Updated grey seal (*Halichoerus grypus*) usage maps in the North Sea

Report to DECC

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Esther L. Jones & Debbie J.F. Russell
Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews,
St Andrews, Fife. KY16 8LB, UK

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1 Executive summary

Currently, little is known about the at-sea distribution of grey seals (*Halichoerus grypus*) which haul out on the UK coast of the southern North Sea, particularly following the large increases in breeding and foraging populations in the area over the last decade. To address this, DECC funded the deployment of 21 telemetry tags on grey seals hauled out on the south-east coast of England in 2015. Historic telemetry from 1991-2011 and population data from 1998-2012 have previously been used to estimate total (at-sea and hauled out) and at-sea distributions of grey seals in the North Sea to support spatial planning.

In this study, data from the most recent telemetry tags and population data were incorporated to provide updated maps of usage in the North Sea. This included data from the 21 tags deployed in south-east England in 2015 and four tags deployed on the east coast of Scotland in 2013. In total, grey seal movement data comprising 175 telemetry tags from 1991-2015 were combined with population estimates for 2014. Population-level species distribution maps and associated confidence intervals were produced at a resolution of 5 km x 5 km. These maps provide the best current estimate of grey seal usage in the North Sea by animals from UK haulout sites. This report describes how usage maps have been updated using contemporary data and revised methodology to provide the best estimate of distribution scaled to 2014 population estimates with associated uncertainty.

2 Introduction

In 2013, telemetry and population data were used to estimate total (at-sea and hauled out combined) and at-sea distributions of grey seals in the North Sea to support spatial planning. A paper was also published in 2015 which reflected methodological developments and incorporated additional data (Jones *et al.* 2015); these usage maps are available to download (http://www.smru.st-andrews.ac.uk/smrudownloader/uk_seal_usage_of_the_sea). Grey seal usage maps can be used in assessments for which seal distribution needs to be taken into account. Usage maps are produced as 'at-sea' usage (number of seals in each 5 km x 5 km grid cell), showing their marine distribution, and 'total' usage, which combines at-sea and hauled out usage. Total usage maps should be used when considering, for example, potential terrestrial or marine effects of activities in close proximity to haulout sites. It is recommended that at-sea usage maps should be used to determine the distribution of animals in the proximity of areas of interest, such as proposed offshore developments.

DECC's Offshore Energy Strategic Environmental Assessment programme (SEA), requires robust evidence on which to base assessments of the potential impact of anthropogenic activities on the marine environment. Currently, little is known about the at-sea distribution of grey seals (*Halichoerus grypus*) which haul out on the UK coast of the southern North Sea; only 10 grey seals have previously been tracked. Since that deployment in 2005, there have been dramatic increases in the summer foraging and winter breeding populations of grey seals in the southern North Sea. Over the same time period, harbour seal (*Phoca vitulina*) populations on the UK south-east coast, primarily based in the Wash and North Norfolk Coast Special Area of Conservation (SAC), have recovered from earlier declines and are now at historically high levels. There have also been extensive wind farm developments in the area, with many more planned. These changes in population and environment may have affected the at-sea distribution of grey seals. In a DECC funded study in 2015, 21 tags were deployed at the two main grey seal haulout sites in the south-east UK, Blakeney and Donna Nook (Russell 2016). The Donna Nook haulout site is contained within the Humber Estuary SAC, for which grey seals are a qualifying feature. In addition, SMRU deployed four tags on individuals in south-east Scotland thus data from an additional 25 tags have become available since the analyses presented in Jones *et al*. (2015).

This report describes how grey seal usage maps for the North Sea have been updated by incorporating the additional telemetry data described above and recent count data, and by making methodological improvements to maximise the use of the telemetry data. It also outlines how the resulting usage maps should be interpreted along with associated caveats and limitations. The updated usage maps are available in geo-referenced formats from the DECC website (*https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process*).

3 Methods

Methodology based on Jones *et al.* (2015) was used to produce estimates with uncertainty of grey seal distribution in the North Sea. The maps were updated to include additional telemetry and terrestrial count data. Furthermore, to maximise use of telemetry information terrestrial haulouts were clustered.

3.1 Study area

A study area measuring 1200 km x 450 km with a spatial resolution of 5 km x 5 km was delineated to include the majority of grey seal movement data around the east coast of the UK (Figure 1). Analyses were conducted using R 3.1.2 (R Core Team 2014) and GIS software Manifold 8.0.29.0 (Manifold Software Limited 2013) and all maps were projected using Universal Transverse Mercator zone 30 (North), World Geodetic System 1984 datum (UTM30N WGS84).

3.2 Movement data

In the North Sea, 132 adults (defined as any animal more than one year old) and 43 pups were tagged between 1991 and 2015 in locations around the UK (Table 1). Between 1991 and 2008, Satellite Relay Data Loggers (SRDL) were deployed that use the Argos satellite system for data transmission (Argos 2011). Between 2008 and 2015, GPS phone tags that use the GSM mobile network with a Fastloc© hybrid protocol were deployed (McConnell *et al.* 2004). Telemetry data were processed through a set of data-cleansing protocols to remove null and missing values, and duplicated records from the analysis.

Argos transmission is associated with considerable location error. The SRDL locational error was therefore corrected using a Kalman filter and locations estimated at two-hourly intervals (Royer & Lutcavage 2008; Jones *et al.* 2015). The majority of GPS locations have an expected error of ≤ 55 m (Dujon, Lindstrom & Hays 2014), however occasional outliers were excluded using thresholds of residual error and number of satellites, and then straight-line interpolated to give estimated locations at the same two-hourly intervals as SRDL data (Jones *et al.* 2015). Continuous spatial surfaces to represent the proportion of time animals spent in different areas were derived by kernel-smoothing the telemetry data. The *KS* library in R (Chacón & Duong 2010) was used to estimate spatial bandwidth of a 2D kernel applied to each animal/haulout map. Each kernel smoothed map was normalised then reweighted based on the contribution of data each animal made to the analysis (termed Information Content Weighting).

3.3 Terrestrial counts

During annual aerial surveys in August all grey seals at haulout sites are counted and coordinates are recorded to an accuracy of approximately 50 m. Surveys take place within two hours of low tide when low tide is between 12:00 and 18:00 hours (Thompson, Lonergan & Duck 2005). Survey effort is variable between locations and all available data between 1996 and 2014 (the most contemporary data available) were used. Where sufficient time series data were available, recent population trends were identified and extrapolated to give a single 2014 population estimate with associated uncertainty for each haulout. Full details of this method are available from Jones *et al*., 2015; Supplementary information (http://www.int-res.com/articles/suppl/m534p235_supp.pdf.

3.4 Haulout clustering

At the resolution of the analysis, some haulout sites could be identified that presented analytical challenges: (1) the scale of individual haulout sites may not be consistent with animal behaviour and space-use if haulouts form part of a continuous connected aggregation (e.g. seals may return to a haulout area close to the departure haulout), (2) variability of terrestrial counts associated with localised haulout sites was high, and (3) using single haulout sites maximised the number of sites that did not have telemetry data directly associated with them, resulting in inflated uncertainty as the null model (see section 3.5) would contribute more usage to the analysis than necessary. Therefore, haulouts were clustered into groups using a clustering algorithm based on the distances between them (taking account of the complex coastline in the area). An appropriate spatial scale for clustering was determined through analysing locations of haulouts. Hierarchal cluster analysis with a centroid agglomeration method was implemented to generate aggregated haulouts ranging from shortest separation of 5 km (no clustering) to 500 km (maximum clustering) in increments of 5 km (reflecting the scale of the analysis) (Everitt *et al.* 2011). A change point analysis was performed to identify the optimum scale of aggregation using the *changepoint* library (Killick & Eckley 2014). A single change point occurred at 10 km and haulouts were aggregated to this scale for the remainder of the analysis.

3.5 Null modelling

To account for areas in the maps where terrestrial count data were present but telemetry data were not, maps showing predicted usage were produced. A Generalised Linear Model (GLM) was fitted to the telemetry data using a quasi-Poisson distribution with log link function. The response variable was the number of regularised telemetry locations associated with each haulout. Explanatory covariates were at-sea distance from each haulout (to represent accessibility to each haulout), and distance to the shore (to represent accessibility to the coast). An expected distribution of null usage was predicted for each haulout for which terrestrial count data existed but telemetry data did not. Density estimation was used to generate usage maps for those haulout sites for which telemetry data were available.

3.6 Population scaling and estimating uncertainty

The population at each haulout was estimated from terrestrial count data, rescaled to allow for the proportion of animals that were at sea when surveys were carried out. Using the mean species haulout probabilities and their uncertainty (μ=31%, 95% CI 15-50%, Lonergan *et al.* 2011), a likelihood distribution of population estimates were derived (Matthiopoulos 2011) ranging from the value of each terrestrial count (minimum population size) to 100 times the count (maximum population size). The distribution was sampled using parametric bootstrapping 500 times per count to produce a range of estimates. A population estimate and uncertainty for each haulout was calculated from the range of estimates by taking the mean and variance (Jones *et al*., 2015; Supplementary Information).

Within haulout uncertainty was modelled to account for varying numbers of animals using each haulout. Models were fitted using data-rich sites (determined experimentally to be those sites which had ≥7 animals associated with them). Variance was estimated using linear models with explanatory covariates of sample size (number of animals at the haulout) and mean usage of seals. The models predicted variance for data-poor and null usage sites (where population data existed but movement data did not). Within-haulout variance was estimated for null usage sites by setting the sample size of the uncertainty model to 0. Individual and population-level variances were combined to form uncertainty estimates for the usage maps. Usage and variance by haulout were aggregated to a total usage and variance map for each species.

4 Results and interpretation

4.1 Usage maps

Figure 2 shows total (at-sea and hauled out) usage with associated lower and upper 95% confidence intervals. Figure 3 shows at-sea usage with associated lower and upper 95% confidence intervals. The maps can be interpreted as the expected number of animals (based on 2014 population estimates) in each 5 km x 5 km grid cell at any one time. Broadly, spatial patterns remain consistent with those identified by previous usage maps (see section 10) although 95% confidence intervals were reduced substantially in this study. The use of additional data, in terms of number of locations and spatial extent, combined with improved methodology meant that null usage contributed less than 3% of usage (concentrated at the south-eastern tip of England), and allowed for additional fine-scale features to be revealed. For east England particularly, estimates of mean usage were higher due to an increase in population size and use of the null model is now minimal, so that areas of high offshore use towards Dogger Bank are well defined. Previously, usage off East Anglia, Essex and Kent was almost entirely based on the null model but there are now clear hotspots of usage and corridors of movement extending from Donna Nook in the north to Kent in the south. The usage emanating from Donna Nook depicts areas of higher usage over a larger spatial area than previously shown. This may be due to the tripling of the population size since the last telemetry deployment in 2005 causing increased competition for prey near shore. Total and at-sea usage maps show similar spatial patterns (although abundance estimates are higher for total usage). Differences between total and at-sea usage maps only become visually apparent at a local scale (e.g. where seals haul out on tidal sandbanks).

4.2 Confidence intervals

Upper and lower 95% confidence intervals of usage estimates are provided in separate maps. These show confidence in the estimate of *mean* usage in each cell, rather than showing the actual day to day variability in usage. There will be greater uncertainty surrounding haulouts for which: (1) the number of tagged animals represented a small sample size compared to the population, (2) there were limited or no telemetry data and so usage was modelled, or (3) there was large uncertainty in the 2014 population estimate. Uncertainty can vary between haulouts because spatial and temporal tagging and terrestrial count effort were not constant.

5 Caveats and limitations

1. Colour scale and corresponding estimates of seal numbers were calculated by grid cell, and numbers will depend on the size of the grid cells used (i.e. the number of seals per 5km x 5km grid cells are given). Grid cells that partially overlap land are treated as complete 'at-sea' grid cells.

2. Estimated means from grid cells can be summed to estimate the total abundance of seals in an area. In many areas the uncertainty in estimates for neighbouring cells cannot be considered independent of spatial smoothing within the model. A conservative approach to quantify the associated uncertainty is to use the sum of the lower bounds and upper bounds for individual cells as the lower and upper bounds for the whole area. This is likely to overestimate the size of the confidence interval because it ignores both the different data points contributing to the usage estimate of each grid cell and the gradual decay, with distance, in the spatial correlation implicit in the movement data (i.e. high usage in one cell increases the probability that an adjacent cell will also have high usage).

3. Telemetry data were collected over many years and have been integrated using the assumption that spatial usage by grey seals is in equilibrium (i.e. spatial patterns are constant over time).

4. Analysis presented here does not distinguish between habitat that may be important for specific functions (e.g. for foraging, breeding, avoidance of predators) from areas that may be used as 'commuting corridors' between such sites but instead displays usage over all types of activity.

5. Maps show usage as a 'snapshot' in time. They do not show the rate of flow of animals through an area, and therefore connectivity between areas is not quantified.

6. Usage maps account for seal movement in two-dimensions (longitude and latitude) and do not provide information about how animals use depth.

7. The maps are scaled to reflect the population size in 2014. Changes in population size, especially if these changes differ spatially, will influence spatial patterns in usage. To effectively support spatial planning, Marine Scotland commission updates of seal usage maps every three years. The usage maps can be updated more frequently but it is expected that more frequent updates would result in only minor changes in patterns of seal usage.

6 Acknowledgements

Historical telemetry and population data were funded by Department of Energy and Climate Change, ELIFONTS EU (95/078), Marine Scotland, Natural Environmental Research Council, Natural England and Scottish Natural Heritage. This report was funded by Department of Energy and Climate Change.

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8 Tables and Figures

Table 1. Summary of grey seal telemetry deployments by year. Tag type denotes satellite relay data logger (SRDL) or global positioning satellite (GPS).

Year	Tag type	Number of tags	Sex ratio (M:F)	Age (adult:pup)	Tagging locations
1991	SRDL	5	4 : 1	5 : 0	NE England
1992	SRDL	12	8 : 4	12 : 0	Moray Firth, NE England
1993	SRDL	5	2 : 3	2 : 3	NE England, SE Scotland
1994	SRDL	4	2 : 2	0 : 4	NE England
1995	SRDL	3	2 : 1	3 : 0	Western Isles
1996	SRDL	17	5 : 12	17 : 0	Orkney & NE coast, SE England, W Isles
1997	SRDL	7	4 : 3	7 : 0	NE England, SE England
1998	SRDL	24	17 : 7	24 : 0	Orkney & NE coast, SE England, Shetland
2001	SRDL	12	6 : 6	1 : 11	SE Scotland
2002	SRDL	12	5 : 7	2 : 10	SE Scotland
2003	SRDL	1	1 : 0	1 : 0	W Scotland
2004	SRDL	1	0 : 1	1 : 0	SE Scotland
2005	SRDL	11	5 : 6	11 : 0	SE England, SE Scotland
2006	SRDL	2	1 : 1	2 : 0	SE Scotland
2008	SRDL/GPS	19	9 : 10	19 : 0	NE England, SE Scotland
2010	GPS	14	5 : 9	0 : 14	Orkney & N coast
2013	GPS	5	3 : 2	4 : 1	SE Scotland
2015	GPS	21	8 : 13	21 : 0	SE England

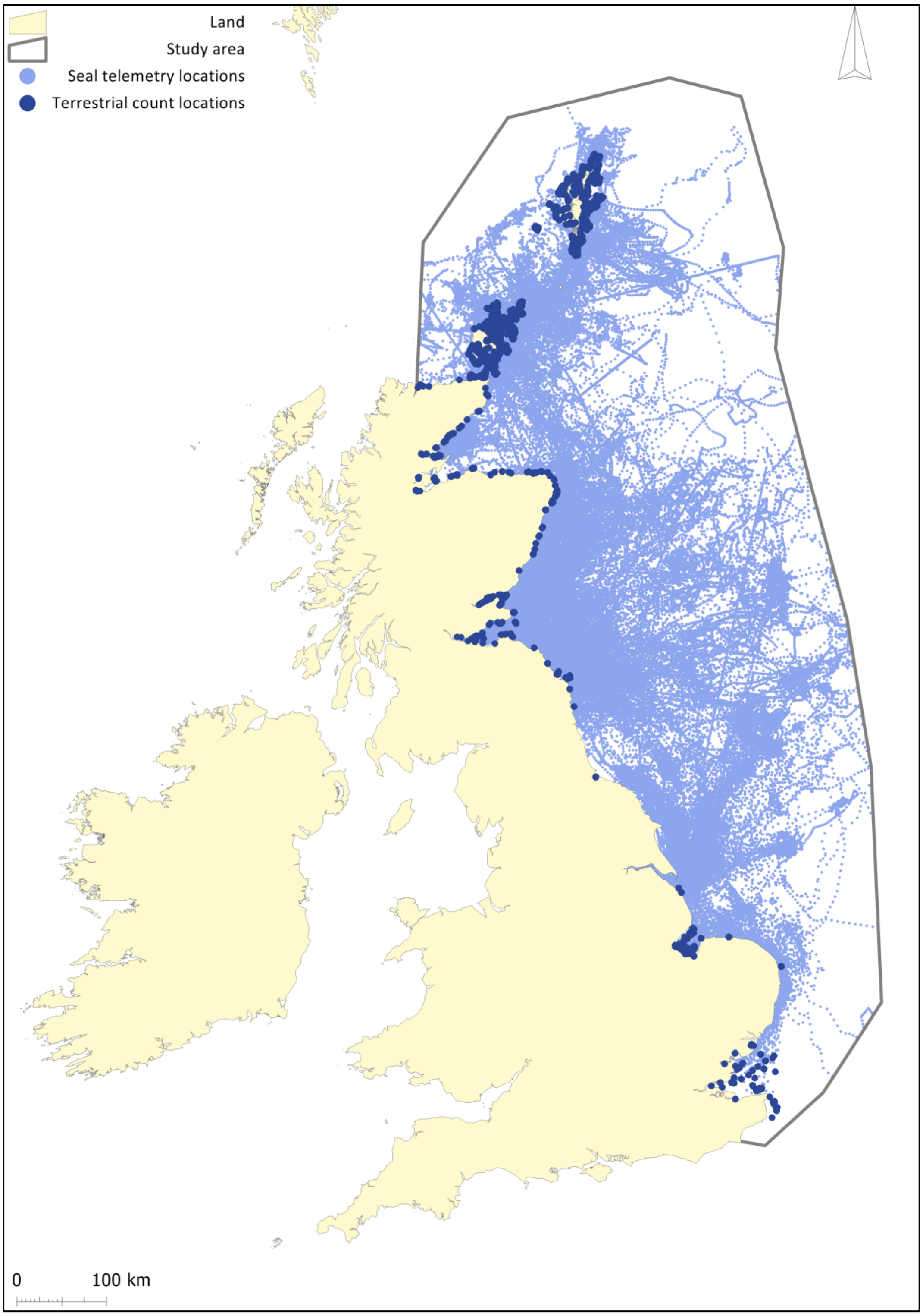

Figure 1. Map of seal telemetry locations (pale blue points) and terrestrial count locations (dark blue points) where seals were counted whilst hauled out in August, within the study area (grey boundary). Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) shoreline data from NOAA were used in all figures where the coastline is represented (available from www.ngdc.noaa.gov/mgg/shorelines/gshhs.html).

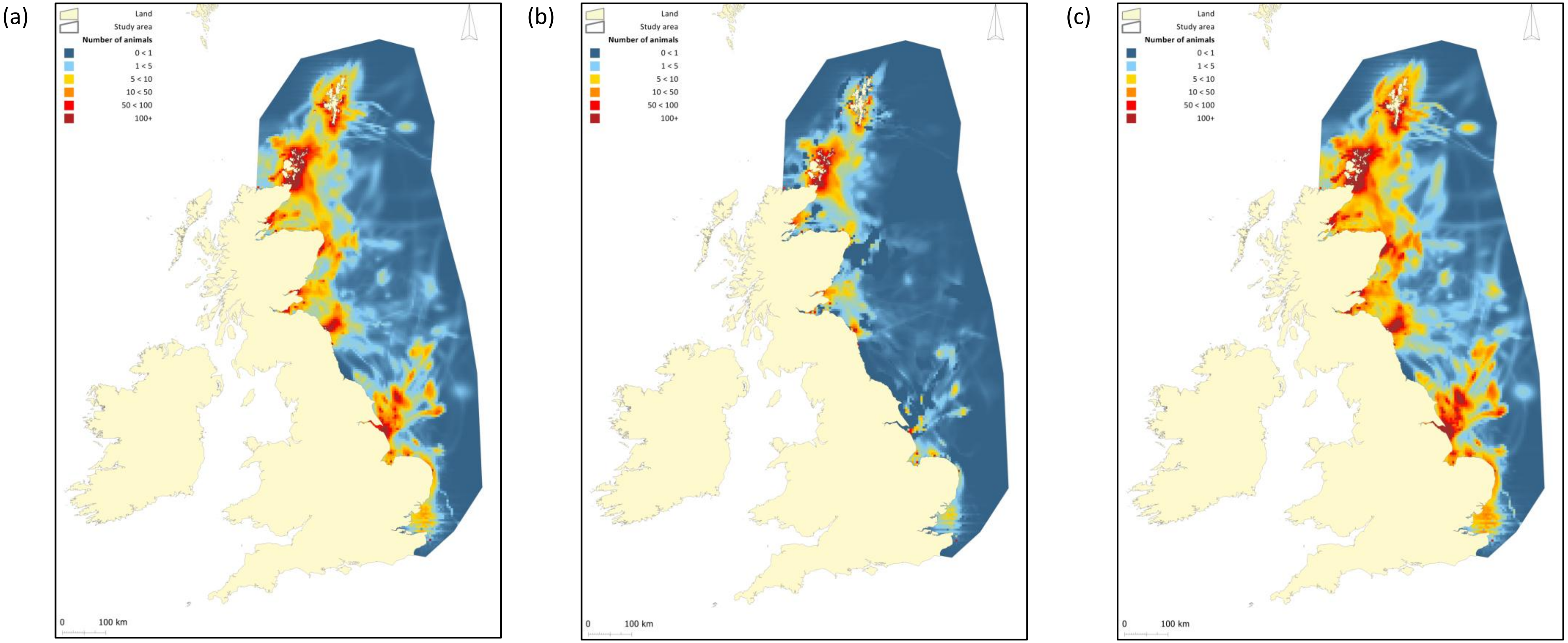

Figure 2. Grey seal total (at-sea and hauled out) North Sea usage map showing number of animals in each 5 km x 5 km grid cell within the study area (a), as well as the lower (b) and upper (c) 95% confidence intervals.

(a) (b) (c)

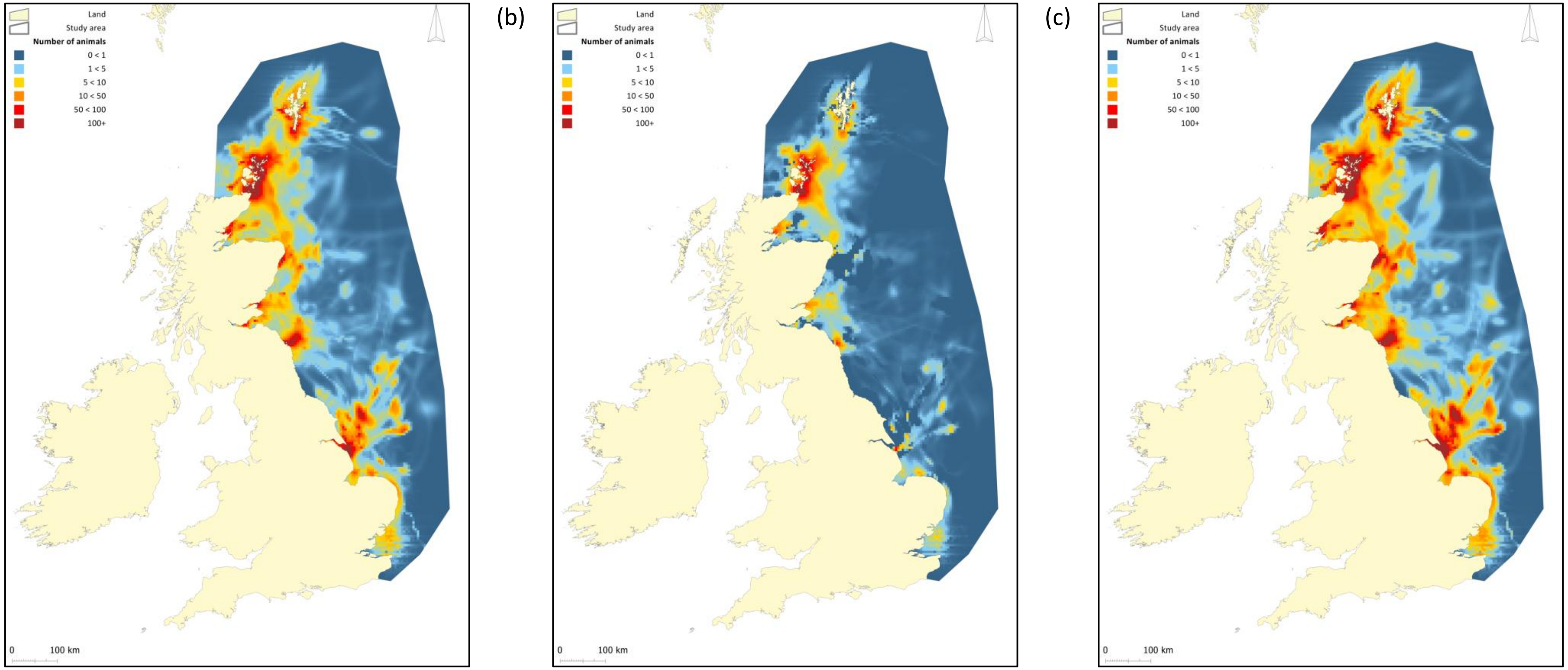

Figure 3. Grey seal at-sea North Sea usage map showing number of animals in each 5 km x 5 km grid cell within the study area (a), as well as the lower (b) and upper (c) 95% confidence intervals.

9 Downloadable files

Figures 2 and 3 are available as shapefiles (see below) for download at *https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process*. Upon their use, please reference this report. All shapefiles are in Universal Transverse Mercator zone 30 (North), World Geodetic System 1984 datum (UTM30N WGS84) projection.

In the table below the shapefile names are given along with the associated figure number.

Shapefile name	Figure
HgTotUsage	2a
HgTotLower	2b
HgTotUpper	2c
HgSeaUsage	3a
HgSeaLower	3b
HgSeaUpper	3c

10 Appendix

(a) (b) (c)

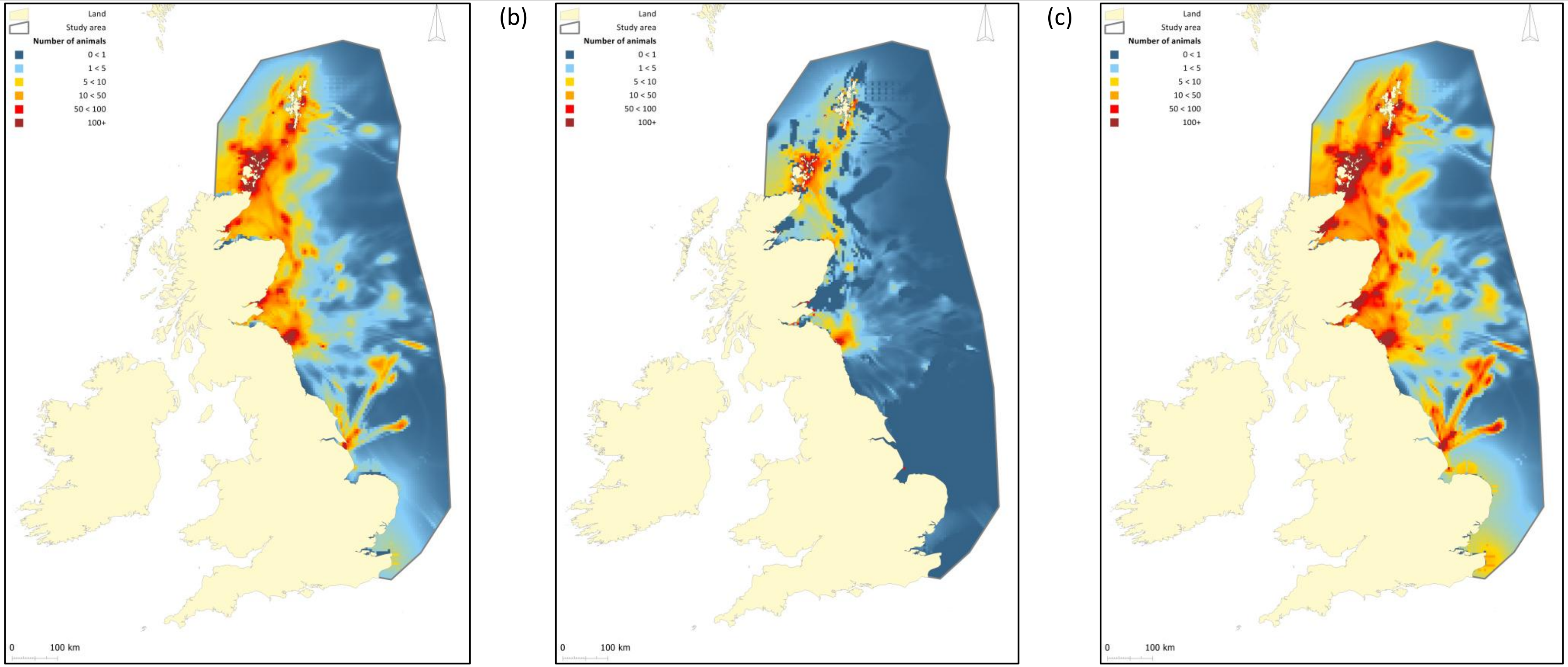

Figure 4. 5 km x 5 km usage maps produced for the Scottish Government in 2013. Adapted from Jones *et al.* (2013). Grey seal total (at-sea and haulout) North Sea usage map showing number of animals in each 5 km x 5 km grid cell within the study area (a), as well as the lower (b) and upper (c) 95% confidence intervals.

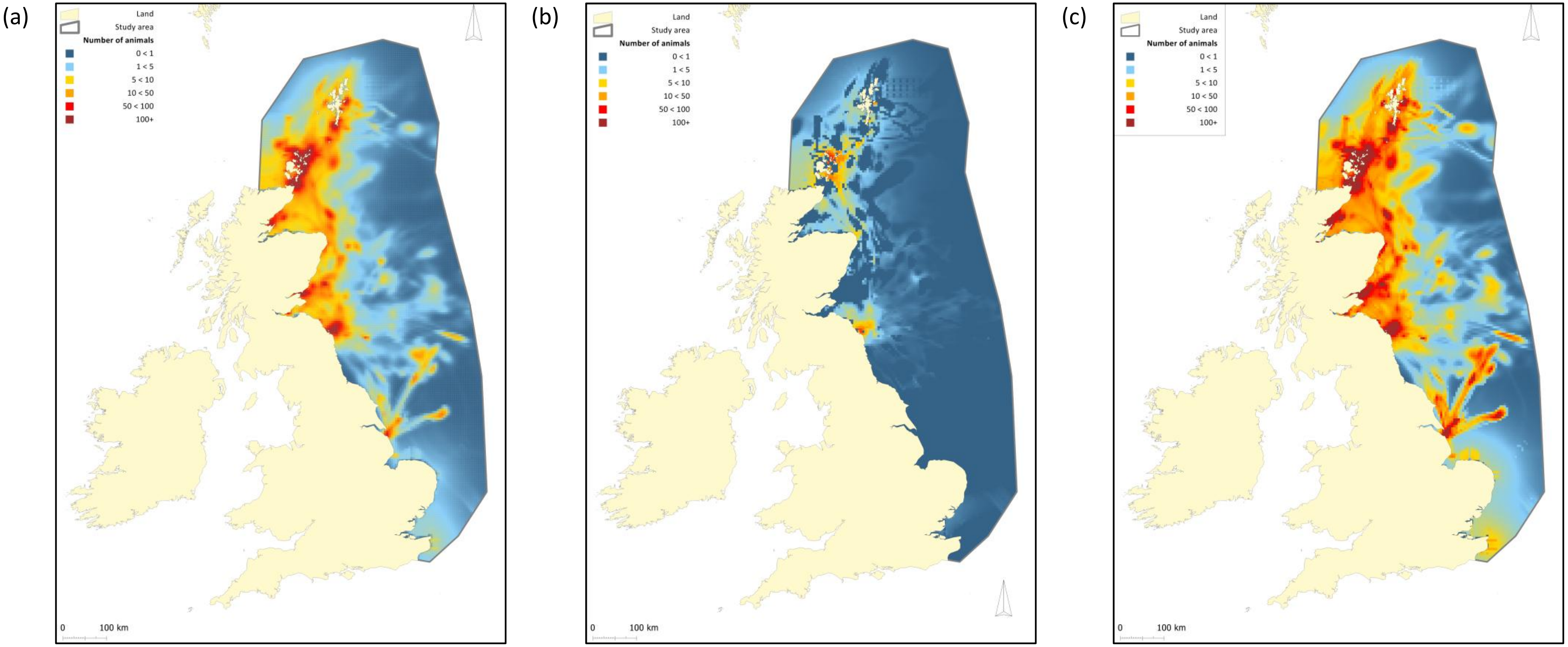

Figure 5. 5 km x 5 km usage maps produced for the Scottish Government in 2013. Adapted from Jones *et al.* (2013). Grey seal at-sea North Sea usage map showing number of animals in each 5 km x 5 km grid cell within the study area (a), as well as the lower (b) and upper (c) 95% confidence intervals.