Marine Strategy Framework Directive

Estimating the European Grey Seal population

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Abstract

The European Marine Strategy Framework Directive (MSFD) aims to ensure Good Environmental Status (GES) of the EU's marine environment by 2020. To achieve this, a suite of indicators of marine environmental health have been adopted and will be monitored across European Member States. One metric considered under the MSFD is the trend in abundance of grey seals in the North-east Atlantic.

In the UK, pup production estimates and prior knowledge of life history parameters are incorporated into a Bayesian state-space model to estimate total population size between 1884 and 2015. This model is fitted to pup production data from four regions: Inner Hebrides, Outer Hebrides, Orkney and the North Sea. Pup survival is assumed to be density dependent and thus dependent on how close regional pup production estimates are to an estimated carrying capacity. The model also incorporates a second source of data; an independent estimate of the UK population size in 2008 (excluding South-west UK).

Here the above described population model was extended to incorporate four additional regions and an initial run of the model was conducted to estimate the population of grey seals in the North-east Atlantic (excluding Norway) between 1991 and 2015. In addition to regional pup production data, an independent estimate of total North-east Atlantic population size in 2008 was included in the model. The number of pups produced in the Netherlands has increased rapidly in recent years; such an increase was reliant upon recruitment of females born in the UK. Thus a movement model, last included in UK model in 2008 (Thomas and Harwood 2008), was included here. With the exception of the movement model, the priors used in the population model were consistent with those used in the UK model in 2015 (Thomas, 2015). Here an update to the model results currently under review as part of OSPAR's Intermediate Assessment 2017 (ICES, 2016) is presented. For this update, a revised independent summer population estimate was used; this was derived from an updated estimate of the proportion of time hauled out during the survey window (Russell *et al.* 2016).

As expected, the results suggest that the North-east Atlantic grey seal population is increasing; there was no evidence of a decline. Further work is required to refine the population estimates and regional trend predictions. In a particular, a review of the movement model and associated priors is required to ensure they are biologically plausible.

Introduction

In 2008, the European Commission agreed upon a Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC). The aim under this directive is to achieve, by 2020, Good Environmental Status (GES) of the EU's marine environment which comprises four regions: the Baltic Sea, the North-east Atlantic Ocean, the Mediterranean Sea and the Black Sea. To achieve this, a suite of indicators of marine environmental health have been adopted and will be monitored across European Member States.

For the North-east Atlantic, progress towards defining and achieving GES 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.

Quantitative metrics of the state of grey and harbour seal populations are to be included in the MSFD assessment of environmental status in the Greater North Sea and Celtic Sea under Descriptor 1: biological diversity is maintained (see Hanson & Hall 2015). Two assessment values were used to assess grey seal abundance, similar to those stipulated by reporting of 'Favourable Conservation Status' under Article 17 of the Habitats Directive. The assessment values were: **no decline of > 1% per year within the 6-year period** (rolling baseline), and **no decline of > 25% since the fixed baseline** at the start of the Habitats Directive in 1992 (or closest value).

The relevant indicators (and corresponding MSFD criteria and targets) are (Defra 2015):

- 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).
- M-5: Grey seal pup production (1.3 Population condition, 1.3.1 Population demographic characteristics).

A draft submission of both M-3 and M-5 assessments was made to OSPAR's Intercessional Correspondence Group on Coordinated Biodiversity Assessment and Monitoring (ICG-COBAM) in December 2015. The assessment was then reviewed by the ICES Working Group on Marine Mammal Ecology (WGMME) in February 2016 (ICES, 2016), and by the OSPAR Secretariat in June 2016. A draft assessment of indicator M-3 which incorporates some of the outputs of this model will be published on the OSPAR website in 2017. With the exception of the abundance of Grey seals (M-3), a detailed review of metrics was described in Hanson & Hall (2015). Here the work undertaken to assess the abundance of grey seals in the North-east Atlantic as part of M-3 is described in more detail. A single large assessment unit (encompassing the Greater North Sea and Celtic Sea) was adopted for the quantitative assessment of this metric against the assessment values noted above; grey seal pup production is assessed separately on a more local scale under M-5.

In the UK, pup production estimates and prior knowledge of life history parameters are incorporated into a Bayesian state-space model to estimate life history parameters (maximum pup survival, adult survival, fecundity, a density dependent parameter, and regional carrying capacities) and total population size between 1984 and 2015. This model is fitted to pup production data from four regions: Inner Hebrides, Outer Hebrides, Orkney and the North Sea. Pup survival is presumed to be density dependent and thus dependent on how close regional pup production estimates are to an estimated carrying capacity. The model also incorporates a second source of data; an independent estimate of the UK population size in 2008 (excluding South-west UK). Here the above described model was extended to provide a preliminary estimate of the population size of grey seals in the North-east Atlantic (excluding Norway) between 1991 and 2015.

The regions used in the model were the four previously included in the UK model (except that non–annually monitored colonies (e.g. Shetland) were included) and four additional regions: South-west UK & France; Ireland; Netherlands; and Germany. The model had to be fitted by region (eight in total) as previous work in the UK has shown that pup survival is density dependent, which occurs on a regional rather than European wide scale. These regions were delineated pragmatically on the basis of geographic proximity and data availability; for some regions there were annual pup production data whereas for others there were only sparse data. In the present analysis, the Ireland region includes pup production data from both Northern Ireland (SMRU) and the Republic of Ireland (n = 4 years; Ó Cadhla *et al.* 2007, 2013). During the OSPAR and ICES review process described above, it became clear that the Republic of Ireland has not adopted Common Indicator M3 for grey seals. Any future population model runs for the MSFD will therefore only include data from Northern Ireland in the Ireland region.

Immigration of grey seals may account for as much as 35% of the observed population growth in the Dutch Wadden Sea (Brasseur *et al.* 2014). Thus a movement model, last included in the UK population model in 2008 (Thomas & Harwood 2008), was included to allow females born in one region to recruit into another. Like pup survival, movement was assumed to be density dependent; the level of movement between regions is dependent on differences in density dependent pup survival, and distances between regions, given fidelity to their natal region. Fitting the population model in this way allowed regional population dynamics to be taken into account while allowing movement, to produce the most accurate estimates of population size in the North-east Atlantic.

The priors used in this model were consistent with those used in the UK population models (Thomas 2015; movement priors: Thomas & Harwood 2008). As with the UK model, an independent estimate of total population size in 2008 for the North-east Atlantic was incorporated into the model to refine the population estimates. Unfortunately, due to a lack of data, this independent estimate did not include Norway. Thus Norway was excluded from the population estimate. The 2008 independent estimate originally used within the model was based on 31% (95% CI: 15-50%; Lonergan *et al.* 2011) of the population being hauled out and available to count during the surveys. This scalar has now been revised to 23.9% (95% CI: 19.2-28.6%; Russell *et al.* 2016) resulting in a revised population estimate being included in the model. As a consequence, the results presented here differ from those reviewed in ICES (2016).

Materials and Methods

<u>Pup production data</u>

For the majority of UK and Irish colonies, pup production data were available; if four or more counts per season were conducted, a pup production curve was fitted to pup counts to generate an estimate of pup production (Duck & Morris 2014). Only pup count data were available from most other regions; for a key non-UK pupping region (Wadden Sea), three counts are conducted per season. Comparing pup production estimates to their peak counts can be used to generate a scalar to raise peak counts to pup production estimates.

One of the parameters included in the UK pup production models is ‘time to leave’ (the age at which pups leave their natal colony; TTL), which is currently set to 31.5 days (sd = 7). Recent work shows such a value for TTL may often be too low (Russell *et al.* 2015) and result in an artificially high pup production. The scalar required to convert peak counts into pup production (when TTL is 31.5 days) is approximately 0.8. Recognising that this ratio is likely too low, to estimate a scalar to convert peak counts to pup production, TTL had to first be estimated. In 2008, five or more counts were made for most colonies in the UK; this number of counts allowed TTL to be estimated within the pup production model. The mean (weighted by peak pup count) ratio between peak count and estimated pup production when TTL was estimated was 0.9. Thus if less than four counts were conducted, this scalar was used to raise the peak pup count to pup production. The majority of the pup counts for the Inner Hebrides, Outer Hebrides, Orkney and the UK North Sea consist of four or more counts, and pup production has been estimated with a set TTL of 31.5 days. Thus there is an inconsistency in pup production data used in the population model - estimates for the majority of UK colonies may be artificially high compared to elsewhere. However it was thought that such inconsistency was preferable to over-estimating pup production by using the scalar estimated using TTL of 31.5 days (0.8) in regions for which there are peak counts.

In contrast to the UK population model, here the non-annually monitored colonies in the four UK regions were also included; these make up about 7.66% of pup production accross these regions. Due to the reduced availability of data for such colonies, the first year of data for which there were pup production data was 1991 (cf. 1984 in the UK pup production model). In some years only partial surveys of a region were conducted. In these years, the proportion of the pup production of these surveyed regions in years in which the whole region was surveyed, was used to estimate regional pup production.

Pup count and production data were extracted from the literature and provided by individuals: South-west UK & France (Baines *et al.* 1995; Westcott 2002, 2008; Westcott & Stringell 2003; Morgan 2014; Strong *et al.* 2015, C. Vincent, T. Stringell and K. Lock), Ireland (Duck & Mackey 2006; Ó Cadhla *et al.* 2007, 2013), UK regions (C. Morris and C. Duck), Netherlands (S. Brasseur) and Germany (S. Klöpper, Common Wadden Sea Secretariat).

<u>Independent counts</u>

Summer counts (mostly in August) of grey seals conducted during low tide (mostly within two hours either side of low tide) were available for all regions except Norway. If no counts were made in 2008 for a region but there were counts made both before and after 2008, an estimated count in 2008 was interpolated from the adjacent years. If there were only counts before or after 2008, the count from the nearest year was used. Using the proportion of time grey seals in the UK haul during the usual survey window (estimated using telemetry data; Lonergan *et al.* 2011), the total population size in summer 2008 was estimated. In the most recent run of the model, the independent estimate was based on a revised scalar (proportion of the population hauled out; Russell *et al.* 2016). For both versions of the independent estimates, uncertainty surrounding the estimate was represented using a right-shifted gamma distribution that was fitted to the non-parametric bootstrap distribution produced from the telemetry analysis (Lonergan *et al.* 2011; Russell *et al.* 2016) , after scaling, using maximum likelihood.

Outwith the UK, grey seal moult counts are often conducted and favoured compared to the summer counts which are conducted during the harbour seal moult. However, for this analysis only summer counts were used for two reasons: (1) in the UK, which holds the majority of European grey seal population, surveys are not conducted during grey seal moult; (2) there are estimates of proportion of time hauled out for summer from telemetry data (Russell *et al.* 2016). There are sex- and age-specific temporal moult patterns in grey seals (females moult first) so numbers during the moult may not be representative of the population, and may be highly variable.

August count data were extracted from the literature and provided by individuals: South-west UK & France (Westcott & Stringell 2004; Westcott 2008, 2009; Sayer 2009; Boyle 2010; Leeney *et al.* 2010; Sayer, Hockley & Witt 2012; L. Morgan; C. Vincent), Ireland (C Morris and C Duck), UK regions (Russell *et al.* 2016; C. Morris and C, Duck), Netherlands (S. Brasseur) and Germany (links to publicly available datasets provided by Lower Saxony & Schleswig-Holstein local government officials).

<u>Priors and Movement Model</u>

The priors used here were those used for the UK population model (Table1; Thomas 2015). The movement model was originally developed for the UK population model (Thomas & Harwood 2008) and allows recruitment of females into regions other than their natal region. The model does not allow movement once a female has recruited into a region. Movement is assumed to be density dependent and is proportional to the difference in pup survival between regions. It also recognizes that movement is likely to occur more frequently between regions which are closer together. Finally the model also allows for natal fidelity such that even if conditions are better elsewhere, females may not move.

Movement from each region is modelled as a multinomial random variable where probability of movement from region *r* to region *i* at time *t* is:

$$\rho_{r\to i,t} = \begin{cases} \dfrac{\theta_{r\to i,t}}{\sum_{j=1}^{4}\theta_{j\to i,t}} & : \sum_{j=1}^{4}\theta_{j\to i,t} > 0 \\ I_{i=r} & : \sum_{j=1}^{4}\theta_{j\to i,t} = 0 \end{cases}$$

where $I_{i=r}$ is an indicator that is 1 when *i=r* and 0 otherwise, and

$$\theta_{r\to i,t} = \begin{cases} \gamma_{sf} & : i = r \\ \dfrac{\gamma_{dd}\max(\Delta_{i,r,t},0)}{\exp(\gamma_{dist} d_{r,i})} & : i \neq r \end{cases}$$

where γ_{sf}, γ_{dd}, and γ_{dist} are three movement parameters that index the strength of the site fidelity, density dependence and distance effects respectively, $\Delta_{i,r,t}$ is the difference in the density dependent parameter between regions *i* and *r*, and $d_{r,i}$ is an index of the distance between regions *r* and *i*.

Although the same prior distributions on parameters in the movement model were used here as previously (Thomas and Harwood 2008), the distance matrix was altered, which specifies the value of *d* in the above equations. The variable sizes of the regions and distances between concentrations of seals within regions, led to difficulties in assigning a distance matrix. On the basis that it is actually the number of regions a seal would have to pass through without stopping which may be limiting rather than distance itself, the distance matrix was populated with 1s to represent neighbouring regions to 4s to represent regions separated by 3 other regions. The distances were standardized so that the maximum distance was one.

Fitting Procedure

The model and fitting procedure are described in Thomas 2016. Here 200 replicate runs of 1,000,000 samples were generated.

Results and Discussion

The independent estimate in 2008 was 132,800 (95% CI: 110,800 – 165,100). As expected the European grey seal population is predicted to be increasing with a population prediction of 209,000 individuals in Europe in 2015 (95% CI: 90,100 – 402,300) without the independent estimate and 156,500 (95% CI: 93,200 – 275,800) with the independent estimate (Fig. 1). These results suggest that currently the trajectory of the grey seal population in the North-east Atlantic is above the MSFD assessment values (**no decline of > 1% per year within the 6-year period** (rolling baseline), and **no decline of > 25% since the fixed baseline** at the start of the Habitats Directive in 1992 (or closest value).

The parameter estimates from this model (Table 1, Fig. 2) are more comparable with Thomas (2015) than Thomas (2016) for two reasons: (1) as in this analysis Thomas (2015) did not include the latest pup production estimate (2014); (2) the priors used here match those of the main analyses in Thomas (2015); in Thomas (2016), as per additional analyses in Thomas (2015), a maximum on adult survival of 0.97 was set which led to a reduced estimate on adult survival (Thomas 2015). However, the revised scalar for the independent estimate (Russell et al. 2016) was not used in Thomas 2015 making only the estimates without the independent estimates comparable between the two runs. The posteriors on carrying capacity for the population production model fitted here (to pup production data only) were higher than those estimated from the UK model (Thomas 2015). This may be partly because in the model considered here 7.66% more pups were included within these regions. However, despite these higher carrying capacities, density dependence still had an important role to play with the density dependence parameter having an estimated mean of 8.59 (sd = 4.25) compared to 4.31 (sd = 1.95) in Thomas (2015).

Further work

Although these preliminary results are useful in the context of seal abundance trend assessment under the MSFD, improvements are required to make the results useful on a regional level and to allow accurate estimation of movement between regions.

The mean on the prior for the carrying capacity of the UK North Sea (Thomas 2015) was historically 10,000 which was considerably higher than pup production (6,617 in 2008). However, pup production for the North Sea was estimated to be 12,487 in 2015 (Duck & Morris 2016). In the model presented here, the posterior for carrying capacity (14,400) does not allow the predictions to follow the exponential increase of the counts. This results in an effect of density dependence on pup survival in the North Sea which is likely to be exaggerated.

Secondly, the movement model and the associated priors require review. The movement model was generated in 2008 (Thomas and Harwood 2008) before pup production in any region had approached carrying capacity. The movement model requires review in light of the recent population trends and now that pup production is approaching carrying capacity in all the UK regions with the exception of the North Sea (Thomas 2016).

The pup production data used were the output from a pup production model for the majority of the UK and Irish colonies, and the result of scaling up peak counts in other regions. The pup production estimates from the pup production model may be overestimates (see above). Furthermore, a regional CV surrounding pup production should be incorporated into the population model. For regions in which pup production estimates are produced, this CV could be estimated. In other regions, uncertainty in the scalar used to convert peak counts to pup production, should be utilised to estimate uncertainty in pup production. Currently, regional uncertainty estimates are not available from the pup production model. Thus a value for regional uncertainty is fixed within the population model.

Acknowledgements

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Table 1. Prior and posterior parameter distributions.

Parameters	Prior distribution	Mean (sd)		
		Prior	Posterior	
			Pup production only	Independent estimate incorporated
Adult survival ϕ_a	0.8+0.2*Be(1.6,1.2)	0.91 (0.05)	0.946 (0.03)	0.969 (0.02)
Pup survival ϕ_j	Be(2.87,1.78)	0.62 (0.20)	0.462 (0.21)	0.317 (0.12)
Fecundity α_{max}	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.826(0.09)	0.85 (0.09)
Movement γ_{dd}	Ga (2.25, 1.33)	3 (2)	2.37 (1.81)	1.86 (1.71)
Movement γ_{dist}	Ga (2.25, 0.49)	1.10 (0.70)	1.61 (0.74)	1.5 (0.77)
Movement γ_{sf}	Ga (2.25, 0.22)	0.5 (0.33)	0.61 (0.36)	061 (0.29)
Dens. dep. ρ	Ga(4,2.5)	10 (5)	8.59 (4.25)	8.81 (4.29)
Sex ratio ω	1.6+Ga(28.08, 3.70E-3)	1.7 (0.02)	1.7 (0.02)	1.7 (0.02)
Carrying capacities				
SW UK & France	Ga(4,1250)	5000 (2500)	4070 (2820)	3560 (2100)
Ireland	Ga(4,1250)	5000 (2500)	5900 (4110)	5100 (3620)
Inner Hebrides	Ga(4,1250)	5000 (2500)	4820 (2430)	4150 (1990)
Outer Hebrides	Ga(4,3750)	15000 (7500)	15100 (5450)	12100 (4160)
Orkney & Shetland	Ga(4,10000)	40000 (20000)	49000 (34100)	38800 (28100)
UK North Sea	Ga(4,2500)	10000 (5000)	14900 (6990)	14400 (7620)
Netherlands	Ga(4,1250)	5000 (2500)	5790 (3980)	5160 (3620)
Germany	Ga(4,1250)	5000 (2500)	5920 (3490)	5550 (3150)

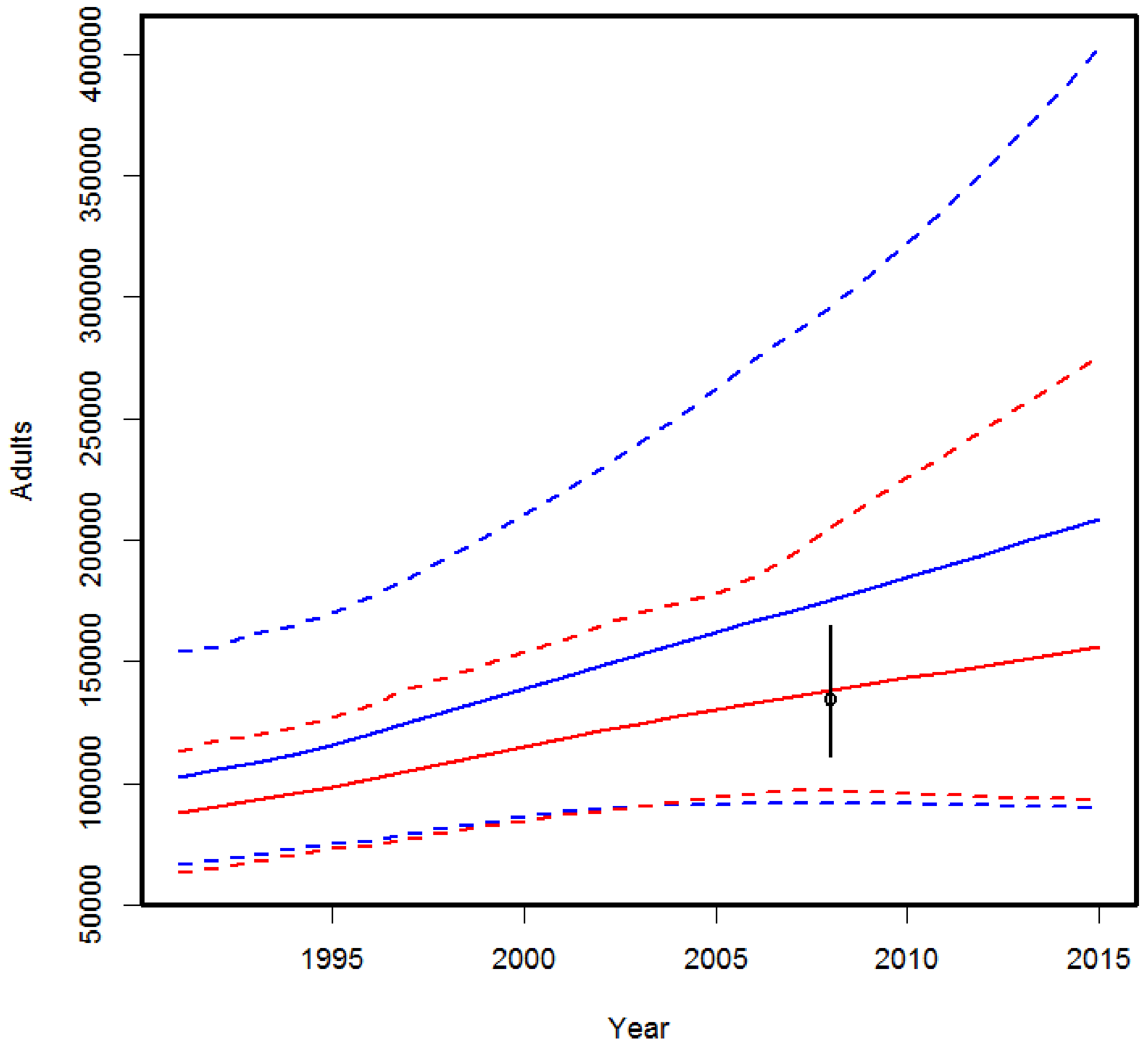
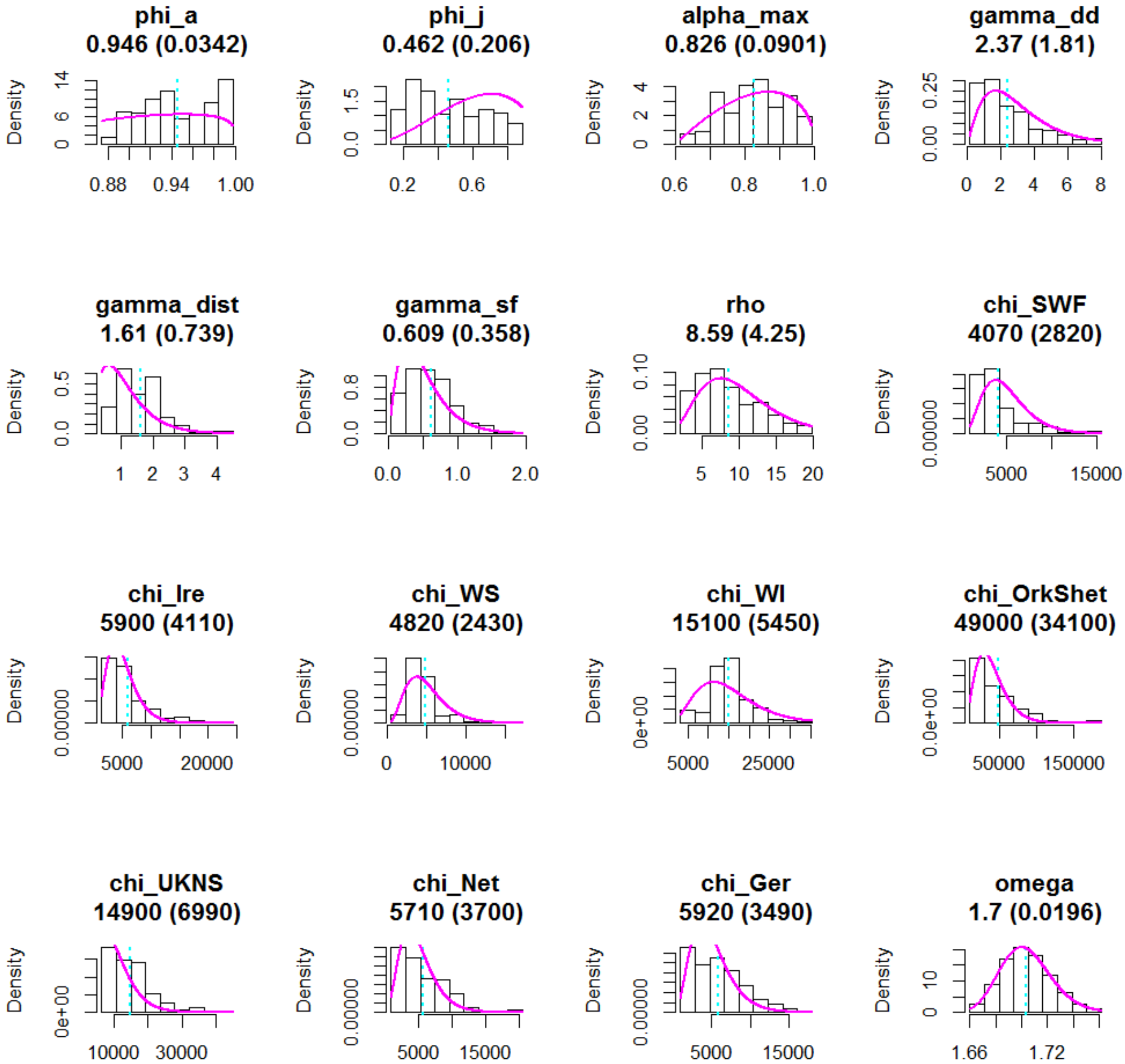


Figure 1. Posterior mean estimates of total population size from two models of grey seal population dynamics, fit to pup production estimates from 1991-2013 and a total population estimate from 2008 (circle, with horizontal lines indicating 95% confidence interval on the estimate). Lines show the posterior mean bracketed by the 95% credibility intervals for model using pup production data only (blue) and including the 2008 independent estimate (red).

(a)


phi_a
0.946 (0.0342)
phi_j
0.462 (0.206)
alpha_max
0.826 (0.0901)
gamma_dd
2.37 (1.81)
gamma_dist
1.61 (0.739)
gamma_sf
0.609 (0.358)
rho
8.59 (4.25)
chi_SWF
4070 (2820)
chi_Ire
5900 (4110)
chi_WS
4820 (2430)
chi_WI
15100 (5450)
chi_OrkShet
49000 (34100)
chi_UKNS
14900 (6990)
chi_Net
5710 (3700)
chi_Ger
5920 (3490)
omega
1.7 (0.0196)
Density

(b)

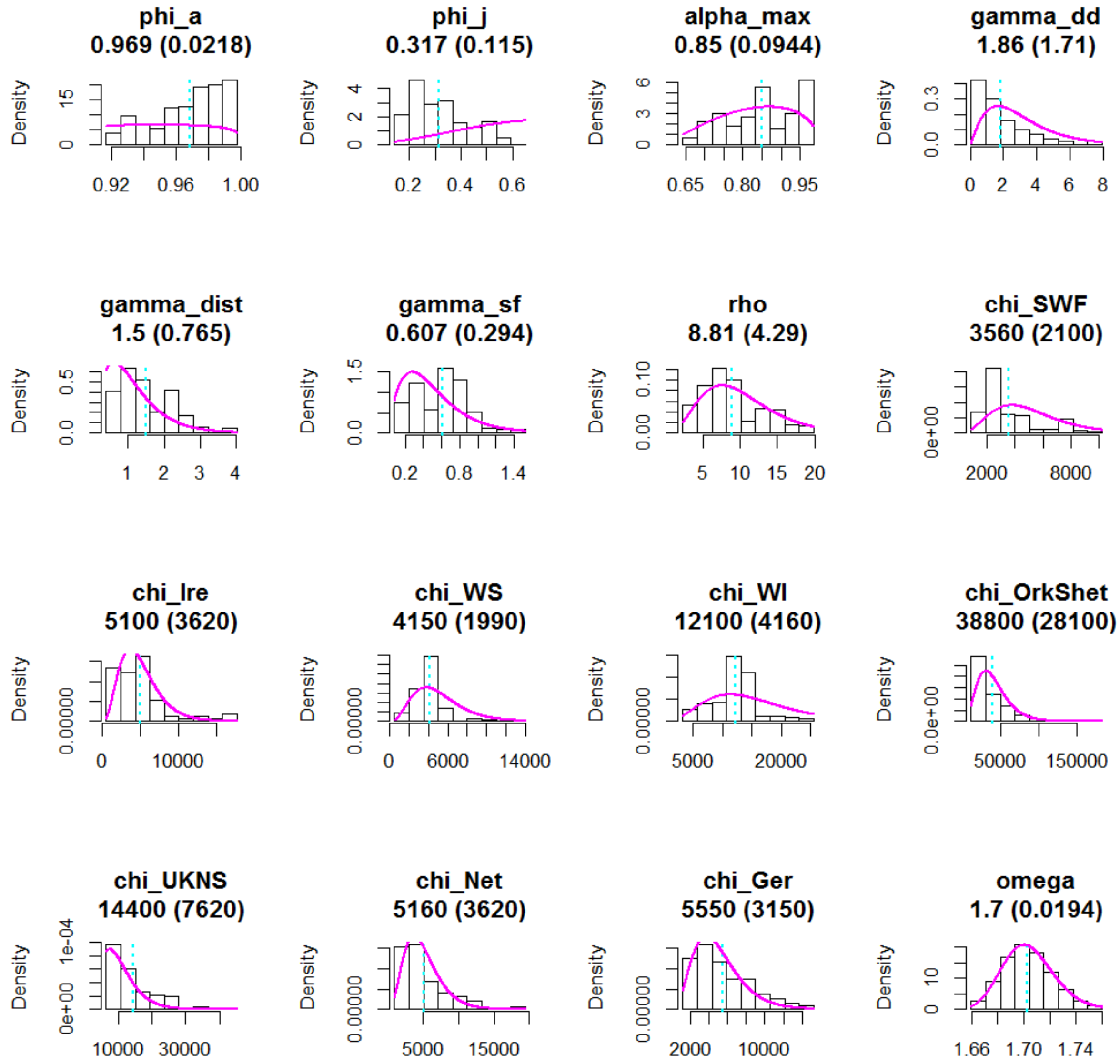


Figure 2. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1991-2013 and total populations estimate from 2008. The vertical line shows the posterior mean; its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses. The carrying capacity (chi) parameters refer to South-west UK & France (SWF), Ireland (Ire), Inner Hebrides (WS), Outer Hebrides (WI), Orkney & Shetland (OrkShet), UK North Sea (UKNS), Netherlands (Net), and Germany (Ger). These posteriors are from (a) Pup production data alone and (b) Pup production data and 2008 population estimate.