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Grey seal and harbour seal indicators for the Marine Strategy Framework Directive

Sea Mammal Research Unit
Report to
Scottish Government

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Introduction

Under the Marine Strategy Framework Directive (MSFD), Member States are responsible for coordinating strategies to protect and restore the marine environment to 'Good Environmental Status'. To achieve this, a suite of indicators of marine environmental health is to be adopted and monitored across European Member States.

Seals are an important component of marine biodiversity. As top predators they integrate information about the state of the marine ecosystem. Their abundance and distribution can respond to various natural and anthropogenic drivers including disease, interspecific competition, shifts in resources, disturbance, and fisheries interactions. In some cases, the primary driver(s) affecting population abundance or distribution can be identified, characterised, and managed (for example in the Moray Firth where shooting has been the cause of a decline in the mid to late 1990s). In many more cases detailed characterisation of the pressures affecting the state of the population is lacking due to the inherent difficulty in assessing wild population demographic parameters and the fact that populations can be responding to multiple drivers. Thus, changes in the abundance and distribution of apex predators as general indicators of ecosystem health should be viewed in the context of changes to other biodiversity indicators as it is often difficult to pinpoint the specific causes of change.

Long-term monitoring programs are widely recognised as necessary to assess population states, and to contextualise what is meant by 'good environmental status' (GES). Such programs exist for several components of the North-East Atlantic marine environment including plankton, fish, seabirds and marine mammals. There are two species of pinniped found regularly in the waters and coasts of the North Sea and Celtic Sea: grey seals (*Halichoerus grypus*) and harbour (or 'common') seals (*Phoca vitulina*). Both species were hunted into the 20th century, but are now protected from recreational or subsistence hunting. Various monitoring programs began in the late 20th century and continue on an annual, biennial or 5-year basis.

Quantitative metrics of the state of grey and harbour seal populations are to be included in the MSFD assessment of environmental status in the North Sea and Celtic Sea under Descriptor 1: *Biological diversity*. The relevant indicators (and corresponding MSFD criteria and targets) are:

- M-3: Abundance and distribution each of harbour and grey seals (1.1 Species distribution, 1.1.2 Distributional pattern within range; 1.2 Population size, 1.2.1 Population abundance);
    - *"At the scale of the MSFD sub-regions the distribution of seals is not contracting as result of human activities: in all of the indicators monitored there is no statistically significant contraction in the distribution of marine mammals caused by human activities"*
    - *"At the scale of the MSFD sub-regions abundance of seals is not decreasing as a result of human activity: in all of the indicators monitored, there should be no statistically significant decrease in abundance of marine mammals caused by human activities"*
- M-5: Grey seal pup production (1.3 Population condition, 1.3.1 Population demographic characteristics).
    - *"At the scale of the MSFD sub-regions seal populations are in good condition: there is no statistically significant decline in seal pup production caused by human activities"*

At the North-East Atlantic regional level, progress towards defining good environmental status for these indicators is coordinated by the Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) across Contracting Parties (CPs), with technical advice from the International Council for the Exploration of the Sea (ICES). The UK acts as lead developer for the seal indicators and the Joint Nature Conservation Committee (JNCC) coordinates this work. Specification of the metrics and associated targets and baselines for these indicators must be appropriate to the data available through existing monitoring programs both in the UK, and internationally. The present report focuses on the seal abundance and distribution data collected by the Sea Mammal Research Unit (SMRU) at the University of St Andrews and funded by the Natural Environment Research Council (NERC), Scottish Natural Heritage (SNH) and Natural England. This programme estimates the abundance and distribution of the major grey and harbour seal populations in the UK and receives additional information about the other minor populations from various non-governmental groups across the country. Monitoring programmes in most other relevant CPs are similar to the UK programme, but some discrepancies exist (see summary in Appendix 1: Monitoring programmes in other countries) and this has an effect on what metrics can reasonably be adopted at the regional seas level.

Several indicator-level metrics have been proposed for M-3 and M-5. Abundance indices for both grey and harbour seals are relatively straightforward to measure or estimate and are already reported annually elsewhere (e.g. Special Committee on Seals, SCOS; Common Wadden Sea Secretariat, CWSS). These indices are more readily available in part because population trends previously were assessed under OSPAR's Ecological Quality Objectives (OSPAR 2009). However, 'seal distribution' is less well defined and more difficult to quantitatively assess over time. Recently, grey and harbour seal usage of the marine and coastal environments was modelled using available haulout counts and satellite telemetry data (Jones et al. 2011). This work produced the most up-to-date assessment of seal distribution around the UK but insufficient telemetry data exists to assess changes in distribution through time, nor is such data available across all MSFD sub-regions. Furthermore, an assessment of this type would require an ambitious collation of all available datasets across CPs. A trade-off exists between providing the best possible assessment of seal indicators using all available data and statistical tools, and the feasibility of conducting such an ambitious analysis. As a first step towards an integrated Intermediate Assessment in 2017, simple numerical indices of seal metrics restricted to data derived from regular (terrestrial) monitoring programmes could be compiled and assessed.

Challenges that are common to the development of abundance and distribution metrics under both indicators and for both species are i) spatial aggregation of datasets (both within the UK, and across CPs) ii) temporal and spatial variability in sampling effort and resolution, iii) defining baselines and iv) setting statistically achievable targets. Primarily within the context of the UK, but with reference to other relevant CPs where applicable, the present report aims to:

Task 1: Provide background information on indictor-level metrics;
Task 2: Identify and assess proposed targets and baselines;
Task 3: Present knowledge gaps;
Task 4: Discuss caveats and data limitations.

Task 1: Background information on indicators

The following section aims to describe the UK contribution to species-specific metrics included under M-3 and M-5. A subset of the following information on, and preliminary assessment of, targets and baselines associated with the indicator metrics was compiled in October – December 2014 and submitted to the OSPAR Inter-sessional Correspondence Group on the Coordination of Biodiversity Assessment and Monitoring (ICG-COBAM).

M – 3: Abundance and distribution each of harbour and grey seals

The exact technical specifications for M-3 will depend on harmonisation across member states of monitoring methods and of monitoring frequency, both of which vary between Assessment Units (AUs) and species. Because the specific metrics to be used for the 2017 Intermediate Assessment have not been agreed upon for the distribution aspect of this indicator, this report summarises some potential approaches to define a distribution metric. Input is expected from other CPs in March 2015 at a workshop to be held at the University of St Andrews, dedicated to MSFD seal indicators.

A note on distribution

Quantifying species distributions or ranges is not straightforward (Gaston & Fuller 2009), let alone describing change in distribution over time. The two most commonly applied metrics in macroecological studies are Extent of Occupancy (EOO) and Area of Occupancy (AOO); for harbour and grey seals in MSFD regions, EOO (i.e. the outermost limits of a species distribution) is not applicable because the species true range would encompass, and eclipse, all Assessment Units. In the sections below, we explore several metrics to describe the empirical AOO and relative density within occupied areas. We do not attempt to incorporate observations into a statistical model that could also include variability in detection probabilities, amongst other processes; although such an approach would be more informative, it is outside the scope of the present report.

For the MSFD, the extent to which quantitative targets/baselines could be applied to changes in seal distribution metrics depends on the metrics that are adopted. In any case, describing the distribution of seals from surveys that are designed primarily to assess abundance is problematic and any distribution metric based on these data will have inherent limitations arising from three areas:

- Spatial coverage: Seal abundance surveys necessarily census animals seen hauled out on land and do not address the distribution at sea. To estimate at-sea usage, telemetry data would be necessary (e.g. Jones et al. 2011).
- Sampling effort: In Scotland, harbour seal moult surveys cover the entire coastline, but across the whole of the UK, and in other countries, the surveys do not cover potential haulout sites or breeding colonies in a systematic way. Haulouts and breeding sites are sampled preferentially based on past experience of seal occurrence. This means that the surveys will not necessarily detect expansions of ranges; new haulouts or breeding sites are only added to the survey coverage as anecdotal data on seal occurrence accumulate. This leads to a bias in seal distribution due to *preferential sampling*.
- Temporal coverage: the surveys only cover narrow windows during key life-stages such as moulting, breeding and pupping seasons.

These general limitations are applicable to most studies of animal abundance and distribution (Fortin et al. 2005, Thomas 2009). Despite these limitations, survey data may be useful to detect large-scale contractions in population distributions in terms of reduced use or abandonment of haulouts or breeding areas, depending on the resolution with which data are reported. Shifts in distribution density within the area covered by the surveys could also be described at the spatial resolution provided in the data.

In the sections below, indicator-level metrics are introduced for abundance and various potential metrics proposed to describe distribution.

Grey seal abundance

Grey seals aggregate at remote breeding colonies, away from human habitation. Many of the same colony sites have been used year after year since records began. Females often return to the same colony to give birth to a single white pup. In the UK, major breeding colonies are surveyed by the Sea Mammal Research Unit (SMRU) from fixed wing aircraft or – for some colonies in England – by various NGOs conducting ground surveys. For a few colonies, surveys have been conducted regularly since the 1950s but most monitoring began in 1987. For colonies surveyed in Scotland, three to five counts per colony are generated from aerial images taken over the course of the autumn breeding season. The number of pups born (pup production) is estimated using a model of the birth process and the development of pups (Duck & Morris; SCOS-BP 14/01). Elsewhere in the UK, colonies are surveyed

from the ground and the methods for calculating total pup production are different. All known major breeding sites in Scotland are covered by SMRU dedicated aerial surveys; a few colonies in the Outer Hebrides and those on Shetland are surveyed by Scottish National Heritage; the Firth of Forth is surveyed by the Forth Seabird Group and colony surveys in England are made by various NGOs or individuals including the National Trust, Natural England, Lincolnshire Wildlife Trust, the Countryside Council for Wales and the Cornwall Seal Group. Surveys in most areas have been conducted annually; however, due to funding constraints from NERC, surveys conducted by SMRU are now biennial from 2010 (Duck 2010). All estimates feed into a UK-wide Bayesian state-space model that is used to estimate the size of the adult population (Thomas 2014). Total population size is considered under indicator M-3; estimates of grey seal pup production are used for indicator M-5.
For the MSFD common indicator, two Assessment Units (AUs) were proposed by the ICES WGMME (2014): the ‘Greater North Sea’, and ‘Western Britain, Ireland & France’. Within the UK, colonies previously have been aggregated into smaller Seal Management Units (MUs; as for harbour seals) that correspond to the MSFD Assessments Units as in Table 1.

Table 1: Attribution of UK Seal Management Units (MUs) to MSFD common indicator Assessment Units (AUs)

UK Management Unit (MU)	Assessment Unit (AU)
East coast Scotland	Greater North Sea
Moray Firth	Greater North Sea
Northeast England	Greater North Sea
Orkney and North coast	Greater North Sea
Shetland	Greater North Sea
Southeast England	Greater North Sea
Southwest England & Wales	Western Britain, Ireland & France
West Scotland	Western Britain, Ireland & France
Western Isles	Western Britain, Ireland & France

What is the metric?
In the UK, total grey seal population size is estimated from pup counts. Pup counts from all major colonies are modelled to produce pup production estimates for each region. A Bayesian state-space model is then fitted to pup production estimates and any other relevant information (e.g. population vital rates) included. Various model structures are tested and compared; the most recent model has density dependence affecting pup survival. The results are reported to SCOS by Thomas (2014) for four regions: North Sea, Inner Hebrides, Outer Hebrides and Orkney. Under the proposed MSFD Assessment Unit boundaries, the North Sea and Orkney regions would fall under ‘Greater North Sea’ AU and the Inner and Outer Hebrides would fall under ‘Western Britain, Ireland & France’ AU. Importantly, population demographic models such as the one developed at SMRU also describe the uncertainty in the estimated populations size – which often is large.

In all regions, and regardless of model structure or priors, estimated grey seal population size is increasing or stable. Pup production increased exponentially in the 1960s – 1990s after which it stabilised in the Inner and Outer Hebrides regions. In the Orkney and North Sea regions, pup production continues to increase but the rate of increase has slowed in recent years (Duck & Thompson 2007, Lonergan et al. 2011). Since 1987/88 the total British population size estimates have doubled (Thomas 2014). The final 2017 assessment of this indicator metric will need to include population size estimates from other CPs, so some degree of coordination of how population sizes are modelled and reported is needed. Ultimately, it is the change in population size (i.e. population growth rate) rather than ‘true’ population size that is of interest for assessing GES.

Harbour seal abundance

Harbour seals do not form colonial breeding aggregations. Due to the life history of this species, monitoring takes place during their annual moult (in August in the UK) when the probability that animals will haul out is higher (Thompson et al. 2005). The SMRU conducts aerial surveys during the moulting period to monitor the abundance of harbour seals in the UK. The coastline is surveyed either from a fixed wing aircraft using conventional photography or from a helicopter using thermal imaging in the period two hours before and after low tide (details of survey methods in Thompson et al. 2010b). Survey frequency varies between AUs from annual to every five years. From the mid-1990s onwards, survey frequency in some areas was increased to better monitor declines in harbour seal populations. The majority of the east and north coast populations in Scotland are now surveyed annually.

Survey counts represent an index of minimum population size because some animals will be in the water and unavailable to be counted. To obtain an estimate of the total population size, counts are multiplied by a scaling factor of the proportion of animals that can be expected to be hauled out, and available to be seen, during the aerial survey period. In the UK, satellite telemetry tags were used to track haul-out behaviour during the moult in two harbour seal populations and provided an estimate of 0.72 (95% CI: 0.54, 0.88) for the proportion of animals that can be expected to be hauled out (Lonergan et al. 2013). Information on the use of similar scaling factors in other CPs needs to be collated. In the present analysis only un-scaled (i.e. counted) seal numbers are presented.

The ICES WGMME proposed 17 - 21 Assessment Units (AUs) covering OSPAR regions II, III and IV (2014, p 99-100). The geographical limits are similar to the Seal Management Units (MUs) already in place for the 11 AUs within UK waters. For the purpose of illustrating metrics and assessing power, the data used in this report were from Scottish harbour seal moult surveys conducted between 1996 and 2013.

What is the metric?

The metric is the number of hauled out harbour seals counted during the moult period (Figure 2). It is important to emphasise that survey counts are not necessarily conducted at the scale of the AU; some sub-regions or sub-populations within an Assessment Unit may be counted more frequently or thoroughly. Survey effort is variable both between and within Assessment Units.

Grey seal distribution

There are two potential sources of information for assessing grey seal distribution: surveys of pup production during the breeding season (Oct – Dec), and counts of grey seals hauled out during summer harbour seal moult surveys (August). During the latter, the proportion of grey seals hauled out is considered too variable to provide accurate indices of inter-annual change in population size or distribution. Pup production surveys, however, cover all of the major grey seal breeding colonies at a time when most females are present and hauled out. In the UK, most of the large colonies are located in Scotland (Figure 1) and surveyed frequently (annually or biennially) from the air. In some areas of England and Wales, grey seals breed on rocky shores or in caves that make detection more difficult.

The location coordinates assigned to colonies are for a general area/colony (e.g. an island) rather than a polygon of actual habitat occupied by breeding females, or points per group of females. Traditional spatial statistics (e.g. area of occupancy, relative density), therefore, will not be helpful for assessing change in the area of space occupied by breeding grey seals. These surveys are designed to inform current management practices and as such focus on providing the most up-to-date estimates of total grey seal pup production in the UK; the surveys were not designed to assess the area or extent of grey seal breeding sites *per se*. Simple metrics using only these data to extrapolate distribution will neglect the nuances of the dataset and there is a limit to the inferences that can be made. However, in combination with abundance information, the presence and number of colonies can provide information on the *distribution pattern* of grey seals within their *breeding range*. These methods assume that all major breeding sites are included in surveys.

What are potential metrics?

1. **Number of breeding colonies**: One metric that has been proposed (see M-3 Technical Specifications) is simply the number of breeding colonies in each AU in each year. Assuming that sampling effort is constant an increase in the number of breeding colonies signals an expansion of the population into new breeding areas. If sampling effort is not constant, however, then a distinction must be made between 'new' colonies due to expansion of the population into new areas and colonies that appear 'new' in the dataset because survey effort was increased or survey design improved. This last distinction may be difficult, however, because new survey areas generally are not added until after some anecdotal or external (e.g. NGO) evidence accumulates that seals are breeding in the area. For example, Figure 3 shows a steady increase in the number of grey seal breeding colonies in both AUs. However, the step increase in the number of colonies in the Greater North Sea in 2004 was not due to a dramatic increase in the population that year; rather, a number of small colonies in Shetland were added to the database. Grey seals were known to breed in this area prior to 2004 (Anderson 1981).

   The number of colonies in large Assessment Units that include multiple countries and/or municipalities gives a *very general* picture of the population and will be susceptible to 'false patterns' depending on how and when new colonies are recorded. Furthermore, because of the tight link between population size and the number of colonies, the metric is redundant and does not provide information about the distributional pattern of grey seal breeding sites.

2. **Assessment Unit - wide occurrence:** The occurrence of grey seal breeding sites can be generalised to larger areas by mapping presence observations to a regular grid. Here, both a 5km x 5km grid and 10km x 10km grid were explored.
   a. **Area of Occupancy (AOO):** The number of 'occupied' grid cells can be tallied to give an approximate Area of Occurrence. Expectedly, the number of occupied grid cells closely matches the pattern of increase in the number of colonies (Figure 4).
   b. **Proportion of maxAOO:** Change in occurrence can also be described relative to the maximum AOO over the time series (Figure 5).

3. **Density of pup production:** Area of occupancy is closely linked with population size. Expansion into new breeding areas is likely to coincide with an increase in population size (i.e. the two metrics are positively correlated) so a more informative metric of population expansion (or contraction) may be the density of pup production estimates in each AU (pups per 5km or 10km grid cell). From Figure 6 it is apparent that the rapid increase in grey seal pup production has been accompanied by a concomitant expansion in breeding distribution. The pattern is the same at the 5km grid cell level and 10km grid cell level.

4. **Gridded relative density:** The above metrics have the benefit of being easily condensed to simple time series, but are not informative about the underlying spatial patterns. Simple linear regressions of trends in abundance (relative to the AU total) through time for each grid cell illustrate areas of relatively high or low growth rates in pup production in each Assessment Unit (Figure 7).

These are four relatively simple metrics that could be applied to grey seal breeding distribution data. It is important to consider that the above approaches, focused on breeding colonies, will not detect expansion of grey seal haulout usage in areas at the edge of their range (e.g. in France). Only maps of gridded relative density contain spatial information about the pattern of population growth/contraction. None of the approaches incorporate uncertainty in detection, counts, or pup production estimates.

Harbour seal distribution

Location and number of harbour seals is recorded directly onto Ordnance Survey 1:50,000 maps. Spatial resolution of seal locations varies; in Scotland, resolution is close to 50m, whereas in other regions seals are counted across a much larger region and a single location recorded.

In Scotland, harbour seal haulout locations are recorded in real-time during aerial surveys by marking the location of groups of animals on an Ordinance Survey (OS) map. Harbour seals can be more or less spread out along the coastline and there is a degree of subjectivity involved in defining a group of animals as a 'haulout'. The resolution of haulout definitions is therefore likely to differ between individual surveyors. However, these discrepancies should only affect fine-scale mapping of seal distribution.

The primary 'problem' underlying these calculations is that survey flight paths are not designed to survey a specific Assessment Unit boundary each year. Sampling effort is thus uneven over time and space. In Scotland, this can be overcome by pooling available annual data into 'census' periods (Figure 8). For each AU, there are three to four census periods with complete, or high, sampling effort (defined here as percentage of coastline surveyed).

What are potential metrics?

As for grey seals, a number of metrics of harbour seal distributional pattern during the moult are presented and discussed. For occupancy and density, metrics are calculated for 10km x 10km and 5km x 5km grid cells.

1. **Number of haulouts**: The number of harbour seal haulouts counted during abundance surveys in each AU has little merit as a metric of distribution around the UK. It is tightly linked to survey effort and susceptible to large changes as a result of small deviations in area covered by surveys in a year or census period (compare Figure 8 with Figure 9). As described above, demarcation of what constitutes a haulout (i.e. how many animals, how close) is a subjective decision and thus likely to vary with surveyor. When aggregated by census period, the maximum number of haulout sites recorded in an AU is more stable, but still highly variable (e.g. coefficient of variation in maximum number of haulout sites was 60% in one Assessment Unit).

2. **Assessment Unit - wide occurrence:** Occupancy can be a valuable state variable with which to assess populations and is defined here as the Area of Occupancy (AOO). Various metrics of species occupancy exist to describe patterns of presence/absence, but there are two important considerations to bear in mind: first, occupancy detection is of course restricted to the spatial and temporal extent of the surveys. As aerial surveys are designed primarily for the purpose of estimating total abundance, they are focused on areas of known and high seal usage. Areas where fewer animals are present will be under-represented in the dataset but may be important to distribution metrics – especially if, for example, the area is located at the edge of the species distributional range. Second, failure to detect an organism does not necessarily mean it is absent. This is especially apparent with harbour seal moult surveys where a proportion of the population associated with a haulout are in the water and unavailable to be surveyed during aerial imaging.

The first of these concerns can be taken into consideration by including estimates of survey effort (e.g. proportion of coastline and/or grid cells surveyed). Such data is available for Scotland (compiled in Morris, C.D. et al. 2014) and could be collated for the rest of the UK; however, it is not known if other CPs have such data readily available. In the absence of annual survey effort data, harbour seal moult counts can be aggregated into census periods as described above. We describe metrics for both scenarios below.

The second concern is a common problem in occupancy studies of any wildlife species. Typically, the problem is addressed by incorporating detection probabilities into occupancy models; an analysis of this type is beyond the scope of the present report.

Without spatial sampling effort data

a. **Area of Occupancy (AOO):** Over each census period, the maximum number of grid cells found occupied by harbour seals during the moult surveys can be counted to give an index of the AOO. In most cases, the number is greater at 5km x 5km resolution, but the overall pattern through time is similar to 10km x 10km resolution (Figure 10).
b. **Proportion of maxAOO:** Change in AOO can also be described relative to the maximum AOO over the census periods (Figure 11).

With spatial sampling effort data

a. **Area of Occupancy (AOO):** Without survey effort data, it is not possible to correctly interpret observed values of occupancy because a low AOO could be due to either a real spatial contraction in the observed seal locations, or to less than 100% survey coverage. Furthermore, AOO as defined above does not include information on *non-detection* of animals in areas that were surveyed. While non-detection does not equal absence, it is still a useful piece of information and shows a more nuanced picture of the underlying data. Figure 12 shows 5km x 5km AOO (number of occupied grid cells).

3. **Density of moult counts:** Harbour seal abundance is declining rapidly in several regions of Scotland (Lonergan et al. 2007, 2013, Thompson et al. 2010). Combining information about the decline in abundance with information about changes in distributional pattern would better characterise the declines. For example, a shrinking population may or may not become more restricted to particular haulout areas.
   a. **Seals per km^2:** The number of seals per square kilometre (or per 5km or 10km grid cell) is one common metric of species distribution. In this case, the metric can serve as an index of density but does not represent real patterns of terrestrial distribution because seal haulouts are confined to narrow strips of coastal regions. Nonetheless, a crude metric of density can be calculated from the average number of seals counted per grid cell, and expressed as seals per km^2 (Figure 13).
   b. **Seals per km^2 scaled by survey effort:** Where survey effort data is available, multiplying the density estimates by the proportion of the coastline surveyed in each year is a very simple way to scale down the density estimates based on spatial survey effort (Figure 14).

4. **Gridded relative density:** Simple linear regressions of trends in abundance (relative to the AU total) through time for each grid cell illustrate areas of relatively high or low rates of number of seals counted in each Assessment Unit (Figure 15).

M – 5: Grey seal pup production

What is the metric?

The metric for M-5 is the estimated number of pups born in each Assessment Unit. Because grey seal AU boundaries cross municipal and national borders, it is necessary to sum pup production estimates across surveys. The evidence underpinning the geographical boundaries for grey seal AUs has been described in detail elsewhere (ICES 2014). One consequence of these large AUs is that harmonisation of monitoring across CPs is likely to be required. Most CPs conduct regular aerial surveys of breeding colonies to estimate pup production. But in some areas (e.g. English & Welsh coasts, Helgoland, Rogaland) land-based assessment methods are used (e.g. Stringell et al. 2014; Appendix 1). In the UK, pup production estimates from these land-based counts are summed with those derived from aerial surveys to produce national estimates of pup production.

UK grey seal total pup production is increasing in both Assessment Units; in the Greater North Sea region (which includes large colonies in Orkney and the East coast of Scotland), production continues to increase while in the Western Britain, Ireland & France region, mean pup production has stabilised (Figure 16) suggesting this population may have reached carrying capacity.

Task 2: Targets & baselines

OSPAR provided some guidance to setting biodiversity targets and baselines in its 2012 MSFD Advice Manual (ICG-COBAM 2012). Baselines can be set as an un-impacted 'reference state', some past state reflecting the least impacted conditions, or a current state. Targets can then be set to the particular baseline, as deviation from the baseline, or could be trends-based.

Statistical power

Reliability of estimates of changes in population size or distribution depends on the quantity and quality of monitoring data. The ability to detect trends with sufficient confidence ('power') is greatly affected by the number of survey years included in the analysis (and the interval between them, the number of surveys performed with a single year, the variability of data within and between years and the initial size of the population (smaller populations are more susceptible to stochastic, or random, variability) (Teilmann et al. 2010).

In the present context, statistical power is the percentage chance of <u>not</u> making a Type II error where a Type II error, or 'false negative,' would be concluding that no trend in abundance is occurring when in fact it is. The ICES WGMME (ICES 2014) recommended that monitoring should achieve a minimum of 80% power – which equates to a 20% chance of making a Type II error. The same group also recommended that the threshold for detection of a 'significant' trend be relaxed from the traditional $\alpha = 0.05$ to $\alpha = 0.20$. The α parameter, or significance level, equates to the probability of concluding that a significant trend exists when in fact it does not (Type I error). A α value of 0.2 and power of 80% means there is equal probability of making an incorrect conclusion (either Type I or Type II error) about the detection of a trend.

The values input into the power analysis are point estimates only; i.e. there is no consideration for the fact that input values will have (in some cases considerable) uncertainty associated with them. The results thus act as a rough guide with which to exclude some candidate targets/baseline sets on the basis of 'detectability'. A more thorough analysis would include uncertainty in the variance component and present a distribution of detectable trend magnitudes achievable with 80% power.

The results of a power analysis that accounted for unequal sampling intervals demonstrated that the minimum detectable annual rate of decline (with an acceptable level of confidence) varies between Assessment Units and is related to the factors mentioned above (see Table 2, Table 3 & Appendix 2: Methods).

GES is to be determined at the regional or sub-regional scales (ICG-COBAM 2012). For harbour seals, the OSPAR area includes 11 Assessment Units. If GES is achieved only if targets are met in all AUs (i.e. 'one-out-all-out'; M-3 Technical Specification), then the targets and baselines that are set must be detectable in the AUs with the *least* data - or separate targets and baselines need to be set for each AU individually.

M – 3: Abundance and distribution each of harbour and grey seals

What are the proposed metric-level targets/baselines?

The M-3 indictor-level target for GES is defined in the MSFD as "*no statistically significant decrease in abundance/contraction in distribution of marine mammals caused by human activities"*. Various metric-level targets have been proposed for seal abundance by the ICES Working Group for Marine Mammal Ecology (WGMME; ICES 2014) and others (Härkönen et al. 2013, Hall 2014). An additional suggestion (item G in the list below) is introduced here and follows a non-parametric method developed in the UK for demersal fish biodiversity indicators under the MSFD (Greenstreet et al. 2012).

For the current assessment year:

A. *≤ 10% decline in population size in previous 10 years as represented by a 5 or 3 year running mean or point estimates (OSPAR EcoQO metric; ICES 2014)*

    A version of this target was previously used to determine 'Favourable Conservation Status' under the OSPAR Ecological Quality Objectives, but did not specify a definitive temporal period. The ICES WGMME recommended that targets for indicators be time bound, but also recognised that it is not possible to detect a *≤ 1% per annum* (i.e. 10% over 10 years) trend with sufficient statistical power (see Table 2 & Table 3 below). The target has also been expressed as '*taking to account natural population dynamics and trends, there should be no decline in population size of ≥ 10% as represented in a five-year running mean or point estimates (separated by up to five years).*

B. *≤ 50% decline in population size in previous 15 years (Taylor et al. 2007)*

    Taylor et al. (2007) explored scientists' ability to detect the 'precipitous decline' of 50% in 15 years. They reasoned that this threshold represented a state in which most marine mammal populations would be considered 'depleted' under the Marine Mammal Protection Act (the primary legislation in the USA) or 'vulnerable' or 'endangered' under the IUCN Red List. A decline of this magnitude is detectable in most AUs for both grey and harbour seals; however, depletion of 50% of the population is considerable and may obviate any management action to restore populations.

C. *≤ 25% decline in population size since reference level (ICES 2014)*

    This target was discussed at the ICES WGMME (2014) for cetaceans but could also be applied to pinnipeds. The advantage of the target is that it would be detectable in most AUs and if a 'favourable reference level' were set population size in a particular year then power to detect the trend since that year would increase with each assessment round. However, defining a favourable baseline is difficult; a default year suggested is the start of the Habitats Directive in 1992. This is an arbitrary baseline set on a legislative basis. Specification of suitable reference levels would need to include exploration of the historical state and population dynamics of seal populations in each AU.

D. *≤ 30% decline in population size in three generations (IUCN 2012)*

The International Union for Conservation of Nature uses defines as 'Vulnerable' populations that have been 'observed, estimated, inferred or suspected' reduced by ≥ 30% over the longer of 10 years or three generations. Generation length for grey seals is 14 years and 14.8 for harbour seals (Pacifici et al. 2013; Thompson, D. & Härkönen, T. 2008), so three generations is approximately 45 years. While this trend target would be detectable over 45 years, it would be difficult to assess progress towards achieving GES over such a long timescale.

E. ≤ 1% per annum decline in population size in previous 6 years (Habitats Directive 92/43/EEC)

This target was initially proposed in the EU Habitats Directive legislation. However, it is not possible to detect with sufficient power (see Table 2, Table 3).

F. For populations below carrying capacity, population growth rate should be close to intrinsic growth rate to achieve GES (Härkönen et al. 2013)

The theoretical basis for this criterion is outlined in Annex 1 of Härkönen et al. (2013). It has been adopted as a Core Indicator of Biodiversity for seal species in the Baltic under the HELCOM CORESET project. For grey seals the maximum intrinsic growth rate is 10%; for harbour seals it is 12%. In the Baltic, both grey seals and harbour seals are below carrying capacity and near to GES under this target. In the Greater North Sea AU, grey seal populations are still increasing exponentially and this target may be appropriate for GES. However, the population in the Western Britain, Ireland & France AU may have reached carrying capacity and a current, or rolling, baseline should be used. Whether or not harbour seal populations reached carrying capacity in any of the AUs is not known; however, the decline of this species in several AUs in Scotland means that the populations would certainly fail to meet GES under this target.

G. Value should be in the upper X%[1] of all values in the time series 'reference period'[2] (Greenstreet et al. 2012)

Greenstreet et al. (2012) propose a nonparametric assessment of demersal fish biodiversity for the MSFD. The authors note that many population abundance time series are not monotonic (i.e. they are not entirely non-decreasing or non-increasing), invalidating a standard parametric trends-based approach. They defined a species-level target on the basis of the distribution of all available points in the 'reference period', using the entire available time series as a reference period. The metric-level target can then be set so that the value for the current assessment year should fall within the upper Xth percentile of all the values in the time series[3]. The specific percentile could be set depending the level of ambition considered appropriate for the AU.

Grey seal abundance

Is sufficient statistical power achievable?

Because the model of total populations size is based on the pup production time series, please see the results of power analyses of pup production surveys below.

[1] The percentage here can be set according to the management goals (e.g. to increase populations, or to maintain them)

[2] This could be a bespoke reference period for each Assessment Unit; however, here we consider it to be the entire time series available.

[3] The method is for multi-species indicators; Greenstreet et al. (2012) then use the number of fish species meeting thier metric-level targets to assess the 'indicator-level target' as a departure from the binomial distribution.

Harbour seal abundance

Is sufficient statistical power achievable?

For these analyses, un-scaled values of harbour seal counts during the moult were used. The ability to detect the magnitude of the trend implied in each target varies with the sampling effort in each Assessment Unit and time period. The time period assessed depends on the target; for example, target A *"≤ 10% decline in population size in previous 10 years as represented by a 5 or 3 year running mean or point estimates"* implies a duration of 10 years. The assessment would thus include count data from the previous 10 years. Importantly, this does not mean there will be 10 data points because many AUs are not surveyed annually (see Appendix 2: Methods for more details).

Table 2: The ability to detect significant trends in harbour seal abundance over the time period specified in the target with 80% power and a significance level of 0.20. Checks indicate the target is detectable; crosses indicate it is not detectable. NA indicates that power analyses are not applicable to these targets.

Target	East Scotland	Moray Firth	North coast & Orkney	Shetland	Southeast England	Southwest Scotland	West Scotland	Western Isles
A	▯	▯	▯	▯	▯	▯	▯	▯
B	▯	▯	▯	▯	▯	▯	▯	▯
C	▯	▯	▯	▯	▯	▯	▯	▯
D	▯	▯	▯	▯	▯	▯	▯	▯
E	▯	▯	▯	▯	▯	▯	▯	▯
F	NA	NA	NA	NA	NA	NA	NA	NA
G	NA	NA	NA	NA	NA	NA	NA	NA
H	NA	NA	NA	NA	NA	NA	NA	NA

The results of the power analysis clearly eliminated two targets: A (*"≤ 10% decline in population size in previous 10 years as represented by a 5 or 3 year running mean or point estimates"*) and E (*"≤ 1% per annum decline in population size in previous 6 years (Habitats Directive 92/43/EEC")* were not detectable in any Assessment Unit. Southwest Scotland is particularly data-sparse and this was reflected in the power analyses. Target C (*≤ 25% decline in population size since reference level*[4] *(ICES 2014)*) was not met in Shetland or West Scotland, but the minimal detectable net decline in these regions was 28%; furthermore, target C sets a fixed baseline reference level (here taken to be 1992) resulting in an increase in trend detectability over time as the duration and number of surveys increases.

Grey seal and harbour seal distribution

What are the proposed metric-level targets?

No targets have been proposed for either distribution metric because an appropriate metric has not yet been agreed by CPs. All of the targets/baselines above could conceivably be applied to a quantitative index of seal distribution. However, the same concerns of how to best choose an appropriate target/baseline for abundance apply also to distribution.

Input on this issue is anticipated during a workshop dedicated to defining MSFD seal indicators to be held March 18th/19th at the University of St Andrews.

In some other areas of their distribution, harbour seals are monitored on an annual basis (e.g. Wadden Sea); while the quality of harbour seal assessments in Scotland is very high, the nature and extent of the coastline makes more regular monitoring unfeasible. Increasing power to detect trends in abundance by, for example, increasing the number of surveys within a year is not feasible; nor is

[4] Suitable reference levels to be determined by after analysis of population dynamics. Default to baseline used for Habitats Directive, 1992.

increasing the total number of surveys. Using data from the existing monitoring program aggregated into 'census periods' could alleviate some numerical problems in those Assessment Units with few data points.

M – 5: Grey seal pup production

Is sufficient statistical power achievable?

The ability to detect the magnitude of the trend implied in each target varies with the sampling effort in each Assessment Unit and time period. Grey seal pup production data from the UK are annual up to 2010, biennial thereafter so power to detect trends in these data generally is sufficiently high. The time period assessed depends on the target; for example, target A "*≤ 10% decline in population size in previous 10 years as represented by a 5 or 3 year running mean or point estimates"* implies a duration of 10 years. The assessment would thus include count data from the previous 10 years (see Appendix 2: Methods for more details).

Table 3: The ability to detect significant trends in grey seal pup production over the time period specified in the target with 80% power and a significance level of 0.20. Checks indicate the target is detectable; crosses indicate it is not detectable. NA indicates that power analyses are not applicable to these targets.

Target	Greater North Sea	Western Britain, Ireland & France
A	▯	▯
B	▯	▯
C	▯	▯
D	▯	▯
E	▯	▯
F	NA	NA
G	NA	NA
H	NA	NA

As for harbour seals, the results of the power analysis clearly eliminated two targets: A ("*≤ 10% decline in population size in previous 10 years as represented by a 5 or 3 year running mean or point estimates"*) and E ("*≤ 1% per annum decline in population size in previous 6 years (Habitats Directive 92/43/EEC")* were not detectable in any Assessment Unit.

Task 3: Knowledge gaps

Distribution metrics need to be agreed upon by CPs, taking into account the limitations of data collection and analysis. A few relatively simple metrics are presented here but this is by no means an exhaustive list. Each has its own particular disadvantages and/or biases. Most of these methods rely on having the spatial coordinates of haulouts or breeding colonies that were counted to assess gridded spatial metrics; such data is readily available for the UK, but the resolution of available datasets in other CPs needs to be discussed.

Statistical analysis of such datasets is not straightforward due to problems such as zero-inflation, missing values, spatial and temporal autocorrelation. Some newer statistical methods may be capable of dealing with these issues (e.g. using integrated nested Laplace approximation; Rue et al. 2009), but require specialist knowledge to implement.

Data aggregation will be necessary across CPs for the grey seal Assessment Units where different methods are used both for monitoring, and for population size estimation. The evidence underpinning the geographical boundaries for grey seal AUs has been described in detail elsewhere (ICES 2014). For harbour seals, Assessment Units correspond to pre-existing management boundaries. How total grey seal population abundance data, in particular, is aggregated is still unclear. At present, total grey seal population size is estimated in various ways by other CPs although most published estimates use some form of Bayesian state-space model similar to the one used at SMRU (Øigård et al. 2012, Brasseur et al. 2014). Importantly, these models are sensitive to the choice of priors – i.e. the 'known' information about demographic parameters that is used to inform the model. In Ireland, grey seal population size is also based on pup production. Researchers there use the same model as used by SMRU to estimate pup production from counts but scales these by a factor of 3.5 – 4.5 to estimate total population size (Ó Cadhla, O. et al. 2007)

For the 2017 intermediate assessment, it may be sensible to simply sum total population size estimates across Assessment Unit regardless of how they were generated. Future assessments could explore the feasibility of using a common model structure and priors to generate population estimates from pup counts for each AU. However, population trajectories are variable through time and space (e.g. some populations appear to have reached carrying capacity while exponential growth occurs in others) and population-specific parameterisation of the demographic models may be preferable to aggregating pup production estimates across regions.

Setting targets/baselines has been discussed at length in other reports (e.g. Section 10 ICES 2014), and is a common problem across biodiversity indicators. The ICG-COBAM (2012) cautions against the use of a current or rolling baseline: 'the use of a current baseline may not be appropriate in the context of the GES because it does not indicate what the aspirations for seal populations should be' but there appears to be a fundamental knowledge gap on what the 'aspirational' goals for seal populations should be, and who is responsible for setting them. Scientists would likely argue that this is a societal decision that should balance the needs of various stakeholders (e.g. fisherman, conservationists, the general public). Furthermore, setting 'recovery' targets for species – especially apex predators – in isolation and without consideration for other ecosystem components seems short-sighted and doomed to failure.

Task 4: Caveats and data limitations

Animal behaviour

- All abundance data represents a snapshot of animal behaviour at a particular period of time. In Scotland, one particular grid cell might be surveyed once every 5 years for a matter of minutes. Biases in haul out behaviour (e.g. sex related haul out groups), disturbance of animals on survey day, and variation in environmental conditions might result in anomalous counts.
- Surveys are undertaken for each species during the time of year they are most likely to be hauled-out and relatively stationary. Nonetheless, both species may transition between haul-out sites during the survey window.
- For grey seals, distribution of breeding colonies can only detect a change during a restricted time of the year. There is evidence that grey seal breeding distribution can be considerably different from their foraging distribution (Russell et al. 2013)

Monitoring methods

- Accessibility is not uniform – some areas are more difficult to monitor due to distance, weather, access – and will affect detection probability.
- With regards to distribution metrics, the entire coastline of the UK is not surveyed. The metric represents the distribution of animals in known areas of distribution.
- Different survey methods (e.g. ground counts, boat-based counts, fixed wing, helicopter counters) may have different resolution, levels of uncertainty and detection probabilities.

Data analysis

- The geographical scale at which calculations are performed will affect the ability to detect change. At smaller spatial scales, the area of occupancy will be smaller than at larger spatial scales; and at larger spatial scales, fewer unoccupied areas will be recorded increasing the risk of overestimating species range.
- The present analysis does not incorporate estimates of uncertainty in detection, or estimates of population abundance or distribution.

Conclusion

Grey seal and harbour seal MSFD indicator metrics for population abundance are readily available. Several simple metrics to describes changes in seal distribution on land are presented. For both abundance and distribution, appropriate targets/baselines need to be set to allow preliminary assessment of Good Environmental Status in 2016. These issues will be discussed at a workshop dedicated to the topic on 18th – 19th March at the University of St Andrews. Seal experts from most relevant Contracting Parties will be present.

References

Anderson SS (1981) Seals in Shetland waters. Proc R Soc Edinb Sect B Biol Sci 80:181–188

Brasseur SMJM, Polanen Petel TD van, Gerrodette T, Meesters EHWG, Reijnders PJH, Aarts G (2014) Rapid recovery of Dutch gray seal colonies fueled by immigration. Mar Mammal Sci:n/a–n/a

Cunningham L, Baxter JM, Boyd IL (2010) Variation in harbour seal counts obtained using aerial surveys. J Mar Biol Assoc U K 90:1659–1666

Duck C (2010) Charting Progress 2 Healthy and Biological Diverse Seas Feeder Report: Section 3.5: Seals. In: Hawkridge J (ed) UKMMAS (2010) Charting Progress 2 Healthy and Biological Diverse Seas Feeder Report. Department for Environment Food and Rural Affairs on behalf of UKMMAS, p 506–539

Duck CD, Thompson D (2007) The status of grey seals in Britain. NAMMCO Sci Publ 6:69–78

Fortin M-J, Keitt TH, Maurer BA, Taper ML, Kaufman DM, Blackburn TM (2005) Species' geographic ranges and distributional limits: pattern analysis and statistical issues. Oikos 108:7–17

Gaston KJ, Fuller RA (2009) The sizes of species' geographic ranges. J Appl Ecol 46:1–9

Gibbs JP, Ene E (2010) MONITOR. State University of New York, College of Forestry and Environmental Science, Syracuse, NY 13210 USA

Greenstreet SPR, Rossberg AG, Fox CJ, Quesne WJF Le, Blasdale T, Boulcott P, Mitchell I, Millar C, Moffat CF (2012) Demersal fish biodiversity: species-level indicators and trends-based targets for the Marine Strategy Framework Directive. ICES J Mar Sci 69:1789–1801

Hall A (2014) Seal targets and indicators for determining Good Environmental Status under the Marine Strategy Framework Directive. Sea Mammal Research Unit

Härkönen T, Galatius A, Bräeger S, Karlsson O, Ahola M (2013) Population growth rate, abundance and distribution of marine mammals. HELCOM

ICES (2014) Report of the Working Group on Marine Mammal Ecology (WGMME). ICES, Woods Hole, Massachusetts, USA

ICG-COBAM (2012) MSFD Advice manual and background document on biodiversity. OSPAR

IUCN (2012) IUCN Red List Categories and Criteria: Version 2.1, Second. IUCN, Gland, Switzerland and Cambridge, UK

Jones E, McConnell BJ, Duck C, Morris C, Matthiopoulos J (2011) The marine distribution of grey & harbour seals around Scotland.

Lonergan M, Duck C, Moss S, Morris C, Thompson D (2013) Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. Aquat Conserv Mar Freshw Ecosyst 23:135–144

Lonergan M, Duck CD, Thompson D, Mackey BL, Cunningham L, Boyd IL (2007) Using sparse survey data to investigate the declining abundance of British harbour seals: Harbour seal declines. J Zool 271:261–269

Lonergan M, Duck CD, Thompson D, Moss S, McConnell B (2011) British grey seal (Halichoerus grypus) abundance in 2008: an assessment based on aerial counts and satellite telemetry. ICES J Mar Sci 68:2201–2209

Morris, C.D., Duck, C.D., Lonergan, M., Baxter, J., Middlemas, S., Walker, I. (2014) Method used to identify key seal haul-out sites in Scotland for designation under the Marine (Scotland) Act Section 117. NERC Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews

Ó Cadhla, O., Strong, D., O'Keeffe, C., Coleman, M., Cronin, M., Duck, C., Murray, T., Dower, P., Nairn, R., Murphy, P., Smiddy, P., Saich, C., Lyons, D., Hiby, A.R. (2007) An assessment of the breeding population of grey seals in the Republic of Ireland, 2005. National Parks & Wildlife Service, Department of the Environemtn, Heritage and Local Government, Dublin, Ireland

Øigård TA, Frie AK, Nilssen KT, Hammill MO (2012) Modelling the abundance of grey seals (Halichoerus grypus) along the Norwegian coast. ICES J Mar Sci J Cons:fss103

OSPAR (2009) EcoQO Handbook: Handbook for the application of Ecological Quality Objectives in the North Sea.

Pacifici M, Santini L, Marco M Di, Baisero D, Francucci L, Grottolo Marasini G, Visconti P, Rondinini C (2013) Generation length for mammals. Nat Conserv 5:89–94

Rue H, Martino S, Chopin N (2009) Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. J R Stat Soc Ser B Stat Methodol 71:319–392

Russell DJF, McConnell B, Thompson D, Duck C, Morris C, Harwood J, Matthiopoulos J (2013) Uncovering the links between foraging and breeding regions in a highly mobile mammal. J Appl Ecol 50:499–509

Stringell TB, Millar CP, Sanderson WG, Westcott SM, McMath MJ (2014) When aerial surveys will not do: grey seal pup production in cryptic habitats of Wales. J Mar Biol Assoc U K 94:1155–1159

Taylor BL, Martinez M, Gerrodette T, Barlow J, Hrovat YN (2007) Lessons from monitoring trends in abundance of marine mammals. Mar Mammal Sci 23:157–175

Teilmann J, Rigét F, Harkonen T (2010) Optimizing survey design for Scandinavian harbour seals: population trend as an ecological quality element. ICES J Mar Sci J Cons 67:952–958

Thomas L (2009) Potential use of Joint Cetacean Protocol Data for determining changes in species' range and abundance: exploratroy analysis of Southern Irish Sea data. Centre for Research into Ecological and Environmental Modelling, University of St Andrews

Thomas L (2014) Estimating the size of the UK grey seal population between 1984 and 2014, using established and draft revised priors. Sea Mammal Research Unit

Thompson D, Duck CD, Lonergan ME (2010) The status of harbour seals (Phoca vitulina)in the United Kingdom. NAMMCO Sci Publ 8:117–128

Thompson D, Lonergan M, Duck C (2005) Population dynamics of harbour seals Phoca vitulina in England: monitoring growth and catastrophic declines. J Appl Ecol 42:638–648

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Figures

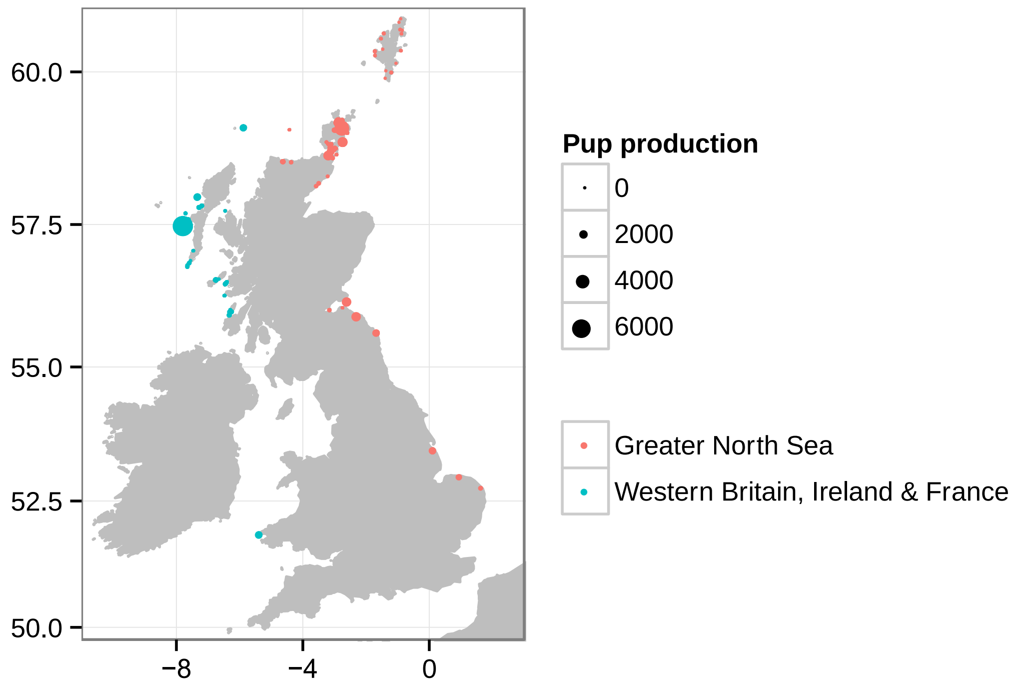

Figure 1: The distribution and size of grey seal breeding colonies surveyed in the UK from 1987 - 2013

Figure 2: Harbour seal counts during the moult. These data are from SMRU aerial surveys conducted during the August moult period. Red points are years in which the surveys covered the whole Assessment Unit; blue triangles are years where part of the AU was surveyed. NB: y-axis scales vary between Assessment Units.

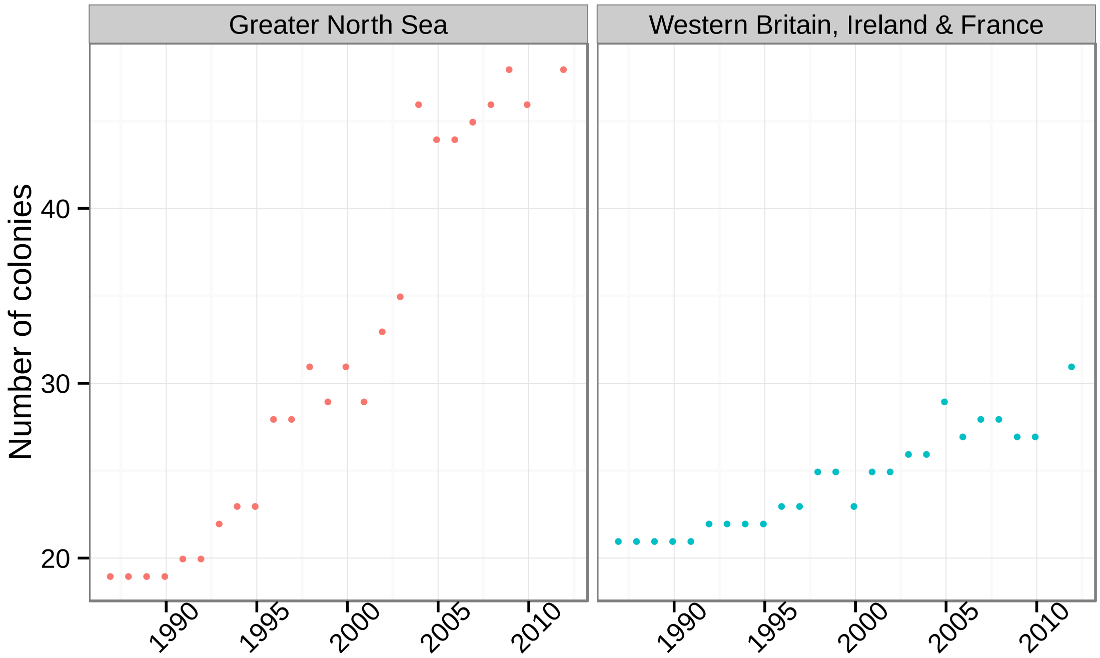

Figure 3 The number of grey seal breeding colonies in UK & Ireland Assessment Units

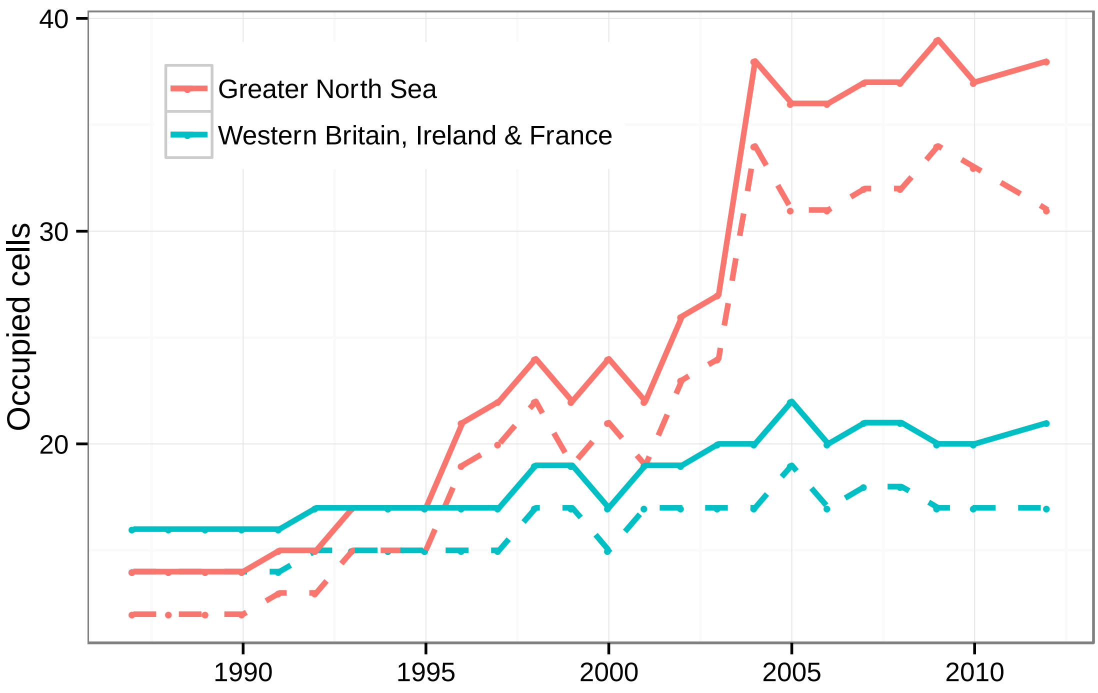

Figure 4: The number of occupied grid cells where breeding sites were surveyed in the UK (5km solid, 10km dashed).

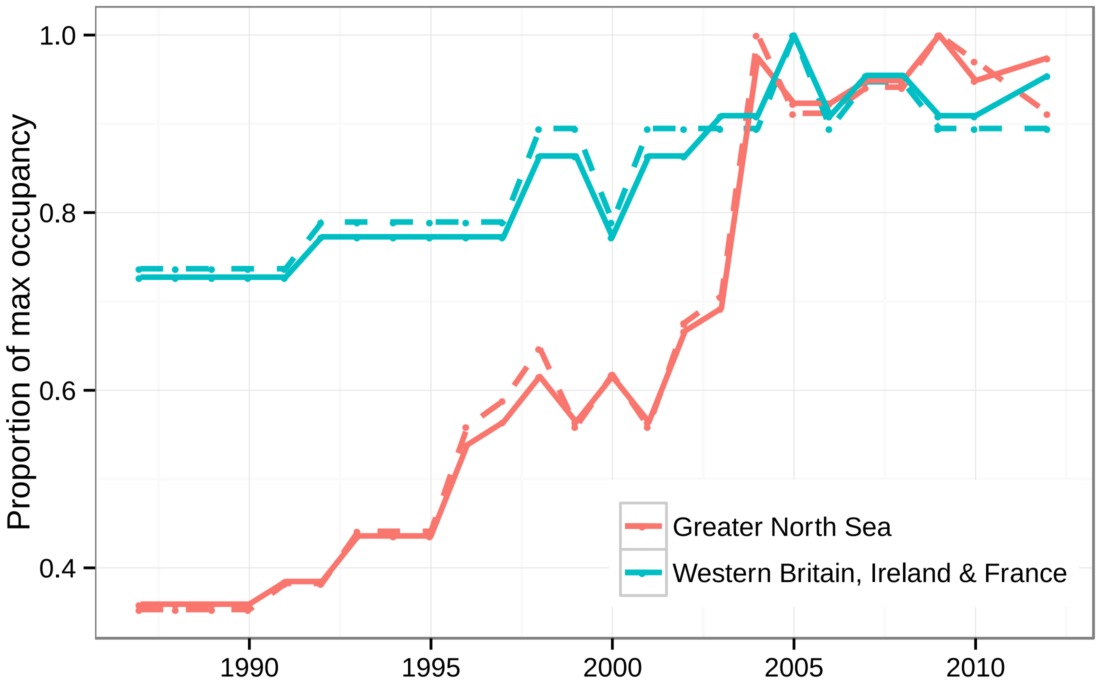

Figure 5 Grey seal breeding site occupancy relative to maximum area of occupancy over the time series. 5km x 5km cells are in solid lines, 10km x 10km cells are in dashed lines.

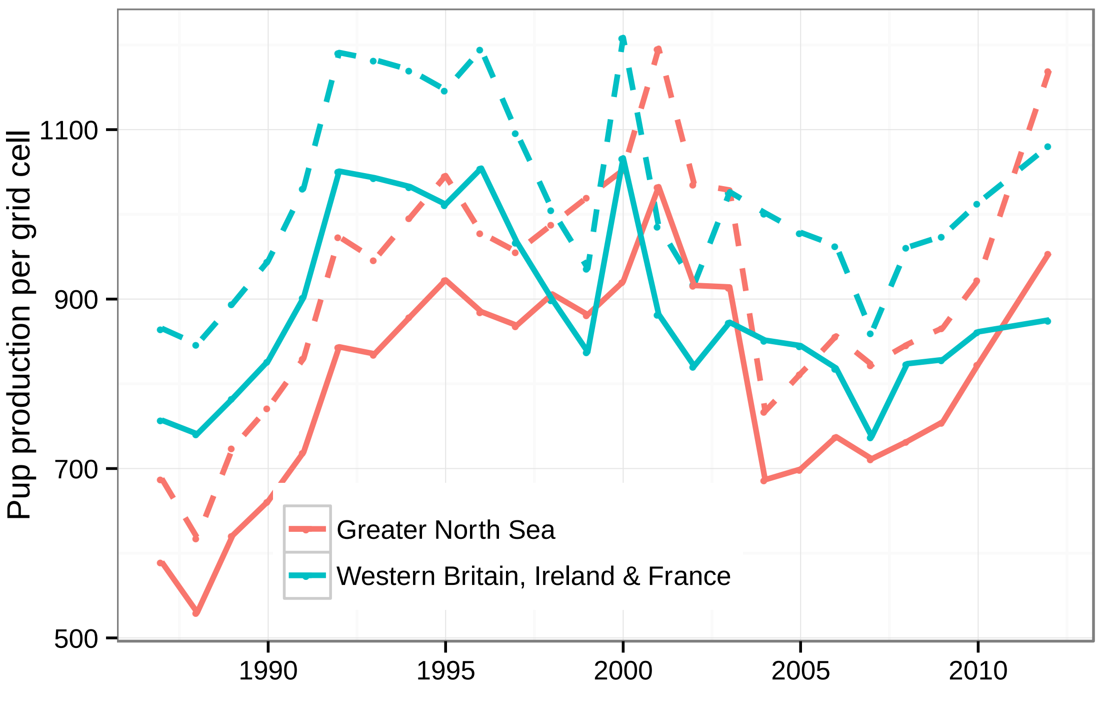

Figure 6: Relative density of grey seal pup production in occupied grid cells. 5km x 5km cells are in solid lines, 10km x 10km cells are in dashed lines.

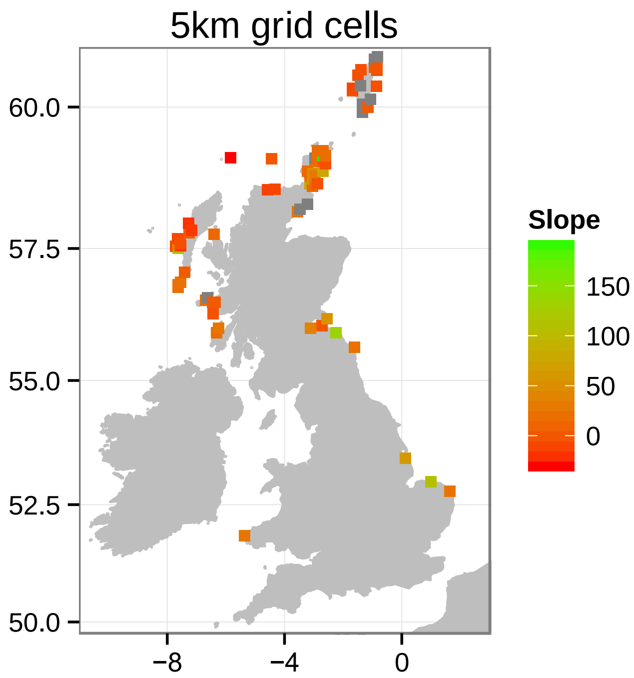

Figure 7: Trends in pup production relative to total production for each Assessment Unit. Linear regression slopes were calculated for each 5km x 5km grid cell over the period 1987 - 2012. Grey squares are data deficient.

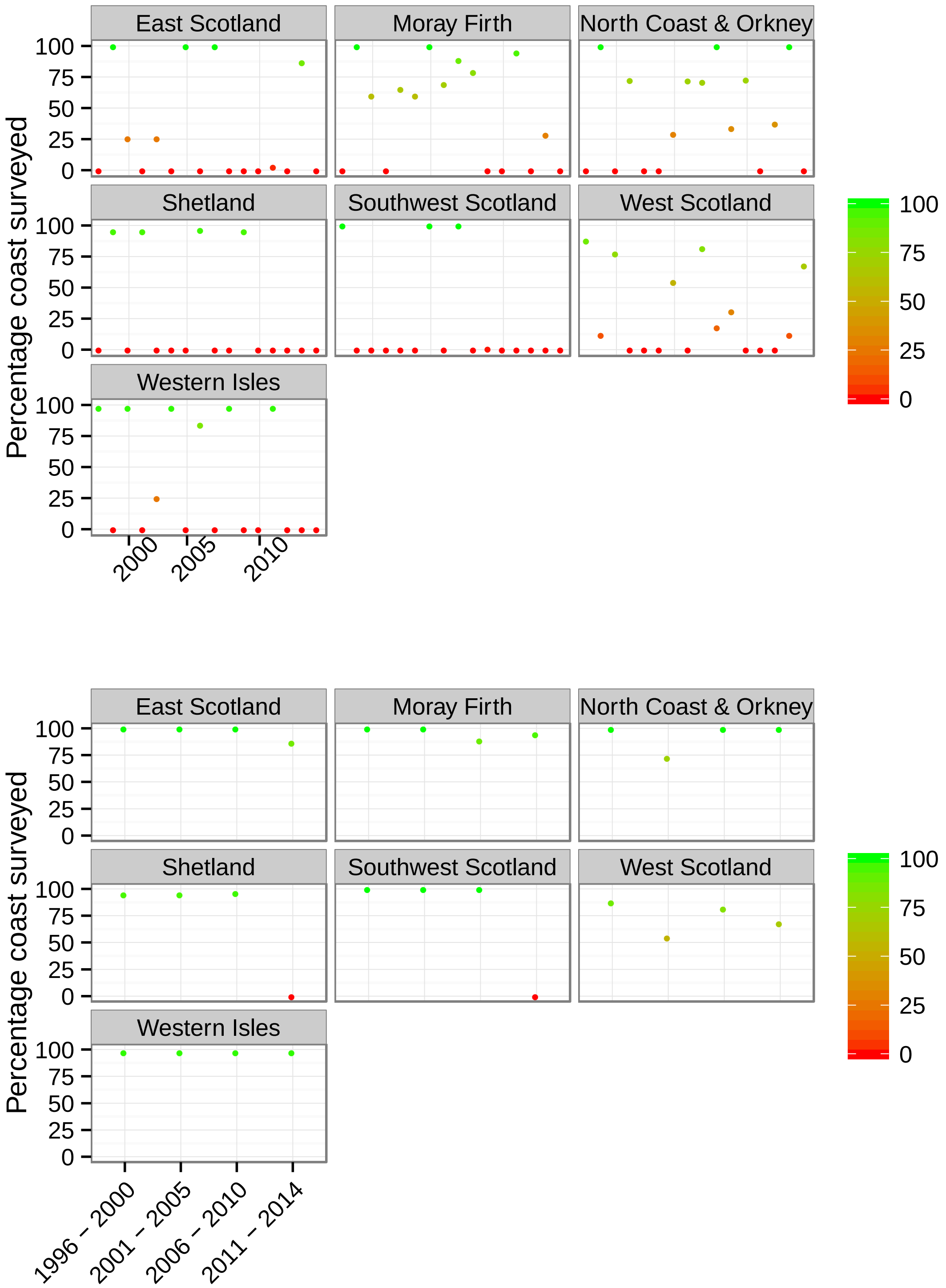

Figure 8 The percentage of Scottish coastline surveyed during harbour seal moult counts in each Assessment Unit between 1996 and 2013 (upper), and between census periods (lower).

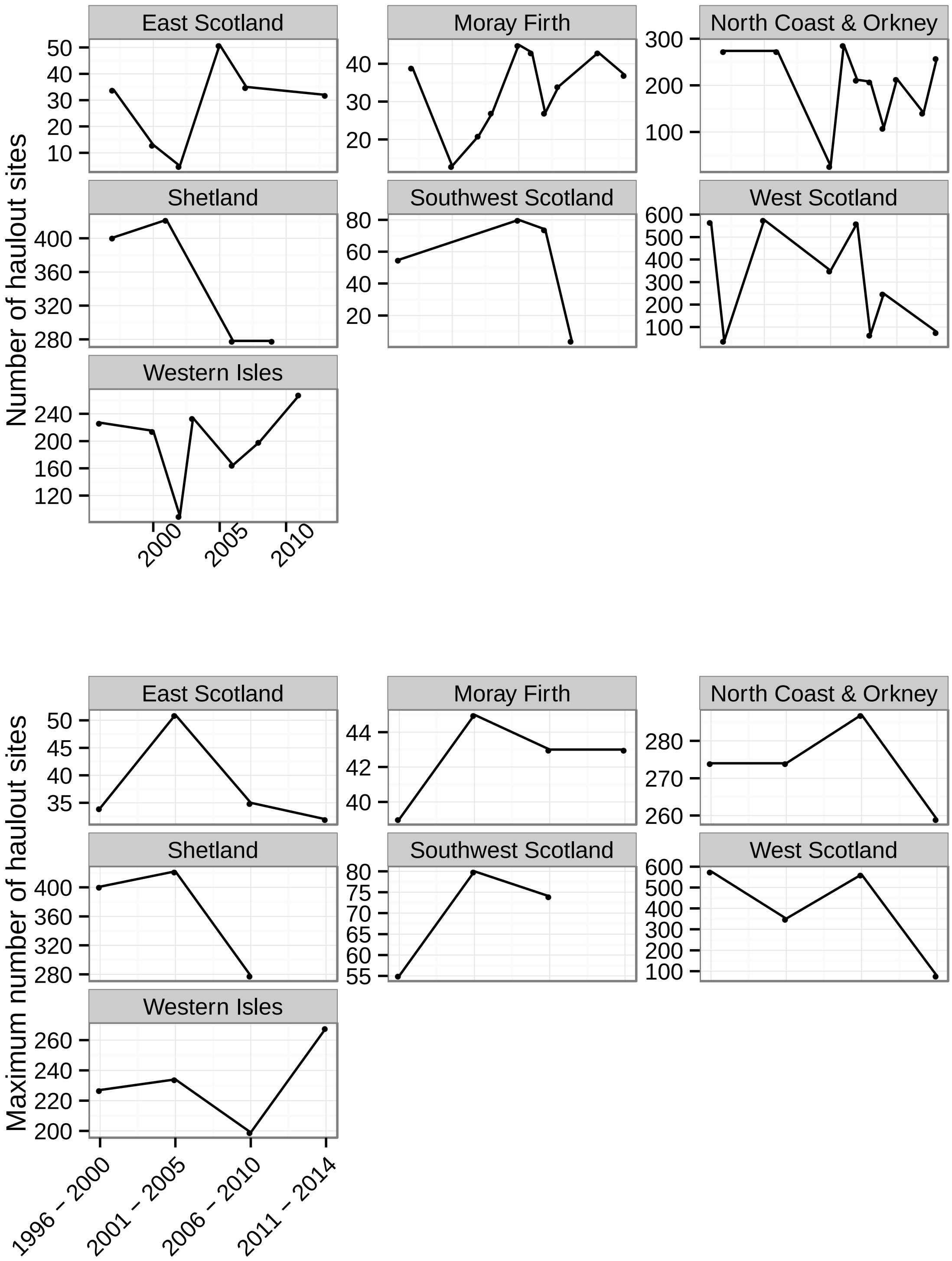

Figure 9: The number of harbour seal haulout sites surveyed in each survey year (upper panel) or census period (lower panel).

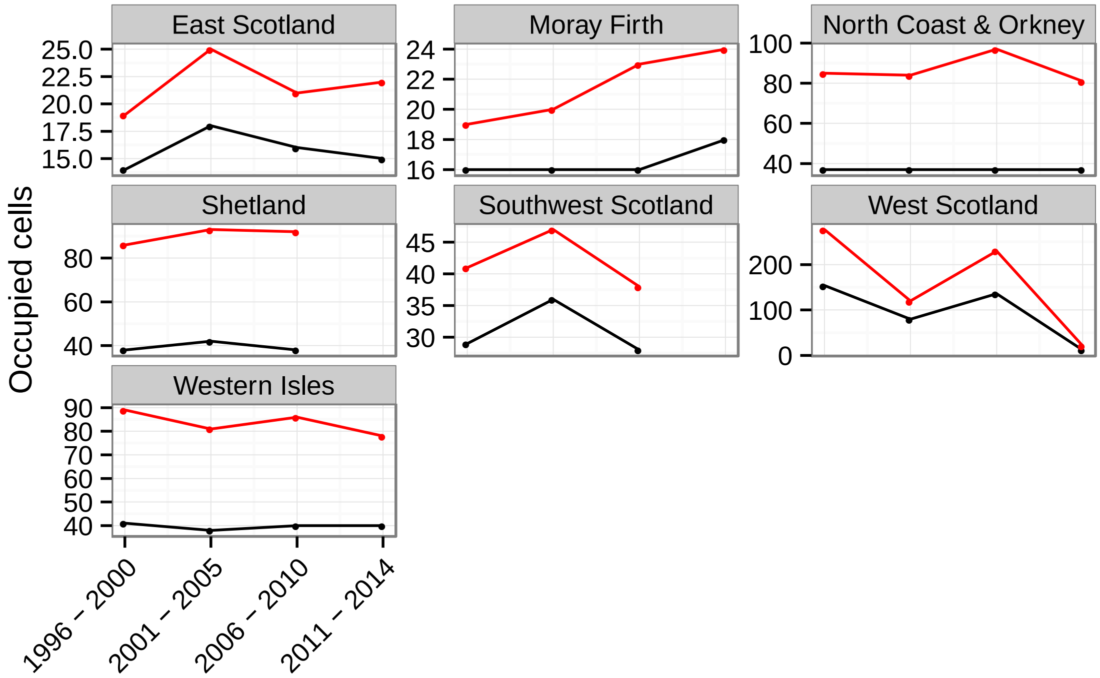

Figure 10: Harbour seal Area of Occupancy calculated here as the number of occupied cells surveyed during August moult counts. Red = 5km x 5km grid cells, black = 10km x 10km grid cells.

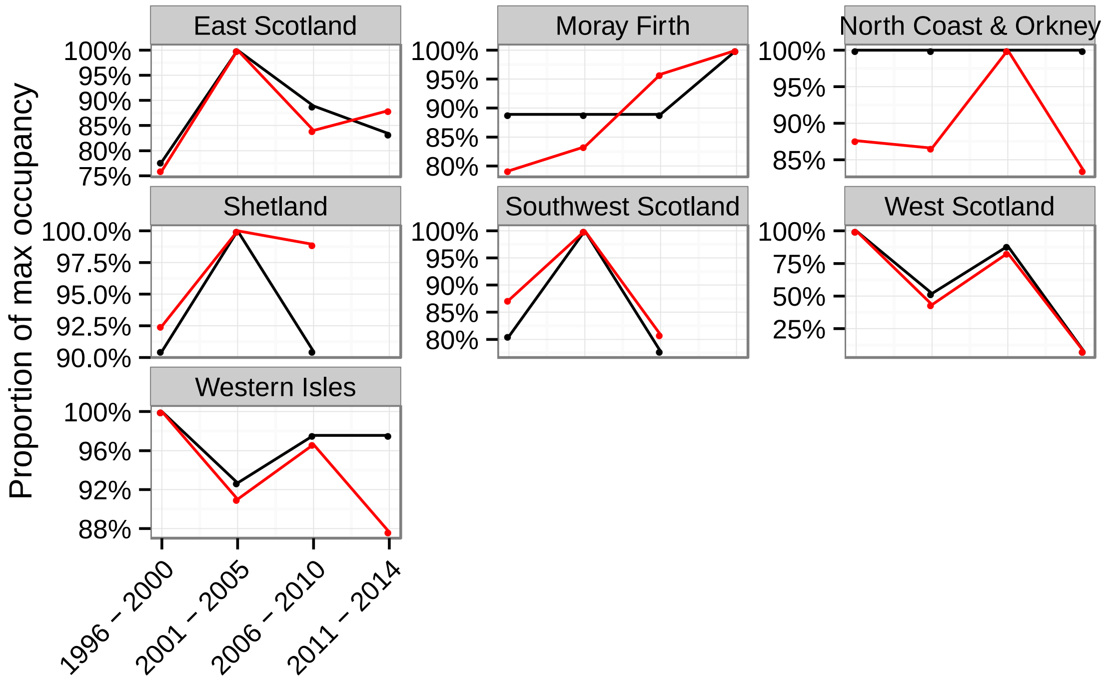

Figure 11: Harbour seal moult occupancy relative to maximum area of occupancy over the census periods. Red = 5km x 5km grid cells, black = 10km x 10km grid cells.

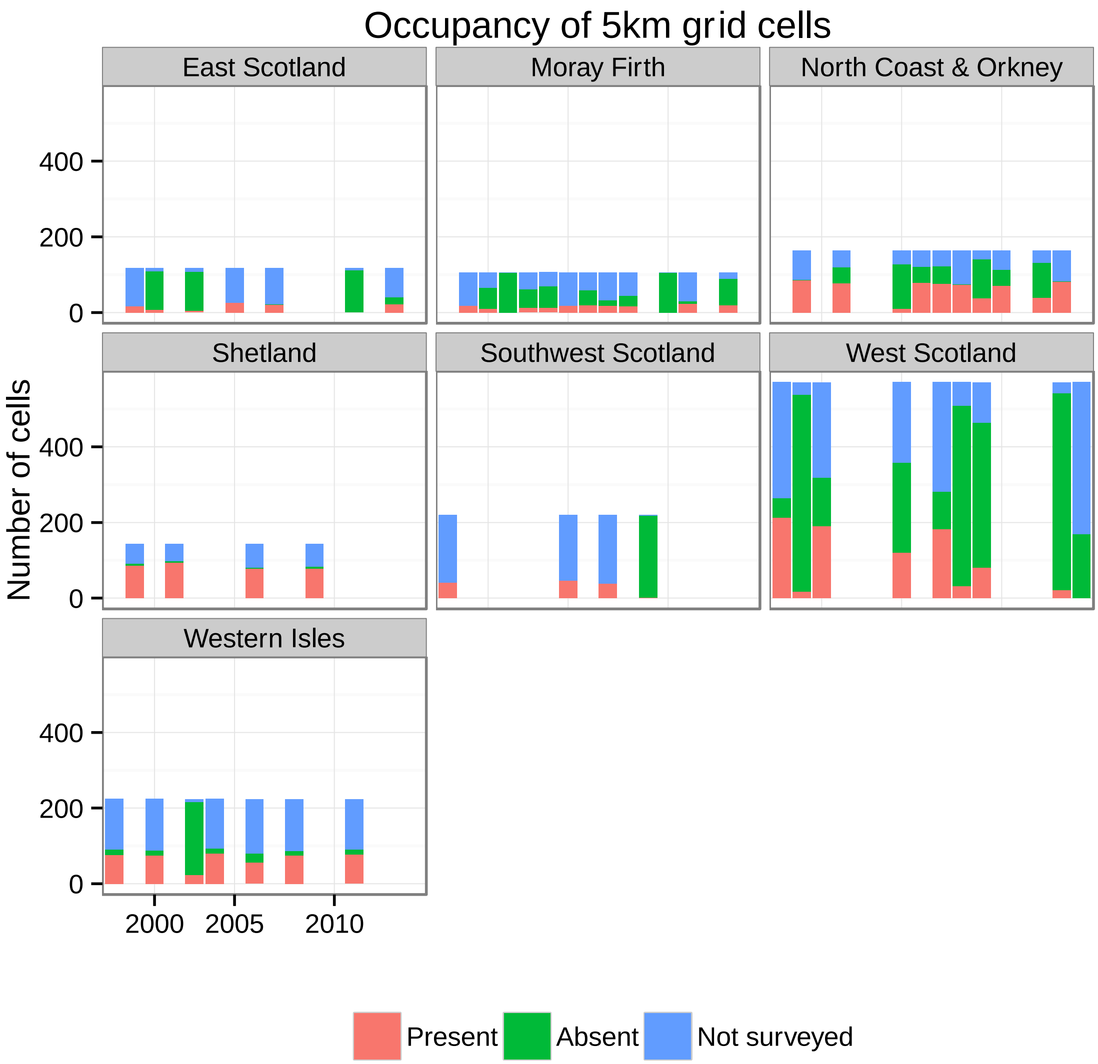

Figure 12: Harbour seal occupancy of 5km x 5km grid cells.

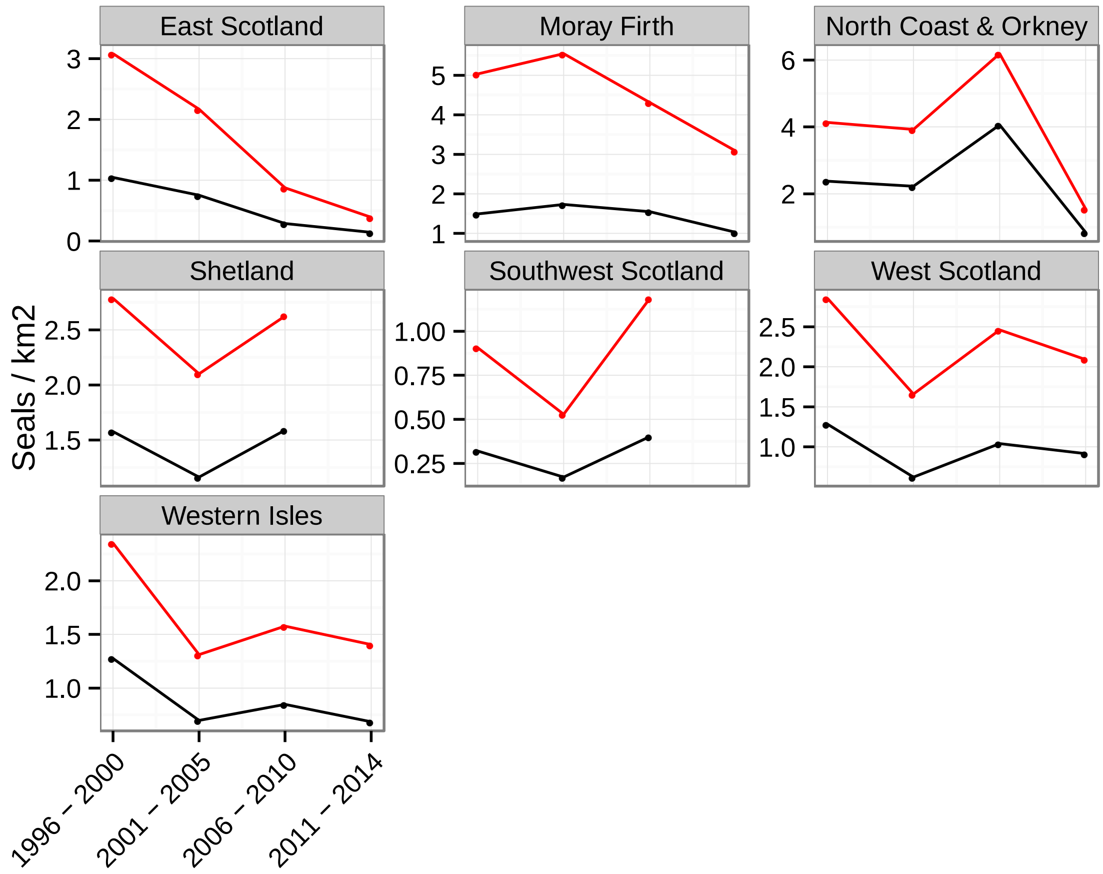

Figure 13: Harbour seal density during August moult counts. Red = 5km x 5km grid cells, black = 10km x 10km grid cells.

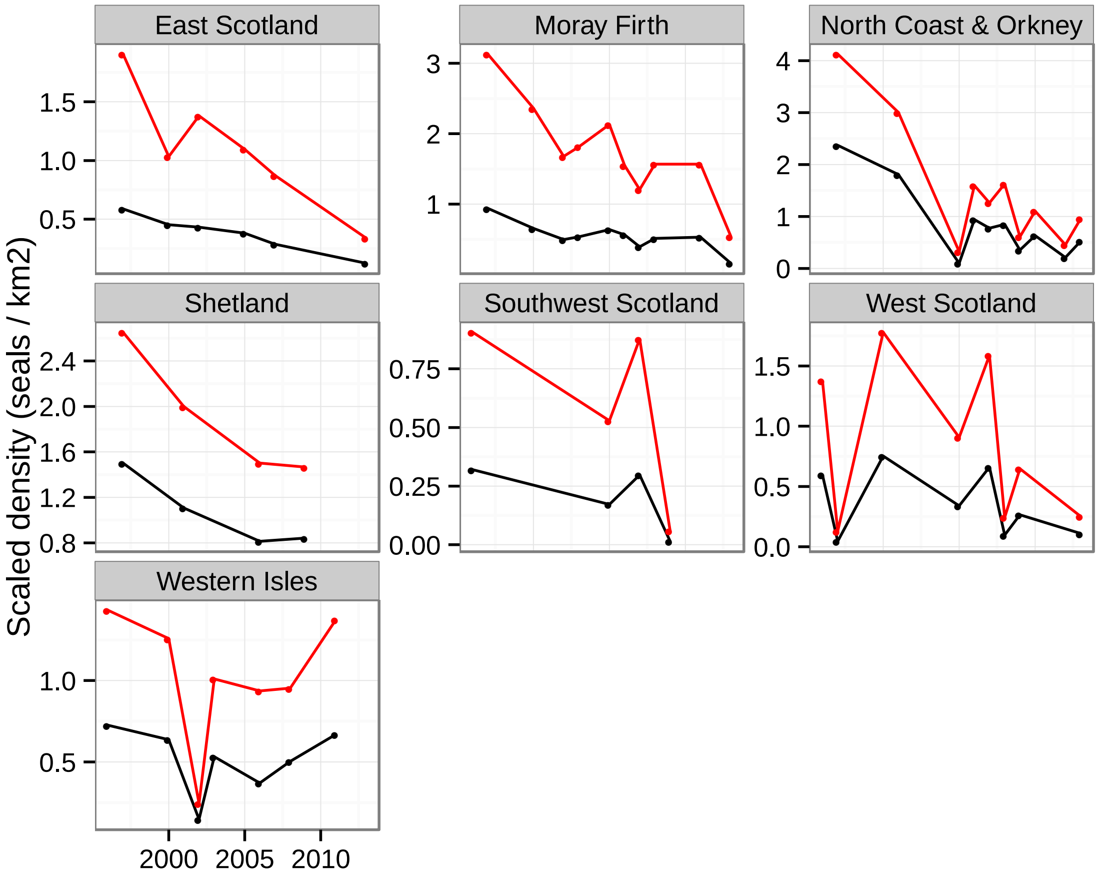

Figure 14: Harbour seal density (seals per kilometre squared) scaled down by the proportion of the coastline that was surveyed that year.

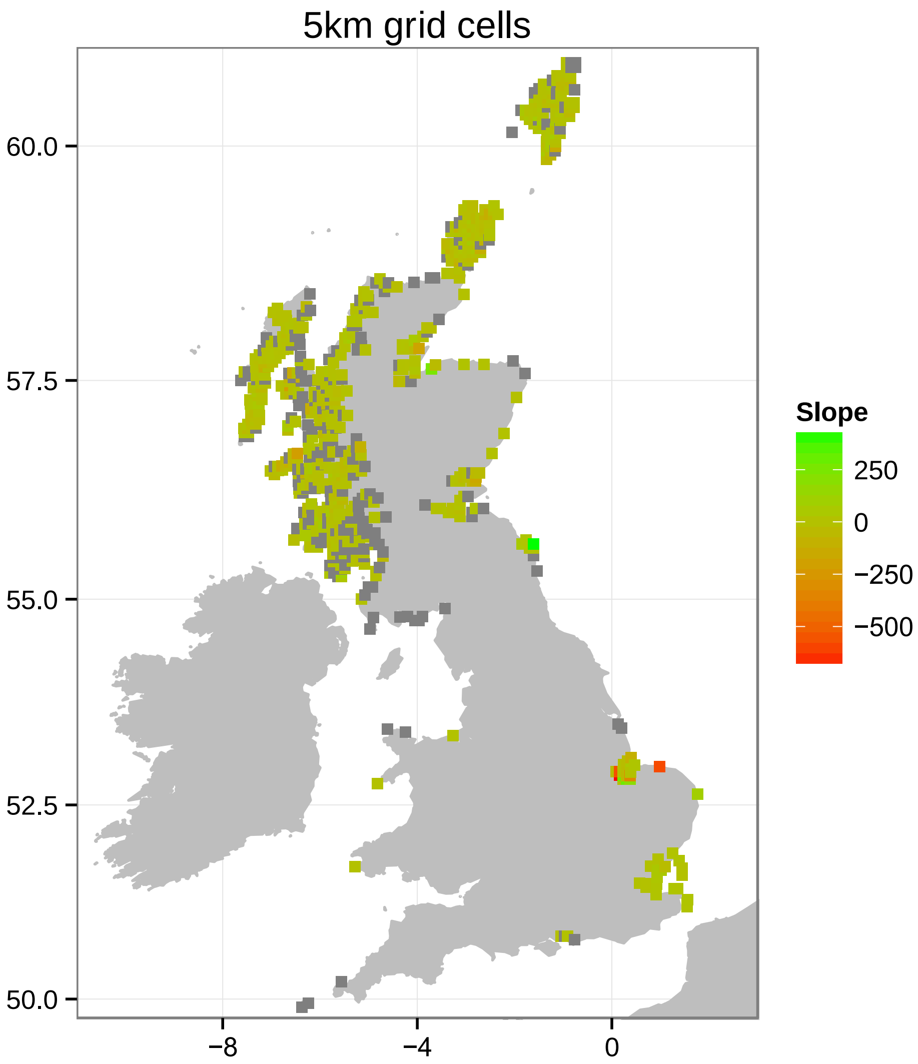

Figure 15: Trends in harbour seal counts relative to total counted in each Assessment Unit. Linear regression slopes were calculated for each 5km x 5km grid cell over the period 1987 - 2012. Grey squares are data deficient.

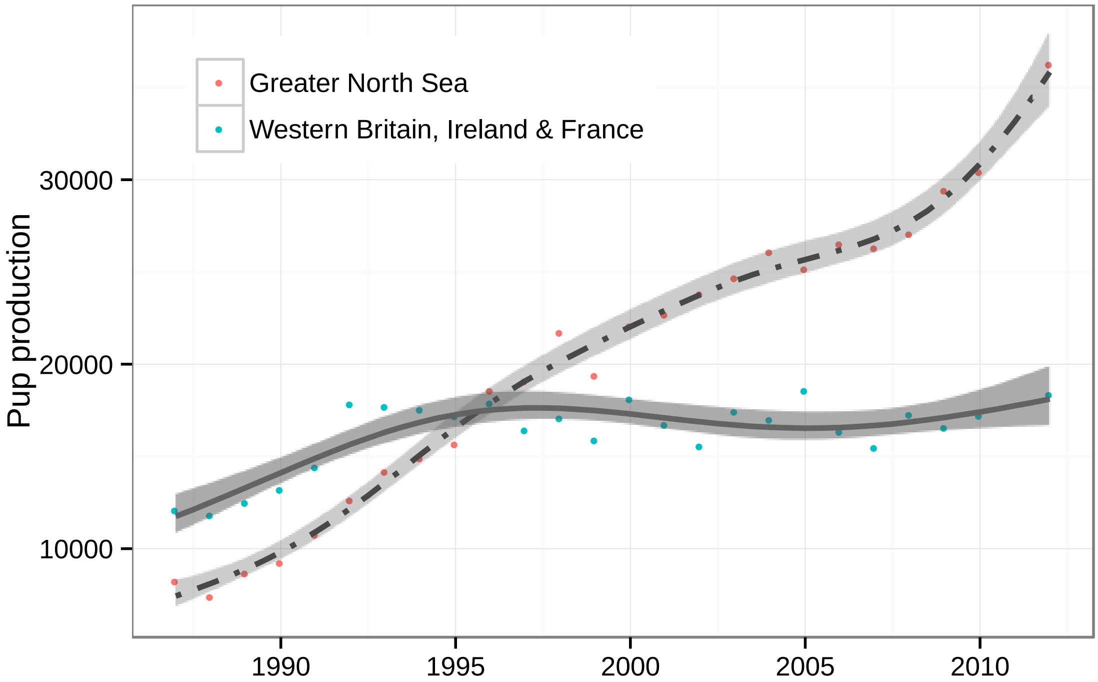

Figure 16: Total (sum) grey seal pup production from SMRU aerial surveys in each Assessment Unit. The smoothed line was fitted with a genearlised additive model with log link function and quasi-Poisson error structure. The shaded region indicates 95% confidence intervals.

Appendix 1: Monitoring programmes in other countries

Table 4: Current and known plans for monitoring harbour seals in the OSPAR regions

Country	MSFD assessment unit	Monitoring method	Comments
United Kingdom	Shetland	Single aerial survey, approximately every five years.	_
United Kingdom	Orkney and North Coast	Single aerial survey, approximately every five years.	_
United Kingdom	Moray Firth	Repeat annual aerial survey	_
United Kingdom	East coast Scotland	Single aerial survey, approximately every five years. Single annual aerial survey in Firth of Tay.	_
United Kingdom	Southeast England	Repeat annual aerial survey.	_
United Kingdom	Southwest Scotland	Single aerial survey, approximately every five years.	_
United Kingdom	West Scotland	Single aerial survey, approximately every five years.	_
United Kingdom	Western Isles	Single aerial survey, approximately every five years	_
Netherlands/ Germany/ Denmark	Wadden Sea, Dutch Delta and Helgoland	Wadden Sea and Dutch Delta: Repeat annual aerial survey.	Monitoring also undertaken during pupping.
Germany	Helgoland	Daily land counts.	_
Denmark	Limfjord	Repeat annual aerial survey.	_
Norway/Sweden	Northern Skagerrak and Oslo Fjord	Annual aerial survey.	_
Denmark/Sweden	Kattegat	Repeat annual aerial survey. Breeding only monitored in Denmark.	Monitoring also undertaken during pupping.
Denmark/Germany	Belt seas	Repeat annual aerial survey. Breeding only monitored in Denmark.	Monitoring also undertaken during pupping.
Norway	West coast, south of 62°N	Aerial survey, every five years.	_
France	French North Sea and Channel coasts	Baie du Mont Saint Michel – aerial surveys, 18 per year + 15 census (boat and land).	Monitoring also undertaken during pupping.

France	Baie de Somme and adjacent haul-outs – land census every ten.	days (January–June). Daily from June to September	_
France	Baie des Veys.	Monthly land and aerial surveys	_
Ireland/United Kingdom		Single aerial survey, approximately every five years in Northern Ireland.	No formal monitoring programme in place yet for Irish section but is currently under consideration.
Ireland	South and southeast Ireland	_	No formal monitoring programme in place yet but is currently under consideration.
Ireland	West Ireland	_	No formal monitoring programme in place yet but is currently under consideration.

Table 5: Current and known plans for monitoring grey pup production in OSPAR regions

Country	MSFD assessment unit	Monitoring method	Comments
United Kingdom	North Sea: Shetland, Scotland	Annual ground count since 2004.	Difficult area to monitor.
United Kingdom	North Sea: Orkney, Scotland	Annual aerial survey until 2010, biennial thereafter.	_
United Kingdom	North Sea: Fast Castle, Isle of May and adjacent colonies, Scotland	Annual aerial survey until 2010, biennial thereafter.	_
United Kingdom	North Sea: Moray Firth, east Scotland	Annual aerial survey until 2010, biennial thereafter.	_
United Kingdom	North Sea: Farne Islands, East England	Annual ground count.	_
United Kingdom	North Sea: Donna Nook and Norfolk colonies, Southeast England	Annual ground count.	_
Netherlands	North Sea: Wadden Sea	Aerial survey.	_
Netherlands	North Sea: Delta	Monthly aerial survey.	_
Germany	North Sea: Schleswig–Holstein, Wadden Sea	Aerial survey conducted five times per year from November to April/May; annual boat and land survey also.	_
Germany	North Sea: Helgoland	Annual ground count.	_
Norway	North Sea: Rogaland	Ground count, every five years at least.	_
France	North Sea: Archipelago of Sept Îles and adjacent haul-outs	Regular (monthly) census and photo identification.	_

France	North Sea: Archipelago of Molene and adjacent haul-outs	Regular (monthly) census and photo identification.	_
France	North Sea: Baie de Somme and adjacent haul-outs	Regular (monthly) census and photo identification.	_
United Kingdom	Celtic Sea: West Scotland	Annual aerial survey until 2010, biennial thereafter.	_
United Kingdom	Celtic Sea: Western Isles, Scotland	Annual aerial survey until 2010, biennial thereafter.	_
United Kingdom	Celtic Sea: Welsh coasts and Southwest England	Ground counts in caves or from cliff tops.	Pup counts in caves is difficult to undertake.
Ireland	Celtic Sea: Sturrall (near Glen Head) to Maghera in southwest Co. Donegal	Aerial surveys on rotational basis, each surveyed once in the last four years.	No formal monitoring programme in place yet but is currently under consideration.
Ireland	Celtic Sea: the Inishkea Island group off northwest Co. Mayo	Aerial surveys on rotational basis, each surveyed once in the last four years.	No formal monitoring programme in place yet but is currently under consideration.
Ireland	Celtic Sea: Inishshark, Inishgort and associated islands off northwest Co. Galway	Aerial surveys on rotational basis, each surveyed once in the last four years.	No formal monitoring programme in place yet but is currently under consideration.

Appendix 2: Methods

Power analyses

The software program MONITOR (Gibbs & Ene 2010) was used to assess whether or not target threshold population declines could be detected using retrospective power analysis. Power was set to 80% and α = 0.20. The coefficient of variation (CV) was set to 0.105 for grey seals (Thomas, SCOS-BP 14/02) and 0.15 for harbour seals (from repeated surveys of harbour seals carried out on the west coast of Scotland; Cunningham et al. 2010). It was assumed to be constant through time. A simple regression (univariate time series) model was assumed with a single survey in a year. The duration, initial abundance, standard deviation (calculated assuming a fixed CV), and survey intervals were specified as inputs to the MONITOR model. The number of surveys in the time series over the duration gives an indication of survey frequency in the AU. Detection of the target was assessed by comparing the results of the power analysis with the per annum or net decline specified in the target.

Table 6: Examples of M-5 grey seal pup production assessments in each Assessment Unit for five proposed targets/baselines. Data included were from the UK, 1987 - 2012. NB: these data represetna subset of all data available for the UK and are for illustrative purposes only.

Target /baseline	Assessment Unit	Duration (yrs)	Target start year	Start of count series	No. Surveys	Target met	Target detectable
	Greater North Sea	10	2004	2004	8	No	No
	Western Britain, Ireland & France	10	2004	2004	8	No	No
	Greater North Sea	15	1999	1999	13	Yes	Yes
	Western Britain, Ireland & France	15	1999	1999	13	Yes	Yes
	Greater North Sea		1992	1992	20	Yes	Yes
	Western Britain, Ireland & France		1992	1992	20	Yes	Yes
	Greater North Sea	45	1969	1987	25	Yes	Yes
	Western Britain, Ireland & France	45	1969	1987	25	Yes	Yes
	Greater North Sea	6	2008	2008	4	No	No
	Western Britain, Ireland & France	6	2008	2008	4	No	No

Table 7: Power analysis of trends in grey seal pup production going forward with biennial surveys.

Target	Duration	Target-specific *p.a.* decline limit (%)	Target-specific net decline limit (%)	Minimum detectable *p.a.* decline (%)	Minimum detectable net decline (%)	Survey frequency
A	10	-1	-10	-3	-21	Biennial
B	15	-3	-50	-1.5	-18	Biennial
C	20	< -1	-25	-1	-17	Biennial
D	45		-30		-12	Biennial
E	6	-1	-6	-7.5	-27	Biennial

Table 8: Examples of M-3 abundance assessment outcomes for eight harbour seal Assessment Units for five proposed targets/baselines. Data considered were from 1996/97 to 2013 and were raw (un-scaled) counts of animals hauled out. Green rows indicate that the target would be detectable with 80% power and α = 0.20. Red cells indicate where the target was detectable and not met. NB: these data represent a subset of all data available in the UK are and for illustrative purposes only.

Target/ baseline	Assessment Unit	Duration (yrs)	Target start year	Start of count series	No. Surveys	Target met	Target detectable
	East coast Scotland	10	2004	2004	10	No	No
	Moray Firth	10	2004	2004	10	No	No
	Orkney and North coast	10	2004	2005	8	No	No
	Shetland	10	2004	2006	2	Yes	No
	Southeast England	10	2004	2004	10	Yes	No
	Southwest Scotland	10	2004	2005	2	Yes	--
	West Scotland	10	2004	2005	5	Yes	No
	Western Isles	10	2004	2006	3	Yes	No
	East coast Scotland	15	1999	2000	13	No	Yes
	Moray Firth	15	1999	2000	13	Yes	Yes
	Orkney and North coast	15	1999	2001	9	No	Yes
	Shetland	15	1999	2001	3	Yes	No
	Southeast England	15	1999	1999	15	Yes	Yes
	Southwest Scotland	15	1999	2005	2	Yes	No
	West Scotland	15	1999	2000	6	Yes	Yes
	Western Isles	15	1999	2000	5	Yes	Yes

Target/ baseline	Assessment Unit	Duration (yrs)	Target start year	Start of count series	No. Surveys	Target met	Target detectable
C	East coast Scotland		1992	1997	14	No	Yes
	Moray Firth		1992	1994	15	No	Yes
	Orkney and North coast		1992	1993	11	No	Yes
	Shetland		1992	1993	5	No	No
	Southeast England		1992	1995	19	Yes	Yes
	Southwest Scotland		1992	1996	3	Yes	No
	West Scotland		1992	1997	7	Yes	No
	Western Isles		1992	1992	7	Yes	Yes
	East coast Scotland	45	1969	1997	14	No	Yes
	Moray Firth	45	1969	1994	15	Yes	Yes
	Orkney and North coast	45	1969	1991	11	No	Yes
	Shetland	45	1969	1991	5	No	Yes
	Southeast England	45	1969	1995	19	Yes	Yes
	Southwest Scotland	45	1969	1996	3	Yes	No
	West Scotland	45	1969	1991	7	Yes	Yes
	Western Isles	45	1969	1992	7	Yes	Yes
	East coast Scotland	6	2008	2008	6	No	No
	Moray Firth	6	2008	2008	6	Yes	No
	Orkney and North coast	6	2008	2008	5	No	No
	Shetland	6	2008	2009	1	--	--
	Southeast England	6	2008	2008	6	Yes	No
	Southwest Scotland	6	2008		0	--	--
	West Scotland	6	2008	2008	3	Yes	No
	Western Isles	6	2008	2008	2	Yes	No