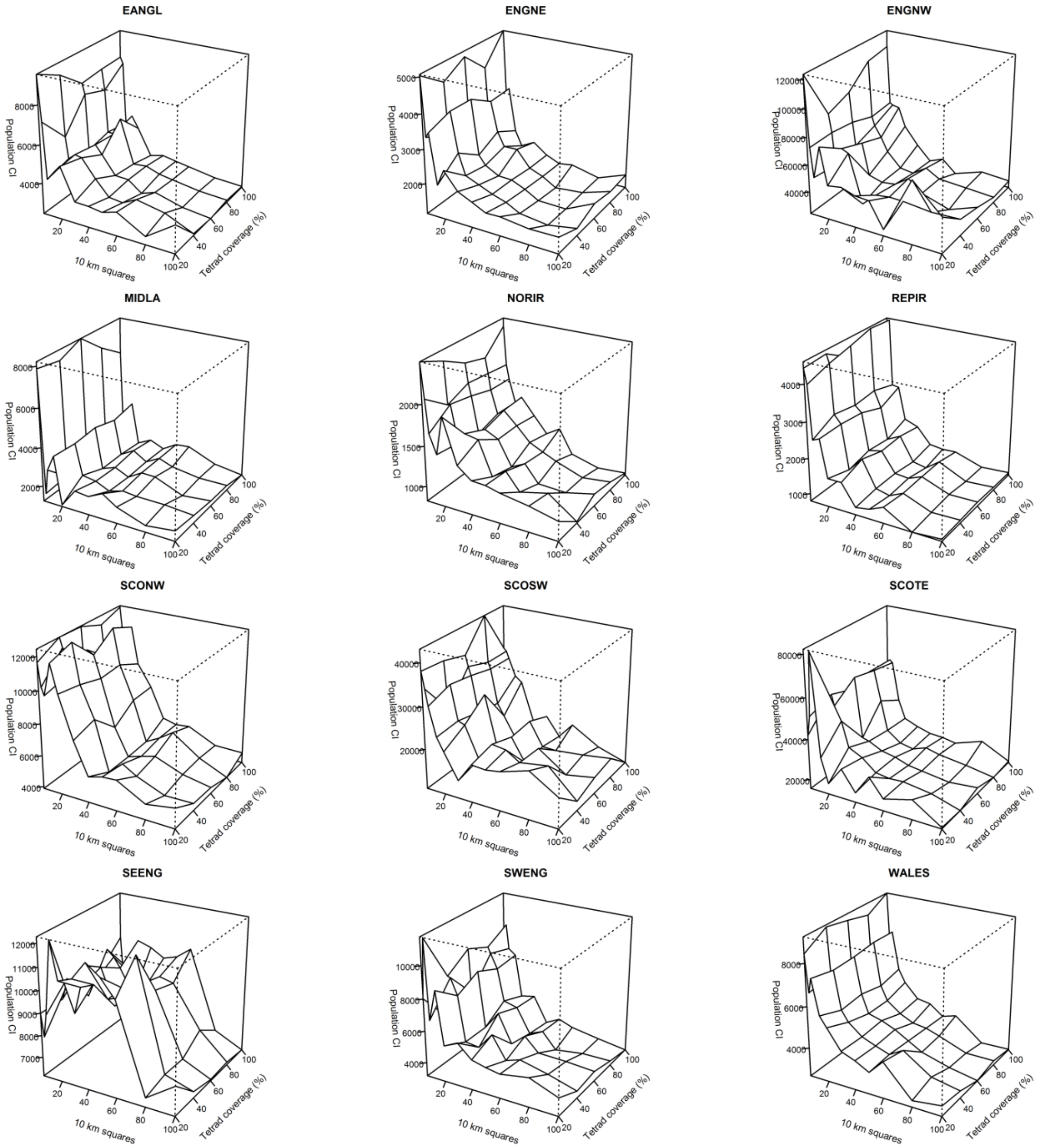
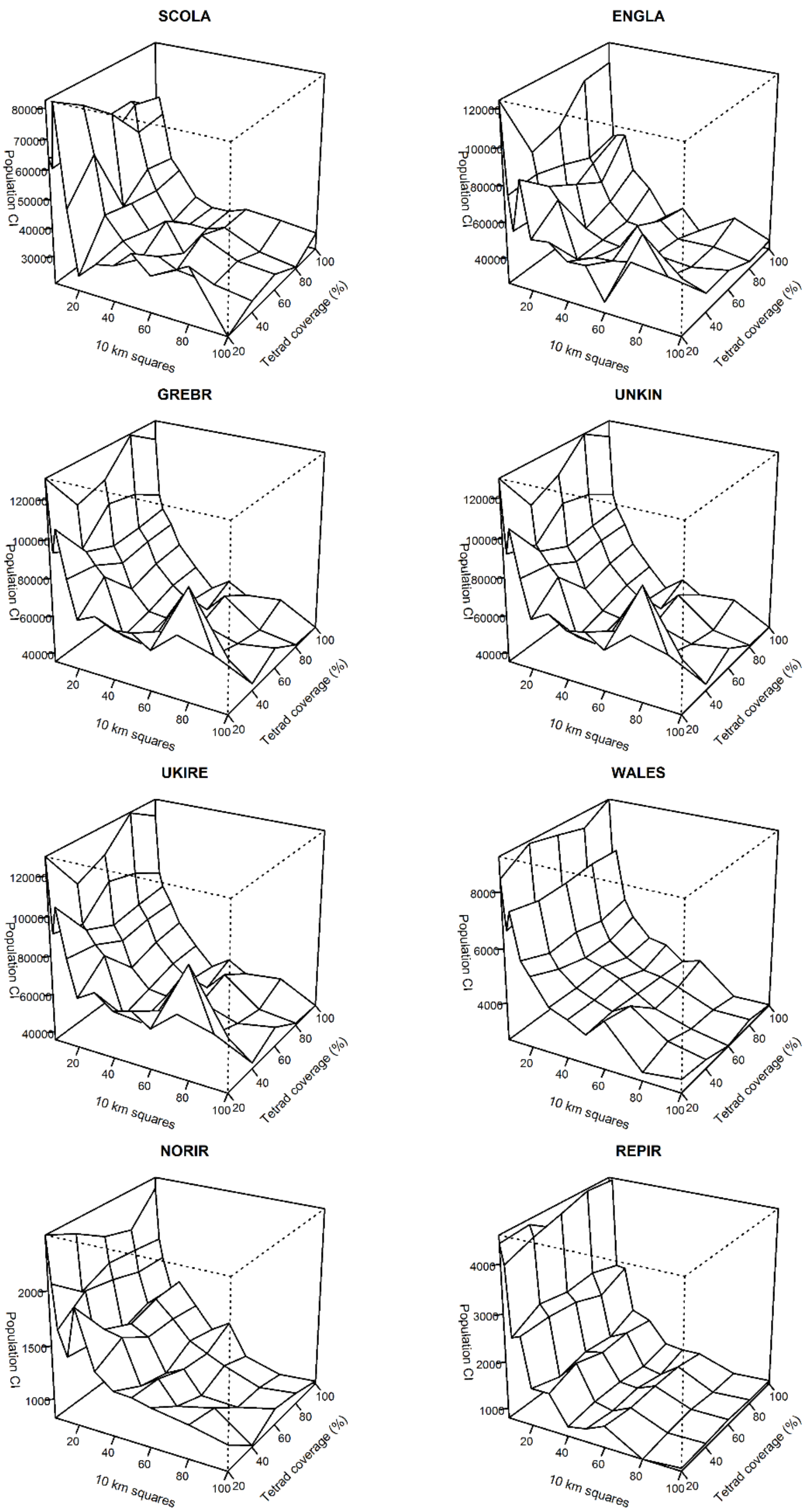
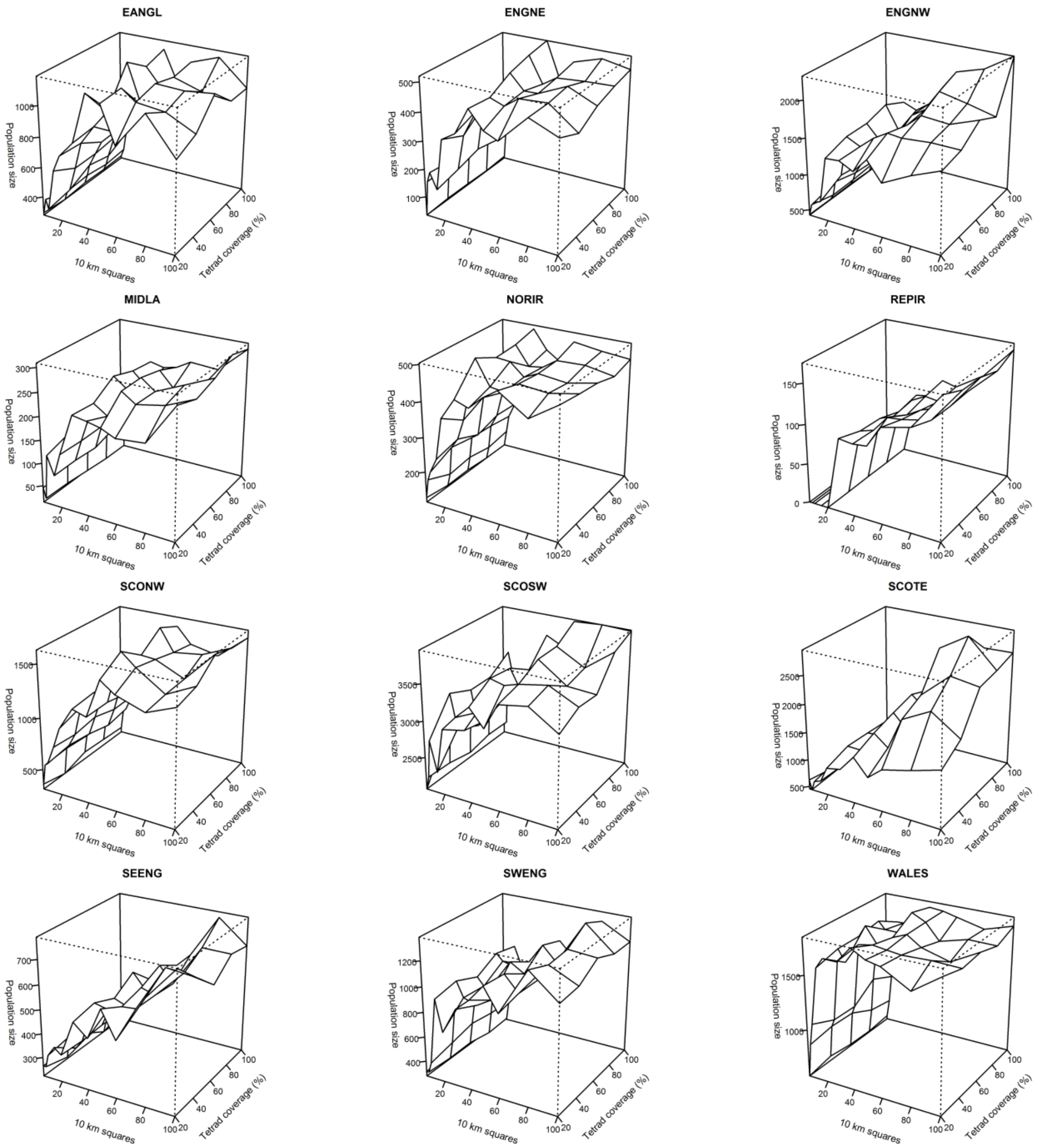
Appendix 1a Confidence intervals around population estimates of Lesser Black-backed Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



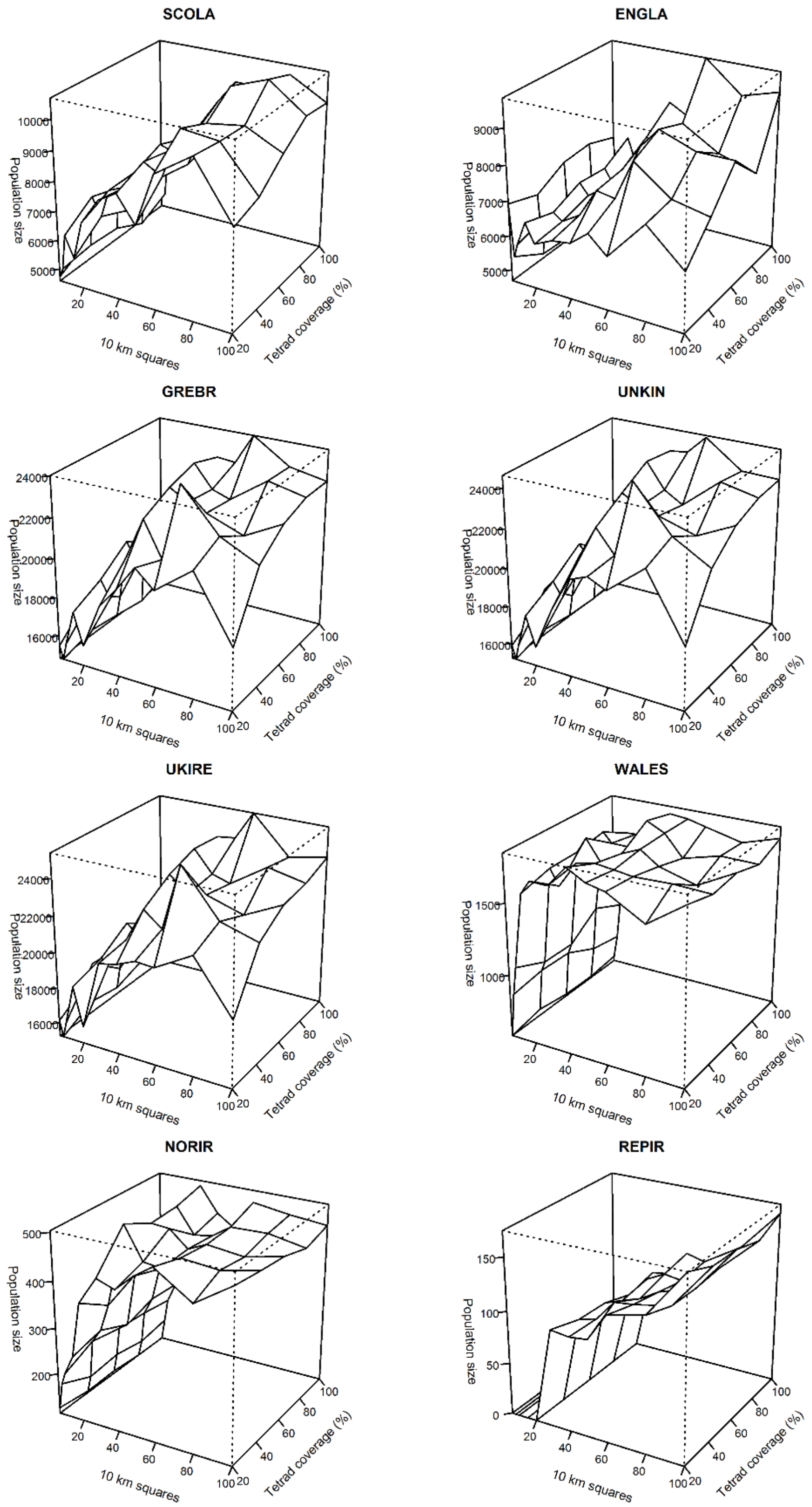
Appendix 1b Confidence intervals around population estimates of Lesser Black-backed Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



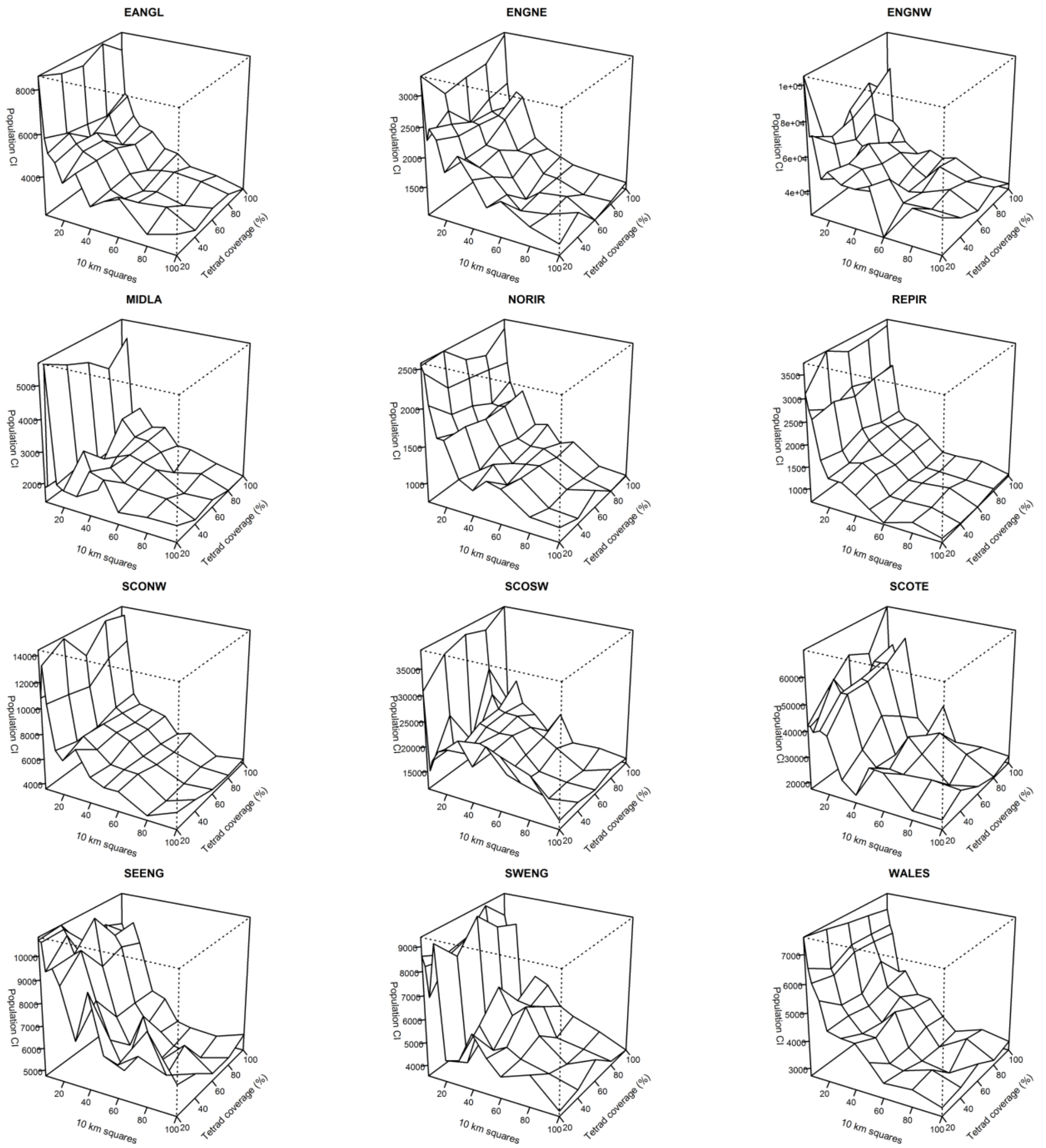
Appendix 2a Median population estimates of Lesser Black-backed Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



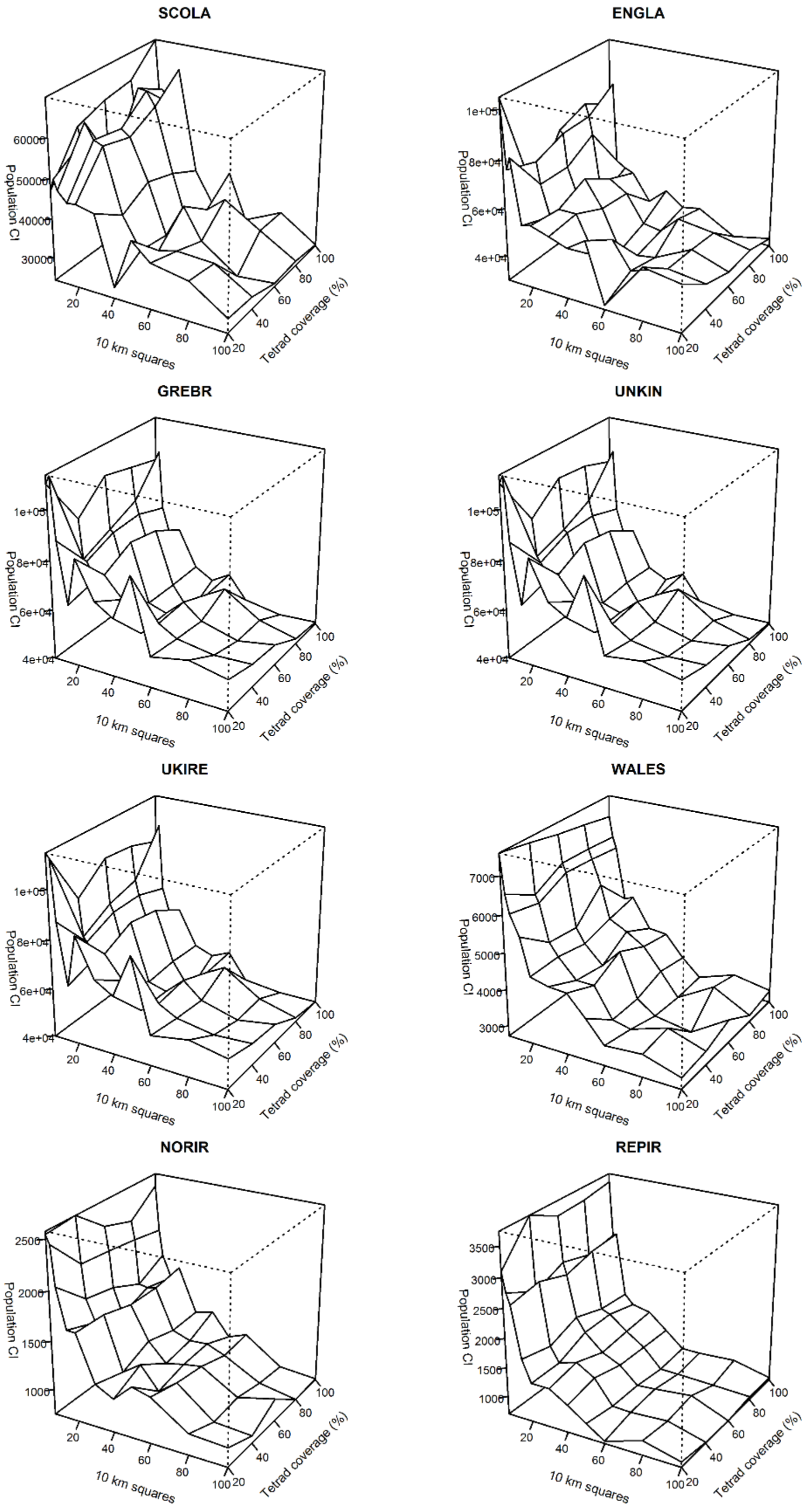
Appendix 2b Median population estimates of Lesser Black-backed Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



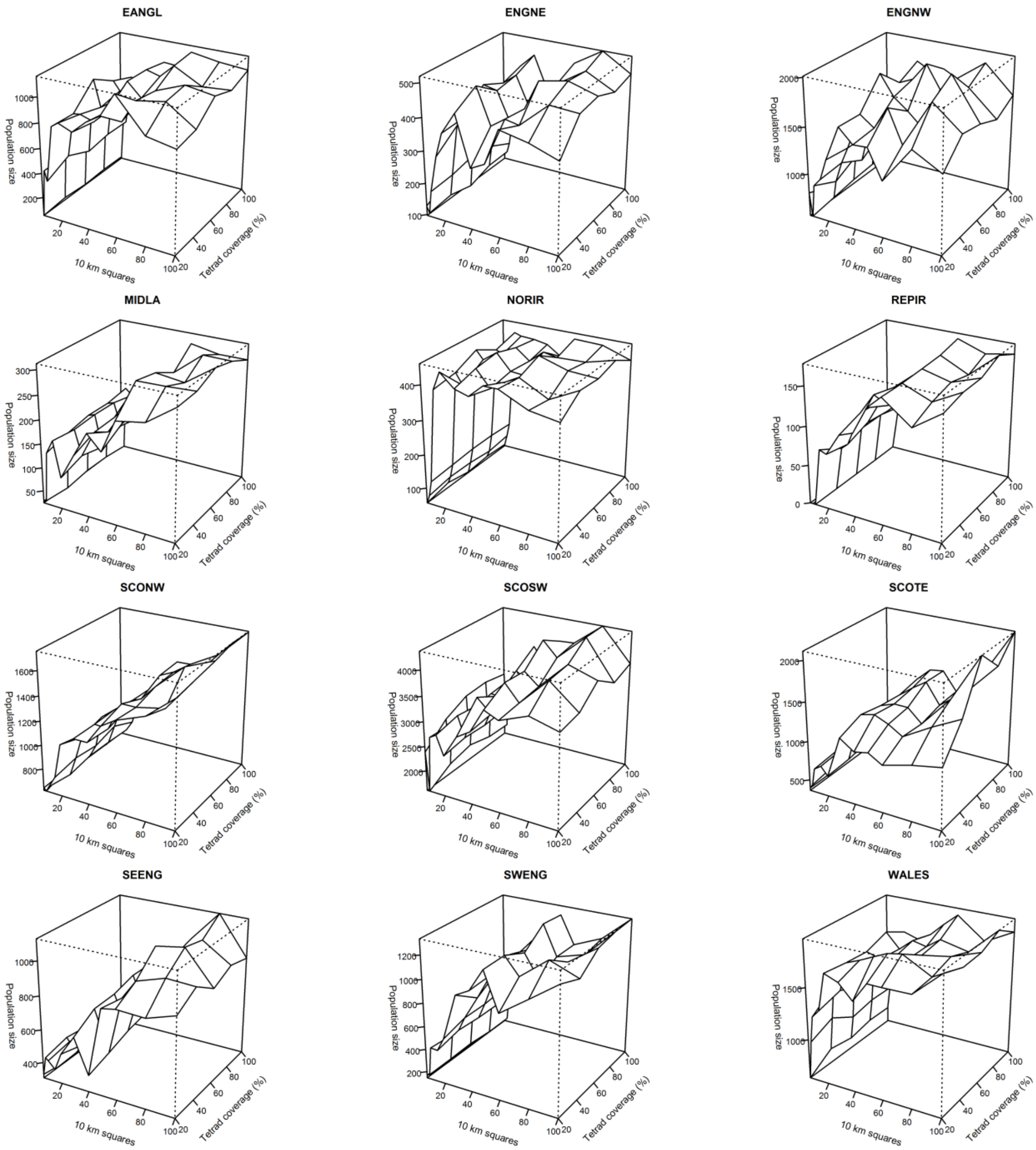
Appendix 3a Confidence intervals around population estimates of Lesser Black-backed Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares (see methods).



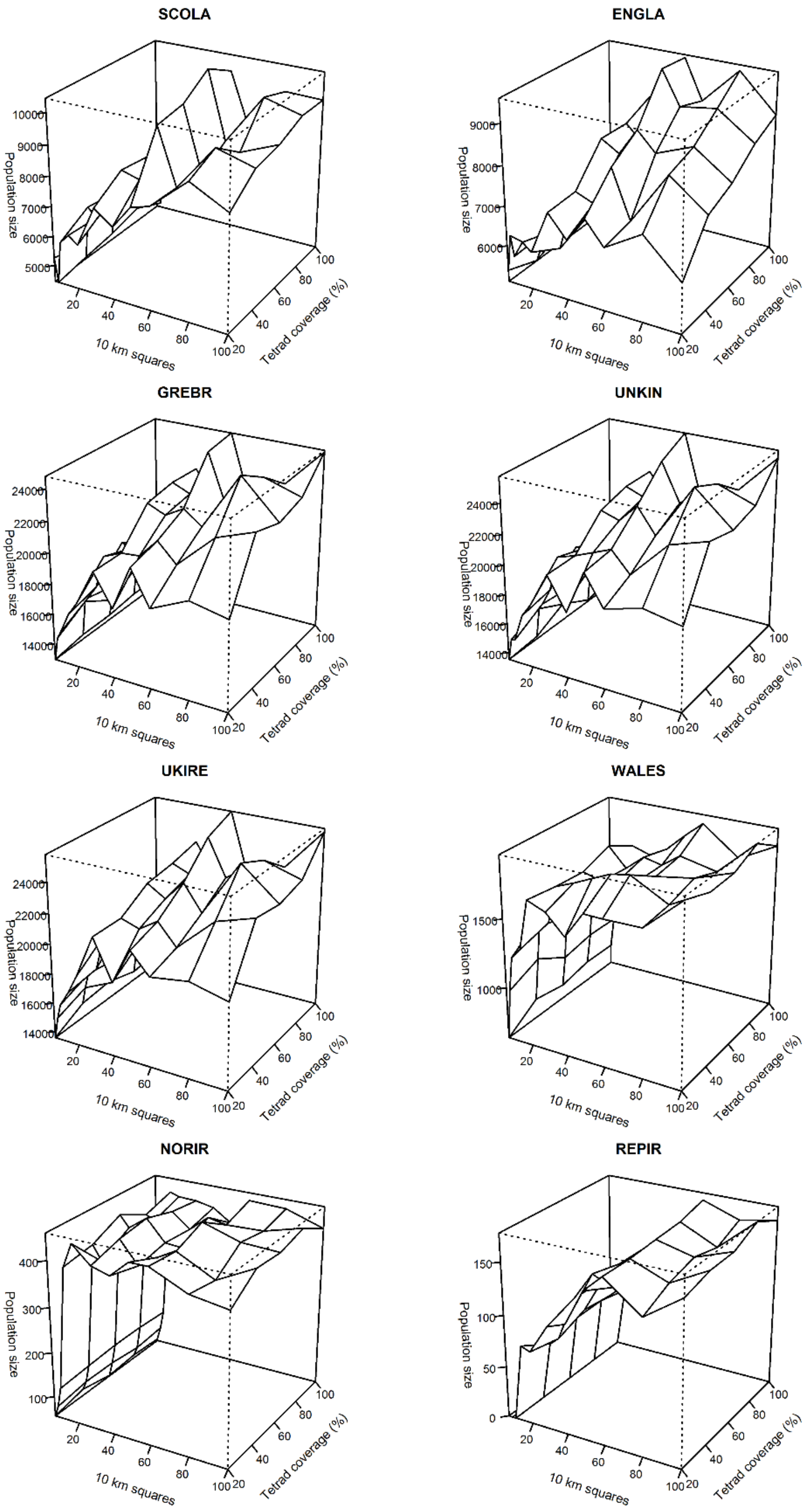
Appendix 3b Confidence intervals around population estimates of Lesser Black-backed Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares (see methods).



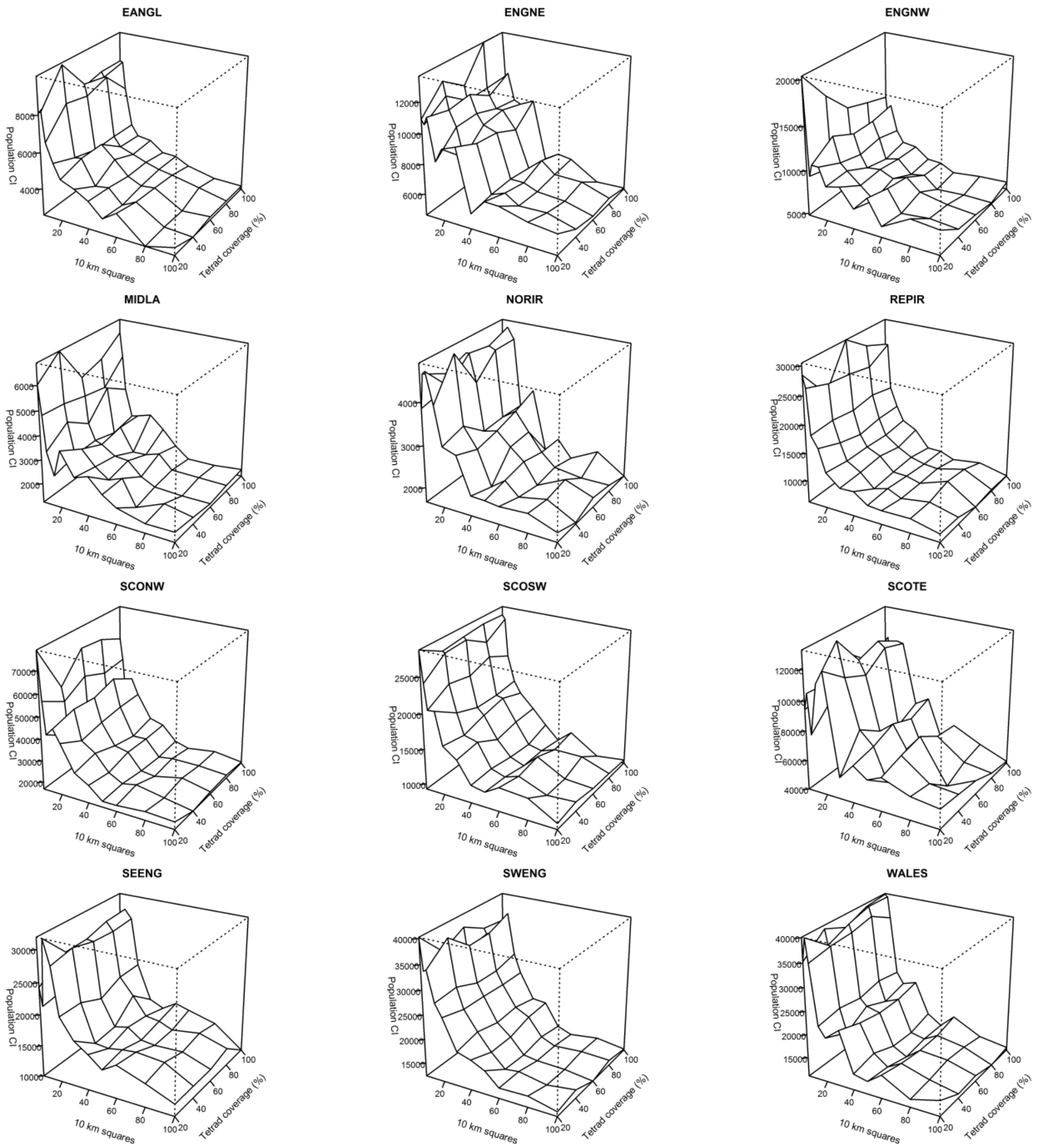
Appendix 4a Median population estimates of Lesser Black-backed Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares in the coastal strata.



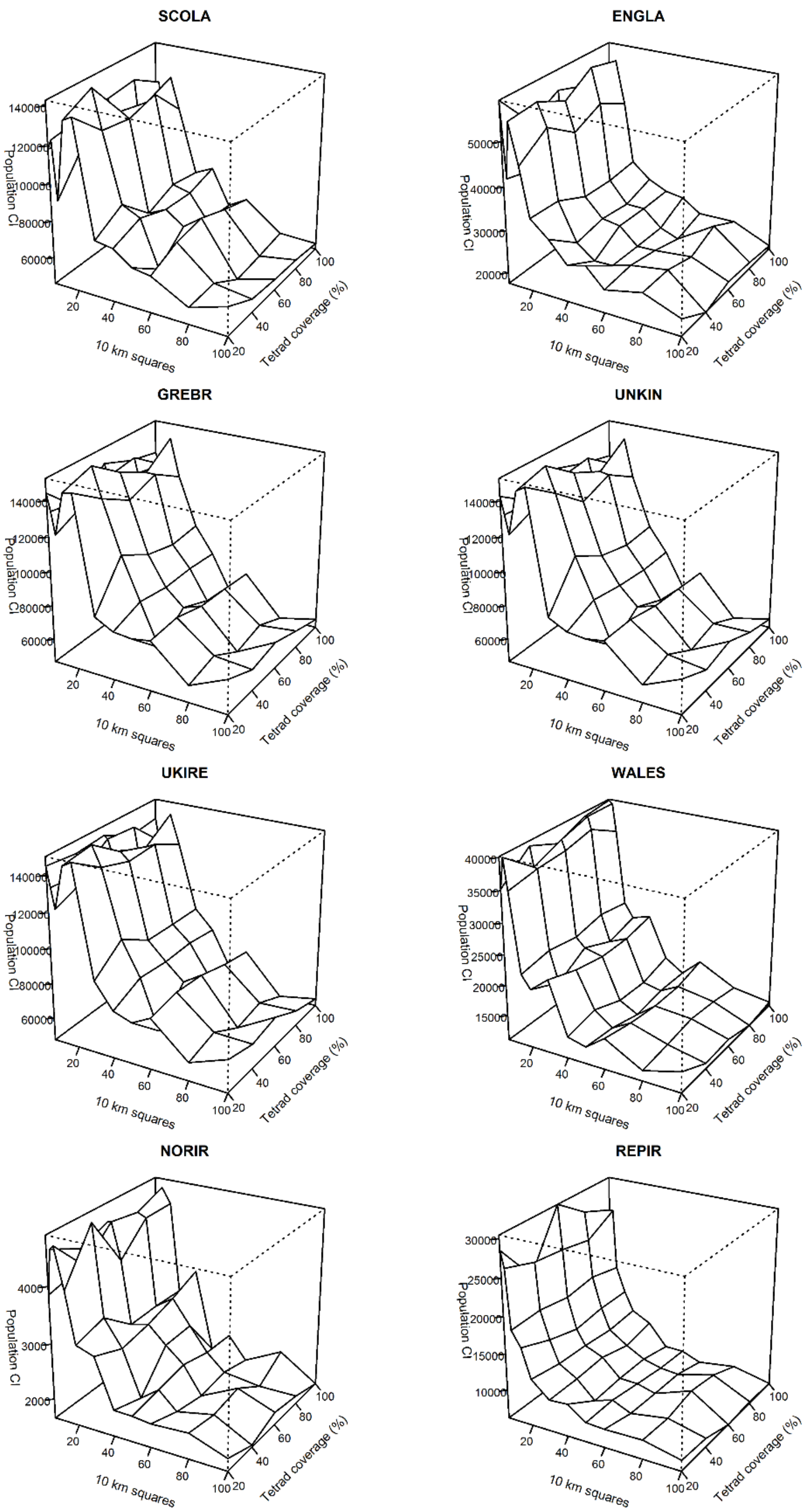
Appendix 4b Median population estimates of Lesser Black-backed Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares.



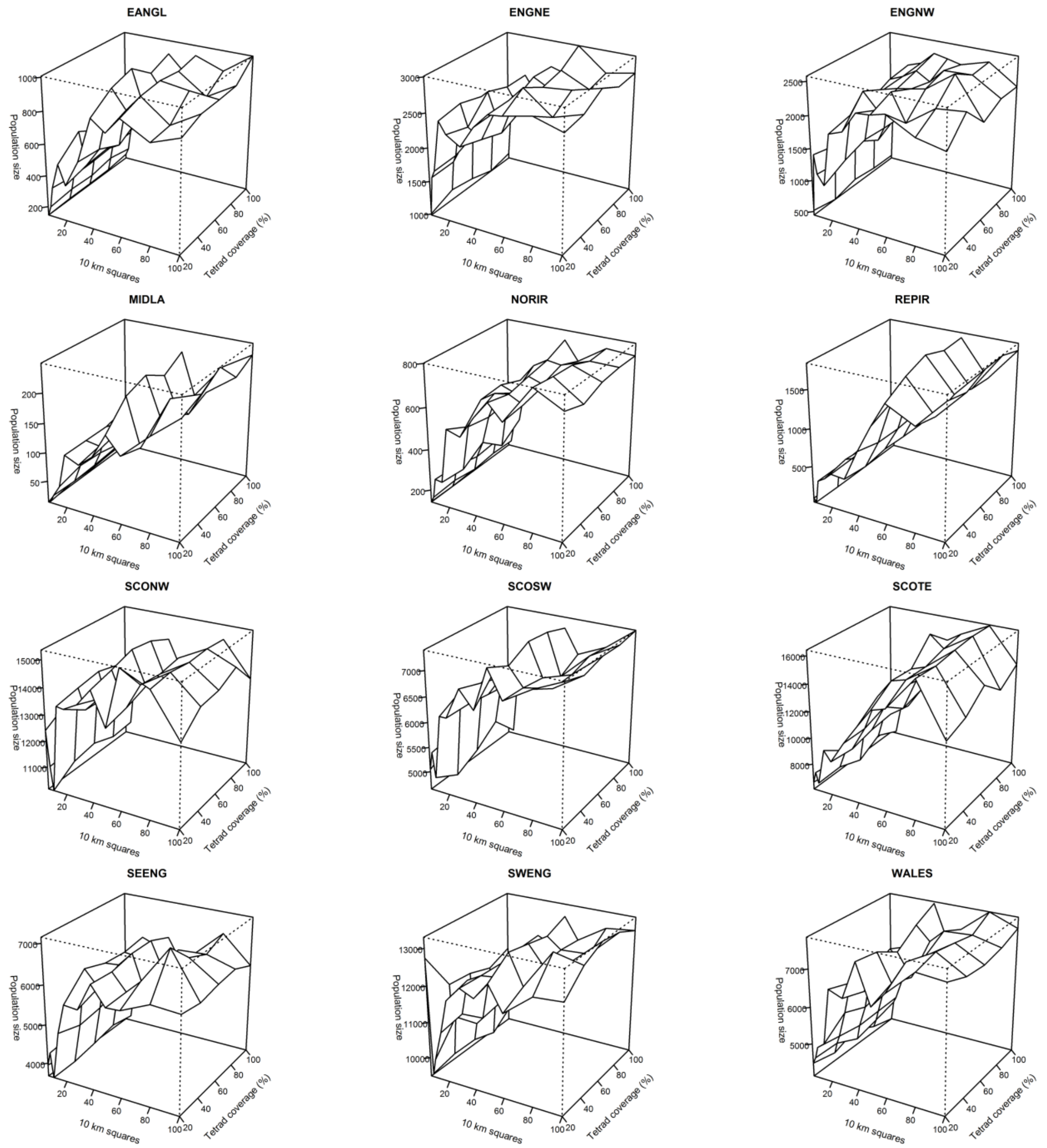
Appendix 5a Confidence intervals around population estimates of Herring Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



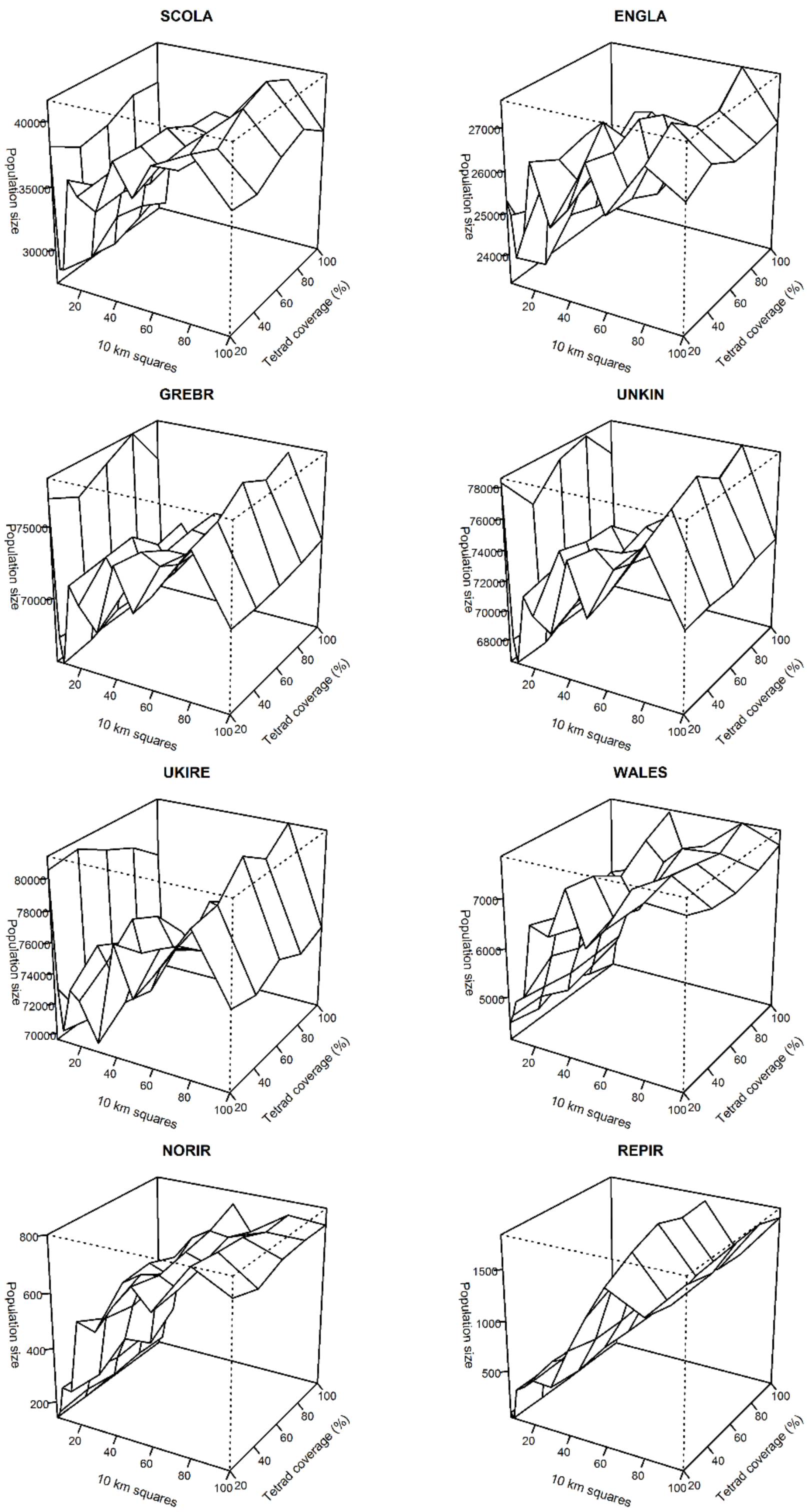
Appendix 5b Confidence intervals around population estimates of Herring Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



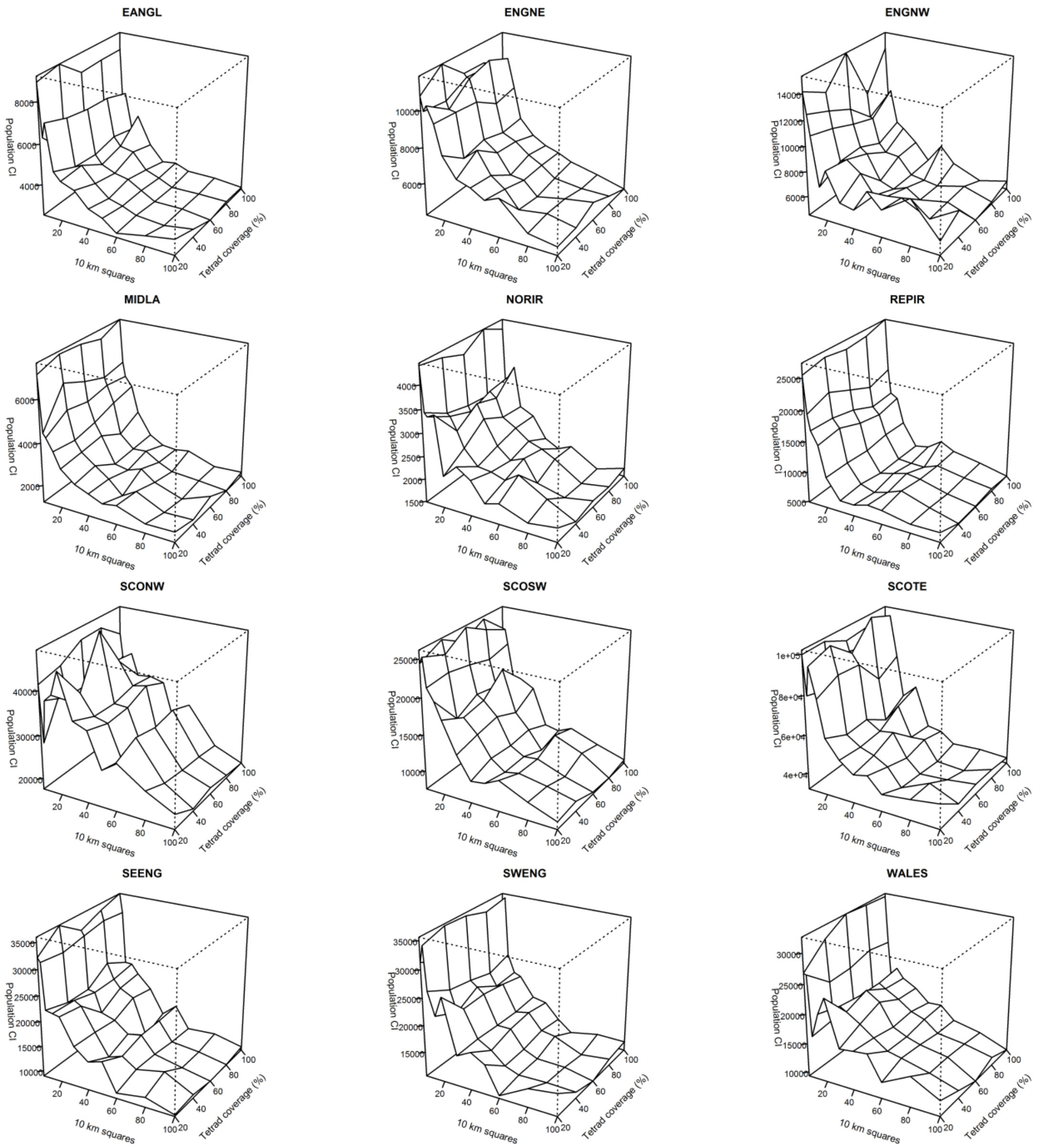
Appendix 6a Median population estimates of Herring Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



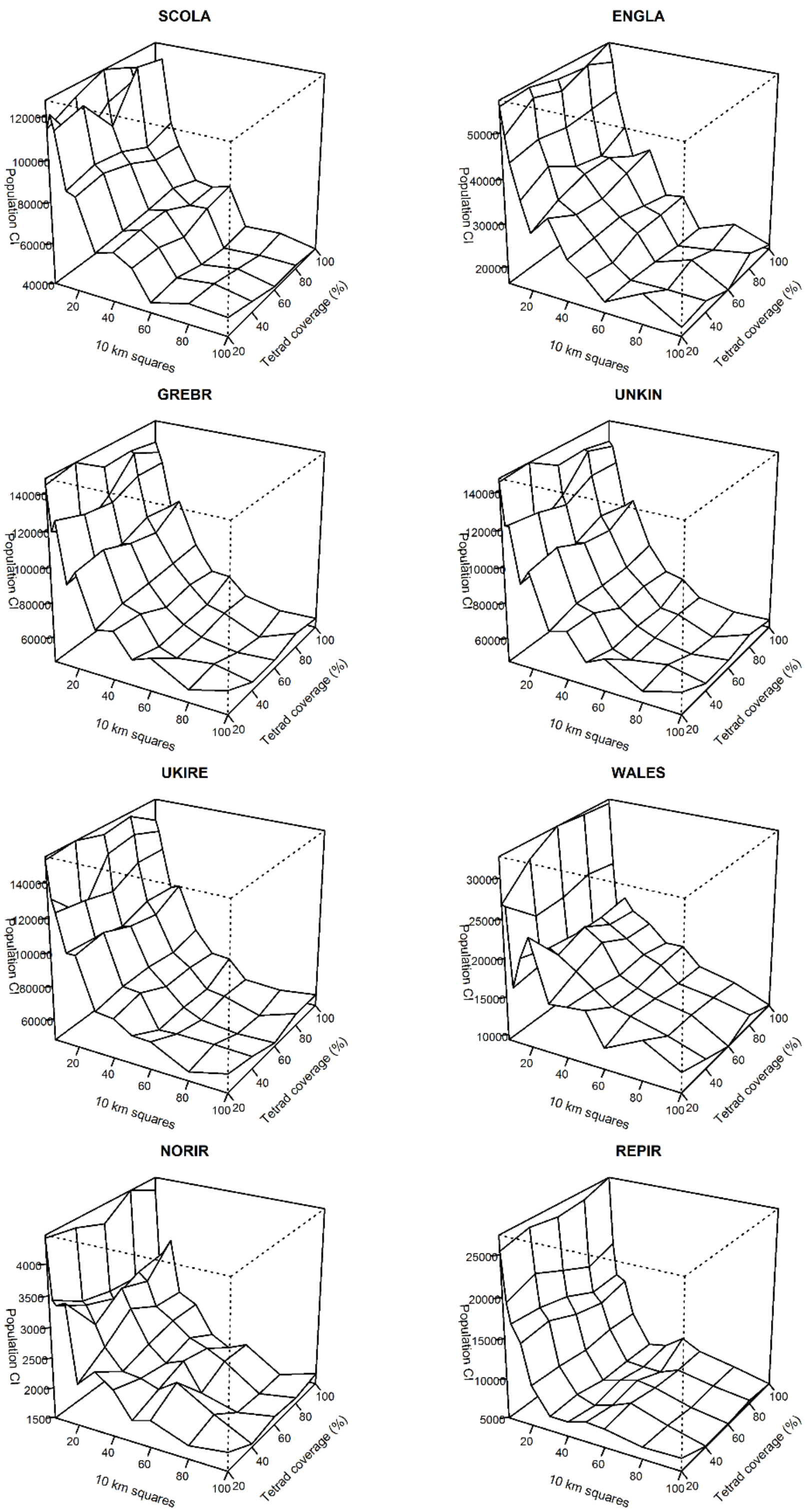
Appendix 6b Median population estimates of Herring Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares (see methods).



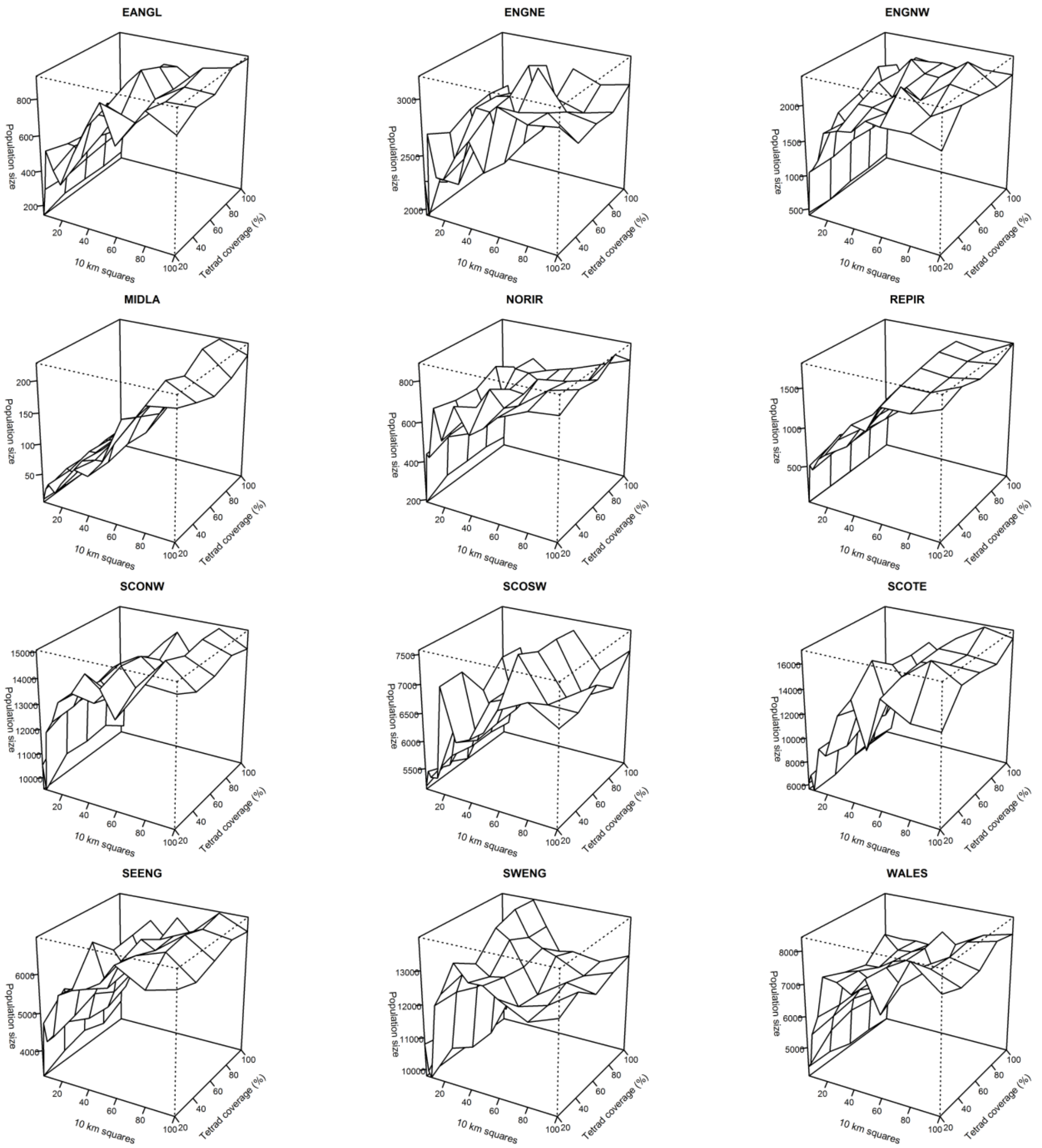
Appendix 7a Confidence intervals around population estimates of Herring Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares (see methods).



Appendix 7b Confidence intervals around population estimates of Herring Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares (see methods).



Appendix 8a Median population estimates of Herring Gulls in regions of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to urban 10-km squares in the coastal strata.



Appendix 8a Median population estimates of Herring Gulls in constituent countries of the UK and Ireland based on different levels of survey coverage simulated by sampling from the Bird Atlas 2007-11 data and with sample coverage weighted to coastal 10-km squares.