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Regional baselines for marine mammal knowledge across the North Sea and Atlantic areas of Scottish waters: Appendix 4 - Seal abundance and distribution

Scottish Marine and Freshwater Science Vol 11 No 12

marine scotland

Appendix 4: Seal Abundance and Distribution

Seal abundance and distribution in the Scottish Northern North Sea region and Scottish Atlantic waters

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1. Introduction

This short note presents a review of the available predictions of at-sea seal distribution and abundance around Scotland, and highlights priorities for future work to improve these estimates. Based on the most up-to-date predictions, the report also makes an assessment of the likely seal density levels in each of the Draft Plan Option areas, and of the confidence in these assessments. Finally, the analytical work required to quantify the relative abundance of seals in these areas is outlined as well as the areas for which data collection would be required to make a robust assessment of density levels specifically within Draft Plan Option areas.

2. Background

Estimation of the at-sea distribution (here defined to include abundance as well as presence/absence) of grey (*Halichoerus grypus*) and harbour (common; *Phoca vitulina*) seals in Scottish waters requires count data from haulouts, activity budget estimation (proportion of time hauled out/at sea), and movement data on multiple temporal and spatial scales. Surveys (mostly aerial) of haulouts are conducted annually in August and cover the whole coast of Scotland within a five-year cycle. The counts are used to estimate haulout specific population size (hereafter haulout abundance) by scaling upwards using an estimate of the proportion of the population hauled-out during the survey windows (within 2 hours either side of low tide in August). Population estimates are then converted to at-sea population estimates using the mean proportion of time seals spend at-sea during the main foraging season. Both these scalars are derived from animal-borne electronic tracking (hereafter telemetry) data.

There are an estimated 35,000 harbour seals (95% Confidence Interval (CI): 28,500 – 45,000; Thompson et al. (2019)) in Scotland based on counts between 2011 and 2016; this represents approximately 80% of the UK population. The summer grey seal population size in Scotland, based on counts largely from between 2013 and 2015, is estimated to be 94,500 (95% CI: 79,000 - 117,500; Russell et al. (2016)); this represents approximately 60% of the UK population. However, there is considerable movement of grey seals between the summer foraging season and the winter breeding season leading to seasonal variation in abundance in Scotland

(Russell et al. 2013). In addition, for both species, there are fine-scale seasonal changes in activity budgets and at-sea distribution emanating from haulout sites (Thompson et al. 1994, Russell et al. 2015). On a multi-year temporal scale, marked changes in haulout abundance at a Seal Management Unit (SMU) level will lead to vastly different estimates of at-sea distribution. The Scottish coast has been divided into seven SMU areas: Southwest Scotland, West Scotland, Western Isles, North Coast and Orkney, Shetland, Moray Firth, and East Scotland. In recent years, there have been dramatic declines in harbour seal abundance in the northern and eastern SMUs; e.g. 85% decrease in the harbour seal count from the mid-1990s to 2016 in the North Coast and Orkney SMU (Thompson et al. (2019).

This report reviews the currently available estimates of at-sea distribution (on a 5 x 5 km resolution), including discussion of the data and the methods used to generate them (Table 1). For all predicted distributions, there are three values given per cell: the mean prediction from the model, and the associated lower and upper confidence limits (95%). The value given in each cell is the percentage of the at-sea population (or number of seals in the usage maps) estimated to be present in that cell at any one time. For each cell, the confidence intervals provide a measure of the range of predictions in which (based on the underlying model) the true abundance is likely encompassed, and the mean provides a measure at the centre of this range. Thus the confidence intervals do not reflect any temporal variation in seal distribution. The sum of all cells in the mean distribution map is 100% (or equal to the total size of the at-sea population in usage maps). However, as confidence intervals are estimated on a cell-by-cell basis, the sum for the lower and upper confidence interval maps will be much lower or greater than 100% (or estimated total at-sea population size in usage maps) respectively. As such the mean can be interpreted at various spatial scales (i.e. summed across cells), whereas the confidence intervals can only be interpreted on a cell-by-cell basis (i.e. cannot be summed across cells).

Previous Scotland-wide at-sea distribution maps have been based on smoothing telemetry data to produce relative density contour maps, and scaling those to population estimates (usage maps; Jones et al. (2013, 2015), Russell et al. (2017)). Recent telemetry deployments on grey seals, and advances in the quality and spatial extent of at sea environmental data, across the British Isles have made it possible to predict at-sea distribution on the basis of habitat preference modelling (quantifying the relationship between abundance and environmental covariates). This work, funded by the Department of Business Energy and Industrial Strategy (BEIS) with contributions from the Natural Environment Research Council, Scottish Government and EU Interreg funding to University College Cork (MarPAMM), is ongoing but the methods and preliminary results are discussed here. Final results of the habitat preference modelling project are expected to be available in autumn 2020.

Table 1. Seal usage (Jones et al. 2013, 2015, Russell et al. 2017) and habitat preference modelling (Carter et al. *In Prep*) input data.

Type	Reference	Prediction Year	Countries considered	Years of Data		Grey seal telemetry data		Harbour seal telemetry data	
				Count	Telemetry	Seasonal extent	Sample size (of which were pups)	Seasonal extent	Sample size (of which were pups)
Usage maps	Jones et al. 2013	1988-2012	UK, ROI, France	1988-2012	1991-2012	July-October	234 (57)	December - April	196 (6)
	Jones et al. 2015	2013	UK, ROI, France	1996-2013	1991-2013		259 (69)		277 (0)
	Russell et al. 2017	2015	UK (ROI for count but not telemetry)	1996-2015	1991-2016		270 (0)		330 (0)
Habitat modelling	Carter et al. In Prep	2018	UK, ROI	Most recent only (up to 2018)	2005-2019	May - August	114 (0)	October - May	239 (0)

3. Usage Maps

There are three published versions (Jones et al. 2013, 2015, Russell et al. 2017) of Scotland-wide estimates of at-sea seal distribution; these are widely referred to as usage maps. The methods used and guidance on appropriate interpretation of these maps is included with the associated documentation. However, for the purposes of this report, key aspects of the methods will be briefly summarised, with emphasis on the differences between the versions. The premise of these maps was to combine estimated (1) haulout abundance, (2) proportion of the population at sea at any time, and (3) haulout-specific movement data (telemetry data).

3.1. Jones et al. 2013

As part of a Scottish Government funded project, seal usage maps were generated for each seal species. The study area encompassed the maximum foraging range of seals hauling out in the British Isles and France. Haulout counts were aggregated across years (though weighted towards more recent counts), and thus the resulting maps represent averaged at-sea usage over this time period. The counts were scaled to population size using estimates (from telemetry tags) of the proportion of the population hauled out during surveys (Lonergan et al. 2011, 2013). The population at-sea at any one time during the main foraging season (Table 1) was then estimated using the telemetry data included in the study.

The telemetry tags record data on a seal's location at irregular intervals, which were linearly interpolated to generate locations at regular intervals (2 hours). For each haulout, the tracks of seal trips departing from that haulout were essentially smoothed across space, and the resulting at-sea density maps scaled to represent the haulout-specific number of seals estimated to be at sea at any one time. A key consideration is that the maps were based on the spatial distribution of tagged individuals, and only a subset of all haulout sites for which there were counts of grey and harbour seals were visited by tagged individuals. Therefore, for the remaining haulouts, predicted distributions were based on "null usage"; an assumption that usage declines with distance from the haulout, based on a distance-density relationship from all haulout sites in the study area for which there were associated movement data.

The associated confidence intervals incorporate multiple sources of uncertainty: (1) the reported uncertainty surrounding the scalar used to raise counts to population estimates; (2) the variation in counts over the study period; (3) the sample size of tagged individuals; and (4) a measure of the individual-level variation in distribution. It should be noted that the last source is based on modelled 'between individual variation’ as a function of number of tagged individuals for each species (compared to the haulout-specific population); the implicit assumption being that the level of variation in movements between individuals is the same across the study area.

3.2. Jones et al. 2015

This study was broadly based on Jones et al. (2013) with minor differences in the count and telemetry data used (Table 1). The main difference was in how the count data were used; usage was estimated for 2013 alone, rather than averaged over a 24-year period. Depending on the number of years of count data available, either the most recent count was used, or a trend was fitted to predict the count in 2013. Uncertainty estimates were as in Jones et al. (2013), but incorporated uncertainty as a result of the predicted count for 2013 (rather than the variation in counts across a 24-year period). For the entire study region (maximum foraging range of seals hauling out in the British Isles and France; Table 1), null usage accounted for 48% and 16% of the total usage for harbour and grey seals, respectively (these percentages are not available for the other usage maps).

3.3. Russell et al. 2017

Scottish Government funded an update to the usage maps of Jones et al. (2015). Although largely based on methods of Jones et al. (2015), there were four main differences: (1) changes in the telemetry data used (Table 1); (2) incorporation of updated count data resulting in estimates of usage scaled to the estimated population size in 2015; (3) improvement in how count data were incorporated into the usage map framework and (4) clustering of haulout sites to increase the proportion of sites for which there are associated telemetry data.

For Scotland, there was a large increase in the sample size of tagged harbour seals (compared to Jones et al. (2015)). Although some new data were available for grey seals, the sample size for Scotland decreased due to the exclusion of pup data that were previously included in Jones et al. (2013, 2015). A subsequent study showed that pup movements differ from those of juveniles or adults (Carter et al. 2017), and thus their distribution is not likely to be representative of the population. For the first time, haulout survey effort data were explicitly considered – ensuring zero counts were incorporated (rather than being included as missing data). Finally, because usage emanating from neighbouring haulouts is likely to be similar, haulouts were aggregated into clusters, meaning that null usage was only used if there were no telemetry data associated with a cluster, rather than individual haulout sites.

4. Habitat Preference Models

Habitat preference modelling involves relating spatially resolved abundance data to spatial information about the environment. Quantification of this relationship allows abundance to be predicted across space despite incomplete or non-uniform spatial effort. This approach is often used with line transect data to generate distribution maps, e.g. for cetacean surveys (SCANS; Hammond et al. (2013)). Such an approach is not directly applicable to animal-borne tag data because, by definition, such data are presence-only. Thus, to infer relative levels of preference for particular environments, we must make a statistical comparison of conditions where tagged individuals *went* (i.e. telemetry locations) with where they *could have gone* (i.e. a representative sample of habitat accessible to the tagged individual; Boyce and McDonald (1999)). In such a use-availability framework, telemetry locations are matched to a sample of control points, randomly distributed throughout the accessible range of the individual (Aarts et al. 2008). A particular set of conditions (i.e. habitat) is considered to be preferred if it has disproportionately high use compared to its availability (Johnson 1980).

Limits on the space accessible to the individual are generally derived heuristically. In the current project (Carter et al. *In Prep*), the maximum trip extent for each species was used to generate an accessibility polygon for each haulout site. A key aim of this project was to model region-specific habitat preference, recognising that the environment, prey composition, and likely the importance of any intra or inter-specific competition, differs across regions. Regions were based on SMUs, availability and differences in habitat preference (based on exploratory analyses). Presence (1s) and control locations (0s) were modelled as a function of environmental covariates in a binomial framework. The covariates considered were those which had previously been shown to relate to presence of seals and or their prey: distance to haulout (controlling for accessibility); water column depth (relating to accessibility in the vertical dimension, but also to prey distribution); substrate type; seabed topography (e.g. slope and rugosity); mean winter sea surface temperature (lagged by 1 year - relating to sandeel abundance; Carroll et al. (2017)); and metrics of water column stratification (relating to persistent habitat features that may help seals navigate to or identify foraging areas). Individual seal was included as a blocking factor (random intercept) to account for the different sample sizes (tag durations) associated with each individual. Covariates were removed from a maximal model through backwards model selection to arrive at the final model. Predictions were made by region and summed to provide at-sea distribution estimates for the British Isles. The map units (by cell) were the percentage of the UK and Ireland at-sea population. In other words, summing all of the cells in the mean predicted distribution map results in a total of 100%. Full details are provided in Carter et al. (*In Prep*).

Since Russell et al. (2017), additional count (up to 2018) and telemetry data have become available. Specifically, updated count data are available for Republic of Ireland (Morris and Duck 2019) and the majority of Scotland (with the notable exception of Shetland). Further, BEIS funded a large-scale deployment of high-resolution (GPS) telemetry tags on grey seals. Along with the deployment of reconditioned tags (in collaboration with University of Aberdeen), this resulted in additional data (of the quality suitable for habitat preference modelling) for 71 grey seals. There has also been an increase in telemetry data available for harbour seals, as a result of various projects at SMRU, University of Aberdeen, and University College Cork (UCC).

For the current BEIS project, data from the lower resolution Argos tags were not included (see Discussion). Slight differences in the criteria for inclusion of data from a given GPS tag (compared to usage maps) meant the year-specific samples sizes for GPS tags differ between usage and habitat preference models. In total, data from tags deployed (by or in collaboration with SMRU, University of Aberdeen, UCC and Zoological Society London) on 239 harbour and 114 grey seals were used. The sample size from tags deployed in Scotland was 59 and 162 for grey and harbour seals respectively. However, seals tagged in both the ROI and England used haulouts in Scotland.

5. Discussion

There are substantial differences in the predicted at-sea distribution between the usage and habitat preference models as a result of differences in the input data and the essence of the underlying model. In addition, there are important differences in the presentation (estimated numbers versus percentage of the population) and uncertainty estimates, both in terms of calculation and interpretation. The reliability of the respective predicted maps is dependent upon the assumptions associated with each method, which are discussed in detail below.

5.1. Presentation

For usage maps, the estimates per cell represent predicted numbers of seals within that cell (i.e. absolute abundance) whereas for habitat preference maps, they represent the percentage of the at-sea population (i.e. relative abundance). Although the former is more readily usable, it is reliant on accurate estimates of two population scalars: (1) the proportion of the population hauled out (and available to count) during surveys, and (2) the proportion at sea during the main foraging season. The first scalar is currently under review for grey seals; preliminary work suggests a 30% higher population size for a given count than previously reported (Russell et al. 2016)

– this percentage increase should be applied to each cell of the grey seal usage maps. The findings of Russell et al. (2016) also likely have ramifications for the second scalar – it is likely that the proportion of each species' population at sea (and thus abundance) is currently underestimated in the usage maps. By using relative density estimates (i.e. percentages of at-sea population) for the habitat preference modelling predictions, the distributions emanating from specific haulout sites (e.g. Special Areas of Conservation) and their associated confidence limits can be used even once the count data are out-of-date.

Another key difference in the presentation is the way in which predictions are made in coastal cells. A consequence of the smoothing of tracks in the usage maps is some overlap in at-sea usage with land. This means that abundance estimates in coastal cells are not adjusted to reflect that a proportion of the cell is on land (and thus in reality cannot contribute to at-sea distribution), and that there is some usage in cells that are entirely land. In the habitat preference modelling, this issue was resolved by weighting cell density estimates by the proportion of the area of the cell that was sea.

5.2. Input Data

Although predicted distribution maps were made for a particular year (with the exception of Jones et al. (2013)), they are based on telemetry data collected over multiple years. Thus, there is an implicit assumption of stability in the movements of seals through years. In reality, this is unlikely to be the case, particularly in areas of population change (Russell 2015). In the habitat preference models, the impact of this assumption is minimised to some degree by (1) the recent large-scale telemetry tagging of grey seals, (2) excluding older data, (3) accounting for any changes in distribution as a result of changing sea surface temperature (by including it as a covariate).

For Scotland, with the exception of the East Scotland SMU, the usage maps for grey seals were entirely informed by telemetry data collected prior to 2005. Indeed, the most recent data for Orkney were from 1998, and since then pup production has increased by over 15% and the population appears to have reached carrying capacity. Evidence suggests this is a result of density dependent pup survival (Thomas et al. 2019) which is likely mediated by limited resources at sea (Russell et al. 2019); this would presumably also influence the at-sea distribution of both grey and harbour seals. Furthermore, almost all the grey seal telemetry data available for the usage maps were from lower resolution tags (Argos tags; not used in habitat preference models); the associated location data are on a relatively coarse temporal and spatial resolution resulting in potential inaccuracies in locations, particularly following linear interpolation. There were also slight differences in the seasonal extent of data considered between the usage and habitat preference models (Table 1). Fine-scale and, for grey seals, large-scale seasonal movements mean that, for both species, both the usage and habitat preference maps should be considered to represent spatial abundance during the main foraging season only (Table 1). Incorporating up-to-date counts is critical for accurately predicting at-sea distribution around Scotland, particularly in areas with marked trends in abundance (e.g. harbour seals in the North Coast & Orkney and East Scotland SMUs). The predicted densities (percentage of UK and Ireland population at sea) from the habitat preference model were generated using the most recent count data available for each haulout (Table 1; section 4). However, there were also key differences in how the count data are incorporated into the two types of model. In the latest versions of the usage maps (Jones et al. 2015, Russell et al. 2017), a decision tree was applied, and the count used was either a mean of (some or all) previous counts or extrapolated by fitting a temporal trend to the data. In contrast, for the habitat preference models the most recent count available was used. Although the approach used in the habitat preference models will result in some spatial inconsistences in the age of count data used, it was deemed preferable for two reasons: (1) recent evidence demonstrates that regional harbour seal trends are often complex (Thompson et al. 2019), and such complexity would be more marked on a finer scale, (2) prior to data collected for Lonergan et al. (2011), counts made of grey seals during the harbour seal moult were opportunistic (i.e. grey seal-only haulouts may not have been surveyed). In any case, the vast majority (Scotland: c.97%) of counts used in the current habitat preference project were from the last five years.

5.3. Methodological differences and associated caveats

The fundamental differences in the underlying methods have ramifications for both the mean predictions and associated uncertainty, as well as the caveats. There are caveats associated with any modelling exercise, particularly in the spatial modelling required to provide spatial density estimates. For the usage maps, there are two types of prediction: (1) null usage for haulout clusters with no associated tracking data (section 3.1), and (2) predicted usage which is based on smoothing across the tracks associated with a haulout cluster.

The key caveat of the usage maps is associated with null usage: the modelled distance/abundance relationships on which null usage was based were UK-wide and the relationship. Hotspots of usage are likely to occur as good foraging habitat is distributed heterogeneously in space, but would be overlooked by null usage predictions. In addition, there are magnitude-level differences in the mean harbour seal trip extent between regions (Sharples et al. 2012) ranging from <5 km in

Chichester Harbour (Southern England SMU) to > 100 km in The Wash (Southeast England SMU).

In some areas (e.g. Southwest England) the large contribution of null usage is apparent (clear uniform bands of decreasing usage emanating from haulout clusters and associated large uncertainty) which will indicate that the end-user should exercise caution when using these estimates. However, usage emanating from different clusters of haulouts (and even regions) overlap, and thus assessing the contribution of null usage to cell-specific abundance estimates is often not possible. This is particularly pertinent for harbour seal usage in the west coast of Scotland where the complex coastline and scattered haulouts means that, despite a reasonable sample size of tracked seals, a substantial proportion of predictions were a result of the null usage model. Furthermore, the accuracy of the predicted distributions based on smoothing tracks (2) is dependent on these movements being representative of the haulout as a whole – this is likely to be particularly problematic for haulouts for which there is a small sample of tagged individuals and/or substantial variation in movements made from the haulout.

The habitat preference method has the advantage that the effective sample size of tagged individuals for each haulout is the total for the entire region, and that only habitat preference, rather than movements, of tagged individuals need to be representative of populations at haulouts (and regions). Specifically, if no individuals visited a foraging patch while tagged, for usage maps no seals would be predicted for that patch (unless based on null usage), whereas in habitat preference modelling, the density of seals would be based on the level of use of similar habitats. As mentioned above, predicted distributions can be generated for haulouts that are not used by tagged seals based on the modelled species-environment relationship, thus providing a more ecologically relevant estimate than the null usage.

Nevertheless, the habitat preference approach has a number of limitations. The reliability of the predictions is dependent on the modelled relationship between abundance and environmental variables. Such a model may not accurately represent the true underlying relationship for four main reasons: (1) caveats and assumptions associated with the modelling framework (2) key environmental drivers of distribution may not have been included (due to lack of knowledge of those drivers, or lack of appropriate environmental data); (3) variation (between individuals at a haulout or between haulouts with a region) in habitat preference may make quantifying the mean population preference difficult; and/or (4) there may be different drivers depending on activity (e.g. foraging versus travelling). In regions for which there are localised preferences (e.g areas of high current in Kyle Rhea; Hastie et al. (2016), combining data across a region may lead to combining two or more distinct preferences. Resulting predicted distributions would therefore be derived from a mean of these preferences (which may have reduced ecological relevance). Unfortunately, the use-availability design prohibits the generation of standard goodness-of-fit metrics due to the complexities associated with the availability sample being comprised of control points, rather than true recorded absences (e.g. as in transect data).

An implicit assumption of the habitat preference modelling is that foraging, and all other activities are associated with the same preference. Activity-specific preference, or lack of preference associated with a particular activity, will potentially impact the accuracy of the habitat preference modelling and the resulting predicted density maps. However, in most areas there is unlikely to be an environment preferred for travelling distinct from that for foraging. The influence of the inclusion of travelling locations on the habitat preference modelling will vary with region in a species-specific manner. For example, harbour seals exhibit distinct travelling and foraging behaviour in the East Scotland SMU but not in the West Scotland SMU. For grey seals, there are typically distinct travelling and foraging areas, particularly for individuals from the Western Isles foraging on the shelf edge, and those in East Scotland SMU. In areas where haulout availability is tidal, seals spend prolonged periods of time in the water near haulouts. It is unclear the degree to which such behaviour is associated with foraging, and thus relates to foraging habitat preference. To some extent, inclusion of the ‘distance from haulout’ can account for bimodal preferences associated with such nearshore behaviour. Preliminary analyses indicate biologically reasonable predictions from habitat preference models (Carter et al. *In Prep*). Nevertheless, to understand the importance of particular environmental conditions and areas for foraging, habitat preference modelling should also be conducted using only foraging locations; such locations would first have to be derived from the tracking data (Russell et al. 2015). This is particularly important in the context of marine spatial planning because there will likely be large differences in the impact on energy budgets of changes in habitat or even displacement from travelling versus foraging areas.

5.4. *Uncertainty*

In both the usage and habitat preference maps, the uncertainty presented represents the uncertainty of the mean prediction in a given cell, rather than day-to-day variation in usage. As a result, to get lower and upper limits of abundance within an area, the lower and upper confidence intervals of the encompassed cells cannot be simply be summed (the resulting confidence intervals would be overstated). Although both the usage and habitat preference maps present confidence limits on cell abundance, there are important differences in how this is calculated. For null usage, the confidence intervals incorporate the variation in the modelled distance from haulout/abundance relationship. For haulouts with associated tracking data, the confidence intervals encompass ‘between individual variation’ as a function of number of tagged individuals for each species (as a proportion of the haulout specific population). However, this relationship was modelled on a study area scale, and thus assumes that the level of variation between individuals is spatially uniform. Preliminary habitat preference analyses revealed it was not possible to explicitly model between-individual variation in the project and thus, although the confidence intervals take into account uncertainty in the relationship between habitat and use (across all individuals), they do not explicitly account for individual variation.

Compared to the habitat preference maps, usage map confidence intervals encompass two additional sources of uncertainty related to the population estimates: (1) uncertainty resulting from estimating the count for the year of prediction, and (2) uncertainty (through individual variation) in the scalars used to convert count data into at-sea population size. For the habitat preference models, the first source of uncertainty is negated by the use of the most recent count. The second source of uncertainty is not considered in the habitat preference modelling because the habitat preference maps represent abundance as percentage of a given at-sea population (thus the count data are used directly). The lack of incorporation of uncertainty in the scalar used to convert the counts into population and then at-sea population may lead to artificially narrow confidence intervals. However, to understand the relative significance of areas at sea, the key consideration is the uncertainty derived from the relationship between abundance and the environment which is considered in the habitat preference models. Furthermore, the lack of incorporation of uncertainty related to population estimates means the accuracy of the habitat preference confidence intervals is not dependent on the accuracy of the proportions of seals hauled out either during the survey or the main foraging season, which are currently under review (section 5.1).

For the habitat preference maps, high uncertainty (wide confidence intervals) is indicative of insufficient sample size or tagged individuals representing multiple foraging strategies and thus types of habitat preference. Preliminary results of the habitat preference modelling indicate wide confidence intervals in the North Coast and Northern Isles for both grey and harbour seals, and in the Western Isles and East Coast for harbour seals. These areas would therefore benefit from an increased sample size.

A critical aspect of uncertainty that cannot be quantified is how representative the telemetry data are of the regional habitat preference; this is dependent on both spatial and temporal stability of preference. There are stark differences in regional preference demonstrating that such spatial stability does not hold on a large scale. This is a particular issue for Shetland; ideally preference here for both species would be modelled as a separate region to Orkney. Unfortunately, no GPS phone tags have been deployed in Shetland and thus habitat preference and resulting distribution estimates were based entirely on preference of individuals hauling out in Orkney. Comparisons of seal diet between Orkney and Shetland revealed seasonal and spatial differences in the importance of different prey groups between the two locations (Wilson and Hammond 2019). For example, the diet of harbour seals in Orkney is dominated by sandeels in spring-summer, and gadids and pelagic prey in autumn-winter, whereas pelagic prey form the largest prey group in Shetland during spring-summer, and sandeels in autumn-winter. Grey seal diet is dominated by gadids in both areas, but secondary prey groups differ between Orkney and Shetland. These differences in diet may relate to differences in the environment (i.e. proximity to shelf edge, differences in water depth, seabed topography and seasonal mixing and stratification dynamics), suggesting possible differences in habitat preference. Such extrapolation was also necessary in the East Scotland SMU; grey seals were only tagged within the Firth of Tay and Eden, but c. 50% of the SMU population haul out c. 100 km further north (Ythan Estuary).

On a finer scale, the assumption of spatial stability will hold better for grey than harbour seals. Grey seals are wide-ranging and there is considerable overlap in the distributions emanating from haulouts within the same area. However, for harbour seals, there will be no overlap of usage from seals hauling out across multiple distinct haulout clusters, especially in the West Scotland SMU. In the East Coast SMU, nine seals were tagged in the Eden Estuary, and foraged largely to the east of St Andrews Bay, with three undertaking repeated trips to Wee Bankie; a known sandeel fishing ground 40 km east of St Andrews Bay. However, two seals tagged at Kirkcaldy in the Firth of Forth remained within the Forth and did not visit Wee Bankie. Density was not predicted to be high for the Wee Bankie suggesting the habitat preference relationship was conflated by combining the two different strategies. Ideally biological rationale (from existing movement, haulout and diet data) would be used to define habitat preference regions and tagging efforts focussed on ensuring an adequate sample size in these regions. Assumptions of temporal stability are unlikely to hold especially given the marked trends in abundance. This is a particular problem for the East Scotland SMU where changes in grey seal movements through time have been observed (Russell 2015) and the majority of tagging occurred in 2008.

6. General Conclusion

On the basis of this review, the best available seal density maps for marine spatial planning are those resulting from the more recent habitat preference project (expected to be published in autumn 2020). This is due to three key differences to the usage maps: updated count data, use of recent telemetry data, and inherent advantages of habitat preference maps that do not need to rely on assumed null usage distributions. However, as described above some important limitations remain. There are data and analytical requirements that need to be fulfilled to address these key limitations.

In terms of data, additional tagging is required in areas for which current habitat preference models may not be representative. In addition, further tagging and analyses would be required to extend the seasonal range for which predicted distributions are available. Currently, regulators are having to rely on maps that in reality pertain to only a proportion of the year (four months in the case of grey seals; Table 1). In addition to improving the tracking datasets, further environmental covariates relevant to seals could be considered, provided they were available for the entire region accessible to the seals. For example, data on the distribution and abundance of key fish species (such as sandeels, gadids and other common prey species) may improve the models, particularly if foraging is considered separately. However, choosing the most appropriate data requires detailed knowledge of seal diet and fish distribution, both of which may vary regionally and seasonally (Wilson and Hammond 2019). Likewise, high resolution data on tidal currents may be informative, especially for regions where seal distribution in certain areas may be spatially and temporally impacted by tidal flow (e.g. Pentland Firth, Kyle Rhea). Such data were not considered in the current habitat preference project as only covariates that were available for the entire study area were considered, to facilitate ecological comparisons of preference among regions.

To increase confidence in predicted densities as a whole and to enable identification of important foraging areas, two methodological developments are needed: (1) combining usage maps and habitat preference methods, and (2) modelling foraging habitat preference. The former has already been conducted for harbour seals in Orkney and the Pentland Firth (Jones et al. 2017) but there are methodological challenges associated with such work on a larger spatial scale. In brief, habitat preference would be modelled as described here except where sufficient tagging data was available to indicate that high levels of individual variability warrant using smoothing of the tracks (usage maps) instead. This two-pronged approach would generate more accurate density maps than those based on one method. Using a habitat preference modelling framework would also allow some of the limitations of usage maps to be negated including seal density predictions on land.

7. Draft Plan Options (Table 2)

7.1. Predicted density and associated confidence

Draft Plan Option sites have been identified by Marine Scotland. In this report the preliminary results of the habitat preference modelling have been used to rate the relative **cell-specific** density of seals within these sites for each seal species. The density ratings were based on four cell-specific density categories indicating the percentage of the population predicted to be in cells within the Draft Plan Option sites: very low (< 0.005% of the at-sea population of the British Isles), low (<0.01%), medium (<0.05%), high (<0.5%). These four categories represent approximately <10, <15, <75, and <750 grey seals, and <2, <4, <20, and <200 harbour seals within a cell at any time. It should be noted that these categories do not represent equal numbers of cells in the study area (maximum foraging range of seals that haul out in British Isles) the mean prediction for ≥ 90% of cells for both species is ‘very low’. The lowest density rating for a Draft Plan Option site was based on the highest density category of cells in the lower CI prediction, and the highest rating based on the highest density category in the upper CI prediction (Table 2). In other words, if a Draft Plan Option site encompassed five cells which were categorised as very low or low for the lower CI limit, and medium or high for the upper limit, the Draft Plan Option site would be rated as low-high. Because the density rating is based on the density category of the encompassed cells, the total abundance of seals within a Draft Plan Option site depends on its size (i.e. number of grid cells) as well as the density rating. Thus, for example, a medium grey seal rating for a Draft Plan Option site encompassing 10 cells would represent a prediction of up to 750 seals at any time.

Confidence in the density ratings has been judged on the basis of unmodelled sources of uncertainty (discussed above). However, even where such uncertainty is considerable, if counts of seals at the haulouts in the vicinity of a Draft Plan Option site were low then confidence in a very low or low density rating could still be high. For both species, the lowest confidence in the density rating is NE1; this is because no GPS tagging data are available for Shetland and thus the predictions are entirely based on the habitat preference of individuals hauling out in Orkney. For grey seals, there is also low confidence for the east coast areas, particularly E2 and E3. This was due to the age of the telemetry data used to inform the model and the lack of any data for the nearest large haulout (Ythan Estuary). Although there is considerable unmodelled uncertainty for the harbour seal density predictions for the East Coast, the location of the Draft Plan Option sites means that the confidence in the density ratings are high. However, for harbour seals N3 is an area of low confidence. No harbour seals have been tagged in northern Western Isles or West Scotland, but one individual tagged in Kyle Rhea appeared to forage on the boundary of N3. If other seals from distant haul out sites are travelling to N3 to forage then the density level may be underestimated.

Table 2. Predicted by-cell seal density rating (from habitat preference modelling; Carter *et al.* In Prep) within Draft Plan Option sites and associated confidence. For an idea of total abundance within Draft Plan Option sites the size of area should also be considered; number of cells refers to the total number of complete and partial cells.

Draft Plan Option	Habitat preference region	Number of cells (complete)	Grey seals		Harbour seals	
			By-cell density rating	Rating confidence	By-cell density rating	Rating confidence
E1	E Coast	187 (127)	very low-low	medium	very low	high
E2	E Coast	78 (34)	very low-low	low	very low	high
E3	E Coast	30 (9)	low-medium	low	very low	high
N1	N Coast & N Isles	63 (31)	very low - medium	high	very low	medium
N2	Western Isles	35 (9)	very low	high	very low	high
N3	Western Isles	62 (30)	very low-low	high	very low-low	low
N4	Western Isles	17 (2)	very low	high	very low-medium	medium
NE1	N Coast & N Isles	46 (17)	very low - medium	very low	very low-medium	very low
NE2	N Coast & N Isles	31 (7)	low-high	high	very low-low	high
NE3	N Coast & N Isles	27 (6)	medium-high	high	very low	high
NE4	Moray Firth	32 (6)	very low-medium	high	very low	high
NE5	Moray Firth	34 (9)	very low-medium	high	very low-low	medium
NE6	Moray Firth	45 (15)	very low-medium	medium	very low	high
NE7	Moray Firth	61 (25)	very low-low	high	very low	high
NE8	Moray Firth	27 (4)	very low-medium	high	very low	high
SW1	Irish Sea N	23 (3)	very low-low	high	very low	low
W1	West Scotland & Ireland N	63 (29)	medium-high	high	medium	medium

7.2. Specific research priorities (Table 3)

In addition to the future work required to increase the accuracy of UK at-sea seal density maps as a whole, there are specific priorities to enable robust predictions of seal abundance within the Draft Plan Option sites. The ratings listed in Table 2 are based on density estimates and associated confidence limits of the encompassed cells. To obtain estimates of relative abundance for Draft Plan Option sites or associated footprints, mean estimates and confidence intervals need be produced on that scale (rather than on a cell-by-cell basis; Table 3).

Table 3. Approximate time or costs (to nearest £5,000) associated with key priorities for assessing and maximising confidence in predictions of seal density within Draft Plan Option sites. For Item 1, the time associated is shown because the cost would be dependent on the funding model. For items 2 and 3, costs are for data collection only; the costs of analyses would depend on the degree to which current proposed and funded projects encompass such analyses.

Item	Description	Approximate Time/Cost
1	Predictions (and associated confidence) for Draft Plan Option sites	1 month
2	Shetland telemetry tagging (10 Grey and 10 Harbour Seals)	£110,000
3	Ythan Estuary/Cruden Bay telemetry tagging (10 Grey Seals)	£50,000

To enable reasonable confidence in specific Draft Plan Option sites, further tag deployments would be required. The sites for tagging depend on whether the priority is to gain a minimum threshold of confidence for as many Draft Plan Option sites as possible or to gain relatively high confidence for specific sites. Shetland clearly represents an important data gap in terms of reducing uncertainty in seal abundance within a single Draft Plan Option site (NE1). Predicted density in the encompassed cells for both species shows wide confidence intervals, and as discussed above, the uncertainty is underestimated. A dual tagging program of both species would also inform other projects (e.g. Harbour Seal Decline). The second key site to increase the accuracy of, and confidence in, predictions in the East Scotland SMU would be tagging of grey seals in the Ythan Estuary. The approximate costings of such work are outlined in Table 3. Note that analyses of data resulting from any additional tagging is not included. Discussions would be required to determine to what degree current workplans encompass such analyses.

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