# Scientific Advice on Matters Related to the Management of Seal Populations: 2017

Contents

# Executive Summary

**Executive Summary**

Under the Conservation of Seals Act 1970 and the Marine (Scotland) Act 2010, the Natural Environment Research Council (NERC) has a duty to provide scientific advice to government on matters related to the management of seal populations. NERC has appointed a Special Committee on Seals (SCOS) to formulate this advice. Questions on a wide range of management and conservation issues are received from the UK government and devolved administrations. In 2017, 30 questions were received from Marine Scotland, Defra and Natural Resources Wales. SCOS's answers to these questions are provided in detail in the main Advice below and summarised here.

**Current status of British grey seals (*Halichoerus grypus*)**

Grey seal population trends are assessed from the counts of pups born during the autumn breeding season, when females congregate on land to give birth. Outside of the breeding season animals may re-distribute themselves, thus, regional differences in population estimates do not necessarily reflect the abundance of animals in each region at other times of the year.

The most recent surveys of the principal Scottish grey seal breeding sites were flown in 2016. The image processing and counting is not yet complete but the data will be available for SCOS 2018. The most recent results from the 2014 surveys together with the 2014 estimates from the annually ground counted sites in eastern England, produced a pup production estimate of 54,600. Adding in an additional 5,900 pups estimated to have been born at less frequently surveyed colonies in Shetland and Wales as well as other scattered locations throughout Scotland, Northern Ireland and South west England, resulted in an estimate of 60,500 (95% CI 53,900-66,900, rounded to the nearest 100) pups (Table s1).

The pup production estimates are converted to estimates of total population size (1+ aged population) using a mathematical model and projected forward to 2016. The stages in the process (pup production → mathematical model → total population size) and the trends observed at each stage are presented in detail in SCOS BP 16/01 and SCOS-BP 16/02 and SCOS-BP 17/01. The pup production model is currently under review and being updated.

The population model provided an estimate of 139,800 (approximate 95% CI 116,500-167,100) UK grey seals (1+ aged population) in 2015. Projecting the model forward one year, using the same pup production time series and prior distributions for the demographic parameters provided an estimate of 141,000 (approximate 95% CI 117,500-168,500) in 2016 (SCOS-BP 17/01).

Summary *Table s1.* ***Grey seal pup production estimates in 2014***.

| Location | Pup production in 2014 |
|---|---|
| **England** | **6,900** |
| **Wales** | **1,600** |
| **Scotland** | **51,900** |
| **Northern Ireland** | **100** |
| **Total UK** | **60,500** |

There is evidence for regional differences in grey seal demographics but detailed information on vital rates are lacking. Regional information on fecundity and survival rates would improve our ability to provide advice on population status. However, this would require considerable new investment in resources.

**Current status of British harbour seals (*Phoca vitulina*)**

Harbour seals are counted while they are on land during their August moult, giving a minimum estimate of population size. Not all areas are counted every year but the aim is to cover the UK coast every 5 years. Combining the most recent counts (2008-2016) gives a total of 31,300 counted in the UK (Table s2). Scaling this by the estimated proportion hauled out (0.72 (95% CI: 0.54-0.88)) produced an estimated total population for the UK in 2016 of 43,500 (approximate 95% CI: 35,600-58,000).

Overall, the UK population has increased since the late 2000s and is close to the 1990s level. However, there are significant differences in the population dynamics between regions. As reported in SCOS 2008 to 2016, there have been general declines in counts of harbour seals in several regions around Scotland but the declines are not universal with some populations either stable or increasing.

Harbour seal counts were stable or increasing in all regions until around 2000. Since then there have been rapid declines in Orkney (down 85% between 1997 and 2016), and along the East coast of Scotland (down 52% between 1997 and 2016). Shetland declined by 30% between 2000 and 2009, but then increased by 10% between 2009 and 2015. The most recent counts for the West Scotland region (2013 to 2015) and for the Western Isles (2011) were 43% and 50% respectively higher than the previous estimates (2007 to 2009). The most recent composite count for Scotland for 2011 to 2016 is 25% higher than the equivalent estimate for 2007-2009.

Counts for the East coast of England also appear stable, although the 2016 count was approximately 10% higher than in 2015, driven mainly by a doubling of the count from Essex and Kent.

*Summary Table s2.* ***UK harbour seal minimum population estimates based on counts during the moult.***

| Location | Most recent count (2008-2016) |
|---:|---:|
| **England** | **5,200** |
| **Wales** | **<50** |
| **Scotland** | **25,150** |
| **Northern Ireland** | **950** |
| **Total UK** | **31,300** |

Knowledge of UK harbour seal demographic parameters (i.e. vital rates) is limited and therefore inferences about the population dynamics rely largely on count data from moulting surveys. Information on vital rates would improve our ability to provide advice on population status. At present vital rate estimates for UK harbour seals are only available from a long term study of the Loch Fleet population in the Moray Firth. However, studies are underway to obtain similar data from new sites in Orkney and western Scotland.

Information on the causes of the declines in harbour seals in some Scottish regions is required for SCOS to give advice on appropriate conservation actions. A wide range of potential causes have been discussed at previous SCOS meetings. Causal mechanisms have not been identified, but several factors can now be ruled out as primary causes and research efforts are currently focussed on interactions with grey seals and exposure to toxins from harmful algae.

Conservation orders are currently in place for the Western Isles, Northern Isles and down the east coast as far as the border. On the basis of continued declines or lack of increases in all affected areas SCOS recommended that the measures to protect vulnerable harbour seal populations should remain in place, but no new conservation measures were proposed.

SCOS recommended that there should be a requirement for mandatory reporting of seals killed. From both scientific and management perspectives the absence of any requirement to record and report on numbers of seals killed in England and Wales is a major omission that prevents any assessment of the effects of seal shooting.

**Potential biological Removals (PBR).**
The Potential Biological Removals (PBR) is a relatively simple metric developed to provide advice on the levels of removals from a marine mammal population that would still allow the population to approach a defined target. Provisional regional values for PBR for Scottish seals for 2018 were calculated and are presented below. The PBR for harbour seals in Orkney has been reduced by approximately 30% due to recent survey results. Regional PBRs for grey seals have increased by 50-67% due to revised population estimates and local population increases.

**Interactions with Marine Renewable Energy developments**
SCOS discussed potential interactions between seals and marine renewable developments and discussed the use of Acoustic Deterrent Devices as mitigation measures. A summary of the most recent information on these topics is presented.

**Interactions with Fisheries**
SCOS discussed the current state of knowledge on interactions between seals and salmon fisheries. Work is continuing in Scotland focused mainly on the use of acoustic deterrent devices and capture and removal of problem seals. Modifications to coastal (stake) salmon nets and the use of acoustic deterrent devices have been shown to be effective in limiting if not eliminating depredation.

The issue of seal bycatch in commercial fisheries was discussed. The most recent estimate of seal bycatch in UK fisheries is 610 animals (95% CI 449-1262). However, this is based on assumptions about observed bycatch rates from sampling that is predominantly in the Western Channel and Celtic Sea, where most gillnet effort is located. Sampling levels are too low in other areas to provide reliable area-specific estimates.

Estimated bycatch levels in the Celtic Sea exceed a PBR for the combined grey seal population of SW England, Wales and Ireland. An additional but un-recorded number of seals are bycaught by Irish and French boats operating in the Celtic Sea. Despite the bycatch, grey seal populations in Wales and Ireland are increasing, suggesting that some of the bycaught seals are immigrants from Scottish populations.

**Seal monitoring strategy**
The current monitoring of seals (abundance, distribution, bycatch and strandings) and the legislative drivers for this work, as well as enhanced monitoring options, were discussed. A number of long term research projects were highlighted that could form the basis of future options, particularly to identify population pressures, including: estimating population demography metrics; pathogen, contaminant and toxin analyses; monitoring seal diet; and at-sea seal distribution. Considerable further work would be required in order to design and carry out robust and appropriate monitoring programmes.

**Competition between grey and harbour seals**

Grey seals may have a detrimental effect on the abundance of harbour seals through competition and or direct predation.

An I.C.E.S. workshop was held in 2017 focused on predatory behaviour of grey seals towards other grey seals, harbour seals and harbour porpoises (Phocoena phocoena) in European waters. Reported cases of grey seal predation events have been detected throughout much of the grey seal range, although information is lacking from some key areas. Seasonal trends of predation on pinnipeds peaked during their respective pupping/mating seasons while cases of predation on harbour porpoises peaked in spring months. A total of 737 cases have been reported, peaking in 2016.

The incidence of grey seal predation on other marine mammals steadily increased over the last 10 years although it is not known if this represents a true increase in prevalence, reflects the steady increase in European grey seal numbers over the same period or is due to an increase in effort and reporting. It was noted that if previously high rates of harbour seal mortality due to grey seal predation were sustained, they could potentially account for observed declines in some populations. Coupled with the rise in European grey seal numbers, this could become the most important driver of local harbour seal extinctions in already depressed populations.

**Climate change**

Ongoing work suggests that both grey and harbour are at risk of range contraction at the southern end of their range under predicted climate changes in both the lowest and highest warming scenarios presented by the IPCC. However, these predictions contain considerable uncertainty in part because the scenarios do not take account of potential prey re-distributions.

# Scientific Advice

## Background

Under the Conservation of Seals Act 1970 and the Marine (Scotland) Act 2010, the Natural Environment Research Council (NERC) has a duty to provide scientific advice to government on matters related to the management of seal populations. NERC has appointed a Special Committee on Seals (SCOS) to formulate this advice so that it may discharge this statutory duty. Terms of Reference for SCOS and its current membership are given in Annex I.

Formal advice is given annually based on the latest scientific information provided to SCOS by the Sea Mammal Research Unit (SMRU). SMRU is an interdisciplinary research group at the University of St Andrews which receives National Capability funding from NERC to fulfil its statutory requirements and is a delivery partner of the National Oceanography Centre. SMRU also provides government with scientific reviews of licence applications to shoot seals; information and advice in response to parliamentary questions and correspondence; and responds on behalf of NERC to questions raised by government departments about the management of marine mammals in general.

This report provides scientific advice on matters related to the management of seal populations for the year 2017. It begins with some general information on British seals, gives information on their current status, and addresses specific questions raised by the Marine Scotland (MS) and the Department of the Environment, Food and Rural Affairs (Defra) and Natural Resources Wales (NRW).

Appended to the main report are briefing papers which provide additional scientific background for the advice.

SMRU's long-term funding has recently seen a substantial reduction which will continue into the foreseeable future. This will have an impact on the frequency and types of advice that SMRU will be able to deliver and research activities are being reprioritised as necessary.

## General information on British seals

Two species of seal live and breed in UK waters: grey seals (*Halichoerus grypus*) and harbour (also called common) seals (*Phoca vitulina*). Grey seals only occur in the North Atlantic, Barents and Baltic Sea with their main concentrations on the east coast of Canada and United States of America and in north-west Europe. Harbour seals have a circumpolar distribution in the Northern Hemisphere and are divided into five sub-species. The population in European waters represents one subspecies (*Phoca vitulina vitulina*). Other species that occasionally occur in UK coastal waters, include ringed seals (*Phoca hispida*), harp seals (*Phoca groenlandica*), bearded seals (*Erignathus barbatus*) and hooded seals (*Cystophora crystata*), all of which are Arctic species.

### *Grey seals*

Grey seals are the larger of the two resident UK seal species. Adult males can weigh over 300kg while the females weigh around 150-200kg. Grey seals are long-lived animals. Males may live for over 20 years and begin to breed from about age 10. Females often live for over 30 years and begin to breed at about age 5.

They are generalist feeders, foraging mainly on the sea bed at depths of up to 100m although they are probably capable of feeding at all the depths found across the UK continental shelf. They take a wide variety of prey including sandeels, gadoids (cod, whiting, haddock, ling), and flatfish (plaice, sole, flounder, dab). Amongst these, sandeels are typically the predominant prey species. Diet varies seasonally and from region to region. Food requirements depend on the size of the seal and fat content (oiliness) of the prey, but an average consumption estimate of an adult is 4 to 7 kg per seal per day depending on the prey species.

Grey seals forage in the open sea and return regularly to haul out on land where they rest, moult and breed. They may range widely to forage and frequently travel over 100km between haulout sites. Foraging trips can last anywhere between 1 and 30 days. Compared with other times of the year, grey seals in the UK spend longer hauled out during their annual moult (between December and April) and during their breeding season (between August and December). Tracking of individual seals has shown that most foraging probably occurs within 100km of a haulout site although they can feed up to several hundred kilometres offshore. Individual grey seals based at a specific haulout site often make repeated trips to the same region offshore, but will occasionally move to a new haulout site and begin foraging in a new region. Movements of grey seals between haulout sites in the North Sea and haulout sites in the Outer Hebrides have been recorded as well as movements from sites in Wales and NW France to sites in the Inner Hebrides

Globally there are three centres of grey seal abundance; one in eastern Canada and the north-east USA, a second around the coast of the UK, especially in Scottish coastal waters, and a third, smaller group in the Baltic Sea. All populations are increasing, although numbers are still relatively low in the Baltic where the population was drastically reduced by human exploitation and reproductive failure, probably due to pollution. In the UK and Canadian populations, there are clear indications of a slowing down in population growth in recent years.

Approximately 38% of the world's grey seals breed in the UK and 88% of these breed at colonies in Scotland with the main concentrations in the Outer Hebrides and in Orkney. There are also breeding colonies in Shetland, on the north and east coasts of mainland Britain and in SW England and Wales. Although the number of pups throughout Britain has grown steadily since the 1960s when records began, there is clear evidence that the population growth is levelling off in all areas except the central and southern North Sea where growth rates remain high. The numbers born in the Hebrides have remained approximately constant since 1992 and growth has been levelling off in Orkney since the late 1990s.

In the UK, grey seals typically breed on remote uninhabited islands or coasts and in small numbers in caves. Preferred breeding locations allow females with young pups to move inland away from busy beaches and storm surges. Seals breeding on exposed, cliff-backed beaches and in caves may have limited opportunity to avoid storm surges and may experience higher levels of pup mortality as a result. Breeding colonies vary considerably in size; at the smallest only a handful of pups are born, while at the biggest, over 5,000 pups are born annually. In the past grey seals have been highly sensitive to disturbance by humans, hence their preference for remote breeding sites. However, at one UK mainland colony at Donna Nook in Lincolnshire, seals have become habituated to human disturbance and over 70,000 people visit this colony during the breeding season with no apparent impact on the breeding seals.

UK grey seals breed in the autumn, but there is a clockwise cline in the mean birth date around the UK. The majority of pups in SW Britain are born between August and September, in north and west Scotland pupping occurs mainly between September and late November and eastern England pupping occurs mainly between early November to mid-December.

Female grey seals give birth to a single white coated pup which they suckle for 17 to 23 days. Pups moult their white natal coat (also called "lanugo") around the time of weaning and then remain on the breeding colony for up to two or three weeks before going to sea. Mating occurs at the end of lactation and then adult females depart to sea and provide no further parental care. In general, female grey seals return to the same colony to breed in successive years and often breed at the colony in which they were born. Grey seals have a polygynous breeding system, with dominant males monopolising access to females as they come into oestrus. The degree of polygyny varies regionally and in relation to the breeding habitat. Males breeding on dense, open colonies are more able to restrict access to a larger number of females (especially where they congregate around pools) than males breeding in sparse colonies or those with restricted breeding space, such as in caves or on cliff-backed beaches.

***Harbour seals***

Adult harbour seals typically weigh 80-100 kg. Males are slightly larger than females. Like grey seals, harbour seals are long-lived with individuals living up to 20-30 years.

Harbour seals normally feed within 40-50 km around their haul out sites. They take a wide variety of prey including sandeels, gadoids, herring and sprat, flatfish, octopus and squid. Diet varies seasonally and from region to region. Because of their smaller size, harbour seals eat less food than grey seals; 3-5 kg per adult seal per day depending on the prey species.

Harbour seals come ashore in sheltered waters, often on sandbanks and in estuaries, but also in rocky areas. They give birth to their pups in June and July and moult in August. At these, as well as other times of the year, harbour seals haul out on land regularly in a pattern that is often related to the tidal cycle. Harbour seal pups are born having shed their white coat *in utero* and can swim almost immediately.

Harbour seals are found around the coasts of the North Atlantic and North Pacific from the subtropics to the Arctic. Five subspecies of harbour seal are recognized. The European subspecies, *Phoca vitulina vitulina*, ranges from northern France in the south, to Iceland in the west, to Svalbard in the north and to the Baltic Sea in the east. The largest population of harbour seals in Europe is in the Wadden Sea.

Approximately 30% of European harbour seals are found in the UK; this proportion has declined from approximately 40% in 2002 due to the more rapid recovery and higher sustained rates of increase in the Wadden Sea population. Harbour seals are widespread around the west coast of Scotland and throughout the Hebrides and Northern Isles. On the east coast, their distribution is more restricted with concentrations in the major estuaries of the Thames, The Wash and the Moray Firth. Scotland holds approximately 79% of the UK harbour seal population, with 16% in England and 5% in Northern Ireland.

The population along the east coast of England (mainly in The Wash) was reduced by 52% following the 1988 phocine distemper virus (PDV) epidemic. A second epidemic in 2002 resulted in a decline of 22% in The Wash, but had limited impact elsewhere in Britain. Counts in the Wash and eastern England did not demonstrate any immediate recovery from the 2002 epidemic and continued to decline until 2006. The counts increased rapidly from 2006 to 2012 but have remained relatively constant since. In contrast, the adjacent European colonies in the Wadden Sea experienced continuous rapid growth after the epidemic, but again, the counts over the last 5 years suggest that the rate of increase has slowed dramatically.

Major declines have now been documented in several harbour seal populations around Scotland, with declines since 2001 of 76% in Orkney, 30% in Shetland between 2000 and 2009, and 92% between 2002 and 2013 in the Firth of Tay. However the pattern of declines is not universal. The Moray Firth count apparently declined by 50% before 2005, remained reasonably stable for 4 years, then increased by 40% in 2010 and has fluctuated since, showing no significant trend since 2000. The Outer Hebrides apparently declined by 35% between 1996 and 2008 but the 2011 count was >50% higher than the 2008 count. The recorded declines are not thought to have been linked to the 2002 PDV epidemic that seems to have had little effect on harbour seals in Scotland.

## Historical status

We have little information on the historical status of seals in UK waters. Remains have been found in some of the earliest human settlements in Scotland and they were routinely harvested for meat, skins and oil until the early 1900s. There are no reliable records of historical population size. Harbour seals were heavily exploited mainly for pup skins until the early 1970s in Shetland and The Wash. Grey seal pups were taken in Orkney until the early 1980s, partly for commercial exploitation and partly as a population control measure. Large scale culls of grey seals in the North Sea, Orkney and Hebrides were carried out in the 1960s and 1970s as population control measures. Grey seal pup production monitoring started in the late 1950s and early 1960s and numbers have increased consistently since. However, in recent years, there has been a significant reduction in the rate of increase.

Boat surveys of harbour seals in Scotland in the 1970s showed numbers to be considerably lower than in the aerial surveys, which started in the late 1980s, but it is not possible to distinguish the apparent change in numbers from the effects of more efficient counting methods. After harvesting ended in the early 1970s, regular surveys of English harbour seal populations indicated a gradual recovery, punctuated by two major reductions due to PDV epidemics in 1988 and 2002 respectively.

## Legislation protecting seals

The Grey Seal (Protection) Act, 1914, provided the first legal protection for any mammal in the UK because of a perception that seal populations were very low and there was a need to protect them. In the UK seals are protected under the Conservation of Seals Act 1970 (England, and Wales), the Marine (Scotland) Act 2010 and The Wildlife (Northern Ireland) Order 1985.

The Conservation of Seals Act prohibits taking seals during a close season (01/09 to 31/12 for grey seals and 01/06 to 31/08 for harbour seals) except under licence issued by the Marine Management Organisation (MMO). The Act also allows for specific Conservation Orders to extend the close season to protect vulnerable populations. After consultation with NERC, three such orders were established providing year round protection to grey and harbour seals on the east coast of England and in the Moray Firth and to harbour seals in the Outer Hebrides, Shetland, Orkney and the east coast of Scotland between Stonehaven and Dunbar (effectively protecting all harbour seals along the east coasts of Scotland and England).

The conservation orders in Scotland have been superceded by the designation of seal conservation areas under the provisions of the Marine (Scotland) Act 2010. Conservation areas have been established for the Northern Isles, the Outer Hebrides and the East coast of Scotland. In general, seals in Scotland are afforded protection under Section 6 of the Act which prohibits the taking of seals except under licence. Licences can be granted for the protection of fisheries, for scientific and welfare reasons and for the protection of aquaculture activities. In addition, in Scotland it is now an offence to disturb seals at designated haulout sites. NERC (through SMRU) provides advice on all licence applications and haulout designations.

The Wildlife (Northern Ireland) Order 1985 provides complete protection for both grey and harbour seals and prohibits the killing of seals except under licence. It is an offence to intentionally or recklessly disturb seals at any haulout site under Article 10 of Wildlife and Natural Environment Act (Northern Ireland) 2011.

Both grey and harbour seals are listed in Annex II of the EU Habitats Directive, requiring specific areas to be designated for their protection. To date, 16 Special Areas of Conservation (SACs) have been designated specifically for seals. Seals are features of qualifying interest in seven additional SACs. The six-yearly SAC reporting cycle required formal status assessments for these sites and these were completed in 2013.

# Questions from Marine Scotland, Department for Environment, Food and Rural Affairs and Natural Resources Wales.

Questions for SCOS 2017 were received from the three mainland administrations (Marine Scotland, MS; Department for Environment, Food and Rural Affairs, Defra; Natural Resources Wales, NRW) and are listed in Annex II. Some of these questions were essentially the same, requiring regionally specific responses in addition to a UK wide perspective. These very similar questions were therefore amalgamated, with the relevant regional differences in response being given in the tables and text. The question numbers by administration are shown in the boxes for cross reference. The remaining questions were regionally unique, requiring responses that focussed on the issue for a given area. The questions are grouped under topic headings, in the order and as they were given from the administrations.

| | |
|---|---|
| **1. What are the latest estimates of the number of seals in UK waters?** | MS Q1;<br>Defra Q1;<br>NRW Q1 |

**<u>Current status of British grey seals</u>**

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**The most recent surveys of the principal Scottish grey seal breeding sites were flown in 2016. The image processing and counting is not yet complete but the data will be available for SCOS 2018. The most recent results from the 2014 surveys together with the 2014 estimates from the annually ground counted sites in eastern England, produced a pup production estimate of 54,600. Adding in an additional 5,900 pups estimated to have been born at less frequently surveyed colonies in Shetland and Wales as well as other scattered locations throughout Scotland, Northern Ireland and South-west England, resulted in an estimate of 60,500 (95% CI 53,900-66,900, rounded to the nearest 100) pups (Table 1).**

**The pup production estimates are converted to estimates of total population size (1+ aged population) using a mathematical model and projected forward to 2016. The stages in the process (pup production → mathematical model → total population size) and the trends observed at each stage are briefly described below and presented in detail in SCOS-BP 16/01 and SCOS-BP 16/02 and SCOS-BP 17/01. The pup production model is currently under review and being updated.**

**The population model provided an estimate of 139,800 (approximate 95% CI 116,500-167,100) UK grey seals (1+ aged population) in 2015. Projecting the model forward one year, using the same pup production time series and prior distributions for the demographic parameters provided an estimate of 141,000 (approximate 95% CI 117,500-168,500) in 2016 (SCOS-BP 17/01).**

*Table 1.* ***Grey seal pup production estimates in 2014***.

| Location | Pup production in 2014 |
|---|---|
| England | 6,877 |
| Wales | 1,650* |
| Scotland | 51,863 |
| Northern Ireland | 100* |
| Total UK | 60,490 |

*Estimated production for less frequently monitored colonies, see Table 2 for details.

***Pup Production***

Major colonies in Scotland are now surveyed biennially (see SCOS-BP 14/01). Aerial surveys to estimate grey seal pup production were carried out in Scotland in 2016, using a digital camera system for the third time. Counts of seal pups on these surveys will be completed by late 2017 and will be available for a new population estimation round for SCOS 2018. The most recent available pup production estimates are from the complete surveys carried out in October-December 2014. These data, combined with estimates from less frequently monitored colonies, indicate that the total number of pups born in 2014 at all UK colonies was approximately 60,500 (approximate 95% CI 53,900-66,900).

Regional estimates at biennially surveyed colonies were 4,100 (95% CI 3,200-4,900) in the Inner Hebrides, 14,300 (95% CI 11,300-17,300) in the Outer Hebrides, 23,800 (95% CI 18,800-28,700) in Orkney and 12,700 (95% CI 10,800-14,600) at the North Sea colonies (including Isle of May, Fast Castle, Farne Islands, Donna Nook, Blakeney Point and Horsey/Winterton). An additional 5,500 pups were estimated to have been born at less frequently surveyed colonies in Shetland and Wales as well as other scattered locations throughout Scotland, Northern Ireland and South-west England, producing a total UK pup production of 60,500.

***Trends in pup production***

There has been a continual increase in the total UK pup production since regular surveys began in the 1960s (Figure 1) (see SCOS-BP 16/01 for details). In both the Inner and Outer Hebrides, the estimated pup production in 2014 was similar to the 2012 estimate, with annual percentage changes of less than 1% p.a. Production had been relatively constant between the mid-1990s and 2010, but between 2010 and 2012 showed an annual increase of ~10 and ~5% respectively, the first substantial increase since the 1990s although this may have been partly due to improved survey methods introduced at the time. In Orkney, the estimated 2014 pup production was again similar to the 2012 estimate, representing an annual increase of 1.8% p.a. As in the Hebrides, the rate of increase in Orkney has been low since 2000, with pup production increasing at around 1.8% p.a. between 2000 and 2009. However, again the rate increased to ~6% p.a. between 2009 and 2012.

Pup production at colonies in the North Sea continued to increase rapidly up to 2014 (Table 2). These show an annual increase of 10.8% p.a. between 2012 and 2014, similar to the rate of increase between 2010 and 2012. The majority of the increase up to 2014 was due to the continued rapid expansion of newer colonies on the mainland coasts in Berwickshire, Lincolnshire, Norfolk and Suffolk. Interestingly, these colonies are all at easily accessible sites on the mainland, where grey seals have probably not bred in significant numbers since the last ice age. Although there was little change at the Farne Islands, the more southerly mainland colonies increased by an average of >22% p.a. between 2010 and 2014. Estimates are available for the ground counted colonies on the English east coast (Farne Islands, Donna Nook, Blakeney and Horsey) in 2015 and 2016. The 2015 counts suggest a much lower annual increase for the English mainland colonies, with the largest colony at Blakeney showing a slight decrease after 12 years of extremely rapid (>30% p.a.) increase. The same slowdown in the rate of increase has been observed at both Donna Nook and Horsey. At the Farne islands the pup production estimate increased by 28% between 2014 and 2016, after a period of little change since 2000.

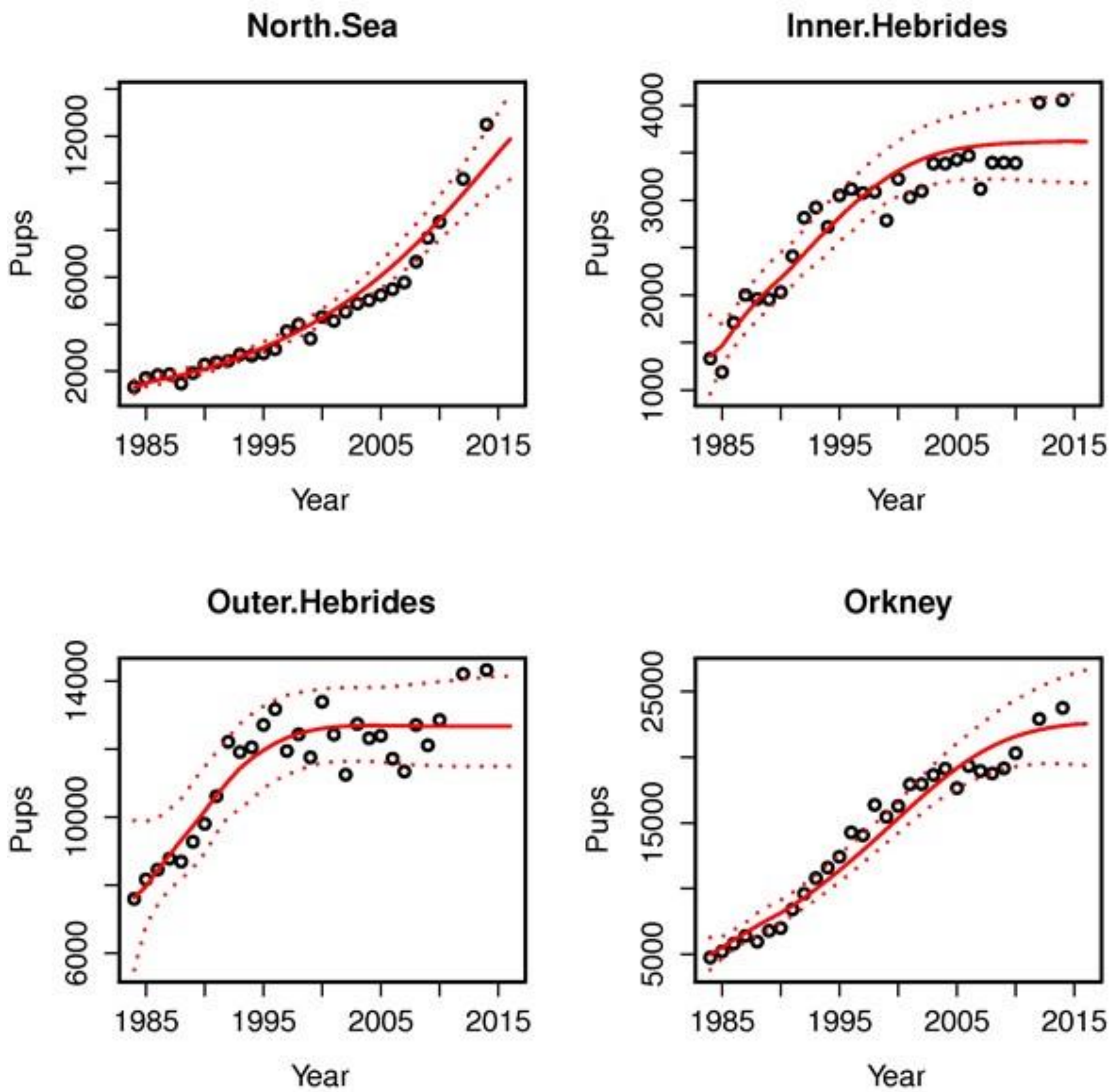



***Figure 1.*** *Mean estimates of pup production (solid lines) and 95% Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 (circles) and two independent total population estimates from 2008 and 2015.*

*Table 2.* ***Grey seal pup production estimates for the UK from 2014 compared with production estimates from 2012 and preceding six-year intervals.***

| Location | Pup production in **2014** | Pup production in 2012 | Average annual change 2012 to **2014** | Average annual change 2002 to 2008 | Average annual change 2008 to **2014** |
|---|---|---|---|---|---|
| Inner Hebrides | 4,054 | 4,088 | -0.4% | +0.5% | +3.8% |
| Outer Hebrides | 14,316 | 14,136 | +0.6% | +0.3% | +2.7% |
| Orkney | 23,758 | 22,926 | +1.8% | +0.6% | +4.4% |
| Firth of Forth | 5,860 | 5,210 | +6.1% | +4.2% | +9.2% |
| **Main annually monitored Scottish island groups** | **47,988** | **46,360** | **+1.7%** | **+1.5%** | **+3.9%** |
| Other Scottish colonies [1] (incl. Shetland & mainland) | 3,875 [1] | 3,665 [1] | +2.8% | | |
| **Total Scotland** | **51,863** | **50,025** | +1.8% | **+0.8%** | **+4.3%** |
| Donna Nook +East Anglia | 5,027 | 3,360 | +22.3% | +15.2% | +16.4% |
| Farne Islands | 1,600 | 1,603 | -0.1% | +0.8% | +3.5% |
| **Annually monitored colonies in England** | **6,627** | **4,963** | **+15.6%** | **+15.2%** | **+12.0%** |
| SW England [3] (last surveyed 1994) | 250 [3] | 250 [3] | | | |
| Wales [2,3] | 1,650 [3] | 1,650 [3] | | | |
| **Total England & Wales** | **8,527** | **6,863** | **+11.5%** | | |
| Northern Ireland [3] | 100 [3] | 100 [3] | | | |
| **Total UK** | **60,490** | **56,988** | **+3.0%** | | |

[1] Estimates derived from data collected in different years

[2] Multiplier derived from indicator colonies surveyed in 2004 and 2005 and applied to other colonies last monitored in 1994

[3] Estimated production for colonies that are rarely monitored

The most recent data for pup production from the major breeding sites in Wales are estimates of 96 pups in North Wales[1]; 465 pups in North Pembrokeshire in 2005[2] and 379 pups born on Skomer and adjacent mainland sites in 2015.[3] The relative size of pup production at the different breeding colonies by region is shown in Figure 2.

[1]Stringell, T., Millar, C., Sanderson, W., Westcott, S. & McMath, A. 2014. When aerial surveys won't do: grey seal pup production in cryptic habitats of Wales. *Journal of the Marine Biological Association of the United Kingdom*, 94, 1155-1159.

[2]Strong, P.G., Lerwill, J., Morris, S.R., & Stringell, T.B. (2006). Pembrokeshire marine SAC grey seal monitoring 2005. *CCW Marine Monitoring Report No: 26*; unabridged version (restricted under licence), 54pp.

[3]https://www.welshwildlife.org/wp-content/uploads/2014/07/Seal-Report-2014-final-.pdf

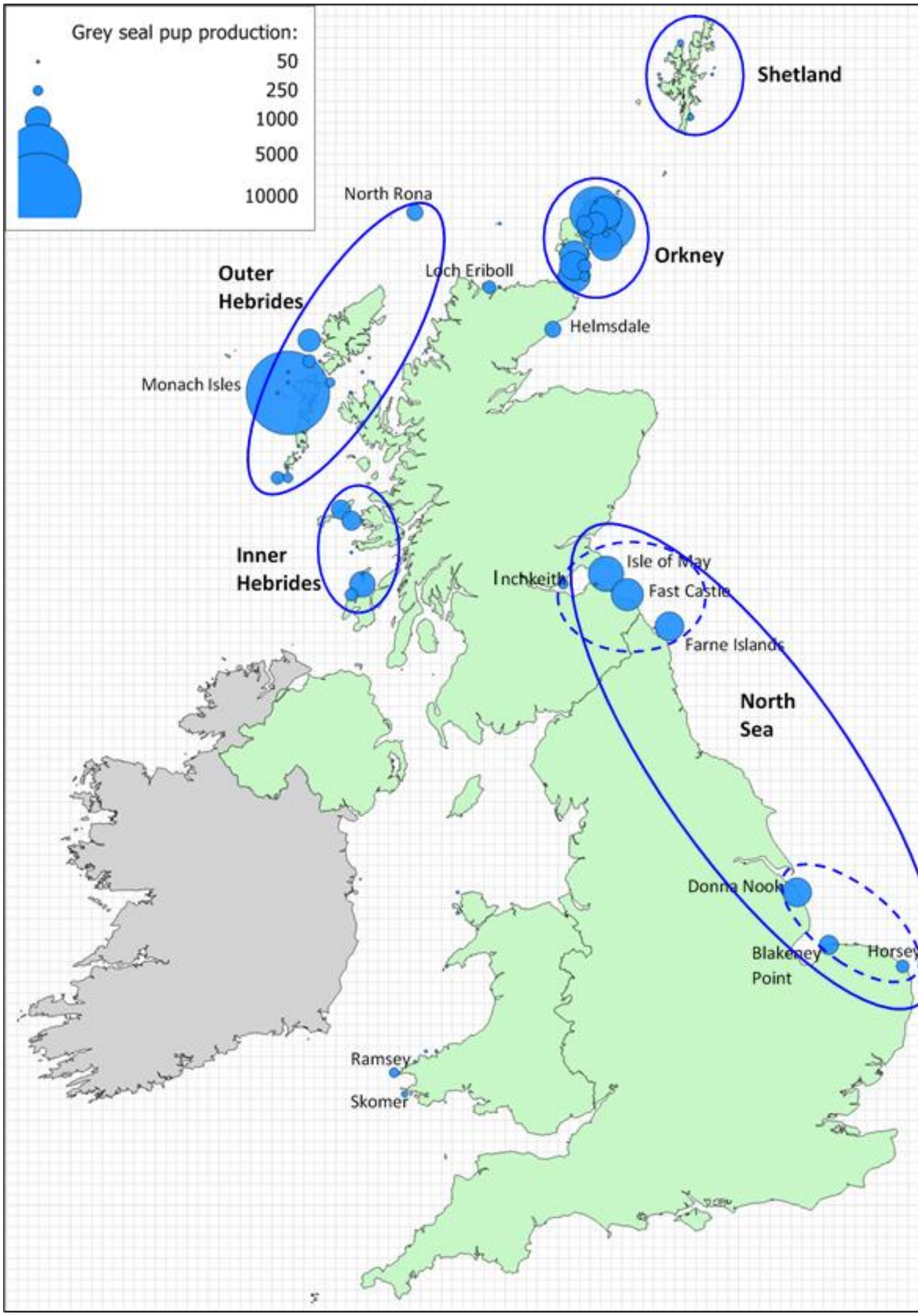



***Figure 2**. Distribution and size of the main grey seal breeding colonies. Blue ovals indicate groups of colonies within each region.*

***Population size***

Converting pup counts from air surveys (i.e. biennially surveyed colonies) into a total population size requires a number of steps as shown in Figure 3.

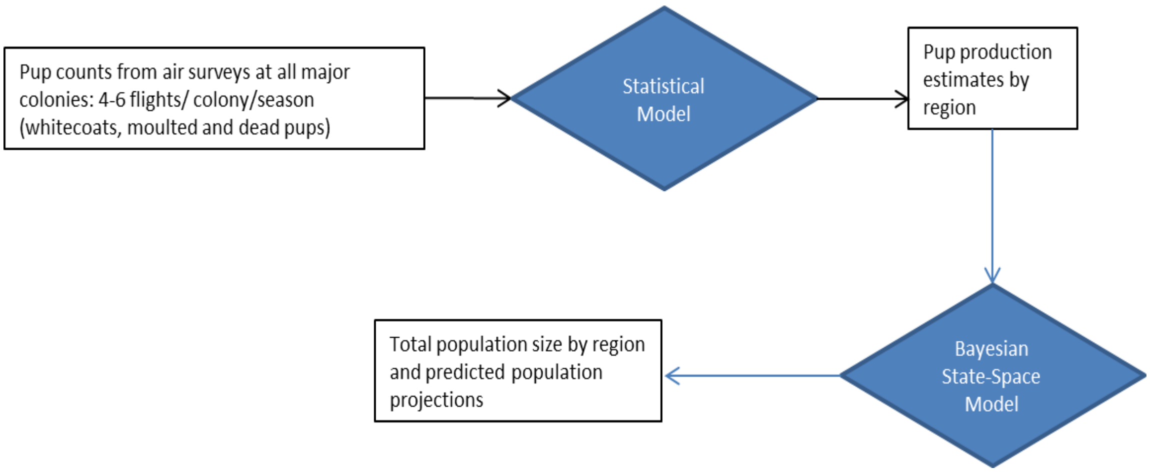



***Figure 3.*** *Schematic diagram of steps involved in estimating total population size from pup counts (see also SCOS BP-09/02, SCOS BP-10/02).*

Using appropriate estimates of fecundity rates, both pup and non-pup survival rates and sex ratio we can convert pup production estimates into estimates of total population size. The estimate of the total population alive at the start of the breeding season depends critically on the estimates of these rates. We use a Bayesian state-space population dynamics model to estimate these rates.

Until the late 1990s all the regional populations grew exponentially, implying that the demographic parameters were, on average, constant over the period of data collection. Thus, estimates of the demographic parameters were available from a simple population model fitted to the entire pup production time series. Some combination of reductions in the reproductive rate or the survival rates of pups, juveniles and adults (SCOS-BPs 09/02, 10/02 and 11/02) has resulted in reduced population growth rates in the Northern and Western Isles.

To estimate the population size we fitted a Bayesian state-space model of British grey seal population dynamics. Initially, alternative models with density dependence acting through either fecundity or pup survival were tested, but results indicated that the time series of pup production estimates did not contain sufficient information to allow us to quantify the relative contributions of these factors (SCOS-BPs 06/07, 09/02). In 2010 and 2011, we incorporated additional information in the form of an independent estimate of population size based on counts of the numbers of grey seals hauled out during the summer and information on their haulout behaviour (SCOS-BP 10/04 and 11/06). Between 2007 and 2009, 26,699 grey seals were counted during harbour seal moult surveys across the UK (excluding southwest UK). Using telemetry data, it was estimated that 31% (95% CIs: 15 - 50%) of the population was hauled out during the survey window and thus available to count[4]. Assuming 4% of the population were in southwest UK, this led to a UK independent population estimate in 2008 of 91,800 (95% CI: 78,400 - 109,900).

Inclusion of the independent estimate allowed us to reject the models that assumed density dependent effects operated through fecundity and all estimates were therefore based on a model incorporating density dependent pup survival. However, SCOS felt that the independent estimate appeared low relative to the pup production and its inclusion forced the model to select extremely low values of pup survival, high values of adult female survival and a heavily skewed sex ratio, with few surviving male seals.

In 2016, an in-depth re-analysis of the telemetry data underlying the estimate of haulout probability within the aerial survey window highlighted a series of inter-related problems with the haulout designation in the data. These have been corrected and a description of the analyses and the corrections applied to the data were presented in SCOS-BP 16/03.

The new analyses resulted in a revised estimate of the proportion of the population hauled out during the survey window of 23.9% (95% CI: 19.2 - 28.6%). As per the analyses of the previous haulout correction factor, no effect of region, length of individual (regarded as a proxy for age), sex or time of day was found.

The new estimate of the proportion of time hauled out resulted in a revised UK population estimate of 116,348 for 2008 (95% CI: 97,059 - 144,662). Between 2013 and 2015, another round of aerial surveys covered the UK grey seal haulout sites (excluding southwest UK); 34,758 individuals were counted. Using the revised scalar, the total population estimate for 2014 was 151,467 (95% CI: 126,356 - 188,327), again assuming (as in 2008) that 4% of the population were in the southwest UK. Note that this increase has major implications for assessing the potential biological removal (PBR) for the grey seal population (see Q7 and SCOS-BP 17/05).

In 2012, SCOS discussed the priors on the model input parameters in some detail, following re-examination of the data being used and the differences made to the population estimates by changing a number of them to less informative priors (SCOS-BP 12/01 and SCOS-BP 12/02). In 2014 SCOS decided to use the results from a model run using these revised priors (SCOS-BP 12/02) and incorporating a prior based on a distribution for the ratio of males to females in the population (see SCOS-BP 14/02 for details) and the independent estimate of total population size from the summer surveys. Work on updating these priors is continuing. A re-analysis of all the combined data available from pup tagging studies (hat tags, phone tags and GPS/GSM tags) suggested that there was no significant sex-specific differences in first year pup survival.

In 2014, SCOS adopted a set of revised priors, including a different prior on adult sex ratio, to generate the grey seal population estimates. The model produced unreasonably high adult survival values of more than 0.99, so it was re-run with a prior on survival constrained to a more reasonable range of 0.8 to 0.97. Posterior mean adult survival with this revised prior was 0.95 (SD 0.03).

For 2015, an identical model to that used to provide 2014's advice was fitted to two sources of data: (1) regional estimates of pup production from 1984 to 2014, and (2) two independent estimates assumed to be of total population size just before the 2008 and 2014 breeding seasons. The model allowed for density dependence in pup survival, using a flexible form for the density dependence function, and assumed no movement of recruiting females between regions. The same model and an identical set of prior

[4]Lonergan, M., C. D. Duck, D. Thompson, S. Moss, & B. McConnell. 2011. British grey seal (*Halichoerus grypus*) abundance in 2008: an assessment based on aerial counts and satellite telemetry. *ICES Journal of Marine Science* 68 (10):2201-2209.

distributions for demographic rates was used, including a prior on sex ratio and a constraint on adult survival to the range 0.80-0.97 for estimating the 2015 population and projecting forward to 2016.

The estimated adult population size in the regularly monitored colonies in 2015 was 127,100 (95% CI 105,900-151,900) for the model incorporating density dependent pup survival, using the revised priors and including the independent estimates for 2008 and 2015 (details of this analysis and posterior estimates of the demographic parameters are given in SCOS-BP 16/02 and SCOS-BP 16/03). A comprehensive survey of data available from the less frequently monitored colonies was presented in SCOS-BP 11/01 and updated in 2015 (SCOS-BP 15/01). Total pup production at these sites was estimated to be approximately 5,500. The total population associated with these sites was then estimated using the average ratio of 2014 pup production to 2015 population size estimate for all annually monitored sites. Confidence intervals were estimated by assuming that they were proportionally similar to the pup survival model confidence intervals. This produced a population estimate for these sites of 12,700 (approximate 95% CI 10,600 to 15,200). Combining this with the annually monitored sites gives an estimated 2015 UK grey seal population of 139,800 (approximate 95% CI 116,500-167,100). Projecting the model forward one year, using the same pup production time series and prior distributions for the demographic parameters provided an estimate of 128,200 (95% CI 106,200-154,400) for the annually monitored colonies (SCOS-BP 17/01). Including the less frequently monitored colonies produces an estimate of 141,000 (approximate 95%CI 117,500-168,500) grey seals aged >1y at the start of the 2016 breeding season.

The estimated population in 2015 was approximately 20% higher than that reported for the models run in 2014. Most of that increase (14%) was apparently due to the higher, recent independent estimate and to changes in the 2008 independent estimate resulting from the new estimate of the proportion of animals hauled out during the survey window; the other 6% was presumably caused by the high 2014 pup count (SCOS-BP 16/02). Projecting the population model forward to 2016 produced a small, <1% annual increase in total population estimate.

The fit of the model to the pup production estimates has been poor in some regions in recent years. Whilst the model accurately captures some aspects of the observed trends in pup production in some regions, the estimated adult survival rate from the model was very high and the maximum pup survival rate was very low. This suggests some other parameters, such as inter-annual variation in fecundity or survival senescence could be causing a mismatch between the estimates from the model and the pup production data. Interestingly, recent analyses of the long-term brand-resight data from the grey seal population breeding at Sable Island, Canada, suggests that the extremely high adult survival rates generated by the model are within the range of observed survival rates. The Sable Island data support the assumption that density dependence is operating mostly through changes in pup survival. Fecundity has remained high there throughout a period of slowing down in rates of population increase. Pup survival has declined dramatically over the same period, although the maximal pup survival rates estimated from the brand data are much higher than the model estimates (SCOS-BP 17/02).

The selection of which parameter estimates are fitted and which are fixed in the pup production model may have a significant effect on the pup production estimates. The effect of this selection process on the estimates is being investigated and preliminary results were presented at SCOS 2015 (SCOS-BP 15/03). This work is continuing.

In addition, the model assumes a fixed coefficient of variation (CV) for the pup production estimates and obtains this value from an initial model run. Ideally, region-level estimates of pup production variance would be produced as part of fitting the pup production model to the aerial pup count data; we plan to investigate this in the coming year. One factor that will require consideration is how to incorporate uncertainty in the ground counts made at some North Sea colonies. A revised pup production model will therefore be developed to estimate pup production with the counts from the most recent set of surveys carried out over the 2016 breeding season.

***Population trends***

Model selection criteria suggest that density dependence is acting mainly on pup survival (see SCOS-BP 09/02). The independent population estimate from 2008 was consistent with this conclusion. Although the 2015 independent estimate and revised 2008 estimate have allowed the model to fit a higher trajectory, they are still consistent with the density dependent pup survival model. This also implies that the overall population should closely track the pup production estimates when experiencing density dependent control, as well as during exponential growth. The model estimated that total population sizes for the biennially monitored colonies have increased by approximately 1% p.a. (SCOS-BP 16/02) between 2012 and 2016. All of this is due to a continuing 4% p.a. increase in the North Sea population; the Orkney and Hebridean populations are effectively stationary, increasing at <0.1% p.a. since 2010.

Even within the North Sea the pattern of increase is not evenly spread. The colonies on offshore islands in the central North Sea have been relatively stable for the past 6 years, while at the colonies on the mainland coast and especially in the southern North Sea, the rates of increase in pup production from 2010 to 2015 have been extremely high (>22% p.a.). This strongly suggests that there must have been some immigration from colonies further north.

***UK grey seal population in a world context***

The UK grey seal population represents approximately 34% of the world population on the basis of pup production estimates. The other major populations in the Baltic and the western Atlantic are also increasing (Table 3).

*Table 3.* ***Relative sizes and status of grey seal populations using pup production as an index of population size. Pup production estimates are used because the largest populations are monitored by means of pup production surveys and because of the uncertainty in overall population estimates.***

| Region | Pup Production | Year | Possible population trend |
|---|---|---|---|
| **UK** | **60,500** | 2014 | Increasing |
| Ireland | 2,100 | 2012[1] | Increasing |
| Wadden Sea | 1,300 | 2016[2] | Increasing |
| Norway | 1,300 | 2008[3] | Increasing |
| Russia | 800 | 1994 | Unknown |
| Iceland | 1,200 | 2012[8] | Declining |
| Baltic | 6,400 | 2013[4,5] | Increasing |
| **Europe excluding UK** | **13,100** | | Increasing |
| Canada - Scotian shelf | 88,200 | 2016[6] | Increasing |
| Canada - Gulf St Lawrence | 10,500 | 2016[6] | Increasing |
| USA | 3,600 | 2014[7] | Increasing |
| **WORLD TOTAL** | **175,900** | | Increasing |

[1]Ó Cadhla, O., Keena, T., Strong, D., Duck, C. and Hiby, L. 2013. Monitoring of the breeding population of grey seals in Ireland, 2009 - 2012. Irish Wildlife Manuals, No. 74. National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Dublin, Ireland.

[2] http://www.waddensea-secretariat.org/sites/default/files/downloads/tmap/MarineMammals/GreySeals/grey_seal_report_2017.pdf.

[3]Øigård, T.A., Frie, A.K., Nilssen, K.T., Hammill, M.O., 2012. Modelling the abundance of grey seals (*Halichoerus grypus*) along the Norwegian coast. ICES Journal of Marine Science: Journal du Conseil, 69(8) 1436-1447.

[4]Data summarised in*: Grey seals of the North Atlantic and the Baltic*. 2007. Eds: T. Haug, M. Hammill & D. Olafsdottir. NAMMCO Scientific Publications, Vol. 6.

[5]Baltic pup production estimate based on mark recapture estimate of total population size and an assumed multiplier of 4.7 HELCOM fact sheets (www.HELCOM.fi) & http://www.rktl.fi/english/news/baltic_grey_seal.html

[6] M.O. Hammill, den Heyer, C.E., Bowen, W.D., and Lang, S.L.C. 2017. Grey Seal Population Trends in Canadian Waters, 1960-2016 and harvest advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2017.

[7]NOAA (2009) http://www.nefsc.noaa.gov/publications/tm/tm238/247_f2015_grayseal.pdf

[8]Erlingur Hauksson pers. com https://www.hafogvatn.is/static/research/files/skra_0069286pdf.

**Current status of British harbour seals**

**Harbour seals are counted while they are on land during their August moult, giving a minimum estimate of population size. Not all areas are counted every year but the aim is to cover the UK coast every 5 years. Combining the most recent counts (2008-2016) gives a total of 31,300 counted in the UK (Table 4). Scaling this by the estimated proportion hauled out (0.72 (95% CI: 0.54-0.88)) produced an estimated total population for the UK in 2016 of 43,500 (approximate 95% CI: 35,600-58,000). Overall, the UK population has increased since the late 2000s and is close to the 1990s level. However, there are significant differences in the population dynamics between regions. As reported in SCOS 2008 to 2016, there have been general declines in counts of harbour seals in several regions around Scotland but the declines are not universal with some populations either stable or increasing.**

**Harbour seal counts were stable or increasing in all regions until around 2000 when declines were seen in Orkney (down 85% between 1997-2016), the East coast (down 52% between 1997 and 2016, but primarily driven by the decline in the Firth of Tay, down 92% between 2000-2016) and Shetland (which declined by 30% between 2000-2009). However, the 2015 count in Shetland was 10% higher than the 2009 count. The most recent counts for the West Scotland region (2013 to 2015) and for the Western Isles (2011) were 43% and 50% respectively higher than the previous estimates (2007 to 2009). Counts along the English east coast were approximately 10% higher than in 2015, driven mainly by a doubling of the count from Essex and Kent.**

*Table 4.* ***UK harbour seal minimum population estimates based on counts during the moult.***

| Location | Most recent count (2008-2016) |
|---:|---:|
| **England** | **5,200** |
| **Wales** | **<50[1]** |
| **Scotland** | **25,150[2]** |
| **Northern Ireland** | **950** |
| **Total UK** | **31,300[3]** |

*[1] There are no systematic surveys for harbour seals in Wales*
*[2] Compiled from most recent surveys, see Table 5 for dates and details*
*[3] This does not include the unknown small number in Wales*

Each year SMRU carries out surveys of harbour seals during the moult in August. Recent survey counts and overall estimates are summarised in SCOS-BP 17/03. Given the length of the mainly rocky coastline around north and west Scotland it is impractical to survey the whole coastline every year but SMRU aims to survey the entire coast across 5 consecutive years. However, in response to the observed declines around the UK the survey effort has been increased and some regions, e.g. Orkney and the Moray Firth have been surveyed more frequently. The majority of the English and Scottish east coast populations are surveyed annually.

Seals spend a higher proportion of their time on land during the moult than at other times and counts during the moult are thought to represent the highest proportion of the population with the lowest variance. Initial monitoring of the population in East Anglia in the 1960s used these maximum counts as minimum population estimates. In order to maintain the consistency of the long term monitoring of the UK harbour seal population, the same time constraints are applied throughout and surveys are timed to provide counts during the moult. Most regions are surveyed using thermographic aerial imagery to identify seals along the coastline. However, conventional photography is used to survey populations in the estuaries of the English and Scottish east coasts.

The estimated number of seals in a population based on these methods contains considerable levels of uncertainty. A large contribution to uncertainty is the proportion of seals not counted during the survey because they are in the water. Efforts are made to reduce the effect of environmental factors by always conducting surveys within 2 hours of low tides that occur between 10:00 and 20:00 during the first three weeks of August and only in good weather. A conversion factor of 0.72 (95% CI: 0.54-0.88) to scale moult counts to total population was derived from haulout patterns of harbour seals fitted with flipper mounted ARGOS tags (n=22) in Scotland[5].

The most recent counts of harbour seals by region are given in Table 5 and Figure 4. These are minimum estimates of the British harbour seal population. Results of surveys conducted in 2016 are described in more detail in SCOS-BP 17/03. It has not been possible to conduct a synoptic survey of the entire UK coast in any one year. Data from different years have therefore been grouped into recent, previous and earlier counts to illustrate, and allow comparison of, the general trends across regions.

Combining the most recent counts (2011-2016) at all sites, approximately 31,300 harbour seals were counted in the UK: 81% in Scotland; 16% in England; 3% in Northern Ireland (Table 5). Including the 3,500 seals counted in the Republic of Ireland produces a total count of ~35,000 harbour seals for the British Isles (i.e. the UK and Ireland).

Apart from the population in The Wash, harbour seal populations in the UK were relatively unaffected by phocine distemper virus (PDV) in 1988. The overall effect of the 2002 PDV epidemic on the UK population was even less pronounced. However, again the English east coast populations were most affected, but the decrease was more gradual than in 1988, and the counts continued to decline for four years after the epidemic. Between 2006 and 2012 the counts approximately doubled in The Wash and increased by 50% for East Anglia as a whole. Since 2012 the counts have been almost constant.

Breeding season aerial surveys of the harbour seal population along the east Anglian coast are flown annually, in addition to the large range wide surveys flown during the moult in August. As in 2015, the east Anglian coast was surveyed five times during the breeding season in June and July[6]. The 2016 peak count was 17% higher than in 2015, which was substantially lower (22%) than the 2014 equivalent count. These wide fluctuations are not unusual in the long term time series and despite the apparently wide inter-annual variation, the pup production has increased at around 7.4% p.a. since surveys began in 2001.

The ratio of pups to the moult counts remained high in 2016, more than double the same ratio in 2001 and substantially higher than the same metric in the larger Wadden Sea population. This ratio can be seen as an index of the productivity of the population. Interestingly, an increase in this apparent fecundity index has recently been noted in the Wadden Sea population.

[5]Lonergan, M, C. Duck, S. Moss, C. Morris, & D. Thompson. 2013. Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. *Aquatic Conservation-Marine and Freshwater Ecosystems* 23 (1):135-144.
[6]Thompson, D., Onoufriou, J. and Patterson, W. 2016. Report on the distribution and abundance of harbour seals (*Phoca vitulina*) during the 2015 and 2016 breeding seasons in the Wash. *Report number SMRUC-DOW-2016-06*, December 2016. http://www.smru.st-andrews.ac.uk/reports/

*Table 5.* ***The most recent August counts of harbour seals at haulout sites in Britain and Ireland by seal management unit compared with three previous periods: 1996-1997, 2000-2006 & 2007-2009.*** *Details of sources and dates of surveys used in each compiled regional total are given in* SCOS-BP 17/03.

| Seal Management Unit / Country | | Harbour seal counts | | | |
|---|---|---|---|---|---|
| | | 2011-2016 | 2007-2009 | 2000-2006 | 1996-1997 |
| 1 | Southwest Scotland | 1,200 | 923 | 623 | 929 |
| 2 | West Scotland | 15,184 | 10,626 | 11,702 | 8,811 |
| 3 | Western Isles | 2,739 | 1,804 | 1,981 | 2,820 |
| 4 | North Coast & Orkney | 1,349 | 2,979 | 4,384 | 8,787 |
| 5 | Shetland | 3,369 | 3,039 | 3,038 | 5,994 |
| 6 | Moray Firth | 940 | 776 | 1,028 | 1,409 |
| 7 | East Scotland | 368 | 283 | 667 | 764 |
| **SCOTLAND TOTAL** | | **25,149** | **20,430** | **23,423** | **29,514** |
| 8 | Northeast England | 86 | 58 | 62 | 54 |
| 9 | Southeast England | 5,061 | 3,952 | 2,964 | 3,222 |
| 10 | South England | 23 | 13 | 13 | 5 |
| 11 | Southwest England | 0 | 0 | 0 | 0 |
| 12 | Wales | 5 | 4 | 4 | 2 |
| 13 | Northwest England | 10 | 5 | 5 | 2 |
| **ENGLAND & WALES TOTAL** | | **5,185** | **4,032** | **3,048** | **3,280** |
| **BRITAIN TOTAL** | | **30,334** | **24,462** | **26,471** | **32,794** |
| **NORTHERN IRELAND TOTAL** | | **948** | **1,101** | **1,176** | |
| **UK TOTAL** | | **31,282** | **25,563** | **27,648** | |
| **REPUBLIC OF IRELAND TOTAL** | | **3,489** | **2,955** | **2,955** | |
| **BRITAIN & IRELAND TOTAL** | | **34,771** | **28,518** | **30,603** | |

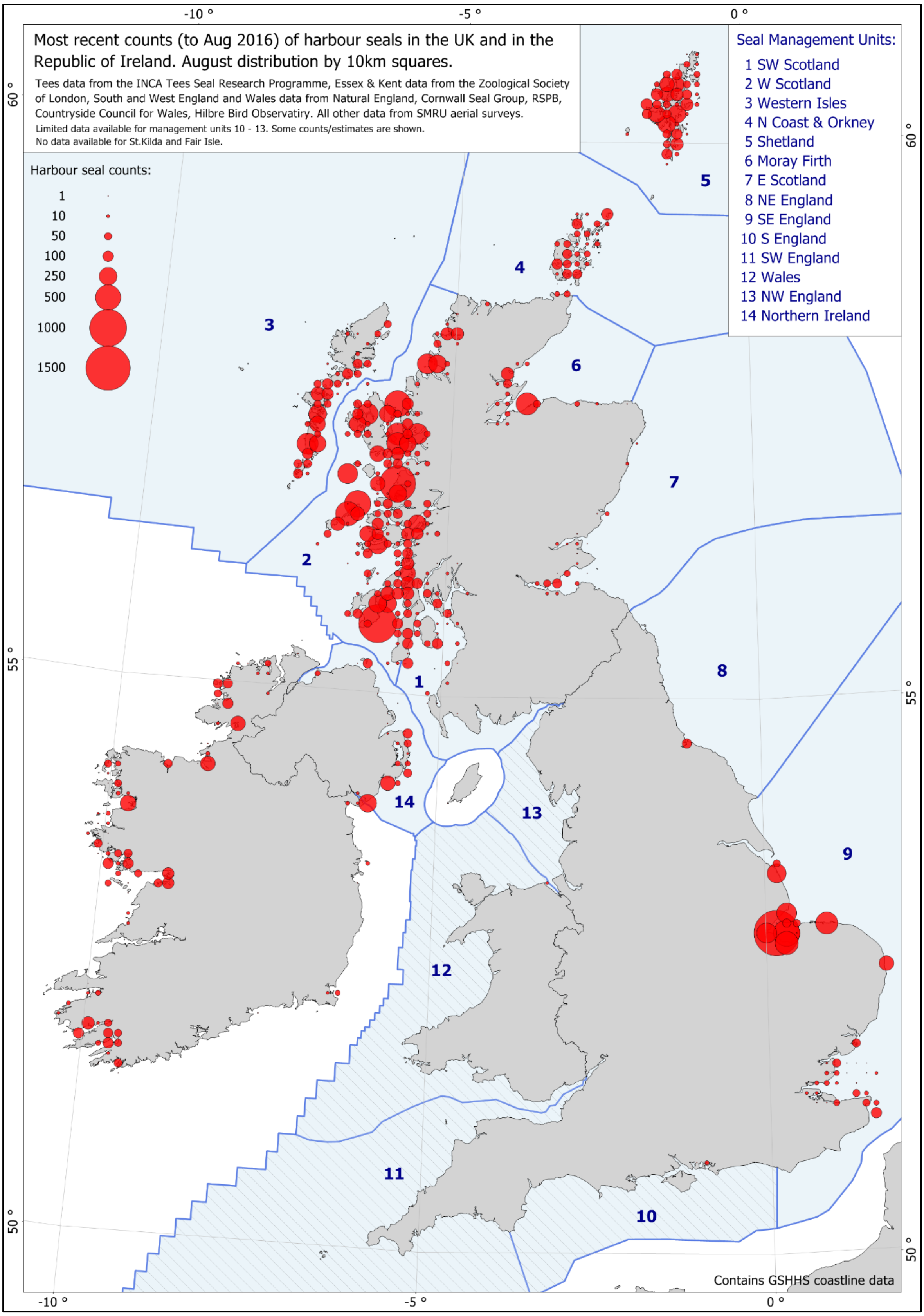



***Figure 4**. August distribution of harbour seals around the British Isles. Very small numbers of harbour seals (<50) are anecdotally but increasingly reported for the West England & Wales management unit, but are not included on this map. Estimates are composites of the most recent survey counts in each region between 2008 and 2016.*

***Population trends***

Overall, the harbour seal population has increased from 25,600 (rounded to the nearest 100) in the 2007-09 period to 31,400 animals during the 2013-2016 period, but remain slightly below the 1996-97 level of 32,800 (Table 5). However, as reported in SCOS 2008 to 2016, patterns of changes in abundance have not been universal; although declines have been observed in several regions around Scotland some populations appear to be either stable or increasing. Details are given in (Figure 5, SCOS-BP 17/03).

A complete survey of Orkney and the North coast was carried out in 2016. **1,349** harbour seals were counted compared with 1,938 in 2013, 3000 in 2008-2009 and 8,800 in 1997 (Table 5, SCOS-BP 17/03). This is a decrease of >30% over three years, equivalent to an average annual decrease of 10%. The latest survey results therefore confirm that the rapid decline in the Orkney harbour seal population since 1997 is continuing.

All of the Southwest Scotland management region was surveyed in August 2015. A total of **1,200** harbour seals were counted compared with 923 counted in 2007 and 2009 (Table 5). This was the highest count of harbour seals for the Southwest Scotland Seal Management Area.

The most recent count of harbour seals in the large West Scotland Management Area is **15,184** from surveys carried out between 2013 and 2015 compared with 10,626 from the previous survey period of 2007-2009 and counts of 8,811 from 1996-1997 period (Table 5). The West Scotland harbour seal count increased by 43% between 2009 and 2015, equivalent to an average annual increase of 5.3%. The most recent estimate available for the Western Isles is the 2011 count. The region was surveyed in 2017 and a new estimate will be presented to SCOS 2018.

A complete survey of Shetland was carried out in 2015. **3,369** harbour seals were counted compared with 3,039 in 2009 and 5,994 in 1997 (Table 5). This is an increase of 12% over six years and is equivalent to an average annual increase of 1.7%. The 2015 Shetland harbour seal count shows the first increase since 1993 following a period of decline[7].

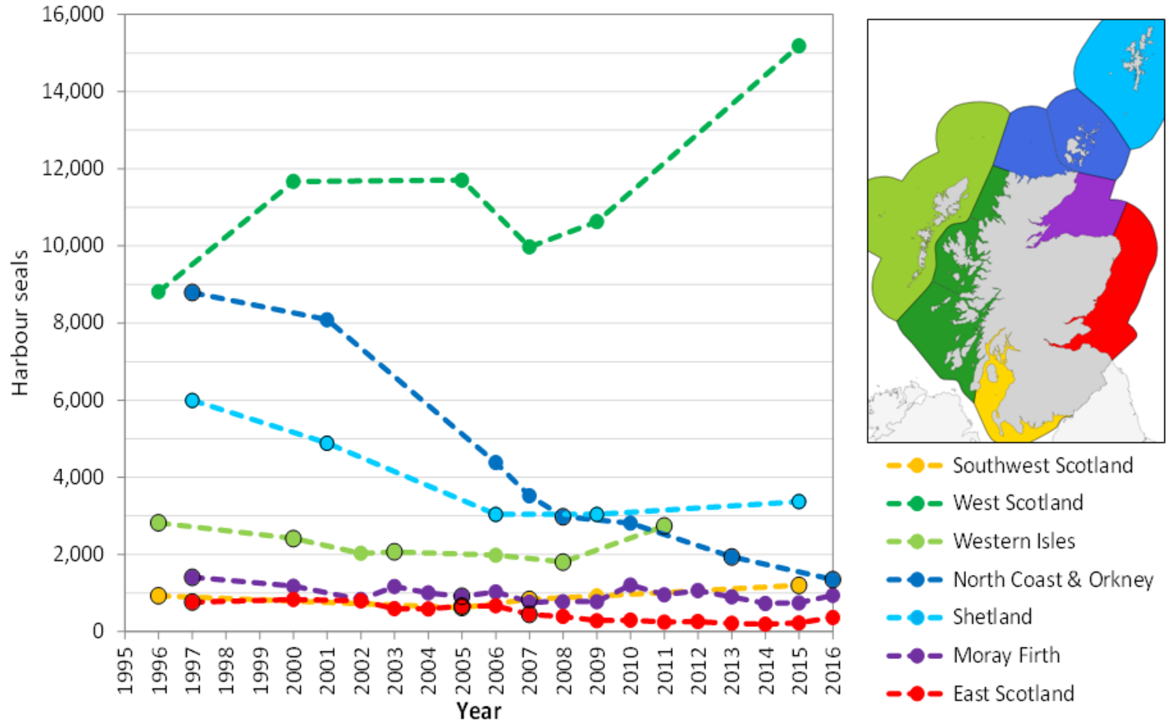
In the Moray Firth, the overall total counts in 2016 were 26% higher than the previous two years and although the count is significantly lower than the 1996-97 counts there does not appear to have been a clear trend since 2000. Within the Moray Firth, the counts in the inner Firths have continued to decline while counts at Culbin Sands and Findhorn have continued to increase rapidly, suggesting substantial re-distribution within the area.

The 2016 harbour seal moult count for the Firth of Tay and Eden Estuary Special Area of Conservation (SAC) (51) was similar to that in 2015 (SCOS-BP 17/03). The 2016 count represents a 90% decrease from the mean counts recorded between 1990 and 2002 (641). The low numbers of harbour seals in this area are of sufficient concern that Marine Scotland has not issued any licences to shoot harbour seals within the East Scotland Management Area since 2010.

The combined count for the Southeast England management unit in 2016 (5,199) was 10% higher than the 2014 and 2015 counts. Although the Southeast England population has returned to its pre-2002 epidemic levels, it is still lagging behind the rapid recovery of the harbour seal population in the Wadden Sea where counts have increased from 10,800 in 2003 to 26,788 in 2013, equivalent to an average annual growth rate of 9.5% over ten years. Interestingly, the 2014, 2015 and preliminary 2016 counts in the Wadden Sea showed a slight decrease that may be related to the effects of an influenza A epidemic but may also be an indication that the rapid growth since the PDV epidemic has slowed or even stopped.

[7] Lonergan, M., C. D. Duck, D. Thompson, B. L. Mackey, L. Cunningham, & I. L. Boyd. (2007). Using sparse survey data to investigate the declining abundance of British harbour seals. *Journal of Zoology* 271 (3):261-269.

a.




b.

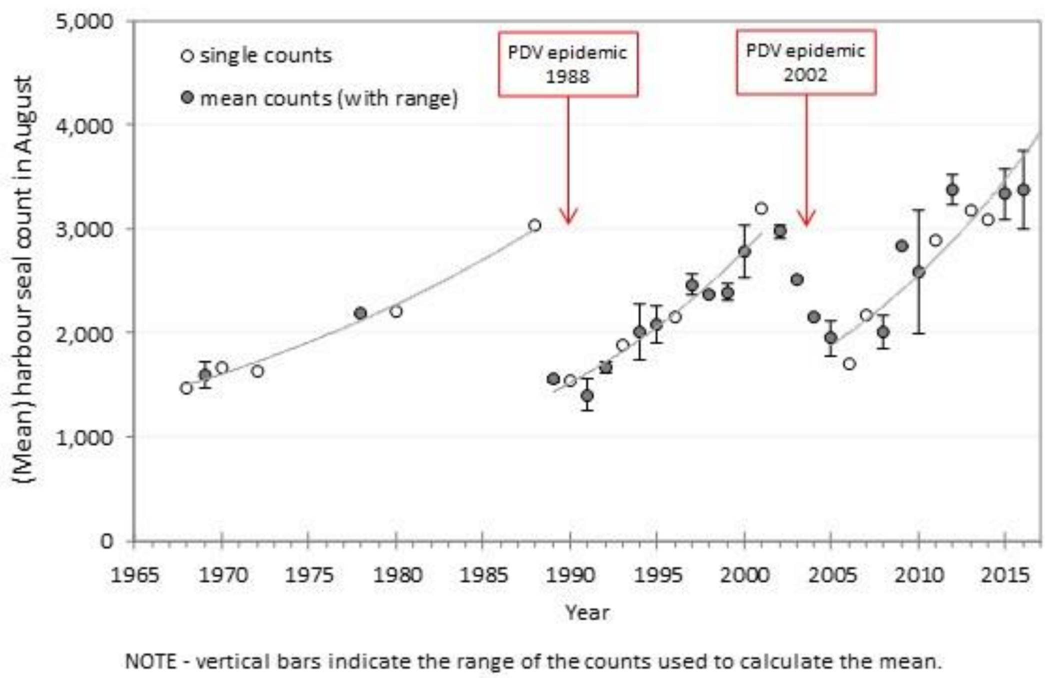



***Figure 5.*** *Recent trends in numbers of harbour seals: a. counted in different Scottish seal management areas, 1996-2016 (black circled points indicate a single count in that year, plain points represent means of multiple counts); b. counted in The Wash, southeast England, 1967-2016 (grey filled points indicate means of multiple counts) (SCOS-BP 17/03).*

***UK harbour seal populations in a European context***

The UK harbour seal population represents approximately 30% of the eastern Atlantic sub-species of harbour seal (Table 6). The declines in Scotland and coincident dramatic increases in the Wadden Sea mean that the relative importance of the UK population is declining.

*Table 6.* ***Size and status of European populations of harbour seals. Data are counts of seals hauled out during the moult.***

| Region | Number of seals counted[1] | Years when latest data was obtained |
|---|---|---|
| **Scotland** | **25,100** | 2011-2016 |
| **England** | **5,200** | 2016 |
| **Northern Ireland** | **900** | 2011 |
| **UK** | **31,200** | |
| Ireland | 3,500 | 2011-12 |
| Wadden Sea-Germany | 15,900 | 2015[2] |
| Wadden Sea-NL | 7,700 | 2015[2] |
| Wadden Sea-Denmark | 2,800 | 2015[2] |
| Limfjorden | 1,500 | 2016 |
| Kattegat | 9,400 | 2016 |
| Skagerrak | 2,600 | 2007 |
| Baltic proper | 1,000 | 2013 |
| Baltic Southwestern | 1,000 | 2016 |
| Norway | 7,100 | 2013 |
| Iceland | 7,000 | 2016 |
| Barents Sea | 1,900 | 2010 |
| **Europe excluding UK** | **61,400** | |
| **Total** | **92,600** | |

[1]Counts rounded to the nearest 100. They are minimum estimates of population size as they do not account for proportion at sea and in many cases are amalgamations of several surveys.
[2]A partial count of the Wadden Sea was obtained out in 2016, giving preliminary estimates of 2,150 in Denmark, 14,000 in Germany and 8,200 in The Netherlands.

Data sources: ICES Report of the Working Group on Marine Mammal Ecology 2014; Desportes,G., Bjorge,A., Aqqalu, R-A and Waring,G.T. (2010) Harbour seals in the North Atlantic and the Baltic. NAMMCO Scientific publications Volume 8; Nilssen K, 2011. Seals – Grey and harbour seals. In: Agnalt A-L, Fossum P, Hauge M, Mangor-Jensen A, Ottersen G, Røttingen I,Sundet JH, and Sunnset BH. (eds). Havforskningsrapporten 2011. Fisken og havet, 2011(1).; Härkönen,H. and Isakson,E. 2010. Status of the harbour seal (*Phoca vitulina*) in the Baltic Proper. NAMMCO Sci Pub 8:71-76.; Olsen MT, Andersen SM, Teilmann J, Dietz R, Edren SMC, Linnet A, and Härkönen T. 2010. Status of the harbour seal (*Phoca vitulina*) in Southern Scandinavia. NAMMCO Sci Publ 8: 77-94.; Galatius A, Brasseur, S, Czeck R et al, 2016, Aerial surveys of harbour seals in the Wadden Sea in 2016, http://www.waddensea-secretariat.org; Härkönen T, Galatius A, Bräeger S, et al HELCOM Core indicator of biodiversity Population growth rate, abundance and distribution of marine mammals, HELCOM 2013, www.helcom.fi; http://www.fisheries.is/main-species/marine-mammals/stock-status/; http://www.nefsc.noaa.gov/publications/tm/tm213/pdfs/F2009HASE.pdf; https://www.hafogvatn.is/en/research/harbour-seal/harbour-seal-census. http://www.nammco.no/webcronize/images/Nammco/976.pdf, Nilssen K and Bjørge A 2014. Seals – grey and harbor seals. In: Bakketeig IE, Gjøsæter H, Hauge M, Sunnset BH and Toft KØ (eds). Havforskningsrapporten 2014. Fisken og havet, 2014(1). Jonas Teilmann pers com.

| 2. What is latest information about the population structure, including survival, fecundity and age structure of grey and harbour seals in UK and European waters? Is there any new evidence of populations or sub-populations specific to local areas? | MS Q2;<br>Defra Q2; |
|---|---|

## Grey seals

**There is evidence for regional differences in grey seal demographics but detailed information on vital rates are lacking. Regional information on fecundity and survival rates would improve our ability to provide advice on population status. However, this would require considerable new investment in resources.**

**There is no new information with which to assess the substructure of the grey or harbour seal populations and therefore no new evidence of sub-populations specific to local areas.**

***Age and sex structure***

While the population was growing at a constant (i.e. exponential) rate, the female population size was directly proportional to the pup production. Changes in pup production growth rates imply changes in age structure. In the absence of a population-wide sample or a robust means of identifying age-specific changes in survival or fecundity, we are unable to accurately estimate the age structure of the female population.

An indirect estimate of the age structure, at least in terms of pups, immature and mature females is generated by the fitted population estimation model. The model takes information from the field studies described below as priors (SCOS-BP 17/02) and generates posterior distributions for the main demographic parameters; fecundity, pup survival and estimates of adult female (1+ age classes) and sex ratio (SCOS-BP 17/01). As currently structured the model fits a single global estimate for each of these parameters and fits individual carrying capacity estimates for each region to account for differing dynamics through density dependent pup survival.

***Survival and fecundity rates***

The only contemporary data that we have on fecundity and adult survival in UK grey seals has been estimated from long term studies of marked or identifiable adult females at two breeding colonies, North Rona and the Isle of May. Results of these studies together with branding studies in Canadian grey seal populations and historical shot samples from the UK and Baltic have been used to define priors for a range of demographic parameters (SCOS-BP 17/02).

In the model used to generate the 2015 and 2016 estimates, density dependence acts through pup survival only, so the fitted values are an estimated fecundity of 0.9 (standard error (SE) 0.06), a constant adult female survival rate of 0.95 (SE 0.01) and a maximum pup survival rate of 0.51 (SE 0.08), i.e. the pup survival rate in the absence of any density dependent control. The fitted values of the demographic parameters are sensitive to the population sex ratio for which we do not have good information. The reported values are produced by a model run with a prior on the sex ratio multiplier of 1.7 (SE 0.02), i.e. seven males to every ten females.

The fitted global parameter estimates are strikingly similar to estimates derived from a long term study of branded grey seals in Canada. In a preliminary study of re-sightings of seals branded as pups on Sable Island, adult female survival was estimated to be 0.92, 0.91, and 0.88 for pups marked in 1985, 1986 and 1987, respectively[8]. Den Heyer and Bowen[9] used a Cormack-Jolly-Seber model to estimate age- and sex-specific adult survival from a long term brand re-sighting programme on Sable Island, effectively an expanded and greatly extended version of the data used by Schwarz and Stobo[6]. Average adult survival was high (male=0.943, SE=0.03; female=0.976, SE=0.01), but male grey seals had lower survival at all ages. The survival rate estimate for adult females is above the upper limit of the prior used in the 2016 model runs. In fact, the Sable data suggests that adult female survival between 4-24 years is 0.989 and then decreases to 0.904 for ages 25+. For males the equivalent rates are 0.97 and 0.77.

Den Heyer and Bowen[7] estimated survival rates of male and female branded seals at Sable Island. The differential survival of males and females would produce an effective sex ratio of 1:0.7 if maximum age is set to 40, reducing to 1:0.69 if maximum age is set to 45. This estimate is remarkably similar to the prior used in the 2016 model runs.

Survival rates and fecundity estimates for adult female grey seals breeding at North Rona and the Isle of May have been estimated from re-sightings of permanently marked animals[10]. Estimates of fecundity rates for populations of marked study animals, adjusted for estimates of unobserved pupping events were 0.79 (95% CI: 0.76 - 0.81) and 0.82 (95% CI: 0.79 - 0.84) for North Rona and the Isle of May, respectively.

***Regional differences in grey seal demographics and genetics***

The difference in population trends between regions for UK grey seals suggests underlying regional differences in demographics. On the basis of genetic differences there appears to be a degree of reproductive isolation between grey seals that breed in the south-west (Devon, Cornwall and Wales) and those breeding around Scotland[11] and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona[12]. Recent telemetry data suggest that there may be significant mixing between these populations outwith the breeding season[13] e.g. observed movements of adult seals between summer haulout sites in Northern France and both the Scottish east coast and Inner Hebrides and between the Wadden Sea and Orkney.

The very rapid increases in pup production at colonies in the Southern North Sea in England, the Netherlands and Germany all point to large scale recruitment to those colonies from colonies in the Northern North Sea[14].

## Harbour seals

**Knowledge of UK harbour seal demographic parameters (i.e. vital rates) is limited and therefore inferences about the population dynamics rely largely on count data from moulting surveys. Information on vital rates would improve our ability to provide advice on population status. At present vital rate estimates for UK harbour seals are only available from a long term study of the**

[8]Schwarz, C.J. & Stobo, W.T. 2000. Estimation of juvenile survival, adult survival, and age-specific pupping probabilities for the female grey seal (*Halichoerus grypus*) on Sable Island from capture-recapture data. *Canadian Journal of Fisheries and Aquatic Sciences*, 57, 247-253.
[9]Den Heyer, C. E., and W. D. Bowen,. 2016. Estimating changes in vital rates of Sable Island grey seals using mark-recapture analysis. *DFO Can. Sci. Advis. Sec. Res. Doc*. 2016/nnn. vi + xx p.
[10]Smout, S., King R., Pomeroy P. Submitted. Environment, body mass and vital rates in a marine top predator. Proceedings of the Royal Society.
[11]Walton, M. & Stanley, H.F. 1997. Population structure of some grey seal breeding colonies around the UK and Norway. European Research on Cetaceans. *Proceedings 11th Annual Conference of European Cetacean Society*. 293-296.
[12]Allen, P.J., Amos, W., Pomeroy, P. & Twiss S.D. 1995. Microsatellite variation in grey seals (*Halichoerus grypus*) shows evidence of genetic differentiation between two British breeding colonies. *Molecular Ecology* 4(6): 653-662.
[13]Russell, D. J. F., B. McConnell, D. Thompson, C. Duck, C. Morris, J. Harwood, & J. Matthiopoulos. 2013. Uncovering the links between foraging and breeding regions in a highly mobile mammal. *Journal of Applied Ecology* 50 (2):499-509.
[14]Brasseur, S. M. J. M., van Polanen Petel, T. D., Gerrodette, T., Meesters, E. H.W.G., Reijnders, P. J. H. and Aarts, G. 2015. Rapid recovery of Dutch gray seal colonies fueled by immigration. *Marine Mammal Science*, 31: 405–426. doi:10.1111/mms.12160

**Loch Fleet population. However, studies are underway to obtain similar data from new sites in Orkney and western Scotland.**

***Age and sex structure***

The absence of any extensive historical cull data or a detailed time series of pup production estimates means that there are no reliable data on age structure of the UK harbour seal populations. Although seals found dead during the PDV epidemics in 1988 and 2002 were aged, these were clearly biased samples that cannot be used to generate population age structures.

***Survival and fecundity rates***

Survival estimates among adult UK harbour seals from photo-ID studies carried out in NE Scotland have been published[15,16]. This resulted in estimates of 0.95 (95% CI 0.91-0.97) for females and 0.92 (0.83-0.96) for males.

A population model for the Moray Firth harbour seals has been developed to investigate the sensitivity of the population to changes in various vital rates. The model suggests that even small changes in the survival of adult females could result in a decline in the population. Further details of the model and the potential impact of various covariates were given in SCOS-BP 15/07.

A study investigating survival in first year harbour seal pups using telemetry tags was carried out in Orkney and on Lismore in 2007. Survival was not significantly different between the two regions and expected survival to 200 days was very low at only 0.3[17].

The apparent fecundity of the large harbour seal population in The Wash has shown extremely wide changes since the early 2000s. The rate has been approximately double that of earlier estimates and much higher than in the larger population in the Wadden Sea[6].

***Genetics***

Genetic data from a study directed toward resolving patterns of population structure of harbour seals from around the UK and adjacent European sites[18] has recently been added to (with funding from Scottish Natural Heritage) and combined with the population trend and telemetry data to investigate source-sink dynamics of harbour seal populations. By estimating connectivity between management areas and comparing them with the regional trends in population abundance, the degree of demographic independence and the importance of fecundity, survival or immigration to the persistence of the different harbour seal management areas is being investigated.

[15]Cordes, L.S. & Thompson, P.M. 2014. Mark-recapture modelling accounting for state uncertainty provides concurrent estimates of survival and fecundity in a protected harbor seal population. *Marine Mammal Science* 30(2): 691-705.

[16]Mackey, B.L., Durban, J.W., Middlemas, S.J. & Thompson, P.M. 2008. A Bayesian estimate of harbour seal survival using sparse photo-identification data. *Journal of Zoology*, 274: 18-27

[17]Hanson, N., Thompson, D., Duck, C., Moss, S. & Lonergan, M. 2013. Pup mortality in a rapidly declining harbour seal (*Phoca vitulina*) population. *PLoS One*, 8: e80727.

[18]Olsen, M.T., V. Islas, J.A. Graves, A. Onoufriou, C. Vincent, S. Brasseur, A.K. Frie & A.J. Hall 2017. Genetic population structure of harbour seals in the United Kingdom. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 0: 1-7.

## Harbour Seal Populations

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| **3. Is the existing harbour seal decline recorded in several local areas around Scotland continuing or not and what is the position in other areas?** | MS Q3 |

**Rapid declines are continuing in Orkney and along the East coast of Scotland. Counts in the Moray Firth are variable, but apparently stable. Counts also appear stable in the Western Isles and Shetland. Counts on the West coast of Scotland indicate a large increase over the last decade. The most recent composite count for Scotland for 2011 to 2016 is 25% higher than the equivalent estimate for 2007-2009. Counts for the East coast of England also appear stable. Overall the harbour population in the UK is increasing slowly, but the status of the local sub-populations varies around the UK.**

As reported in SCOS 2008 to 2016, there have been general declines in the counts of harbour seals in several regions around Scotland but the declines are not universal with some populations either stable or increasing. Details of trends are presented in response to Q1 above and in SCOS-BP 17/03.

In Shetland the 2015 count was 12% higher than the previous count in 2009, an average annual increase of 1.7%. The most recent count of 15,184 in the large West Scotland Management Area represents a 43% increase between 2009 and 2015, equivalent to an average annual increase of 5.3%. Counts in the Southwest Scotland Seal Management Area indicate a 23% increase between 2009 and 2015, equivalent to an average annual increase of 3%.

Conversely, there have been continuing declines in the Firth of Tay and Eden Estuary SAC, where the 2016 count of 51 represents a 90% decrease from the mean counts before 2002, and in Orkney where the 2016 count of 1,349 represents a 78% decrease since 1997. In the Moray Firth there is considerable variability in the August total counts for the entire region. The 2014 and 2015 surveys produced the lowest counts in the time series but the 2016 count was 25% higher. Overall there has been no significant trend in the counts of the Moray Firth since 2000.

The composite count for all of Scotland, based on recent (2015-2016) surveys in all areas except the Western Isles (2011), is approximately 25% higher than the previous composite count based on 2007-2009 surveys, representing a 3% p.a. increase over the last seven years (Figure 5; Table 5). The current estimate is about 15% lower than the equivalent for surveys in 1997-1998.

The combined count for the Southeast England management unit in 2016 (5,199) was 10% higher than the 2014 and 2015 counts. The Southeast England population has returned to its pre-2002 epidemic levels (Figure 5). Pup production in the Wash continues to increase at around 7.5% p.a[19].

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| **4. What is the latest understanding of the causes of the recent decline in harbour seals? It would be useful to have a brief (1 page) updated summary of the causal factors so far eliminated as significant, the causal factors that remain contributory and the causal factors considered most likely to be significant and which should be the main focus for investigation.** | MS Q4 |

[19] http://www.smru.st-andrews.ac.uk/files/2017/09/Report-on-the-distribution-and-abundance-of-harbour-seals-during-the-2015-and-2016-breeding-seasons-in-The-Wash_2016.pdf

**A wide range of potential causes of the decline in Scottish harbour seals in some regions has been discussed at previous SCOS meetings (Table 7). The causal mechanisms have not yet been identified, but several factors can now be ruled out as primary causes for the decrease in numbers and research efforts are currently focussed on two of the remaining potential mechanisms: interactions with grey seals and exposure to toxins from harmful algae.**

The Sea Mammal Research Unit has been funded by Scottish Government to investigate the causes of the declines. Details of the project and progress to date is given in SCOS-BP 17/04.

Several putative causes have been investigated and can now be ruled out; e.g. a recent analysis of the *Brucella* serological data has confirmed that this bacteria is not likely to be a factor in the decline[20]. A list of potential causes and the current assessment of their likely importance in the observed declines is given in Table 7. Additional work is required to investigate the remaining potential causal factors.

*Table 7.* A list of potential causes and the current assessment of their likely importance in the observed declines of harbour seals***.***

| | Factor | Status | Evidence |
|---|---|---|---|
| **1.** | Fisheries bycatch | No | Data from bycatch observer programmes and strandings and the absence of any major gillnet fisheries in the regions of decline suggest that bycatch is unlikely to be a significant factor in the declines. |
| **2.** | Pollution | No | Levels of persistent organic pollutants are very low in the areas of decline and are highest in regions where populations are increasing[21]. |
| **3.** | Loss of habitat | No | Data from aerial surveys and telemetry studies show no evidence that foraging, moulting or breeding sites have been lost. |
| **4.** | Juvenile dispersal | Possible | Data from genetic studies do not indicate large scale dispersal between regions but may have little power to detect recent changes in recruitment patterns. |
| **5.** | Emigration | No | Telemetry data do not indicate large scale, permanent emigration of seals from areas of decline[22], although temporary relocation between regions may be frequent. |
| **6.** | Entanglement in marine debris | No | Data from stranded seals and from faecal samples from haulout sites indicate that entanglement in marine debris or ingestion of plastics are not major issues for UK seals. |
| **7.** | Legal control | No | Introduction of the Marine (Scotland) Act 2010 and the licensing system is ensuring the declining populations are protected. |

[20]Kershaw, J.L., Stubberfield, E.J., Foster, G., Brownlow A., Hall, A.J. and Perrett L.L. In press. Exposure of harbour seals (*Phoca vitulina*) to *Brucella* in declining populations across Scotland. *Diseases of Aquatic Organisms*.
[21]Hall, A.J. & Thomas, G.O. 2007. Polychlorinated biphenyls, DDT, polybrominated diphenyl ethers and organic pesticides in United Kingdom harbor seals - mixed exposures and thyroid homeostasis. *Environmental Toxicology Chemistry*, 26, 851-861.
[22]Sharples, R.J., Moss, S.E., Patterson, T.A. & Hammond, P.S. 2012. Spatial Variation in Foraging Behaviour of a Marine Top Predator (*Phoca vitulina*) Determined by a Large-Scale Satellite Tagging Program. *PLoS ONE*, 7.

| | | | |
|---|---|---|---|
| **8.** | Infectious disease | Unlikely | No evidence of an unusual mortality from strandings or seals taken into rehabilitation. Live capture-release studies show no evidence of disease in areas. No evidence that Brucella infection is responsible[18]. However, other esoteric or secondary disease agents may still be a factor. |
| **9.** | Prey quality and availability | Possible | It is not possible to rule out changes in the prey quantity or quality as factors involved in the decline of harbour seals. |
| **10.** | Competition with other marine predators | Possible | Competition for prey with the increasing grey seal population and/or other marine predators cannot be ruled out. |
| **11.** | Predation | Possible | Predation by grey seals[23] and killer whales is still being reported at several locations. |
| **12.** | Toxins from harmful algae | Possible | Domoic acid and saxitoxin continue to be detected in seals[24] and their prey. |

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| **5. In light of the latest information, should the Scottish Government consider introducing any additional seal conservation areas to protect vulnerable local harbour seal populations or, alternatively, should it consider revoking any existing seal conservation areas? It would be particularly useful to have views on the utility of the current Western Isles Conservation Area.** | MS Q5 |

**Information on the causes of the declines is required for SCOS to give advice on the need for changes to conservation actions. On the basis of continued declines or lack of increases in all affected areas SCOS recommends that the measures to protect vulnerable harbour seal populations should remain in place, but no new conservation measures are proposed. Conservation orders are currently in place for the Western Isles, Northern Isles and down the east coast as far as the border.**

The dramatic decline in the population of harbour seals in the Firth of Tay and Eden Estuary SAC is a clear cause for continued concern. In addition, a further decline was seen in Orkney (see SCOS-BP 17/03 and answer to Q1 and 2 above). The potential biological removal (PBR) is calculated for each region for each year (SCOS-BP 16/08) and the recovery factor is reviewed annually based on the latest survey data.

Conservation areas are currently designated for the Western Isles, Northern Isles and down the east coast as far as the border.

The 2011 survey in the Western Isles indicated that the population had increased since the 2007-09 surveys and was close to the 1996-97 levels. The adjacent and much larger West coast population is at an all-time high since surveys began. In 2016 SCOS advised that reconsideration of conservation measures for the Western Isles population should be deferred until the completion of the next census. The Western Isles are being surveyed in summer 2017 and results should be available for

[23]Brownlow, A., Onoufriou, J., Bishop, A., Davison, N. & Thompson, D. 2016. Corkscrew Seals: Grey Seal (*Halichoerus grypus*) Infanticide and Cannibalism May Indicate the Cause of Spiral Lacerations in Seals. *PLoS ONE*, 11.

[24]Jensen, S.K., Lacaze, J.P., Hermann, G., Kershaw, J., Brownlow, A., Turner, A. *et al.* 2015. Detection and effects of harmful algal toxins in Scottish harbour seals and potential links to population decline. *Toxicon*, 97, 1-14.

SCOS 2018. SCOS would therefore continue to recommend deferring any decision on changes to the Western Isles Conservation Area status until the 2018 meeting.

## Seal Legislation

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| **6. Does the Committee consider that there is a significant scientific requirement or advantage to updating the Conservation of Seals Act 1970, for example, definitions and applications of closed seasons, the netsmen's defence and the potential for the introduction of mandatory recording and/or licencing of shooting?** | **Defra Q9** |

**SCOS recommend that there should be a requirement for mandatory reporting of seals killed. From both scientific and management perspectives the absence of any requirement to record and report on numbers of seals killed in England and Wales is a major omission that prevents any assessment of the effects of seal shooting.**

**For long-lived, annually breeding species such as grey and harbour seals the enforcement of closed seasons associated with the breeding seasons has little effect on the population consequences of removals. From an animal welfare perspective, removal of lactating females will inevitably lead to starvation of their pup and should be avoided.**

## Seal Licensing and PBRs

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| **7. What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system? This seeks an update of the PBR for seal licensing.** | **MS Q6** |

**Provisional regional PBR values for Scottish seals for 2018 are given in SCOS-BP 17/05. The PBR for harbour seals in Orkney has been reduced by approximately 30% due to recent survey results. Regional PBRs for grey seals have increased by 50-67% due to revised population estimates and local population increases.**

PBR values for the grey and harbour seal "populations" that haul out in each of the ten Seal Management Areas in Scotland are presented in SCOS-BP 17/05. Sets of possible values are tabulated for each area with different values of recovery factor. A value is suggested for this parameter in each population, the resulting PBR is highlighted, and a rationale is provided for each suggestion. The PBR values are calculated using the latest confirmed counts in each management area.

The latest survey count for harbour seals in the Orkney and North Coast management region was 30% lower than the previous estimate, resulting in a 30% lower PBR for that management region.

The overall PBR for grey seals in Scotland has increased by 67%. This is in part due to higher counts in Orkney and North coast region but is mainly due to a revised estimate of the ratio between grey seal summer counts and the local population size. The revised estimate is both higher and more precise (SCOS-BP 16/03) and as a consequence the PBR estimate is 50% higher than previously reported.

Recovery factors have been held constant in all management regions.

## Seals and Marine Renewables

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| **8. What is the current state of knowledge of interactions actual or potential between seals and marine renewable devices and possible mitigation measures? What are the questions that remain to be addressed?**<br><br>**What progress is being made in understanding how seals behave around tidal turbine devices, including diving behaviour, and about what might be an appropriate avoidance rate to be applied in collision risk modelling?** | MS Q7;<br>Defra Q7 & 8; |

**Since reporting in 2016 (see SCOS Advice 2016), there have been a number of published updates and preliminary reports of studies on the interactions between seals and marine renewable devices (wind, wave, and tide). Harbour seals showed avoidance of pile driving activity out to ranges of 25km, but did not show avoidance of general construction activity or of operational wind farms. Tests of Acoustic Deterrent Devices (ADDs) as mitigation for pile driving showed that seals exhibited behavioural responses out to 1km range. ADDs may provide improved mitigation at close range compared to current visual observation methods. Telemetry studies at Strangford Lough showed that harbour seals continued to swim past operational tidal turbines. Harbour seals exposed to experimental play back of tidal turbine noise showed significant avoidance within 500m of the source. For tidal turbines, the most effective mitigation for reducing collision risk would be to consider this risk at the turbine design stage and include engineering mitigation measures through early design modifications. Currently proposed mitigation methods are generally based on detection and deterrence.**

**Wind**

Previous results of a behavioural study during the construction of a wind farm using data from GPS/GSM tags on 24 harbour seals in the Wash were reported to SCOS in 2016. In summary, results showed that seals were not excluded from the vicinity of the windfarm during the overall construction phase but that there was clear evidence of avoidance during pile driving, with significantly reduced levels of seal activity at ranges up to 25km from piling sites. Within 2hr of cessation seal distribution returned to pre-piling levels[25]. Analysis of the at sea locations of individual seals during pile driving showed that the closest distance of each seal to pile driving varied from 4.7 to 40.5 km[26]. Based on estimates of sound exposure during piling operations half of the tagged harbour seals were predicted to have been exposed to sound levels that exceeded published auditory damage thresholds for pinnipeds[27]. However, it should be highlighted that these are predictions of auditory damage in marine mammals and there is considerable uncertainty about exposure criteria for impulsive sounds such as pile driving[27].

Recently, further tag deployments on harbour seals which coincide with piling activity at wind farm developments have been carried out in East Anglia and the Moray Firth. A total of 20 seals in the Wash were tagged with GPS/GSM tags in October 2016 and early results suggest that all seals were exposed to pile driving noise during their at-sea trips. Between February and March 2017,

[25]Russell, D.J.F., Hastie, G.D., Thompson, D., Janik, V.M., Hammond, P.S., Scott-Hayward, L.A.S. *et al.* 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology*, 53, 1642-1652.
[26]Hastie, G.D., Russell, D.J.F., McConnell, B., Moss, S., Thompson, D. & Janik, V.M. 2015. Sound exposure in harbour seals during the installation of an offshore wind farm: predictions of auditory damage. *Journal of Applied Ecology*, 52, 631-640.
27 Southall, B.L., Bowles, A.E., Ellison, W.E., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D., MIller, J.H., Nachtigal, P.E., Richardson, W.J., Thomas, J.A. & Tyack Peter, L. (2007) Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals, 33, 411-521.

immediately prior to the start of pile driving for an offshore wind farm, 31 harbour seals were tagged with GPS/GSM tags in the Moray Firth in a combined Aberdeen University and SMRU project. The majority of these seals were individuals for which historical behavioural and reproductive parameters are known (from long term Photo ID studies); this potentially provides the opportunity to link behavioural responses to pile driving with life history data and measure the effects of pile driving to survival and fecundity.

To date there have been few studies of grey seal movements in relation to wind farm developments. In 2015 the Department for Energy and Climate Change (DECC) funded the deployment of total of 21 GPS tags on grey seals at Donna Nook and Blakeney. There was extensive overlap between grey seal movements and present and planned windfarms; 17 of the 21 individuals entered at least one operational wind farm. There was no indication of overt avoidance or use of windfarms, or other anthropogenic structures. Results of this study are presented in detail in Russell et al.[28].

Grey seals have been tracked in the vicinity of pile driving activity in the Netherlands coastal zone[29]. Changes in dive patterns and possible aversive reactions were observed in approximately a quarter of recorded exposures to piling noise. Seals tracked in the vicinity of operational windfarms in Denmark made frequent transits and did not apparently react to the presence of wind turbines[30].

**Mitigation**
Operational protocols to minimise the likelihood of harm to seals during pile driving operations (published by the Joint Nature Conservation Committee (JNCC) in 2010[31]) and the use of bubble curtains to attenuate the noise from piling were described in SCOS 2015.

The use of acoustic deterrent devices (ADDs) as potential measures to mitigate the effects of pile driving on seals has been tested during a series of controlled exposure experiments with tagged harbour seals and results were reported to SCOS 2015. All seals tested out to a range of 1km showed an identifiable change in behaviour. However, not all responses resulted in straight forward movement away from the sound source and responses varied depending on the particular circumstances of the experiment and probably the motivation and status of the subjects. In contrast, recent results of a series of playbacks of a simulated Lofitech ADD (played through an underwater speaker) to harbour seals suggest a lack of avoidance to the ADD sound signals; the number of seal sightings within 100 m of the playback was significantly higher during ADD playbacks than during the silent controls[32]. However, it should be noted that a difference in the source levels between the two previous studies (193 re 1 µPa root mean squared (RMS) vs 165 re 1 µPa peak-peak) may partly explain the marked differences in the observed seal responses.

**Wave**
Data on the interactions between seals and wave energy devices remains limited. However, SNH-commissioned analyses of land based observer data at the European Marine Energy Centre Billia Croo wave energy test site has recently been published[33]. Observations of marine mammals were

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[28]Russell, D.J.F. 2016. Movements of grey seal that haul out on the UK coast of the southern North Sea. Report to DECC, *OESEA-14-47, Feb 2016*, 18pp.
[29]Kirkwood, R., Aarts, G. and Brasseur, S. 2014. Seal monitoring and evaluation for the Luchterduinen offshore wind farm construction 214. Report number C152/14.
[30]McConnell, B., Lonergan, M. and Dietz R. 2012. Interactions between seals and offshore wind farms. The Crown Estate, 41pp. ISBN: 978-1-906410-34-6.
[31]JNCC. 2010. Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise. *JNCC, Aberdeen*.
[32]Mikkelsen, L., Hermannsen, L., Beedholm, K., Madsen, P.T. & Tougaard, J. 2017. Simulated seal scarer sounds scare porpoises, but not seals: species-specific responses to 12 kHz deterrence sounds. *Royal Society Open Science*, 4.
[33]Long, C. 2017. Analysis of the possible displacement of bird and marine mammal species related to the installation and operation of marine energy conversion systems. *Scottish Natural Heritage Commissioned Report No. 947*.

made from a cliff top (110m high) overlooking the Billia Croo site between 2009 and 2015. Sightings of seals in the water were recorded using high powered binoculars (‘Big Eyes’) and horizontal and declination angles from the viewing tripod were recorded to provide locational information; a total of 1,323 seal sightings were made[30]. Spatially-explicit analyses of the distribution of seals in relation to the location of the wave device test berths were carried out. The results suggest that there is no correlation between changes in seal density and the location of wave device test berths, and the authors conclude that changes in seal distribution were not influenced by the installation and operation of devices[33].

**Tidal**

Since reporting in 2016, analysis of the behaviour of harbour seals and an operating tidal turbine (SeaGen in Strangford Narrows, Northern Ireland) has been completed[34]. This analysed data from 32 harbour seals tagged with GPS/GSM tags; results showed that the turbine did not prevent transit of the animals through the channel and therefore did not result in a ‘barrier’ effect. However, the frequency of transits past the turbine by tagged seals reduced by 20% (95% CI: 10–50%) when the turbine was on, relative to when it was off. This effect was stronger when considering daylight hours only, with a reduction of transit rate of 57% (95% CI: 25–64%). Seals tagged during the operational period transited approximately 250 m either side of the turbine suggesting some degree of local avoidance compared with the pre-installation results.

SNH-commissioned analyses of land based observer data at the European Marine Energy Centre Fall of Warness tidal energy test site has also been published recently[33]. Observations of marine mammals were made from a cliff top (50m high) overlooking the Fall of Warness site between 2005 and 2015. The survey area when viewed from the clifftop, was subdivided into a grid system for recording purposes and the number of seals in each grid cell was recorded during regular scans of the test site; a total of 9,511 sightings of seals (not identified to species level) were made during the observations[33]. Results of spatially explicit analyses suggest that there is no obvious correlation between those grid cells where turbine test berths are located and the estimated change in density of seals between baseline conditions and those expected when devices are installed and operating. Inspection of plots of density change with distance from test berth location suggests that there may be a decrease in density immediately adjacent to the potential impact location (single test berth); however, beyond 1km there is no apparent effect[33]. When harbour seals are considered in isolation, results suggest that grid cells where test berths are located show small but statistically significant reductions in density with the installation of infrastructure. However, these cells variously show increases and decreases in estimated density with progression through the site impact levels (devices onsite but not operational and devices installed and operational), but none of these changes are statistically significant. The plots of density change with distance from test berth indicate very little variation with distance away from the test berth location, suggesting that harbour seal abundance may not be influenced by the location of a test berth[33].

The results of a NERC funded RESPONSE project have now been published[35]; a series of acoustic playbacks of tidal turbine sounds were carried out in a narrow, tidally energetic channel on the west coast of Scotland. A concurrent programme of land based visual observations of harbour seal activity during signal playbacks (simulated turbine signal based on SeaGen) plus equivalent control signals was made. Further, the behaviour of ten harbour seals was measured through swimming tracks of high resolution UHF/GPS telemetry tagged seals collected in conjunction with the playback trials[23]. Results of this study showed that there was no significant difference in the total numbers of seals sighted within the channel between playback and silent control periods. However, there was a

[34]Sparling, C., Lonergan, M. and McConnell, B. Harbour seals (*Phoca vitulina*) around an operational tidal turbine in Strangford Narrows: No barrier effect but small changes in transit behaviour. *Aquatic Conservation: Marine And Freshwater Ecosystems*: Early view.

[35]Hastie, G.D., Russell, D.J.F., Lepper, P., Elliot, J., Wilson, B., Benjamins, S. & Thompson, D. In Press. Harbour seals avoid tidal turbine noise: implications for collision risk. *Journal of Applied Ecology*.

localised impact of the turbine signal; tagged harbour seals exhibited significant spatial avoidance of the sound which resulted in a reduction in the usage by seals of between 11 and 41% at the playback location. The significant decline in usage extended to 500 m from the playback location at which usage decreased by between 1 and 9% during playback[35]. In practice, these empirical changes in usage could be used directly as avoidance rates when using collision risk models to predict the effects of tidal turbines on seals.

Scottish Government funded work is currently being carried out to assess the physical damage inflicted upon a seal when struck by a turbine blade in a series of collision impact tests; this was carried out on seal carcasses using a simulated turbine blade attached to the keel of a jet drive boat, driven over the carcasses at known speeds (adjusted displacement speeds varied from 2.07 to 5.67 $m.s^{-1}$ during initial trials)[36]. Post-trial radiographs of each seal showed no discernible evidence of skeletal damage; cranial, abdominal and pelvic bones remained intact. Carcasses were necropsied and again no indications of damage to visceral organs were apparent. These results suggest that collisions with the tips of tidal turbines at these speeds are unlikely to produce serious or fatal injuries in grey seals. However, more recent trials at a range of higher speeds (between 9.3 $m.s^{-1}$ and 10.3 $m.s^{-1}$) revealed varying degrees of spinal fracture and three out of five seals showed signs of damage to the rib-cage. Massive diaphragmatic rupture was also found in all cases. These results indicate that collisions with the tip of a tidal turbine blade travelling at >10.3 $m.s^{-1}$ would be lethal to a juvenile grey seal. Additional trials to identify damaging impact speed thresholds are ongoing.

**Mitigation**

For tidal turbines, the most effective mitigation for reducing collisions would be to consider this risk during the design stage and include engineering mitigation measures through design modifications.

In terms of operational mitigation, the only method that has been attempted for tidal turbines at this stage is the shutdown protocol at Strangford Lough; this required observers to monitor the outputs of an active sonar system on the turbine and effect an automated shutdown if a target thought to be a marine mammal approaches within a pre-defined mitigation zone. However, this is clearly effort intensive and expensive and therefore not a viable option; automated sonar detection systems have been developed and may prove to be an effective alternative[37]. Alternative operational mitigation measures that have the potential to reduce the risk of collisions include the use of ADDs to deter seals from approaching turbines. However, given that behavioural responses by animals are likely to be highly context specific and will depend on factors such as age class, motivation of the animal to remain in the area, and prior exposure history, it is perhaps not surprising that reports of the effectiveness of ADDs are mixed. The use of ADDs was summarised for SCOS 2013.

A report detailing the current state of knowledge and identifying the priority areas for research was drafted by SMRU for Scottish Government and updated in 2016[38].

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[36] Thompson, D. and Onoufriou, J. 2016. Marine Renewable Energy - Individual consequences of tidal turbine impacts. *Report to Scottish* Government MRE2, Sea Mammal Research Unit, University of St Andrews.

[37] Sparling, C.E., Gillespie, D.M., Hastie, G.D., Gordon, J.C.D., MacAulay, J.D. J., Malinka, C.E., Wu, G-M. & McConnell, B.J. (2016) Scottish Government Demonstration Strategy: Trialling methods for tracking the fine scale underwater movements of marine mammals in areas of marine renewable. *Scottish Marine and Freshwater Science* Vol 7 Vol 14. Available at: http://data.marine.gov.scot/dataset/scottish-government-demonstration-strategy-trialling-methods-tracking-fine-scale-underwater

38 http://www.smru.st-andrews.ac.uk/research-policy/reports-to-scottish-government/

## Seals and Fisheries

| **9. We have seen increasing complaints from the fishing industry in certain areas where reports of depredation of large percentages of catch are reported. There is concern around interactions between fishers and seals and the use of lethal means of control. Can the Committee provide advice on what the extent of the issue is in specific problem areas?** | Defra Q11 |
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**SCOS is not aware of any information on the extent of the issue in England and Wales. Some work has been done in Scotland to address the interactions of seals with salmon fisheries. Work with river boards has focused on the use of acoustic deterrent devices to limit access by seals to particular salmon rivers, and identifying individual problematic seals for tagging or removal. Modifications to coastal (stake) salmon nets and the use of acoustic deterrent devices have been shown to be effective in limiting if not eliminating depredation.**

More widely, there are anecdotal accounts that seals cause considerable damage to the catch of many fishermen (Figure 6). Static net fisheries (gillnets, tangle nets etc.) are particularly susceptible, though we are also aware anecdotally of problems with trawl and hook and line fisheries too. The UK Protected Species Bycatch Monitoring Scheme has collected data for 20 years on the bycatch of marine mammals through on board observations, some of which is associated with depredation. It has also collected information on seal-damaged fish recovered from nets. As yet SMRU have not been able to conduct a quantitative assessment of these data, but are actively pursuing funds to do so at present. Qualitatively, it is clear that damaged fish can sometimes account for the majority of the catch brought on deck in some fisheries and areas. This is bound to represent a significant economic loss at times, but may also represent an additional unaccounted for source of mortality in fish stock assessments. The southwest of England (Celtic Sea and Western Channel) contains a high number of static net fishing vessels and a significant number of seals. This is the area where most current SMRU at-sea monitoring is focused and consequently the area from which most complaints about seal damage are heard. This is not to say that seal depredation is not a problem in other areas or fisheries (see Figure 6), but information from elsewhere is more limited or not up to date.

***Figure 6.*** *Much of the catch rendered unmarketable by seal depredation in this net hauled in Yorkshire.*

The SMRU has been working on this issue in Scotland and in relation to salmon fisheries (wild capture fisheries and angling) for several years, funded by Marine Scotland. Documents are available online[39]. Depredation of salmon by seals from coastal static net fisheries represents a significant economic loss to the fisheries concerned and an additional source of mortality for salmonids, a source of mortality that is probably largely dependent upon the presence of the net fishery. We have shown that modifications to coastal (stake) salmon nets and the use of acoustic deterrent devices are effective in limiting if not eliminating such depredation. Work with river boards has focused on the use of acoustic deterrent devices to limit access by seals to particular salmon rivers, and identifying individual problematic seals for tagging or removal.

There is no requirement to record any lethal measures being pursued in English or Welsh waters, but static net fisheries and Salmon River Boards have been issued with licences to shoot problematic seals as a last resort if non-lethal measures fail, under the Marine (Scotland) Act, and returns are published on Marine Scotland's website quarterly.

## Seals and River Fisheries

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| **10. What is the latest understanding of potential non-lethal options for deterring seals from entering and/or transiting up river systems or, if necessary, relocating them from there? Do you have any additional information to further facilitate the development of non-lethal conflict resolution advice? It would be useful to have a short summary of the latest position on the effectiveness of ADDs in this role. It would also be particularly interesting to have the Committee's views on the options of electric barriers and relocation.** | Defra Q3<br>MS Q8 |

**SCOS is not aware of any additional work having been carried out on these issues since the previous SCOS report. ADDs have been successfully trialled to limit the passage of seals up salmon rivers but there are concerns related to how they are deployed and maintained. Electric field barriers have been shown to be effective in some circumstances. A method for trapping seals in rivers has been developed but is untested. For additional information on the use of ADDs around Marine Renewable Energy installations see Q12 below.**

SMRU has been reviewing measures adopted elsewhere in the world to deter seals from entering salmon rivers, but this review is still ongoing. SMRU continues to develop a means of trapping and translocating seals from rivers, though licencing issues have so far prevented the use of a trap. Current efforts are focused on the design and implementation of a net system to trap seals in rivers. No further work has been conducted on the use of ADDs since SCOS 2016, but they proved physically vulnerable in one river system where they were deployed. SCOS is aware that electric systems are being developed commercially for fish farms to keep seals away from pens but no further information is available at this time and no further research has been undertaken since SCOS 2016.

SCOS is not aware of any data on the effectiveness of relocation of grey or harbour seals. There is anecdotal information on a translocation of one harbour seal in the early 1980s from a site 50km up the River Ouse to The Wash. The seal returned to the river site within a week (M. Fedak (SMRU) pers com). Attempts to relocate harbour seals feeding on salmonids at Ballard Locks in Seattle to Hood Canal (>50km) were abandoned because seals returned to the capture site[40] and harbour seals

[39] (http://www.smru.st-andrews.ac.uk/research-policy/)
[40] NOAA-NWFSC Tech Memo-28: Impact of sea lions and seals on Pacific Coast salmonids. http://www.newportbeachca.gov/home/showdocument?id=1590

have been recorded returning to capture sites from release sites between 21 and 421km distant on the west coast of North America [41].

Capture and relocation has also been attempted for California sea lions (*Zalophus californianus*) and both Australian (*Arctocephalus doriferus*) and New Zealand (*A. forsteri*) fur seals. Sea lion relocation attempts were deemed unsuccessful due to animals returning to their capture sites and although California sea lions are still caught in the Columbia River in Oregon and Washington they are no-longer released back into the wild. In 2016 this resulted in the removal and euthanasia of 59 California sea lions[42]. More than 4500 fur seal relocations were undertaken in Tasmania[43]. 56% were recaptured seals with 3% trapped more than 20 times. Recapture intervals were highly variable, ranging from days to years and within the same year, recapture intervals ranged from 4 to 258 days, mean 36 days.

## Seals and Fish Farms

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| **11. What is the latest understanding of interactions between seals and fin fish farms and possible mitigation measures? It would be particularly interesting to have the Committee's views on non-lethal options including improved nets, ADDs, electric barriers, taste aversion and possible relocation.** | MS Q9; Defra Q3 |

**A review of SMRUs activities in this area was presented at SCOS 2016, and a more detailed literature review was commissioned by Marine Scotland in 2014[44].**

A review currently underway for Marine Scotland has highlighted a lack of directed research into novel deterrent options. Research is warranted into several areas including new netting materials, translocation of problem individuals, implementation of electric gradient deterrents and conditioned taste aversion. At present, very limited trials on translocation and of high-density polyethylene (HDPE) netting are being undertaken by commercial operators. Without scientific oversight the results of such trials may remain equivocal and might not enter the public domain. ADDs have been shown to have limited effectiveness, but are thought to be useful in certain circumstances[45] (see also answer to Q12).

A startle response based ADD system was tested at a marine salmon farm over a 19 month period[46]. Predation was monitored at the ADD protected site with and without signal and at two control sites. Results indicate a 91% reduction in lost fish when comparing predation levels with and without the signal at the test site and 97% when comparing the test site against control sites. Harbour porpoise and otter distribution around the farm were not affected by sound exposure.

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[41] Oliver, GW; Morris, PA; Thorson, PH; et al. 1998. Homing behavior of juvenile northern elephant seals MARINE MAMMAL SCIENCE 14:245-256

[42] FIELD REPORT:2016 Pinniped Research and Management Activities at Bonneville Dam R. Brown, S. Jeffries, D. Hatch and B. Wright. www.westcoast.fisheries.noaa.gov/publications/protected_species/marine_mammals/pinnipeds/sea_lion_removals/loa_and_bonneville_field_report_2016.pdf

[43] Robinson, S., Terauds, A., Gales, R. and Greenwood, M. (2008), Mitigating fur seal interactions: relocation from Tasmanian aquaculture farms. Aquatic Conserv: Mar. Freshw. Ecosyst., 18: 1180–1188. doi:10.1002/aqc.971

[44] Coram, A.J., Gordon, J.C.D., Thompson, D. & Northridge, S. 2014. Evaluating and Assessing the Relative Effectiveness of Acoustic Deterrent Devices and other Non-Lethal Measures on Marine Mammals. *Report to Scottish Government*, Sea Mammal Research Unit, University of St Andrews, St Andrews. http://www.gov.scot/Resource/0050/00504418.pdf

[45] Gotz, T. & Janik, V. M. 2013 Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. Marine Ecology Progress Series. 492, p. 285-302 18 p

[46] Götz, T. & Janik, V. M. 2016 Non-lethal management of carnivore predation: long-term tests with a startle-reflex based deterrence system on a fish farm. Animal Conservation. 19, p. 212-221

A seal module for a generic marine wildlife acoustic deterrence system (FaunaGuard, SEAMARCO, Harderwijk, Netherlands) has been tested on harbour seals in a large pool captive setting[47]. Seals responded by reducing time submerged and/or increased haulout time. An estimated effect threshold suggests that this system would effectively deter harbour seals out to ranges of 200-500m.

Capture and relocation of problem seals is currently under investigation (see answer to Q10 above).

## Use of Acoustic Deterrents

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| **12. Following the 2016 summary of limited evidence available, has there been any further work on understanding of the relative effectiveness of existing models of acoustic deterrents for preventing seal predation at fisheries or fish farms (including locations with or without a high level of cetacean presence)?**<br><br>**What advice can be provided on the use of acoustic deterrent devices (i.e. types, frequencies, trigger mechanisms and usage patterns) that might be most effective in deterring seals without disturbing cetaceans? How might these differ in the scenarios of employment of ADDs at fisheries, fish farms and tidal energy devices respectively?** | MS Q10 & Defra Q4; |

**A comprehensive answer to this question was provided last year (SCOS Advice, 2016, Q 16).**

Two low-frequency 'porpoise friendly' devices are in development by two manufacturers, the 'Genuswave'[48] and the FaunaGuard seal module (*SEAMARCO, Harderwijk, The Netherlands)* (see answer to Q11 above).

Recent research (in Denmark) has also shown that some harbour porpoises avoid the area around a simulated 'Lofitech' ADD, a device which has similar frequency characteristics to the Airmar device widely used at Scottish aquaculture sites[32]. This study, showed that harbour porpoises avoided simulated ADD signals but harbour seals did not and instead appeared to approach the device. This does not prove a lack of effectiveness in mitigating fish farm depredation, but does highlight the lack of scientific evidence supporting their widespread use.

During a series of open water behavioural response trials using the same Lofitech device harbour seals showed avoidance behaviour at ranges of up to 1km from the source[49]. These apparently contradictory results suggest that context is important in determining the reactions of seals to ADD signals.

## Seals and their Non-lethal Management

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| **13. Further to your 2015 advice regarding non-lethal mitigation measures to minimise seal interactions with salmon netting stations, river fisheries, fish** | Defra Q3 |

[47] Ronald A. Kastelein, Manon Horvers, Lean Helder-Hoek, Shirley Van de Voorde, Remment ter Hofstede and Heidi van der Meij 2017. Behavioral Responses of Harbor Seals (Phoca vitulina) to FaunaGuard Seal Module Sounds at Two Background Noise Levels Aquatic Mammals 2017, 43(4), 347-363, DOI 10.1578/AM.43.4.2017.347

[48]Note: The University of St Andrews has a commercial interest in this device.

[49] http://www.smru.st-andrews.ac.uk/files/2015/10/MR8-1_ADD_mitigation_VF2.pdf

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| **farms and marine renewable devises, do you have any additional information to add, which would facilitate the development of non-lethal conflict resolution advice?** | |

**See answers to Questions 10, 11 and 12 above**

## Seal Bycatch

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| **14. What is the latest information on the levels of bycatch in local areas? Are there any areas where it has not been possible to collect seal population/bycatch data and can the Committee provide advice on how to collect additional information?**<br><br>**We noted that the conclusions of SCOS 2015 and 2016 estimated that bycatch of grey seals in particular were high, whilst conversely the UK MSFD indicator for seal abundance and distribution concluded that, throughout their range, grey seals have increased in number. How can we best address these differences in findings and present constant messaging?** | Defra Q13<br><br>Defra Q12 |

**The most recent estimate of seal bycatch in UK fisheries is 610 animals (95% CI 449-1262)[50]. However, this is based on assumptions about observed bycatch rates from sampling that is predominantly in the Western Channel and Celtic Sea, where most gillnet effort is located. Sampling levels are too low in other areas to provide reliable area-specific estimates.**

**Estimated bycatch levels in the Celtic Sea exceed a PBR for the combined grey seal population of SW England, Wales and Ireland. An additional but un-recorded number of seals are bycaught by Irish and French boats operating in the Celtic Sea. Despite the bycatch, grey seal populations in Wales and Ireland are increasing, suggesting that some of the bycaught seals are immigrants from Scottish populations.**

Table 8 below shows the estimates by ICES Division and general area. Apart from around 80 animals caught annually in the North Sea, most of the rest of the bycatch is thought to occur in the Celtic Sea and Channel. Area specific biases have not been explicitly explored in this analysis. Sampling has been focused in 7e,f & g, and no doubt further sampling in areas that have received less attention to date would provide better estimates for those regions.

Area based estimates currently suggest that bycatch rates are highest in the Western Channel and Celtic Sea (380 seal per year) which is largely due to the overlap of high levels of fishing effort and relatively high seal densities. Bycatch rates in the Eastern Channel are estimated at around 120 seals per year. There is a need for a more focused exploration of the relationship between seal density or distance from breeding colonies, in relation to bycatch rates or bycatch probability. More sampling in areas closer to and much further from such sites might help improve our understanding of seal bycatch probability.

[50] Northridge, S. P., Kingston, A. R. & Thomas, L. J. 2017. Annual report on the implementation of Council Regulation (EC) No 812/2004 during 2016, *Report to Defra*. 36 pp. http://randd.defra.gov.uk/Document.aspx?Document=14086_UK812Reportfor2016.pdf

The majority of seal bycatch is recorded in large mesh tangle nets and trammel nets. Effort in these fisheries is highly focused in area 7d,e & f (61% of UK tangle net effort). Sampling has been focused mainly in 7e,f, & g. Another way to explore which areas may have been under-sampled is by comparing sampling effort with fishing effort by area. Areas that are under-sampled and where there is a large amount of effort, or a high density of seals, could benefit from further observational data. These would include 4a (northern North Sea), 4c (southern North Sea), 7d (eastern Channel) and 7f (North Devon and Cornwall and South Wales).

Although the total bycatch estimate of 610 is not a large number when considering the entire UK grey seal population of over 140,000 animals, the local populations around the Celtic Sea, where most bycatch is known to occur are much lower. Total combined pup production in SW England, Wales and Ireland was approximately 4100 in 2014. With the same assumptions as used to derive a PBR for the Welsh grey seal population ($N_{min}$ = 2.3*pup production; FR = 0.5 (SCOS 2016 answer to Q9)) this pup production produces a PBR of 283 grey seals. Using the less conservative recovery factor (FR = 1.0) applied to Scottish grey seal populations would increase this PBR to 566. The current estimated bycatch for UK registered vessels in ICES areas 7 a,e,f,g & j was 391 (Table 8), approximately 40% greater than the conservative PBR.

The estimate derived for UK bycatch in the Southwest will be augmented by bycatches (of unknown extent) in both Irish and French gillnets working the same areas. It therefore seems probable that the actual bycatch is significantly higher than even the non-conservative PBR for the combined SW England, Wales and Ireland population.

*Table 8.* ***Seal bycatch estimates by ICES Division 2016 (from Northridge et. al 2017 table A2.11[50])***

| Region | ICES Division | Estimated total bycatch | Two-Sided 95% LCL | Two-Sided 95% UCL | One-sided 90% UCL |
|---|---|---|---|---|---|
| **North Sea** | 4a | 24 | 20 | 29 | 28 |
| | 4b | 12 | 9 | 21 | 19 |
| | 4c | 42 | 29 | 125 | 110 |
| **West Scotland offshore** | 6b | 17 | 14 | 21 | 20 |
| **Irish Sea** | 7a | 8 | 6 | 26 | 23 |
| **Eastern Channel** | 7d | 120 | 70 | 391 | 341 |
| **Western Channel and Celtic Sea** | 7e | 181 | 138 | 330 | 304 |
| | 7f | 163 | 130 | 248 | 233 |
| | 7g | 16 | 13 | 32 | 29 |
| | 7h | 11 | 8 | 17 | 16 |
| | 7j | 12 | 9 | 18 | 17 |
| **Biscay** | 8abcd | 4 | 3 | 5 | 5 |

Despite the fact that the recorded bycatch levels are high relative to local population estimates, the populations in the region generally still continue to rise. A large proportion of the bycaught seals were assessed to be first or second year animals[50] and first year mortality is thought to be high in grey seals (SCOS-BP 17/02). If the bycatch mortality pre-dates this enhanced pup mortality it may have a relatively small effect on the dynamics of the populations. Notwithstanding such effects, the bycatch is unlikely to be sustainable by local populations. That they continue to increase suggests that the removals include or are being compensated for by immigrants from more distant breeding colonies in Scotland (see Q15 below).

| 15. Does immigration potentially override the negative impact of bycatch in the SW or is bycatch a conservation issue that needs to be kept under review? | Defra Q14 |
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| **Are there any local areas that the Committee feel should be prioritised for management and conservation measures related to bycatch in England and Wales?** | Defra Q15 |

**The scale of bycatch relative to local population size in the Celtic Sea suggests that significant immigration must be occurring (see Q 14).**

**We do not know the immigration rate of grey seals into the Celtic Sea although ongoing telemetry studies with grey seals at Islay, the Monach Isles and the Welsh Dee Estuary may help explore this. The lack of information on the source of seals caught in the Celtic Sea needs to be investigated but the status of local grey seal populations does not indicate an immediate conservation concern.**

**There is too little bycatch information at present to highlight any particular area for conservation concern, but grey and harbour seal populations in England are either increasing or are large and stable.**

Samples from bycaught animals that are suitable for DNA analysis are routinely collected from bycaught seals and have also been collected from grey seal pups at breeding sites in Wales with the help of NRW. Additional samples are required for breeding sites in Ireland and Western Scotland. This sampling in conjunction with ongoing work elsewhere to describe the grey seal genome in more detail should help us to determine the natal origin of the seals caught in nets. Progress on this issue will require additional funding.

The bycatch rate of seals certainly needs to be kept under review from a conservation perspective. Although there is no clear conservation concern at present, the disparity between bycatch rates and local population dynamics in SW Britain suggests that seals from other areas may be being taken. As argued above, the most likely source would be the west of Scotland. Although this population is large and apparently stable, the management implications of a potentially large take in a distant management unit should be monitored.

At present there are no indications that the declines in harbour seals in some seal management regions in Scotland are related to bycatch, English harbour seal populations are increasing and there do not appear to be conservation concerns associated with the observed bycatch rates of grey seals, as yet. However, given the scale of static net fisheries in the southwest, the amount of depredation that is being recorded during bycatch monitoring and the estimate of total bycatch in the region, the western channel and Celtic Sea would seem to be an appropriate area for additional work.

## Metrics for Monitoring Seals

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| **16. Are the current metrics for monitoring seal populations the most a) cost effective and b) appropriate for meeting obligations under various legislative drivers (i.e. the Conservation of Seals Act, the Marine (Scotland) Act, MSFD and the Habitats Directive)? If the current metrics used are not considered the most applicable what additional/alternative metrics can the Committee suggest?** | Defra Q6 |

**A seal monitoring options paper was drafted by the SMRU and tabled at the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) in June 2017. The report discusses current monitoring of seals (abundance and distribution, bycatch and seal strandings) and the legislative drivers for this work as well as enhanced monitoring options that could be considered in future.**

**A number of long term research projects are highlighted that could form the basis of future options, particularly to identify population pressures, including: estimating population demography metrics; pathogen, contaminant and toxin analyses; monitoring seal diet and at-sea seal distribution.**

**Considerable further work would be required in order to design and carry out robust and appropriate monitoring programmes.**

The Marine Science Co-ordination Committee (MSCC) is the steering committee set up to identify opportunities for the alignment and development of marine science to forward implementation of the above strategy (https://www.gov.uk/government/groups/marine-science-co-ordination-committee) and the Marine Assessment and Reporting Group (MARG) provides overall direction to the UK monitoring programmes. It defines monitoring programmes required to meet national, European and international obligations and commitments for assessing the state of, and managing, the marine environment. It oversees and coordinates the activities of the four UK Marine Monitoring and Assessment Strategy (UKMMAS) evidence groups, including the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG). This group provides support to deliver the marine biodiversity assessments and both UK seal species are included in this activity as biodiversity indicators.

The UKMMAS data, monitoring and assessment action plan includes developing monitoring and assessment programmes for all its biodiversity indicators. To this end JNCC have drafted monitoring options papers for seabirds, cetaceans and deep seal benthic habitats as part of the UK Marine Biodiversity Monitoring Programme.

However, as seals have specific legislative drivers, a monitoring options paper was drafted by the SMRU and tabled at HBDSEG in June, after review and comments from the Inter-agency Working Group on Marine Mammals and Marine Scotland.

The aspects discussed in the UK Seal Monitoring Options paper include:

(1) current monitoring of seals (abundance and distribution, bycatch (secondary to the primary objective of this scheme to determine cetacean bycatch) and seal strandings (which are included in the scheme in Scotland but not in England and Wales)) and the legislative drivers for this work

and

(2) enhanced monitoring options that could be considered in future.

For the latter, a number of long term research projects are highlighted. These could form the basis of future options, particularly to identify population pressures, including:

- estimating population demography metrics,
- pathogen, contaminant and toxin analyses,
- monitoring seal diet
- monitoring at-sea seal distribution.

Costings for these options were not included. Considerable further work would be required to design and carry-out robust and appropriate monitoring programmes (particularly how and where to monitor, given the wide distribution, different life history and foraging strategies and population variability of UK seals) to estimate appropriate values for these additional parameters.

## Marine Strategy Framework Directive (MSFD)

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| **17. ICES advice to OSPAR in 2014 suggested assessment units for a variety of marine mammals, including harbour and grey seals. However, the 2017 OSPAR M3 interim assessment deviated from the proposed assessment units for grey seal abundance. At the UK scale there are already seal management areas (SMA) in place for Scotland and provisional seal management units for the remainder of the UK that are utilised in the SCOS reporting. It would be helpful to explore and explain the differences between these in order to clearly define a set of assessment and/or management units that can be consistently used for seal management, conservation and reporting in UK waters.** | Defra Q5 |

**The differences between the various management units or areas for UK grey seals have arisen because of differences in the conservation and management objectives of various legislative drivers and therefore the underlying reasons for their specification. The discrepancy is also because grey seals can undertake large scale movements during foraging. In addition, there are differences between the locations of their breeding colonies and non-breeding haulout sites. During the pupping season, thousands of animals may be associated with a particular colony which is rarely used at other times of the year.**

**For UK waters, the 14 areas used to assess pup production trends and to set PBRs using the summer counts of grey seals hauled out are consistent and can be combined if large assessment units or areas are required depending on the context and requirements of the management drivers.**

The areas designated under the Marine (Scotland) Act, 2010 (10 in Scotland) and those used by the Statutory Nature Conservation Bodies (SNCBs) (an additional 4 in England and Wales) are illustrated in Figure 2, SCOS-BP-17/03. The main driver for these management areas was to enable the Scottish Government to use the potential biological removal (PBR) method to estimate permissible anthropogenic takes for each region and use this information to assess licence applications for seal control and other marine activities (see SCOS BP-17/05).

OSPAR covers 5 regions of which two (Region II: Greater North Sea and Region III: Celtic Seas) are relevant to the UK. During the development of the Ecological Quality Objectives for the North Sea it was agreed that for grey seals the population trend objectives should be based on pup production since that metric has been long established as the most robust for determining changes in population dynamics. Thus the agreed regional subunits were based around the critical breeding areas (Q1, Figure 2 above). These are Orkney; Fast Castle/Isle of May; the Farne Islands; Donna Nook[51]; the French North Sea and Channel coasts; the Netherlands coast; the Schleswig-Holstein Wadden Sea; Heligoland; Kjørholmane (Rogaland).

In 2014 the ICES Working Group on Marine Mammal Ecology[52] were asked by OSPAR to advise on appropriate management units for grey seals in the OSPAR Maritime area, with specific consideration be given to the common indicators (grey seal abundance at breeding and haulout sites). There is a considerable amount of movement of grey seals that occurs (as observed from telemetry data) among the different areas and regional subunits of the North Sea and no evidence to suggest that grey seals on the North Sea coasts of Denmark, Germany, the Netherlands or France are independent from those in the UK. Similarly on the west coast there is considerable movement of animals between France, Ireland western Scotland and Wales. Therefore the Working Group recommended that assessment units at a larger spatial scale would be more appropriate to the MSFD indicator assessments since they are not all based on pup production. Thus a single North Sea unit and a single western Britain, Ireland and western France unit was recommended[38].

For UK waters, the 14 areas used to assess pup production trends and to set PBRs using the summer counts of grey seals hauled out are consistent between areas and can be combined if large assessment units or areas are required depending on the context and requirements of the management drivers. In the 2017 OSPAR Interim assessment it was agreed that comparable abundance metrics, whose trends could be reliably assessed over time, would only be possible for a large assessment unit encompassing the Great North Sea and the UK part of the Celtic Sea. This was again because grey seals forage and move so widely and regularly but also because some populations are assessed from pup production which is converted to total population size (UK and the Netherlands) and others from counts of animals during their spring moult (https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/marine-mammals/seal-abundance-and-distribution/). For the pup production metric, 21 assessment units were used. Those in the UK were equivalent to 14 assessment areas described above (https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/marine-mammals/grey-seal-pup/).

## OSPAR seals abundance assessment

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| **18. The draft conclusions of the OSPAR seals abundance assessment identified a number of areas where the potential course in the decline in seal population remains unclear including:**<br>• **The historical and present dynamic between grey seals and harbour seals. As grey seal populations recover, harbour seals may face increased competitive pressure from grey seals that could have a detrimental effect on their abundance.**<br>• **The increase of additional human pressures such as pollution and underwater noise could influence future growth by determining the level of carrying capacity.**<br>**Can the Committee provide their view on the conclusion of the assessment and suggest a way to address these uncertainties?** | Defra Q10 |

[51] SCOS note that the recently established but now large colonies at Blakeney and Horsey are not included in this list, but their inclusion would not alter the area designations.

[52] ICES. 2014. Report of the Working Group on Marine Mammal Ecology (WGMME), 10–13 March 2014, Woods Hole, Massachusetts, USA. ICES CM 2014/ACOM:27. 234 pp.

**Grey seals may have a detrimental effect on the abundance of harbour seals through competition and or direct predation. Factors such as pollution and noise could also affect the potential population growth. Determining their relative importance will require dedicated research studies, the results of which would inform predictive population dynamics models.**

The draft conclusions of the OSPAR seal abundance assessment highlighted some potential causes for the decline in harbour seals in some regions of the UK. They included increased competition between grey and harbour seals. Information on diet composition and the spatial and temporal abundance of the various prey items as well as overlap in foraging areas all need to be considered before inter-specific competition can be confirmed or quantified.

Research into the diet of grey and harbour seals (funded by Scottish Government with additional support from Natural England) carried out in 2011 and 2012[53,54] indicated that these species do feed on similar prey, at the same time of year and in the same regions. However, the fish size classes preferred by the different species varied. Investigating these aspects empirically to reduce uncertainty will be challenging, both from a logistical and a scientific viewpoint. An accurate assessment of prey availability is essential for assessing the potential for and impacts of competition. Ideally, coordinated diet sampling and foraging behaviour studies need to be carried out for both species simultaneously. Grey seals forage over wide areas so investigating overlap between the species requires a broad geographical spread to ensure that animals foraging in one region but hauling out in another are included. Data on fish prey abundance at the fine scale required is not currently available and can only be collected by dedicated fish surveys which target the foraging areas.

Establishing the level of predation by grey seals on harbour seals and estimating the associated uncertainty for a given region is also likely to be difficult. Cases of grey seal predation on harbour seals are geographically widespread and can be identified post mortem. However, the proportion of dead seals washing ashore and then being reported to the strandings schemes is low. Under-reporting and logistical problems mean that stranding scheme coverage is sporadic in most areas even in Scotland where the Scottish Marine Animal Stranding Scheme has a remit to carry out post-mortem examinations on seals. Those that are reported are often too decomposed for cause of death to be established.

Studies to investigate the impact of both pollution (including emerging contaminants as well as the legacy pollutants) and underwater noise (see Q8 above) continue to be carried out. For example, recent results on the concentrations of organochlorine pollutants in grey seal pups from the Isle of May (SCOS-BP 17/06) suggest a modest but significant decrease in PCBs has occurred between 2002 and 2015, whereas DDT levels have increased over the same period. In both cases, the concentrations measured are below the limits that cause immediate negative health effects in seals. The consequences of the observed changes are unknown and investigation of the impact of PCBs, PBDEs and DDTs on measures of energy balance are continuing. Findings from these studies can be used in risk assessments to estimate their likely effect on populations.

It is unlikely that noise or pollution effects will operate by directly reducing the carrying capacity of the environment. Establishing carrying capacity for any marine mammal population has proven to be extremely difficult against a background poorly documented and changing prey abundance. It will be more challenging when two species with similar foraging capabilities and diets are potentially competing for the same resources.

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[53]Wilson, L.J. and Hammond P.S, 2016. Harbour seal diet composition and diversity. Scottish Marine and Freshwater Science Report, Vol. 7, No. 21, Marine Scotland Science.
[54]Hammond, P.S. and Wilson, L.J. 2016. Grey seal diet composition and prey consumption. Scottish Marine and Freshwater Science Vol. 7, No. 20. Marine Scotland Science.

## Climate change

| 19. What are considered the most likely potentially significant impacts of climate change on seal populations? | Defra Q11 |
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**Ongoing work suggests that both grey and harbour are at risk of range contraction at the southern end of their range under predicted climate changes in both the lowest and highest warming scenarios presented by the IPCC. However these scenarios do not take account of potential prey re-distributions.**

**Climate change impacts may include:**

- **Water temperature changes leading to:**
  - **changes in habitat availability**
  - **changes in prey distribution**
- **Sea level rise leading to**
  - **reduced haulout and breeding site availability**
  - **Increased exposure to wave action and flooding.**
- **Increased exposure to Harmful Algal Blooms**
- **Exposure to novel diseases/pathogens**
- **Changes in coastal use patterns**
- **Changes in predation risk**

Most of the research focus on the impact of climate change on marine mammals has been on arctic species that are threatened by shrinking suitable habitats. Changes in cold temperate waters may also be profound and will likely impact on continental shelf marine predators such as seals. SCOS-BP 17/07 presents a preliminary exploration of potential habitat shifts of both harbour and grey seals, in two scenarios of climate change, using seal telemetry data and environmental grids. Core habitat determined through telemetry locations was projected on the lowest and highest scenarios of warming as determined for the IPCC's 2014 report (SCOS-BP 17/07).

The low warming scenario predicted an overall compression of core habitat, with slight loss of habitat in the northern and extensive habitat loss in the southern edges of distribution in the North Atlantic. In the high warming scenario, there was a general northward shift in predicted core habitat in the North Atlantic for both species. In geographical terms the northern expansion of habitat exceeds the southern contraction so that both species would be predicted to have larger habitat extents in the future. However specific loss of the habitat on the Scotian shelf means that areas currently holding the majority of the grey seals in the western Atlantic will likely be lost.

The present methodology seems to be a useful tool for initial exploration of a species' potential climate-related changes in habitat. However, explicit consideration of prey species responses to climate change will be needed to improve predictions.

In temperate regions environmental changes will probably manifest themselves as changes in prey distributions, abundance and availability as a consequence of oceanographic changes. Earlier stratification of warmer water and changes in the timing of plankton blooms and secondary production blooms will likely have effects throughout the food chain. Such changes have already been detected in the North Sea at several levels of the food chain. Changes in flow patterns and locations of frontal systems may also impact seal foraging habitat quality.

An additional concern is the spread of infection into regions where organisms may not previously had the capacity to survive, due to unfavorable environmental conditions. Coupled with this is the concern about the spread and persistence of antimicrobial resistance. Marine mammals can act as reservoirs and vectors of antimicrobial resistance genes (AMRG) which may have consequences for public health, the treatment of zoonoses and animal fitness. Studies on the occurrence of AMRG in seals are currently being undertaken. Early results in grey seals (females and pups) from the Isle of May suggest that seal gut bacteria have acquired a range of antimicrobial genes.

Associated with assessing the risk of emerging diseases to seals is the need to understand and characterize their immune system. Studies on the nature of early immune protection in grey seals are currently being carried out (SCOS-BP 17/08). Results indicate that the transition between colostrum and mature milk in this species is more rapid than yet found in any other mammal and that immune factors, particularly immunoglobulin G, were unusually persistent throughout lactation.

Continued sea level rise is an inevitable consequence of the projected climate trends. Although projected rises are modest they will encroach on seal haulout and breeding sites. In areas such as the Wash, with mainly intertidal haulout sites, there may be some loss of habitat but the scale of such losses will depend on the extent of sea defence efforts. Where sea defences are abandoned new habitat will likely replace these losses. On existing breeding sites, seals will be more exposed to wave action particularly during storms and this is likely to increase pre-weaning pup mortality. Storm frequency and intensity are both expected to increase further exacerbating such problems.

Potential increased tourism associated with increased summer temperatures around the UK coasts may increase and extend the geographical scope of disturbance issues particularly for harbour seals.

Range shifts of other species in response to temperature changes may expose seals to novel and or increased predation risks.

## <u>Grey seal predation</u>

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| **20. The predation of harbour seal, harbour porpoise and grey seal pups by grey seal has been documented in several countries within the Northeast Atlantic (UK, Germany, The Netherlands, Belgium and France). On 30 April 2017 an ICES workshop 'Predator-prey Interactions between Grey Seals and other marine mammals (WKPIGS)' was held to further explore this issue and to:**<br><br>**a ) Define and harmonise the pathological indicators of a grey seal predation event in marine mammal carcasses;**<br>**b ) Describe the known prevalence and spatio-temporal trends of grey seal predation on other seals and harbour porpoises across the North Atlantic;**<br>**c ) Identify potential environmental or demographic drivers of the behaviour and trends;**<br>**d ) Discuss potential methods to quantify the impact of grey seal predation on harbour seal and harbour porpoise populations and to quantify the importance of cannibalism in grey seals;**<br>**e ) Identify knowledge gaps and develop a collaborative program of research to address these.**<br>**Can you provide a summary of the findings/conclusions from WGPIGS, particularly in relation to b and c above, and, if possible, the workshop report (due for completion on 1 June 2017) appended as an information paper to the SCOS report? Can the Committee also advise on how to best progress the findings/conclusions of the working group?** | Defra Q16 |

**The I.C.E.S. WKPIGS workshop report was not available for the SCOS meeting. A preliminary draft was discussed. The report was published shortly after the SCOS meeting[55] and the executive summary is presented below for information.**

A one day Workshop on Predator-prey Interactions between Grey Seals and other marine mammals (WKPIGS) focused on predatory behaviour of grey seals (*Halichoerus grypus*) towards other grey seals, harbour seals (*Phoca vitulina*) and harbour porpoises (*Phocoena phocoena*) in European waters was convened in April 2017. It was attended by 30 scientists from organisations in six nations across Europe, and the USA and aimed to define and harmonise the pathological indicators of grey seal predation events across nations and to collate data on the prevalence and distribution of such events. A further objective was to discuss methods to aid in detection of predation events and potential population level consequences of reported incidences. The report summarises the presentations and discussions held in each of four workshop sessions: pathological indicators, distribution and prevalence, population consequences and research priorities.

The challenge of ascribing grey seal predation as the cause of a mortality event from limited pathological evidence was discussed. In cases where the behaviour has been observed in pinnipeds, a straight-edged wound margin which spirals around the carcass is typical; however, most cases are not directly observed. Inferring grey seal predation as a cause of death from stranding reports, photographs and necropsies occurs by ruling out other potential causes of death and by examining the macroscopic and microscopic pathology. Decision-trees have been reported elsewhere and the workshop focused on the challenges of distinguishing grey seal predation from grey seal scavenging and from scavenging by other (terrestrial or avian) predators. New techniques examining the histo-pathology of wound margins and forensic (DNA) evidence can aid in detection of tearing of warm tissue (indicator of active predation) and in ruling out predators other than grey seals.
Reported cases of grey seal predation events in Europe were collated and summarised. The behaviour has been detected throughout much of the grey seal range, although information is lacking from some key areas. Seasonal trends of predation on pinnipeds peaked during their respective pupping/mating seasons while cases of predation on harbour porpoises peaked in spring months. A total of 737 cases were reported, peaking in 2016.

The implications of these findings for populations of grey seals, harbour seals and harbour porpoises were limited by the challenges of detecting the true prevalence of the behaviour in the grey seal population. The incidence of grey seal predation on other marine mammals steadily increased over the last 10 years although it is not known if this represents a true increase in prevalence, reflects the steady increase in European grey seal numbers over the same period or is due to an increase in effort and reporting. It was noted that if previously high rates of harbour seal mortality due to grey seal predation were sustained, they could potentially account for observed declines in some populations. Coupled with the rise in European grey seal numbers, this could become the most important driver of local harbour seal extinctions in populations already beyond natural recovery.
Future research priorities include continued standardisation of pathological indicators, development of affordable DNA screening techniques and possible targeted ground surveys of for example, breeding sites where the behaviour has been detected to increase our understanding of prevalence. If possible, telemetry devices could be attached to grey seals exhibiting the behaviour to further study their movements at sea and gain an understanding of the ecological importance of the behaviour from both the individual and population level.

[55] http://www.ices.dk/sites/pub/Publication Reports/Expert Group Report/SSGEPD/2017/01 WKPIGS - Report of the Workshop on Predator-prey Interactions between Grey Seals and other marine mammals.pdf

## Seal Foraging

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| **21. What is SCOS' view on the role of foraging radii of grey seals in defining the spatial scale at which effects on a population, in the context of Habitat Regulations Assessments (HRA) or Environmental Impact Assessments (EIA), should be considered?**<br><br>**In relation to question 2, what is SCOS' view on defining foraging ranges (as above) based on energetics rather than travel distances, especially for weaned pups and adult grey seals outside of the breeding season?** | NRW Q2 & NRW Q3 |

**The various Statutory Nature Conservation Bodies in the UK and N.I. use differing metrics to determine the spatial scale at which anthropogenic activities need to be considered in HRAs and EIAs.**

**Foraging radii and energetics models are used to assess effects of the activities of central place foragers such as colonial breeding seabirds, but are not thought useful for grey seals.**

At present the various SNCBs in the UK apply different criteria for assessing the geographical scale at which anthropogenic activity should be considered with respect to impacts on SAC populations. In practice this means that individual permit/licencing applications are treated on a case by case basis taking into account local conditions and relevant available information. Essentially the information required to make such assessments is an estimate of the probability that an animal impacted by human activity is from or is associated with a particular SAC or other protected population or management unit (This issue has already been discussed in the context of bycatch in the Celtic Sea in answer to Q15 above).

Assessing the spatial scale that needs to be considered in the context of HRA and EIAs requires information on movements between breeding sites and other locations used throughout the year. Russell *et al.*[56] argued that there is little requirement to differentiate at-sea time into 'travelling', 'foraging' and 'resting' and the following discussion does not differentiate between movement types. Also, the discussion below is restricted to movement connectivity and does not cover the likely individual consequence (displacement and/or change in reproductive potential) or population consequence of any anthropogenic disturbance or injury.

Grey seals undertake from one- to 20 or more-day foraging trips to sea. Frequently the departure and return haulout sites are the same, but individuals may also travel hundreds of kilometres to a distant site. This inter-haulout movement means that using 'haulout site specific' foraging trip radii to define MU's as applied to bird movement from breeding colonies[57] is not generally applicable for grey seals.

As capital breeders, grey seals have the ability to store large amounts of energy as blubber. Thus well-provisioned weaned pups and adults have the potential to travel over 1,000 km before starvation. Thus the energetic basis for MU delineation is not appropriate for most animals unless in the special case where they are in poor condition or nutritionally stressed.

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[56]Russell, D.J.F., McClintock, B.T., Matthiopoulos, J., Thompson, P.M., Thompson, D., Hammond, P.S. *et al.* (2015). Intrinsic and extrinsic drivers of activity budgets in sympatric grey and harbour seals. Oikos, 124, 1462-1472.

[57]Thaxter, C.B., Lascelles, B., Sugar, K., Cook, A.S.C.P., Roos, S., Bolton, M. *et al.* (2012). Seabird foraging ranges as a preliminary tool for identifying candidate Marine Protected Areas. Biological Conservation, 156, 53-61.

Grey seal movements are extensive and, biologically, their categorisation into management units risks over-simplification. Indeed, recent studies[58] suggest that Evans et al.'s[59] statement that "Telemetry studies suggest that [grey] seals may make foraging trips to highly localised areas, with animals from a particular locality tending to remain in that region." may need to be revisited.

The advantage of MU's is that that they provide a simple and transparent framework. However, they may not capture the variability and extent of grey seal movement. The latter concern can only be addressed by an analysis of available movement data or the use of genetic markers to identify immigration and emigration between populations.

[58] Russell, D.J.F., McConnell, B., Thompson, D., Duck, C., Morris, C., Harwood, J. *et al.* (2013). Uncovering the links between foraging and breeding regions in a highly mobile mammal. *Journal of Applied Ecology*, 50, 499-509.
[59] Evans, P. G. H. 2012. Recommended Management Units for Marine Mammals in Welsh Waters. *CCW Policy Research Report* CCW.

## ANNEX I

### NERC Special Committee on Seals

Terms of Reference

1. To undertake, on behalf of Council, the provision of scientific advice to the Scottish Government and the Home Office on questions relating to the status of grey and harbour seals in British waters and to their management, as required under the Conservation of Seals Act 1970, Marine Coastal and Access Act 2009 and the Marine (Scotland) Act 2010.

2. To comment on SMRU's core strategic research programme and other commissioned research, and to provide a wider perspective on scientific issues of importance, with respect to the provision of advice under Term of Reference 1.

3. To report to Council through the NERC Chief Executive.

**Current membership**

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| Dr M. Hammill (Chair) | Maurice Lamontage Institute, Canada; |
| Professor A. Hall | Sea Mammal Research Unit, University of St Andrews; |
| Dr F. Daunt | Centre for Ecology and Hydrology, Edinburgh; |
| Dr J. Forcada | British Antarctic Survey, Cambridge; |
| Dr K. Brookes | Marine Scotland, Science, Aberdeen; |
| Dr J. Teilmann | Aarhus University, Denmark; |
| Dr C. Lynam | Centre for Environment Fisheries and Aquaculture Science, Lowestoft; |
| Professor P. Thompson | Institute of Biological and Environmental Sciences, University of Aberdeen; |
| Dr O. Ó Cadhla | National Parks and Wildlife Service, Ireland; |
| Dr D. Mason (Secretary) | Natural Environment Research Council, Swindon Office. |

## ANNEX II

## Questions from Marine Scotland

Dear Mrs Mason

MARINE (SCOTLAND) ACT 2010 (CONSEQUENTIAL PROVISIONS) ORDER 2010: ANNUAL REVIEW OF MANAGEMENT ADVICE

Thank you for your letter of 9 May concerning the next meeting of the Special Committee on Seals on 13 and 14 September 2017 and asking whether the Scottish Government has any specific questions on which it would welcome the Committee's scientific advice.

It would be very helpful if the Committee could provide a general update on seal populations and respond to some more specific questions on particular issues as set out below.

We have, as usual, structured our request for advice from the Committee in two broad categories. The first comprises a shorter than usual list of standard questions seeking a update on some of the key information regularly provided by the Committee in previous years:-

**1. What are the latest estimates of the number of seals in Scottish waters?**

**2. What is the latest information about the population structure, including survival and age structure, of grey and harbour seals in European and Scottish waters? Is there any new evidence of populations or sub-populations specific to local areas?**

Specific questions about improving seal management:-

**Harbour Seal Populations**

3. Is the existing harbour seal decline recorded in several local areas around Scotland continuing or not and what is the position in other areas?

4. What is the latest understanding of the causes of the recent decline in harbour seals? It would be useful to have a brief (1 page) updated summary of the causal factors so far eliminated as significant, the causal factors that remain contributory and the causal factors considered most likely to be significant and which should be the main focus for investigation.

5. In light of the latest information, should the Scottish Government consider introducing any additional seal conservation areas to protect vulnerable local harbour seal populations or, alternatively, should it consider revoking any existing seal conservation areas? It would be particularly useful to have views on the utility of the current Western Isles Conservation Area.

**Seal Licensing and PBRs**

6. What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system? This seeks an update of the PBR for seal licensing.

**Seals and Marine Renewables**

7. What is the latest understanding of interactions actual or potential between seals and marine renewable devices and possible mitigation measures? What are the questions that remain to be addressed?

**Seals and River Fisheries**

8. What is the latest understanding of potential non-lethal options for deterring seals from entering and/or transiting up river systems or, if necessary, relocating them from there? It would be useful to have a short summary of the latest position on the effectiveness of ADDs in this role. It would also be particularly interesting to have the Committee's views on the options of electric barriers and relocation.

**Seals and Fish Farms**

9. What is the latest understanding of interactions between seals and fin fish farms and possible mitigation measures? It would be particularly interesting to have the Committee's views on non-lethal options including improved nets, ADDs, electric barriers, taste aversion and possible relocation.

**Use of Acoustic Deterrents**

10. What advice can be provided on the use of acoustic deterrent devices (i.e. types, frequencies, trigger mechanisms and usage patterns) that might be most effective in deterring seals without disturbing cetaceans? How might these differ in the scenarios of employment of ADDs at fisheries. fish farms and tidal energy devices respectively.

**Climate Change**

11. What are considered the most likely potentially significant impacts of climate change on seal populations?

As in previous years, it is our intention to publish a link to the advice provided by the Committee on the Scottish Government web-site. We will liaise about the timing of that in due course.

I also enclose the information requested on licences issued by the Scottish Government during 2016 under The Marine (Scotland) Act 2010. This information can be found on the Scottish Government web-site through the following link (see Tables 1, 2a and 2b):-
http://www.gov.scot/Topics/marine/Licensing/SealLicensing/2011/2016

I am copying this letter to Defra colleagues for information.

Yours sincerely

IAN WALKER
Marine Conservation

## Questions from Defra

Dear Mrs Mason

CONSERVATION OF SEALS ACT 1970: ANNUAL REVIEW OF MANAGEMENT ADVICE

Thank you for your email letter of 09 May 2017, asking if Defra has any specific questions on which it wishes to receive scientific advice.
The following are standard questions seeking a general update on information regularly provided by the Committee in previous years but relating to seals in English waters on the understanding that each devolved administration would ask similar questions so that a UK wide picture would be provided in the annual SCOS report.

**Seal populations in English waters**

1. What are the latest estimates of the number of seals in English waters?
2. What is the latest information about the population structure, including survival and age structure, of grey and common/harbour seals in English waters and is there any new evidence of populations or sub-populations specific to local areas?

The following are specific questions on improving seal management:-

**Seals and their non-lethal management**

3. Following your 2016 advice regarding non-lethal mitigation measures to minimise seal interactions with salmon netting stations, river fisheries, fish farms and marine renewable devices, and deterring seals from entering and/or transiting up river systems, do you have any additional information to further facilitate the development of non-lethal conflict resolution advice?
4. Following the 2016 summary of limited evidence available, has there been any further work on understanding of the relative effectiveness of existing models of acoustic deterrents for preventing seal predation at fisheries or fish farms (including locations with or without a high level of cetacean presence)?

**Marine Strategy Framework Directive (MSFD)**

5. ICES advice to OSPAR in 2014 suggested assessment units for a variety of marine mammals, including harbour and grey seals. However, the 2017 OSPAR M3 interim assessment deviated from the proposed assessment units for grey seal abundance. At the UK scale there are already seal management areas (SMA) in place for Scotland and provisional seal management units for the remainder of the UK that are utilised in the SCOS reporting. It would be helpful to explore and explain the differences between these in order to clearly define a set of assessment and/or management units that can be consistently used for seal management, conservation and reporting in UK waters.

**Metrics for Monitoring Seals**

6. Are the current matrices for monitoring seal populations the most a) cost effective and b) appropriate for meeting obligations under various legislative drivers (i.e. the Conservation of Seals Act, the Marine (Scotland) Act, MSFD and the Habitats Directive)? If the current matrices used are not considered the most applicable what additional/alternative matrices can the Committee suggest?

**Seals and Marine Renewables**

7. Following the 2016 advice, is there any further understanding of interactions actual or potential

between seals and marine renewable devices and possible mitigation measures?

8. What progress is being made in understanding how seals behave around tidal turbine devices, including diving behaviour, and about what might be an appropriate avoidance rate to be applied in collision risk modelling?

**Seal legislation**

9. Does the Committee consider that there is a significant scientific requirement or advantage to updating the Conservation of Seals Act 1970, For example, definitions and applications of closed seasons, the netsmen's defence and the potential for the introduction of mandatory recording and/or licencing of shooting?

**OSPAR seals abundance assessment**

10. The draft conclusions of the OSPAR seals abundance assessment identified a number of areas where the potential course in the decline in seal population remains unclear including:
    a. The historical and present dynamic between grey seals and harbour seals. As grey seal populations recover, harbour seals may face increased competitive pressure from grey seals that could have a detrimental effect on their abundance.
    b. The increase of additional human pressures such as pollution and underwater noise could influence future growth by determining the level of carrying capacity.

    Can the Committee provide their view on the conclusion of the assessment and suggest a way to address these uncertainties?

**Interaction between fishers and seals**

11. We have seen increasing complaints from the fishing industry in certain areas where reports of depredation of large percentages of catch are reported. There is concern around interactions between fishers and seals and the use of lethal means of control. Can the Committee provide advice on what the extent of the issue is in specific problem areas?

**Seal Bycatch**

12. We noted that the conclusions of SCOS 2015 and 2016 estimated that bycatch of grey seals in particular were high, whilst conversely; the UK MSFD indicator for seal abundance and distribution concluded that, throughout their range, grey seals have increased in number. How can we best address these differences in findings and present constant messaging?
13. What is the latest information on the levels of bycatch in local areas? Are there any areas where it has not been possible to collect seal population/bycatch data and can the Committee provide advice on how to collect additional information?
14. Does immigration potentially override the negative impact of bycatch in the SW or is bycatch is a conservation issue that needs to be kept under review?
15. Are there any local areas that the Committee feel should be prioritised for management and conservation measures?

**Grey seal predation**

16. The predation of harbour seal, harbour porpoise and grey seal pups by grey seal has been documented in several countries within the Northeast Atlantic (UK, Germany, The Netherlands, Belgium, France). On 30 April 2017 an ICES workshop 'Predator-prey Interactions between Grey Seals and other marine mammals (WKPIGS)' was held to further explore this issue and to:
    a ) Define and harmonise the pathological indicators of a grey seal predation event in marine mammal carcasses;
    b ) Describe the known prevalence and spatio-temporal trends of grey seal predation on other seals and harbour porpoises across the North Atlantic;

c ) Identify potential environmental or demographic drivers of the behaviour and trends;
d ) Discuss potential methods to quantify the impact of grey seal predation on harbour seal and harbour porpoise populations and to quantify the importance of cannibalism in grey seals;
e ) Identify knowledge gaps and develop a collaborative program of research to address these.
Can you provide a summary of the findings/conclusions from WGPIGS, particularly in relation to b and c above, and, if possible, the workshop report (due for completion on 1 June 2017) appended as an information paper to the SCOS report? Can the Committee also advise on how to best progress the findings/conclusions of the working group?

Yours sincerely

Sarah Jones

Marine Species Protection Policy Advisor

## Questions from Natural Resources Wales

Dear Debbie

**CONSERVATION OF SEALS ACT (1970): ANNUAL REVIEW OF MANAGEMENT ADVICE**

Thank you for your email to ask if Natural Resources Wales (NRW) has any specific questions on which it wishes to receive scientific advice.

It would be very helpful if the Committee could provide a view on the following questions:

1. What is the status of grey seal populations in UK?

2. What is SCOS' view on the role of foraging radii of grey seals in defining the spatial scale at which effects on a population, in the context of HRA or EIA, should be considered?

The context for question 2 comes from the suitability or otherwise of using Marine Mammal Management Units (MMMU) or foraging/travel distances as the appropriate spatial scales for screening in Special Areas of Conservation (SACs) and developments in Habitats Regulations Assessments (HRA).

For sea birds, management units (MU) are not used. Instead, distances from a development or its effect footprint are used to decide which sites (Special Protection Areas -SPAs) and developments should be considered (screened in) in an HRA. Thaxter et al (2012) foraging ranges (mean max distances) are commonly used as the evidence for screening out (ie not considering) sites (SPAs) that are beyond the foraging ranges for particular species.

SCOS (2014) (Q7) provided maximum ranges and mean maximum ranges from satellite tracked grey seal pups and adults from around Wales, and Q6 of SCOS (2014) indicated the connectivity of grey seals between/among SACs in the UK (also see Pomeroy et al 2014 for connectivity in Wales from photoID results). For HRAs in Wales, typically we would include all (multiple) SACs/developments in the large South and West England and Wales Management Unit because it provides the currently agreed spatial scale of the population and its management and is underpinned by evidence of connectivity among colonies within the MU (e.g Baines et al 1995; Keily et al 2000; Pomeroy et al 2015; SCOS 2013, 2014; Thompson 2011; Vincent et al 2005). However, the large size of this MU means that the environmental assessments are often not considered proportionate ie sites and developments far away are arguably unnecessarily considered in an assessment, with little material difference to the outcome of the consent decision, whilst placing an additional administrative burden on applicants and regulators. Further, there could be a risk that undertaking an assessment at such a broad spatial scale detracts from a thorough consideration of local effects and impact pathways.

It would be of value to get SCOS' view on the benefits and disadvantages, from a **scientific perspective**, on the use of foraging or travel ranges (radii) at different times of the year (breeding/non-breeding) as opposed to a fixed spatial scale of the management unit in assessing impacts on populations. Moreover, when using either approach (MU or distances), how would SCOS go about determining proportional contribution, ie what proportion of seals from SAC x and SAC y are impacted from a development at location z. The advice will help will inform management decisions.

3. In relation to question 2, what is SCOS' view on defining foraging ranges (as above) based on energetics rather than travel distances, especially for weaned pups and adult grey seals outside of the breeding season?

Baines ME, Earl SJ, Pierpoint CJL, Poole J (1995) The west Wales grey seal census. CCW Contract Science Report No. 131. Countryside Council for Wales, Bangor

Keily O, Lidgard D, McKibben M, Connolly N, Baines ME (2000) Grey seals: Status and monitoring in the Irish and Celtic Seas. Maritime Ireland/Wales INTERREG Report No. 3

Pomeroy, P, Rosas Da Costa, O & Stringell, TB, (2014). Grey seal movements – photoID. SCOS Briefing Paper. *In* SCOS 2014. Scientific Advice on Matters Related to the Management of Seal Populations: 2014. Special Committee on Seals, SMRU, University of St Andrews

SCOS (2013) Scientific Advice on Matters Related to the Management of Seal Populations: 2013. Special Committee on Seals, SMRU, University of St Andrews

SCOS (2014) Scientific Advice on Matters Related to the Management of Seal Populations: 2014. Special Committee on Seals, SMRU, University of St Andrews

Thaxter, CB, Lascelles, B, Sugar, K, Cook, ASCP, Roos, S, Bolton, M, Langston, RHW & Burton, NHK (2012). Seabird Foraging Ranges as a Preliminary Tool for Identifying Candidate Marine Protected Areas. Biological Conservation 156: 53-61.

Thompson D (2011) Grey Seal Telemetry Study. In: Anon (ed) Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh waters Phase 2 - Studies of Marine Mammals in Welsh High Tidal Waters. RPS for Welsh Government

Vincent C, Fedak MA, McConnell BJ, Meynier L, Saint-Jean C, Ridoux V (2005). Status and conservation of the grey seal, *Halichoerus grypus*, in France. Biological Conservation 126:62-73.

## ANNEX III

### Briefing Papers for SCOS

The following briefing papers are included to ensure that the science underpinning the SCOS Advice is available in sufficient detail. Briefing papers provide up-to-date information from the scientists involved in the research and are attributed to those scientists. Briefing papers do not replace fully published papers. Instead they are an opportunity for SCOS to consider both completed work and work in progress. It is also intended that briefing papers should represent a record of work that can be carried forward to future meetings of SCOS.

### List of briefing papers

**17/01** Estimating the size of the grey seal population between 1984 and 2016. Thomas, L.

**17/02** 2017 Annual review of priors for grey seal population model. Russell, D.J.F.

**17/03** The status of UK harbour seal populations in 2016 including summer counts of grey seals. Duck, C., Morris, C.D. and Thompson, D.

**17/04** Harbour seal decline - vital rates and drivers. A progress report on Year 2. Arso Civil, M., Smout, S., Thompson, D., Brownlow, A., Davison, N., ten Doeschate, M., Duck, C.D., Morris, C.D., Cummings, C., McConnell, B. and Hall, A.J.

**17/05** Provisional Regional PBR values for Scottish seals in 2018. Thompson, D., Morris, C.D. and Duck, C.D.

**17/06** Persistent organic pollutant concentrations in grey seal weaned pups from the Isle of May, 2015 compared to 2002. Robinson, K., Bennett, K., Eppe, G., and Hall, A.J.

**17/07** Potential Future Global Distributions of Grey and Harbour Seals under different climate change scenarios. Zicos, M., Thompson, D. and Boehme, L.

**17/08** Protein and metabolite changes in seal milk from birth to desertion. Lowe, A.D., Bawazeer, S., Watson, D.G., Eadie-McGill, S., Burchmore, J.S., Pomeroy, P.P. and Kennedy, M.W.

# Estimating the size of the UK grey seal population between 1984 and 2016.

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## Abstract

We estimated grey seal population size in 2016 by projecting forwards one year from the outputs of the population model derived in last year's briefing paper. That model is a Bayesian state-space model of seal population dynamics, fitted to regional estimates of pup production from 1984-2014 and two independent estimates of total population size in 2008 and 2014. Estimated adult population size in regularly monitored colonies in 2016 is 128,200 (95% CI 106,200-154,400), an increase of approximately 1% on the 2015 estimate.

## Introduction

This paper presents estimates of British grey seal population size, building on the model fitted by Thomas (2016). No new data were available, and no information came to light requiring revision of the model priors; hence, estimates for 2016 were obtained by projecting forwards from the 2015 estimates, using parameter estimates from the fitted model.

## Methods

Full details of the population dynamics model, data and fitting methods are given by Thomas (2015) and references therein. Model fitting in Thomas (2015) used a stochastic simulation-based procedure, which yielded a set of 28,500,000 weighted samples from the joint posterior distribution of model parameters and states, including age-specific population size in each year 1984-2015. To generate population estimates for 2016, we (1) extracted 100,000 samples from this distribution by sampling with replacement and probability proportional to the weights; (2) projected each sample forward stochastically using the population dynamics model, and the demographic parameter values and 2015 population size for that sample. Estimates given here are the posterior predictive mean (i.e., mean of the projected samples), with 95% equal-tailed credible interval (2.5$^{th}$ and 97.5$^{th}$ percentile of projected samples).

## Results and Discussion

Estimated pup production was 50,700 (95% CI 44,200-58,700) and adult population size was 128,200 (95% CI 106,200-154,400). These estimates are shown in Figures 1 and 2, together with those for previous years from Thomas (2016). Estimated adult population size in 2015, from Thomas (2016), was 127,100 (95%CI 105,900-151,900), so the estimate for 2016 is approximately 1% higher. Adult population estimates for each year are given in the Appendix, from which it is clear that population growth is not uniform across regions: the populations are estimated to be stable in Inner Hebrides, Outer Hebrides and Orkney, but growing (approx. 3% per year) in North Sea.

## References

Thomas, L. 2016. Estimating the size of the UK grey seal population between 1984 and 2015. SCOS Briefing Paper 16/02

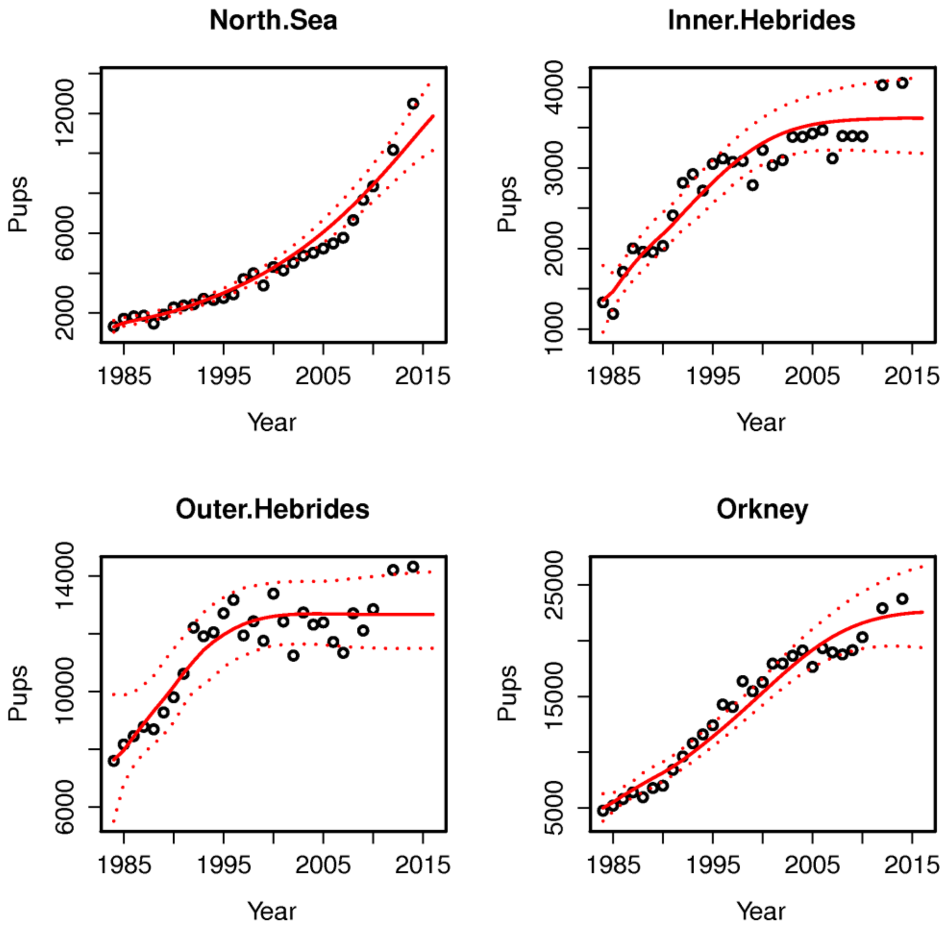


**Figure 1.** Posterior mean estimates of pup production (solid lines) and 95%CI (dashed lines) from the model of grey seal population dynamics, fitted to pup production estimates from 1984-2014 (circles) and the total population estimates from 2008 and 2014. Fit is taken from Thomas (2016), with estimates for 2016 added by simulating forwards from the fitted model.

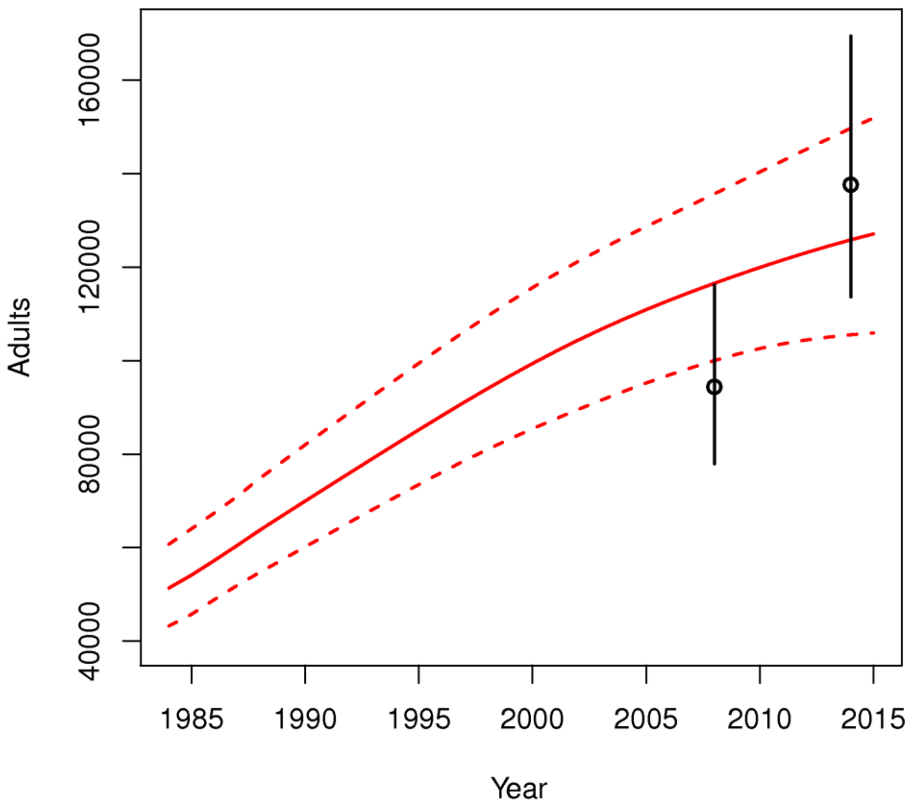


**Figure 2.** Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2016 from the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 and total population estimates from 2008 and 2014 (circles, with vertical lines indicating 95% confidence interval on the estimates). Fit is taken from Thomas (2016), with estimates for 2016 added by simulating forwards from the fitted model.

## Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2015, made using the model of British grey seal population dynamics fit to pup production estimates from 1984-2014 and total population estimates from 2008 and 2014. Numbers are posterior means followed by 95% credible intervals in brackets. Estimates are taken from Thomas (2016), with estimates for 2016 added by simulating forwards from the fitted model.

| Year | North Sea | Inner Hebrides | Outer Hebrides | Orkney | Total |
|---|---|---|---|---|---|
| 1984 | 4.7 (4 5.5) | 5 (4.2 5.9) | 23.3 (19.7 27.6) | 18.4 (15.4 21.7) | 51.4 (43.2 60.7) |
| 1985 | 5 (4.2 5.8) | 5.2 (4.4 6.2) | 24.4 (20.6 29) | 19.5 (16.5 23) | 54.1 (45.8 64) |
| 1986 | 5.4 (4.6 6.3) | 5.5 (4.7 6.5) | 25.5 (21.8 30.3) | 20.8 (17.7 24.3) | 57.2 (48.9 67.4) |
| 1987 | 5.8 (5 6.7) | 5.8 (5 6.9) | 26.5 (22.8 31.4) | 22.3 (19.1 25.9) | 60.4 (51.9 70.9) |
| 1988 | 6.3 (5.4 7.2) | 6.2 (5.3 7.3) | 27.4 (23.5 32.6) | 23.9 (20.5 27.7) | 63.7 (54.7 74.8) |
| 1989 | 6.7 (5.8 7.8) | 6.5 (5.6 7.7) | 28.1 (24.1 33.3) | 25.6 (21.9 29.6) | 66.9 (57.4 78.4) |
| 1990 | 7.2 (6.2 8.3) | 6.8 (5.9 8) | 28.7 (24.6 34) | 27.3 (23.4 31.6) | 70 (60.2 82) |
| 1991 | 7.7 (6.7 8.9) | 7 (6.2 8.3) | 29.2 (25.1 34.5) | 29.1 (25 33.7) | 73 (62.9 85.6) |
| 1992 | 8.3 (7.2 9.6) | 7.3 (6.4 8.6) | 29.6 (25.5 35) | 30.9 (26.6 35.8) | 76.1 (65.6 89.1) |
| 1993 | 8.9 (7.7 10.3) | 7.5 (6.5 8.9) | 29.9 (25.8 35.2) | 32.9 (28.2 38) | 79.2 (68.2 92.5) |
| 1994 | 9.6 (8.3 11.1) | 7.8 (6.7 9.2) | 30.1 (26 35.4) | 34.8 (29.8 40.3) | 82.2 (70.9 96) |
| 1995 | 10.3 (8.9 11.9) | 7.9 (6.8 9.4) | 30.2 (26.2 35.5) | 36.8 (31.5 42.6) | 85.2 (73.5 99.5) |
| 1996 | 11 (9.6 12.8) | 8.1 (7 9.6) | 30.3 (26.4 35.5) | 38.8 (33.1 45) | 88.2 (76.1 102.9) |
| 1997 | 11.8 (10.3 13.7) | 8.2 (7.1 9.7) | 30.4 (26.5 35.5) | 40.7 (34.8 47.2) | 91.1 (78.6 106.2) |
| 1998 | 12.6 (11 14.7) | 8.3 (7.1 9.9) | 30.4 (26.5 35.5) | 42.6 (36.3 49.4) | 94 (81 109.5) |
| 1999 | 13.5 (11.8 15.8) | 8.4 (7.2 9.9) | 30.4 (26.5 35.4) | 44.3 (37.8 51.5) | 96.7 (83.2 112.6) |
| 2000 | 14.5 (12.6 16.9) | 8.5 (7.2 10) | 30.4 (26.5 35.3) | 46 (39.1 53.4) | 99.4 (85.4 115.6) |
| 2001 | 15.5 (13.5 18.2) | 8.5 (7.3 10) | 30.4 (26.5 35.2) | 47.4 (40.3 55.1) | 101.9 (87.5 118.5) |
| 2002 | 16.6 (14.4 19.4) | 8.6 (7.3 10.1) | 30.4 (26.4 35.2) | 48.8 (41.5 56.6) | 104.4 (89.5 121.2) |
| 2003 | 17.8 (15.3 20.8) | 8.6 (7.3 10.1) | 30.4 (26.4 35.1) | 49.9 (42.5 57.9) | 106.7 (91.5 123.8) |
| 2004 | 19 (16.3 22.2) | 8.6 (7.3 10.1) | 30.4 (26.4 35.1) | 50.9 (43.4 59) | 108.8 (93.4 126.3) |
| 2005 | 20.2 (17.4 23.6) | 8.6 (7.3 10.1) | 30.4 (26.4 35) | 51.7 (44.2 59.9) | 110.9 (95.2 128.7) |
| 2006 | 21.5 (18.4 25.2) | 8.6 (7.3 10.1) | 30.3 (26.3 35) | 52.4 (44.8 60.7) | 112.9 (96.9 131) |
| 2007 | 22.9 (19.6 26.8) | 8.6 (7.3 10.2) | 30.3 (26.3 35) | 52.9 (45.3 61.4) | 114.8 (98.5 133.4) |
| 2008 | 24.2 (20.7 28.5) | 8.7 (7.3 10.2) | 30.3 (26.3 35) | 53.3 (45.7 62) | 116.5 (100 135.7) |
| 2009 | 25.6 (21.8 30.2) | 8.7 (7.3 10.2) | 30.3 (26.3 35) | 53.6 (46 62.6) | 118.3 (101.4 138) |
| 2010 | 27.1 (22.8 31.9) | 8.7 (7.3 10.2) | 30.4 (26.3 35.1) | 53.9 (46.2 63.2) | 119.9 (102.6 140.4) |
| 2011 | 28.5 (23.7 33.8) | 8.7 (7.3 10.2) | 30.4 (26.3 35.1) | 54 (46.3 63.7) | 121.5 (103.6 142.7) |
| 2012 | 29.9 (24.5 35.6) | 8.7 (7.3 10.2) | 30.4 (26.3 35.1) | 54.1 (46.3 64.1) | 123 (104.4 145.1) |
| 2013 | 31.2 (25.2 37.5) | 8.7 (7.3 10.3) | 30.4 (26.3 35.1) | 54.2 (46.2 64.5) | 124.5 (105 147.4) |
| 2014 | 32.5 (25.8 39.5) | 8.7 (7.3 10.3) | 30.4 (26.3 35.2) | 54.3 (46.1 64.8) | 125.8 (105.5 149.7) |
| 2015 | 33.7 (26.2 41.4) | 8.7 (7.3 10.3) | 30.4 (26.3 35.2) | 54.3 (46.1 65.1) | 127.1 (105.9 151.9) |
| 2016 | 34.8 (26.6 43.5) | 8.7 (7.3 10.3) | 30.4 (26.3 35.2) | 54.3 (46.0 65.4) | 128.2 (106.2 154.4) |

# 2017 Annual review of priors for grey seal population model

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**Abstract**

Here we review the current priors for the population model; we highlight the changes in comparison to the previous year and also provide justification for the current prior distributions. Only the adult survival prior was modified in this year's model runs.

The adult survival prior in 2015 produced a posterior mean on adult survival (0.99. SD = 0.01) that was considered too high. Therefore, an upper bound of 0.97 was set in 2016. The revised prior resulted in a more realistic posterior mean of 0.96 (SD = 0.01) for adult survival and a higher mean estimate for first year survival (0.37, SD = 0.06). The posterior mean was similar to an independent estimate from a long term branding study of Canadian grey seals.

A fecundity prior with a mean 0.83 and 95% CIs of 0.65 to 0.98 was selected. This is consistent with recent estimates from North Rona and the Isle of May and results from the long term branding study on Sable Island.

An adult female:male sex ratio prior of 1:0.73 has been used since 2014. The value is remarkably similar to the adult sex ratio based on observed adult survival rates in the Sable Island branding study.

## Introduction

Here we review the current priors for the population model; we highlight the changes in comparison to the previous year and also provide justification for the current prior distributions (Table 1). The pup production model and population estimation model have not been updated since 2016. This document presents the priors as defined in 2016 with additional supporting information from Canadian grey seal studies and revised fecundity and survival estimates from the long term studies at North Rona and the Isle of May. These revised estimates fall within the priors used in 2016 and would not lead in themselves to any change is the fitting process.

## Changes compared to SCOS 2015

### *Adult survival*

Only one change was made in the priors used for the main analyses in SCOS 2015 (Thomas 2015); a change in the adult survival prior (annual survival rate from the end of the first year). In the main analysis in 2015, the posterior mean on adult survival was 0.99 (SD = 0.01); this was considered by SCOS to be unrealistically high. In contrast the posterior mean on maximum first year survival, which is negatively correlated with adult survival, was very low (0.27, SD = 0.05). Thus in additional investigations in 2015 (Thomas 2015), a revised prior on adult survival was used which had an upper bound of 0.97, but a similar variance to the previous prior. This revised prior resulted in a more realistic posterior mean of 0.96 (SD = 0.01) for adult survival and a higher mean estimate for first year survival (0.37, SD = 0.06).

**Justification**

The priors on first year survival, adult survival (prior to the change described above), and fecundity are justified in detail in Lonergan (2012). In that briefing paper, the available published and unpublished data were reviewed and in some cases reanalysed.

*Adult survival*

Adult survival refers to the annual female survival rate from the end of the first year. The prior on adult survival (without the upper bound of 0.97) is justified in detail in Lonergan (2012). It is based on multiple data sources (Hewer 1964; Harwood & Prime 1978; Schwarz & Stobo 2000). Aging of teeth collected between 1956 and 1966 by Hewer (1964; 1974, n=239) resulted in an adult survival estimate of 0.93; a reanalysis of which resulted in an adult survival estimate of 0.95 (assuming a population growth rate of 7% per annum; Lonergan 2012). Depending on various assumptions made, the analyses of shot samples from the Farne Islands (544 in 1972 and 482 in 1975), led to adult survival estimates of between 0.86 and 0.95 (Harwood & Prime 1978).

In a preliminary study of re-sightings of seals branded as pups on Sable Island, adult female survival was estimated to be 0.92, 0.91, and 0.88 for pups marked in 1985, 1986 and 1987, respectively (Schwarz & Stobo 2000). Den Heyer and Bowen (2016) used a Cormack-Jolly-Seber model to estimate age- and sex-specific adult survival from a long term brand resighting programme on Sable Island, effectively an expanded and greatly extended version of the data used by Schwarz and Stobo (2000). Average adult survival was high (male=0.943, SE=0.003; female=0.976, SE=0.001), but male grey seals had lower survival at all ages. The survival rate estimate for adult females is above the upper limit of the prior used in the 2016 model runs. In fact, the Sable data suggests that adult female survival between 4-24 years is 0.989 and then decrease to 0.904 for ages 25+. For males the equivalent rates are 0.97 and 0.77.

Lonergan (2012) calculated that the mathematical lower limit of adult female survival was 0.8; the population is currently increasing suggesting that the lower limit is likely to be higher than 0.8. As a result of this review, a prior mean of 0.95 was considered most suitable with limits of 0.8 and 1. As noted above this has now been rescaled from the previous range to 0.80 - 0.97.

Since Lonergan (2012), Hiby et al. (2013) estimated apparent survival at the declining NR colony using a variety of models using photo-id recaptures. Three models produced estimates in the range 0.75-0.89, while a fourth estimated apparent survival at 0.79 (0.66-0.95). Pomeroy *et al.* (2015), based on a capture-mark-recapture study on the Isle of May, estimated apparent adult survival of breeding females to be between 0.92 and 0.94. The current prior incorporates these values.

*Pup survival*

Pup survival refers to survival in a seals' first year of life. There are various published estimates of first-year survival (Harwood & Prime 1978; Hall, McConnell & Barker 2001, 2002; Hall, Thomas & McConnell 2009). Harwood & Prime (1978) estimated a pup survival rate of 0.66, under the assumption of a 7% per annum population growth rate, an adult survival rate of 0.93 and fecundity rate of 0.9 from age 6. A mark-recapture study for which 204 pups were tagged with hat tags in 1997, resulted in a first year survival of females born on the Isle of May of 0.617 (SE = 0.155; Hall, Mcconnell & Barker 2001). Using some of the data (n = 133) from (Hall, McConnell & Barker 2001) and additional data from 158 individuals tagged on the Farne Islands in 1998 (Hall, McConnell & Barker 2002), first year female survival was estimated to be 0.41 and 0.03 for pups born on the Isle of May and Farne Islands, respectively (Lonergan 2012). However, there were some doubts about the reliability of these results as tag loss was not accounted for. In 2002, phone tags were deployed on 27 female pups on the Isle of May (Hall, Thomas & McConnell 2009) and the resulting data suggested first year female survival rate of 0.64. (Hall, Thomas & McConnell 2009) was considered

the most robust study and thus the prior was centred close to a value of 0.64 (Lonergan 2012). The levels of variance which should be included in the prior were unclear, but a study by Pomeroy *et al.* (2010) suggested there can be considerable inter annual variability in pup survival which would increase variance, thus a diffuse prior was used (Figure 4). It should be noted that the data used for pup survival estimates were collected during a time of exponential population growth and thus are appropriate for use in deciding the prior on maximum first year survival (before any density dependent effects come into play).
As in Scotland, the pup production at the large Canadian grey seal colony at Sable Island has shown a reduction in growth rate since the late 1990s, from a previous rate of 13% p.a. to about 4% since 2000. den Heyer *et al*. (2014) reported a reduction in juvenile survival from 0.65-0.8 in the 1980s and early 1990s to 0.27-0.4 in the early 2000s. This decrease is consistent with the pup survival mediated density dependence model used for UK grey seals.

As with the UK based estimates, the value from the 1980s and early 1990s represents a period of rapid exponential growth when the effect of density dependence would be minimal. The range of pup survival estimate during this apparently unconstrained growth period was slightly higher than the equivalent UK estimates. It is worth noting that the North Sea population which is the only segment of the UK population to be increasing exponentially has had a consistent growth rate of XX% throughout the recording period, i.e. over a wide range of population sizes. Even near the start of the time series in the UK the population as a whole has had maximum growth rates around XX%. This lower growth rate may be partially explained by the lower pup survival rates in the UK population compared to the Sable Island population.

*Fecundity*

For the purposes of this population model, fecundity refers to the proportion of females (aged 6 and over) which will give birth to a pup in a year (natality rate). For the most part, studies have measured pregnancy rather than fecundity rates. The resulting estimates will be maxima as abortions will cause pregnancy rates to exceed birth rates. Lonergan (2012) reviewed the following datasets: Hewer 1964; Boyd 1985; Hammill & Gosselin 1995; Bowen *et al.* 2006; Øigård *et al.* 2012; and Smout *et al.* unpublished. Hewer (1964) estimated a pregnancy rate of 0.93 (n=79). Boyd (1985) estimated pregnancy rates of 0.94 (95% CI: 0.89 - 0.97; n=140) and 0.83 (95% CI: 0.74 - 0.89; n=88) from shot samples at the Farne Islands and Hebrides respectively. Hammill & Gosselin (1995) examined 526 dead seals in Canada, and estimated pregnancy rates of between 0.88 and 1 for seals over 5 years of age. In an observational study, Bowen *et al.* (2006) estimated apparent fecundity to be between 0.57 and 0.83 depending on animal age (n=245). Øigård *et al.* (2012) estimated a fecundity rate of adult grey seals in Norway of 0.81, and report slightly higher values from Iceland. Lonergan noted that observational studies may result in lower fecundity estimates due to some females breeding elsewhere in some years, present females not being observed at the colony each year, and/or the mismatch between fecundity and pregnancy rates.

A prior with a mean 0.83 and 95% CIs of 0.65 to 0.98 was selected; this incorporates the estimates from the UK shot samples (Boyd 1985), with a lower extent allowing for the estimates of apparent fecundity resulting from the UK long term studies (Smout *et al.* 2010,2011). Estimates of fecundity rates for populations of marked study animals, adjusted for estimates of unobserved pupping events were 0.79 (95% CI: 0.76 - 0.81) and 0.82 (95% CI: 0.79 - 0.84) for North Rona and the Isle of May, respectively. DenHeyer *et al.* 2016 reported that females on Sable Island that pupped in any year had a probability of 0.85 of pupping the following year. Females that did not pup in a year had a probability of 0.56 of pupping the following year. In combination, this produces an overall fecundity rate of approximately 0.79. This estimate is similar to the NR estimate and although breeding probability varied among years, there was no trend over time suggesting the average natality rate has not changed despite the slowing of the rate of growth in pup production.

The estimates from North Rona and the Isle of May and Sable Island are within the range of the current prior.

*Shape of density dependence*

The first time this parameter is included in the population model is in 2005 (Thomas & Harwood 2005). Upon undertaking sensitivity analyses, they note that the posterior distribution has a reasonably low sensitivity to the prior distribution.

*Carrying Capacities*

It is likely that these priors have a negligible influence on parameter estimates or population size because the posteriors differ considerably from the priors in regions for which carrying capacity is being approached. In the North Sea, in which the population size is still increasing rapidly, it is unlikely that the posterior carrying capacity would influence population size. However, it is worth noting that since the prior on carrying capacity for the North Sea was set, the population has increased considerably. Thus to increase efficiency and to ensure the upper limits of the prior distribution do not constrain the estimate of population size, the North Sea prior should be adjusted next year.

*Observation coefficient of variation (CV)*

The CV on the regional pup production estimates is estimated in a preliminary run of the population model (Thomas 2014). Currently, the pup production model produces CVs on a colony level rather than the regional level required by the population model. The planned revision of the pup production model will involve estimating regional CVs around pup production which can then be included in the population model.

*Sex ratio*

Up until 2009, there was no independent estimate to provide information regarding the sex ratio of non-pups. Thus a fixed multiplier of 1.73 used to scale the female population to the total population up until 2012 (Thomas 2012). This value originated from the shot samples on the Farne Islands in 1972 and 1975 (544 in 1972 and 482 in 1975; Harwood and Prime 1978) for which estimated adult male survival (from age 10) was 0.80. This sex ratio was based on the following assumptions: that the shot males were a representative sample of the population; that female survival was 0.935; and that survival was the same between the sexes up until age 10. More recent evidence (Hall, McConnell & Barker 2001, 2002) suggests that male first-year survival may be lower than female survival which would cause a reduced number of males to females. It should be noted that a similar population model developed for use with the Canadian grey seal population assumes a 1:1 sex ratio.

The inclusion of an independent estimate of total population size provided data to inform the sex ratio, thus a sex ratio prior was defined. Lonergan (2012) suggested a prior on the scalar to raise the female population to the total population that had a mean of 1.2 (SD = 0.63). This was derived by combining pup survival data (Hall, McConnell & Barker 2001) with age and sex data from shot samples (Hewer 1964), making the assumption that these shot sample were representative of the population which Hewer noted was unlikely. Part of the justification for such a sex ratio was that, in comparison to the 1:0.73 sex ratio, it greatly reduced the inconsistency between the population size estimated using the population dynamics model and that estimated by scaling the summer counts. This discrepancy has been reduced as a result of the revised independent estimate for 2008 (Russell *et al.* 2016).

Thomas (2013) implemented both the fixed sex ratio (1:0.73) and the prior suggested by Lonergan (2012; 1:0.2). In 2014, Thomas implemented both the fixed sex ratio (1:0.73) scalar and a prior based on this fixed sex ratio; a highly informative prior with a mean of 1.7 (SD = 0.02); 90% of the prior mass was between 1.68 and 1.73. This revised prior was based on a preliminary re-analyses of hat tag (Hall, McConnell & Barker 2001, 2002) and phone tag data (Hall, Thomas & McConnell 2009), taking into account detection probability inferred by telemetry data. Although there were no significant differences in survival between males and females, the mean male survival was lower than females for both datasets (Table 2). If combined with data from Hewer (1964), the resulting sex ratio would be 0.66-0.68 males per female. Also considered were shot samples from the Baltic (Kauhala, Ahola & Kunnasranta 2012) which indicated that pup survival varied by year, being 0.67 and 0.53 for females in the early and late 2000s, respectively, and 0.33 and 0.50 for males in the early and late 2000s, respectively. This prior has been adopted by SCOS for years following 2014.

Den Heyer and Bowen (2016) estimated survival rates of male and female branded seals at Sable Island. The differential survival of males and females would produce an effective sex ratio of 1:0.7 if maximum age is set to 40, reducing to 1:0.69 if maximum age is set to 45. This estimate is remarkably similar to the prior used in the 2016 model runs.

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Table 1. Prior parameter distributions (The two parameters of the gamma distribution specified here are shape and scale respectively) for both SCOS 2015 and 2016. The distributions in red are those adopted for use in SCOS 2016.

| Parameter | SCOS 2015 | | | | | | SCOS 2016 | |
|---|---|---|---|---|---|---|---|---|
| | Main analysis | | Additional investigation on adult survival | | Additional investigation on sex ratio | | Main analysis | |
| | distribution | mean (SD) | distribution | mean (SD) | distribution | mean (SD) | distribution | mean (SD) |
| adult survival $\phi_a$ | 0.8+0.2*Be(1.6,1.2) | 0.91 (0.05) | 0.8+0.17*Be(1.6,1.2) | 0.90 (0.04) | 0.8+0.17*Be(1.6,1.2) | 0.90 (0.04) | as SCOS 2015 additional analysis on adult survival | |
| pup survival $\phi_j$ | Be(2.87,1.78) | 0.62 (0.20) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| fecundity $\alpha_{\max}$ | 0.6+0.4*Be(2,1.5) | 0.83 (0.09) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| dens. dep. $\rho$ | Ga(4,2.5) | 10 (5) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| NS carrying cap. $\chi_1$ | Ga(4,2500) | 10000 (5000) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| IH carrying cap. $\chi_2$ | Ga(4,1250) | 5000 (2500) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| OH carrying cap. $\chi_3$ | Ga(4,3750) | 15000 (7500) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| Ork carrying cap. $\chi_4$ | Ga(4,10000) | 40000 (20000) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| observation CV ψ | Fixed | 0.89 (0) | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | | as SCOS 2015 main analysis | |
| sex ratio $\omega$ | 1.6+Ga(28.08, 3.70E-3) | 1.7 (0.02) | as SCOS 2015 main analysis | | 1+Ga(0.1,2) | 1.2 (0.63) | as SCOS 2015 main analysis | |

Table 2. Estimates of sex-specific pup survival based on hat tag data, phone tags and telemetry data

| | Females | | | Males | | |
|---|---|---|---|---|---|---|
| Data type | survival | 95% CI | N | survival | 95% CI | n |
| Hat tags (1 year) | 0.65 | 0.39 - 0.85 | 180 | 0.50 | 0.25 - 0.75 | 182 |
| Phone tags (6 months) | 0.54 | 0.18 - 0.86 | 27 | 0.43 | 0.11 – 0.82 | 28 |

# The status of UK harbour seal populations in 2016 including summer counts of grey seals.

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## Abstract

In August 2016, during the harbour seal moult, the Sea Mammal Research Unit (SMRU) thermal image surveys in Scotland covered Orkney, the North Coast of Scotland, the Moray Firth and the East Coast of Scotland from Fraserburgh to North Queensferry, including the Firth of Tay and Eden Estuary. The 2016 survey formed the start of a new round-Scotland harbour seal survey.

The SMRU fixed-wing surveys in England covered the coast of Lincolnshire, Norfolk and Suffolk. The Tees Seal Research Programme kindly provided information on seal numbers in the Tees Estuary (Bond, 2016). Data from surveys carried out in the Thames Estuary, by the Zoological Society of London, are included in the total for England. Grey seals are counted during harbour seal surveys although during the summer months, grey seal counts can vary more than harbour seal counts.

From August surveys carried out between 2011 and 2016, the minimum number of harbour seals counted in Scotland was **25,149** and in England & Wales it was **5,185**, making a total count for Great Britain of **30,334** (**Error! Reference source not found.**). Including **948** harbour seals counted in Northern Ireland in 2011, the UK harbour seal total count for this period was **31,282**.

From August surveys carried out between 2011 and 2016, the minimum number of grey seals counted in Scotland was **25,839** and in England & Wales **14,335** making a total count for Great Britain of **40,194** (**Error! Reference source not found.**). Including **468** grey seals counted in Northern Ireland in 2011, the UK grey seal total count for this period was **40,662**.

The 2016 harbour seal count for Orkney was **1,240** (33.5% lower than previous 2013 count of 1,865) and for the North coast, **109** giving a total of **1,349** for this Seal Management Area (SMA). 30.4% decline for the Orkney and North Coast (ONC) SMA alone. In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn), the moult count was **892**, 26% higher than the low counts from the two previous years (2014 and 2015). The severe decline in the Firth of Tay & Eden Estuary harbour seal SAC showed no sign of recovery, with **51** harbour seals counted in 2016. This represents 8% of the mean of counts between 1990 and 2002 (641).

In contrast to harbour seals, the 2016 grey seal count for Orkney was **9,300.** Including an additional **343** grey seals counted on the North Coast, gives a total of **9,643** for the ONC SMA. This is the biggest grey seal count for the ONC SMA to date.

## Introduction

Most population surveys of harbour seals are carried out in August, during their annual moult. At this point in their annual cycle, harbour seals tend to spend longer at haul-out sites and the greatest and most consistent counts of seals are found ashore. During a survey, however, there will be a number of seals at sea which will not be counted. Thus the numbers presented here represent the minimum number of harbour seals in each area and should be considered as an index of population size, not actual population size.

Although harbour seals can occur all around the UK coast, they are not evenly distributed. Their main concentrations are in Shetland, Orkney, the Outer Hebrides, the west coast of Scotland, the

Moray Firth and in east and southeast England, between Lincolnshire and Kent (Figure 1). Only very small, dispersed groups are found on the south and west coasts of England or in Wales.

Since 1988, SMRU's surveys of harbour seals around the Scottish coast have been carried out on an approximately five-yearly cycle, with the exception of the Moray Firth (between Helmsdale and Findhorn) and the Firth of Tay & Eden Estuary SAC which have been surveyed annually since 2002. Surveys carried out in 2006, revealed significant declines in harbour seal numbers in Shetland, Orkney and elsewhere on the UK coast (Lonergan *et al*. 2007). Between 2007 and 2009, SMRU surveyed the entire Scottish coast including a repeat survey of some parts of Strathclyde and Orkney. In 2010, Orkney was surveyed again to determine whether previously observed declines continued. The last round-Scotland survey started in 2011 and was completed in 2015. Data presented here include those from a new survey that started in August 2016.

Approximately 90% of the English harbour seal population is found on the Lincolnshire and Norfolk coast which is usually surveyed twice annually during the August moult. Since 2004, additional breeding season surveys (in early July) of harbour seals around The Wash (which lies within the August survey area) were undertaken for Natural England. The Suffolk, Essex and Kent coasts were last surveyed by SMRU during the breeding season in 2011 and during the moult in August 2016 by the Thames Harbour Seal Conservation Project, run by the Zoological Society of London.

A complete survey of Northern Ireland and the Republic of Ireland was carried out in 2011 and 2012. A new survey of the Republic of Ireland will start in 2017, to be finished in 2018.

**Methods**

Seals hauling out on rocky or seaweed covered shores are well camouflaged and difficult to detect. Surveys of these coastlines in Scotland are carried out by helicopter using a thermal-imaging camera which is able to detect groups of seals at distances of over 3km (depending on weather conditions). This technique enables rapid, thorough and synoptic surveying of seals inhabiting complex coastlines. Previously, since 2007, oblique photographs were obtained using a hand-held camera equipped with an image-stabilised zoom lens. Both harbour and grey seals were digitally photographed and the images used to classify species composition of groups of seals. The grey seal counts from these surveys have been used elsewhere to inform the models used to estimate the total grey seal population size (Lonergan *et al*. 2011, SCOS BP 10/4).

In August 2016, a new custom-built, 3-camera system, based on Trakka System's SWE-400, was used to survey seals for the first time. The system consists of a gyro-stabilised gimbal containing a thermal imaging camera, a high-resolution video camera, a digital still camera equipped with a 300mm telephoto lens and a laser range finder. Video and still images are recorded on laptops which display a moving map, highlighting areas that have been recently surveyed and the distribution of harbour and grey seals from previous surveys.

Surveys of the estuarine haul-out sites on the east coast of Scotland and England were by fixed-wing aircraft using hand-held oblique photography. On sandbanks, where seals are relatively easily located, this survey method is highly cost-effective.

To maximise the counts of seals on shore and to minimise the effects of environmental variables, surveys are restricted to within two hours before and two hours after the time of local low tides (derived from POLTIPS, National Oceanographic Centre, NERC) occurring between approximately 12:00hrs and 18:00hrs. Surveys are not carried out in persistent or moderate to heavy rain because seals will increasingly abandon their haul-out sites and return into the water, and because the thermal imager cannot 'see' through rain.

In southeast England, from Suffolk to Kent, the Thames Harbour Seal Conservation Project coordinated August surveys by air, from boat and from land between 7$^{th}$ and 10$^{th}$ August 2016 (ZSL unpublished data, see Barker & Obregon, 2015 as example).

**Results and Discussion**

***1. Minimum population size estimate for harbour seals in the UK***

The overall distribution of harbour seals around the British Isles from August surveys carried out between 2011 and 2016 is shown in Figure 1. For ease of viewing at this scale, counts have been aggregated by 10km squares.

The most recent minimum harbour seal population estimates (i.e. counts between 2011 and 2016) for UK Seal Management Areas (SMAs) are provided in Table 1 and are compared with two previous periods (2007 to 2009 and 1996 to 1997).

Mean values were used for any areas where repeat counts were available (primarily in eastern England and occasionally the Moray Firth).

The most recent minimum estimate of the number of harbour seals in Scotland, obtained from counts carried out between 2011 and 2016, is **25,149** (Table 1). This is mid-way between the 2007-2009 count (20,430) and the 1996-1997 count (29,514; Table 1). Since 2001, harbour seal counts have declined in Shetland, Orkney and along the north and east coasts of Scotland (Lonergan *et al*., 2007; Duck & Morris, 2014; 2015; 2016; 2017) while counts in the West Scotland SMA appear to have increased.

The most recent minimum estimate for England & Wales, obtained from surveys carried out mainly in 2016, is **5,199** (Table 1). This is 29% higher than the 2007-2009 count (4,032) and 58% higher than the 1995-1997 count (3,289; Table 1).

The 2011 count for Northern Ireland of **948** was 25% lower than the previous complete count from 2002 (1,267).

The sum of all the most recent counts carried out between 2008 and 2016 gives a UK total of **31,420** harbour seals (Table 1).

***1.1 Grey seals in the UK counted during August harbour seal surveys***

Grey seals are counted in all harbour seal surveys but, because grey seal counts are significantly more variable than harbour seal counts in August, they have not previously been fully reported. In conjunction with grey seal telemetry data, the grey seal summer counts from 2007 and 2008 have been used to calculate an independent estimate of the size of the grey seal population (Lonergan *et al*. 2011). August grey seal counts will similarly be used in future.

The overall UK and Ireland distribution of grey seals from August harbour seal surveys carried out between 2007 and 2016 is shown in **Error! Reference source not found.**. For ease of viewing at this scale, counts have been aggregated by 10km squares. The most recent estimate of the number of grey seals in Scotland, obtained from August counts carried out between 2011 and 2016 is **25,839** (Table 2). This is 36% higher than the total Scotland count of 18,979 from August surveys between 2007 and 2009.

There were **13,033** grey seals counted in eastern England between 2008 and 2016 and, combined with an estimate of **1,302** in West England & Wales and the 2011 count of **468** in Northern Ireland (Table 2), the most recent UK total count of grey seals in August is **40,662**.

***2. Harbour and grey seals within Seal Management Areas in Scotland***

The parts of Scotland surveyed in August 2016 were: Orkney and the North Coast of Scotland, most of the Moray Firth (from Helmsdale to Fraserburgh) and part of the East Coast of Scotland (from Fraserburgh to North Queensferry). Details of the survey methodology can be found in the Scottish Natural Heritage (SNH) Commissioned Report No. 929 (Duck & Morris, 2016).

Figure 3 shows the years when different parts of the Scottish coast were last surveyed between 2008 and 2016. Areas surveyed in 2016 are in dark green. A new round-Scotland survey started in August 2016.

The most up-to-date distribution of harbour seals in Scotland, from surveys between 2011 and 2016, is shown in Figure 4. The trends in counts of harbour seals in different Seal Management Areas in

Scotland, from surveys carried out between 1996 and 2016 are shown in Figure 5. Harbour seal counts from the most recent surveys and from two previous survey periods (2007 to 2009 and 1996 to 1997) are in Table 1.

The most up to date distribution of grey seals in Scotland, from surveys between 2011 and 2016, is shown in Figure 6. Grey seal counts from the most recent surveys and from two previous periods (2000 to 2006 and 1996 to 1997) are in Table 2.

### *2.1 Orkney and the North Coast - harbour seals*

The Isles of Orkney and the North Coast of Scotland were surveyed between 1st and 5th August 2016. The harbour seal count for Orkney was **1,240** and the count for the North coast was **109** giving a total count of **1,349** for the Orkney and North Coast Management Area (Table 1). This is the lowest count of harbour seals in Orkney since 1985 and represents just under 15% of the highest count (8,522) from 1997.

### *2.2 Orkney and the North Coast - grey seals*

In Orkney, in August 2016, a total of **9,300** grey seals were counted with **414** on the North Coast giving a total of **9,714** for Orkney and the North Coast SMA.

### *2.3 Moray Firth, part - harbour seals*

Part of the Moray Firth was surveyed on 10th August 2016 (Findhorn to Fraserburgh). The annually surveyed section of coast (Helmsdale to Findhorn) was surveyed on 10th August 2016. The coast between Helmsdale and Duncansby Head was last surveyed in August 2011. Between Helmsdale and Findhorn Bay, **892** harbour seals were counted with **47** on the North Moray coast, between Findhorn and Fraserburgh (Table 3). Combined with counts from previous years, the total harbour seal count for the Moray Firth SMA was **940**. This is the highest count of harbour seals in the Moray Firth since 2012 (Table 3).

### *2.4 Moray Firth - grey seals*

In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn Bay) **1,194** grey seals were counted, with a further **43** counted between Findhorn and Fraserburgh (Table 4). Combined with counts from previous years, a total of **1,252** grey seals were counted in the Moray Firth (Table 4).

### *2.5 East Scotland - harbour seals*

The coast of East Scotland, from Fraserburgh to North Queensferry was surveyed on 9th August 2016 where **287** harbour seals were counted. Including counts from surveys in 2013 and 2015 for the remainder of East Scotland, the total harbour seal count for the East Scotland SMA was **368** (Table 1).

The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2016 was **51**, slightly lower than the 2015 count of 60 (Table 2, Table 5).

### *2.6 East Scotland - grey seals*

A total of **3,738** grey seals were counted in the section of East Scotland surveyed in 2016 (Fraserburgh to North Queensferry). Including counts from surveys in 2013 and 2015, the total grey seal count for East Scotland SMA was **3,812** (Table 2). This was considerably higher than the total count of 1,238 from surveys carried out between 2007 and 2009 (Table 2). The biggest haul-out of grey seals was at the mouth of the River Ythan, with a count of **1,924**.

In the Firth of Tay and Eden Estuary SAC in 2016, **936** grey seals were counted (Table 2, Table 5).

## *3. Harbour seal surveys in England and Wales*

### *3.1 England and Wales – harbour seal moult season counts (August)*

The coast of England and Wales has been divided into three Management Units (Figure 1). The great majority of English harbour seals are found in Southeast England (Figure 1). In 1988, the previously increasing numbers of harbour seals in The Wash declined by approximately 50% as a result of the phocine distemper virus (PDV) epidemic. Following the epidemic, from 1989, the area has been surveyed once or twice annually in the first half of August (Table 7, Figure 14). After recovering to

1988 levels by 2001, the population was hit by another PDV outbreak in 2002. It was reduced by around 20% but recovered to pre-epidemic levels by 2012.

In Northeast England, small numbers of harbour seals are found at Holy Island and in the Tees Estuary. The 2016 count for Northeast England was **86**, a combined count from 2015 (Holy Island) and 2016 (Tees Estuary; Table 7). Harbour seals in the Tees Estuary are monitored by the Industry Nature Conservation Association (INCA). The very slow increase in numbers seems to be continuing, although the August 2016 mean count of 86 was slightly lower than the 2015 mean count (100; Table 7 in Bond & Gibson, 2016).

Two aerial surveys of harbour seals were carried out by SMRU in Lincolnshire and Norfolk during August 2016 (Table 7). The 2016 count for the coast between Donna Nook and Scroby Sands (**4,367**) was slightly higher (by 5%) than the 2015 count (4,289). The Zoological Society of London surveyed the wider Thames Estuary between Hamford Water (in Essex) and Goodwin Sands (off the Kent coast) and counted **694** harbour seals (Zoological Society of London, unpublished data), 45% more than in 2015 (451; Barker & Obregon, 2015).

The combined counts for the Southeast England Management Unit (Flamborough Head to Newhaven) in 2016 (**5,061**) was 7% higher than the 2015 count (4,740; Tables 1 and 7). Although the Southeast England population has returned to its pre-2002 epidemic levels, it is still lagging behind the rapid recovery of the harbour seal population in the Wadden Sea where counts increased from 10,800 in 2003 to 26,788 in 2013 (Reijnders *et al*., 2003; Trilateral Seal Expert Group, 2013), equivalent to an average annual growth rate of 9.5% over the ten years. For the second successive year, there was a second slight decline in the Wadden Sea total harbour seal count in 2015 (26,435 in 2015; Galatius *et al*., 2015). In August 2016, part of the Wadden Sea (Lower Saxony/Hamburg) could not be fully counted in 2016 due to adverse weather conditions. Although the 2016 count was not complete (Galatius *et al*., 2016), preliminary estimates indicate that the population has not increased for the third year in succession.

No dedicated harbour seal surveys are routinely carried out in the West England & Wales Management Unit. Estimates given in Table 1 are derived from compiling information from the various sources listed in the Table.

### *3.2 England and Wales – harbour seal breeding season counts (June & July)*

A series of five aerial surveys of The Wash were carried out over the breeding season in 2016 (19th, 24th June and 2nd, 8th and 16th July 2016). The results together with results from previous breeding season surveys are presented in Thompson *et al*. (2016). The 2015 count was substantially lower (22%) than the 2014 equivalent count, but the 2016 peak count was 17% higher than in 2015. These wide fluctuations are not unusual in the long term time series. Despite the wide inter-annual variation, the pup production has apparently increased at around 7.4% p.a. since surveys began in 2001.

### *3.3 England and Wales – grey seal counts (August)*

A total of **6,085** grey seals were counted on the East coast of England between Donna Nook and Dover in August 2016. This is similar to counts from the previous four years (Table 8).

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**Table 1. The most recent August counts of harbour seals at haul-out sites in Britain and Northern Ireland**, by Seal Management Area, compared with two previous periods: 2000 to 2006 and 1996 to 1997.

| Seal Management Unit / Country | | Harbour seal counts | | | | | |
|---|---|---|---|---|---|---|---|
| | | **2008-2016** | | **2007-2009** | | **1996-1997** | |
| 1 Southwest Scotland | | 1,200 | (2015) | 923 | (2007; 2009) | 929 | (1996) |
| 2 West Scotland | a | 15,184 | (2013-2015) | 10,626 | (2007-2009) | 8,811 | (1996-1997) |
| 2a West Scotland - South | | 7,645 | (2014-2015) | 5,930 | (2007; 2009) | 5,651 | (1996) |
| 2b West Scotland - Central | | 6,424 | (2014) | 4,004 | (2007; 2008) | 2,700 | (1996) |
| 2c West Scotland - North | | 1,115 | (2013; 2014) | 692 | (2008) | 460 | (1996-1997) |
| 3 Western Isles | | 2,739 | (2011; 2014) | 1,804 | (2005; 2008) | 2,820 | (1996) |
| 4 North Coast & Orkney | | 1,349 | (2013; 2014) | 2,979 | (2008-2009) | 8,787 | (1997) |
| 4a North Coast | | 109 | (2016) | 112 | (2008) | 265 | (1997) |
| 4b Orkney | | 1,240 | (2016) | 2,867 | (2008-2009) | 8,522 | (1997) |
| 5 Shetland | | 3,369 | (2015) | 3,039 | (2009) | 5,994 | (1997) |
| 6 Moray Firth | | 940 | (2008; 2011; 2016) | 776 | (2007-2009) | 1,409 | (1997) |
| 7 East Scotland | | 368 | (2013; 2015-2016) | 283 | (2007; 2010) | 764 | (1997) |
| 7.1 Fraserburgh to Carnoustie | | 53 | (2016) | 24 | (2007) | 15 | (1997) |
| 7.2 Tay & Eden SAC | | 51 | (2016) | 111 | (2009) | 633 | (1997) |
| 7.3 St Andrews to border | | 264 | (2013; 2015-2016) | 148 | (2007) | 116 | (1997) |
| **SCOTLAND TOTAL** | | **25,149** | (2008; 2011; 2013-2016) | **20,430** | (2007-2009) | **29,514** | (1996-1997) |
| 8 Northeast England | b | 86 | (2015; 2016) | 58 | (2008-2009) | * 54 | (1997) |
| 9 Southeast England | c | 5,061 | (2016) | 3,952 | (2008-2009) | 3,222 | (1995; 1997) |
| 10 South England | d | 23 | (estimate) | 13 | (estimate) | 9 | (estimate) |
| 11 Southwest England | d | 0 | (estimate) | 0 | (estimate) | 0 | (estimate) |
| 12 Wales | d | 5 | (estimate) | 4 | (estimate) | 2 | (estimate) |
| 13 Northwest England | d | 10 | (estimate) | 5 | (estimate) | 2 | (estimate) |
| **ENGLAND & WALES TOTAL** | | **5,185** | (2015; 2016) | **4,032** | (2008-2009) | **3,289** | (1995; 1997) |
| **BRITAIN TOTAL** | | **30,334** | (2008; 2011; 2013-2016) | **24,462** | (2007-2009) | **32,802** | (1995-1997) |
| **NORTHERN IRELAND TOTAL** | e | **948** | (2011) | **1,101** | (2002; 2008) | | |
| **UK TOTAL** | | **31,282** | (2008; 2011; 2013-2016) | **25,563** | (2002; 2007-2009) | | |

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by Scottish Natural Heritage (SNH) and the Natural Environment Research Council (NERC). Exceptions are:

a Parts of the West Scotland survey in 2009 funded by Scottish Power and Marine Scotland.

b The Tees data collected and provided by the Industry Nature Conservation Association (Bond & Gibson, 2016). The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

c Essex & Kent data for 2016 collected and provided by the Zoological Society London (e.g. Barker & Obregon, 2015).

d No dedicated harbour seal surveys in this management unit and only sparse info available. Estimates compiled from counts shared by other organisations (Chichester Harbour Conservancy) or found in various reports & on websites (Boyle, 2012; Hilbrebirdobs.blogspot.co.uk, 2012, 2013; Sayer, 2010, 2011; Sayer *et al.,* 2012; Westcott, 2002). Apparent increases may partly be due to increased reporting and improved species identification.

e Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002 & 2011 (Duck, 2006; Duck & Morris, 2012) and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

*Northumberland coast south of Farne Islands not surveyed in 2005 & 1997, but no harbour seal sites known here.

**Table 2. The most recent August counts of grey seals at haul-out sites in Britain and Northern Ireland**, by Seal Management Area, compared with two previous periods: 2000 to 2006 and 1996 and 1997. Grey seal summer counts are known to be more variable than harbour seal summer counts. Caution is advised when interpreting these numbers.

| Seal Management Unit / Country | | Grey seal counts | | | | | |
|---|---|---|---|---|---|---|---|
| | | **2008-2016** | | **2007-2009** | | **1996-1997** | |
| 1 Southwest Scotland | | 374 | (2015) | 233 | (2007; 2009) | 75 | (1996) |
| 2 West Scotland | a | 5,064 | (2013-2015) | 2,526 | (2007-2009) | 3,435 | (1996-1997) |
| 2a West Scotland - South | | 3,618 | (2014-2015) | 1,788 | (2007; 2009) | 2,125 | (1996) |
| 2b West Scotland - Central | | 1,056 | (2014) | 561 | (2007; 2008) | 931 | (1996) |
| 2c West Scotland - North | | 390 | (2013; 2014) | 177 | (2008) | 379 | (1996-1997) |
| 3 Western Isles | * | 4,065 | (2011; 2014) | 3,808 | (2005; 2008) | 4,062 | (1996) |
| 4 North Coast & Orkney | | 9,714 | (2013; 2014) | 8,525 | (2008-2009) | 9,427 | (1997) |
| 4a North Coast | | 414 | (2016) | 504 | (2008) | 597 | (1997) |
| 4b Orkney | | 9,300 | (2016) | 8,021 | (2008-2009) | 8,830 | (1997) |
| 5 Shetland | | 1,558 | (2015) | 1,536 | (2009) | 1,724 | (1997) |
| 6 Moray Firth | | 1,252 | (2008; 2011; 2016) | 1,113 | (2007-2009) | 551 | (1997) |
| 7 East Scotland | | 3,812 | (2013; 2015-2016) | 1,238 | (2007; 2010) | 2,328 | (1997) |
| 7.1 Fraserburgh to Carnoustie | | 2,265 | (2016) | 400 | (2007) | 145 | (1997) |
| 7.2 Tay & Eden SAC | | 936 | (2016) | 450 | (2009) | 1,891 | (1997) |
| 7.3 St Andrews to border | | 611 | (2013; 2015-2016) | 388 | (2007) | 292 | (1997) |
| **SCOTLAND TOTAL** | | **25,839** | (2008; 2011; 2013-2016) | **18,979** | (2007-2009) | **21,602** | (1996-1997) |
| 8 Northeast England | b | 6,948 | (2015; 2016) | 2,350 | (2008-2009) | | |
| 9 Southeast England | c | 6,085 | (2016) | 1,786 | (2008-2009) | | |
| 10 South England | d | 0 | (estimate) | 0 | (estimate) | | |
| 11 Southwest England | d | 480 | (estimate) | 425 | (estimate) | | |
| 12 Wales | d | 422 | (estimate) | 378 | (estimate) | | |
| 13 Northwest England | d | 400 | (estimate) | 350 | (estimate) | | |
| **ENGLAND & WALES TOTAL** | | **14,335** | (2015; 2016) | **5,289** | (2008-2009) | | |
| **BRITAIN TOTAL** | | **40,194** | (2008, 2011,2013-2016) | **24,268** | (2007-2009) | | |
| **NORTHERN IRELAND TOTAL** | e | **468** | (2011) | **243** | (2002; 2008) | | |
| **UK TOTAL** | | **40,662** | (2008, 2011,2013-2016) | **24,513** | (2002; 2007-2009) | | |

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by Scottish Natural Heritage (SNH) and the Natural Environment Research Council (NERC). Exceptions are:

a Parts of the West Scotland survey in 2009 funded by Scottish Power and Marine Scotland.

b The Tees data collected and provided by the Industry Nature Conservation Association (Bond & Gibson, 2016). The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

c Essex & Kent data for 2016 collected and provided by the Zoological Society London (e.g. Barker & Obregon, 2015).

d No SMRU surveys in this management unit but some data available. Estimates compiled from counts shared by other organisations (Natural Resources Wales, RSPB) or found in various reports & on websites (Boyle, 2012; B üche & Stubbings, 2014; Hilbrebirdobs.blogspot.co.uk, 2012, 2013; Leeney *et al*., 2010; Sayer, 2010, 2011, 2012a, 2012b; Sayer *et al*., 2012; Westcott, 2002, 2009; Westcott & Stringell, 2004). Apparent increases may partly be due to increased

e Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002 & 2011 (Duck, 2006; Duck & Morris, 2012) and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

f Surveys carried out by SMRU and funded by the National Parks & Wildlife Service (Cronin et al., 2004; Duck & Morris, 2013a, 2013b).

* During the 2011 survey, warm weather probably kept hundreds of grey seals from hauling out at the Monach Isles. Therefore the 2011 count for the Monach Isles has been replaced with the 2008 count .

**Table 3. August counts of harbour seals in the Moray Firth between 1992 and 2016.** Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 7 for the 2016 distribution of seals within the Moray Firth and Figure 8 for a histogram of these data.

| | Area | 1992 | 1993 | 1994 | 1997 | 2000 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Survey method | fw | fw | fw | ti | fw | fw &ti | fw | 2fw | 2fw &1ti | fw &ti | fw &ti | fw &ti | fw | fw | ti | fw | fw | fw | fw | ti |
| (MEAN) COUNTS | Duncansby Head to Helmsdale | | 2 | | 1 | | | | | 1 | | | 1 | | | | | | | | |
| | Helmsdale to Brora | | 92 | | 193 | | 188 | | | 113 | 150 | 54 | 73 | 19 | 101 | 87 | 102 | 70 | 1 | 21 | 40 |
| | Loch Fleet | | 16 | | 27 | 33 | 59 | 56 | 64 | 71 | 80 | 83 | 82 | 65 | 114 | 113 | 133 | 135 | 156 | 144 | 145 |
| | Dornoch Firth (SAC) | 662 | | 542 | 593 | 405 | 220 | 290 | 231 | 191 | 257 | 144 | 145 | 166 | 219 | 208 | 157 | 143 | 111 | 120 | 85 |
| | Cromarty Firth | 41 | | 95 | 95 | 38 | 42 | 113 | 88 | 106 | 106 | 102 | 90 | 90 | 140 | 101 | 144 | 63 | 100 | 22 | 72 |
| | Beauly Firth (incl. Milton & Munlc | 220 | | 203 | 219 | 204 | 66 | 151 | 178 | 127 | 176 | 146 | 150 | 85 | 140 | 57 | 60 | 30 | 37 | 34 | 30 |
| | Ardersier (incl. Eathie) | | | 221 | 234 | 191 | 110 | 205 | 202 | 210 | 197 | 154 | 145 | 277 | 368 | 195 | 183 | 199 | 28 | 34 | 36 |
| | Culbin & Findhorn | | | 58 | 46 | 111 | 144 | 167 | 49 | 93 | 58 | 79 | 92 | 73 | 123 | 163 | 254 | 218 | 260 | 330 | 484 |
| | Burghead to Fraserburgh | | | 0 | 1 | | | | | 3 | | 0 | | | | 29 | | 39 | | | 47 |
| TOTALS | Dornoch Firth to Ardersier | | | 1,061 | 1,141 | 838 | 438 | 759 | 699 | 634 | 736 | 546 | 530 | 618 | 867 | 561 | 544 | 435 | 276 | 210 | 223 |
| | Loch Fleet to Ardersier | | | | 1,168 | 871 | 497 | 815 | 763 | 705 | 816 | 629 | 612 | 683 | 981 | 674 | 677 | 570 | 432 | 354 | 368 |
| | Loch Fleet to Findhorn | | | | 1,214 | 982 | 641 | 982 | 812 | 798 | 874 | 708 | 704 | 756 | 1,104 | 837 | 931 | 788 | 692 | 684 | 852 |
| | Helmsdale to Findhorn | | | | 1,407 | | 829 | | | 911 | 1,024 | 762 | 777 | 775 | 1,205 | 924 | 1,033 | 858 | 693 | 705 | 892 |
| | Moray Firth SMA * | | | | 1,409 | | 831 | | | 915 | 1,028 | 763 | 778 | 776 | 1,206 | 954 | 1,063 | 898 | 733 | 745 | 940 |

* For years where only the main area was surveyed (i.e. Helmsdale to Findhorn), the most recent counts for the outlying areas are used to give a total for the Moray Firth Seal Management Area.

fw, fixed-wing survey; ti, thermal imager helicopter survey; SMA, Seal Management Area.

**Table 4. August counts of grey seals in the Moray Firth between 1992 and 2016.** Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 7 for the 2016 distribution of seals within the SAC and Figure 9 for a histogram of these data.

| | Area | 1992 | 1993 | 1994 | 1997 | 2000 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Survey method | fw | fw | fw | ti | fw | fw &ti | fw | 2fw | 2fw &1ti | fw &ti | fw &ti | fw &ti | fw | fw | ti | fw | fw | fw | fw | ti |
| (MEAN) COUNTS | Duncansby Head to Helmsdale * | | 33 | | 0 | | | | | 59 | | | 9 | | | 15 | | | | | |
| | Helmsdale to Brora | | | | 3 | | 6 | | | 111 | 102 | 52 | 449 | 72 | 635 | 156 | 316 | 81 | 27 | 161 | 28 |
| | Loch Fleet | | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 7 | 7 | 20 | 18 | 7 | 10 | 31 |
| | Dornoch Firth (SAC) | 233 | | 903 | 456 | 121 | 321 | 79 | 473 | 431 | 748 | 516 | 523 | 819 | 717 | 679 | 74 | 604 | 127 | 716 | 387 |
| | Cromarty Firth | 9 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 3 | 1 | 0 | 1 |
| | Beauly Firth (incl. Milton & Munlo | 8 | | 2 | 3 | 8 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 2 | 3 | 1 | 5 | 2 | 0 | 2 |
| | Ardersier (incl. Eathie) | | | 36 | 24 | 85 | 0 | 3 | 44 | 55 | 142 | 74 | 142 | 94 | 331 | 74 | 24 | 109 | 2 | 14 | 28 |
| | Culbin & Findhorn | | | 0 | 0 | 0 | 0 | 10 | 0 | 11 | 11 | 28 | 75 | 58 | 58 | 179 | 121 | 218 | 93 | 743 | 717 |
| | Burghead to Fraserburgh | | | 30 | 65 | | | | | 205 | | 61 | | | | 18 | | 258 | | | 43 |
| TOTALS | Dornoch Firth to Ardersier | | | 941 | 483 | 214 | 321 | 82 | 517 | 486 | 894 | 594 | 665 | 913 | 1,051 | 758 | 100 | 721 | 132 | 730 | 418 |
| | Loch Fleet to Ardersier | | | | 483 | 214 | 321 | 82 | 517 | 486 | 895 | 597 | 666 | 913 | 1,058 | 765 | 120 | 739 | 139 | 740 | 449 |
| | Loch Fleet to Findhorn | | | | 483 | 214 | 321 | 92 | 517 | 497 | 906 | 625 | 741 | 971 | 1,116 | 944 | 241 | 957 | 232 | 1,483 | 1,166 |
| | Helmsdale to Findhorn | | | | 486 | | 327 | | | 608 | 1,008 | 677 | 1,190 | 1,043 | 1,751 | 1,100 | 557 | 1,038 | 259 | 1,644 | 1,194 |
| | Moray Firth SMA † | | | | 551 | | 392 | | | 872 | 1,272 | 797 | 1,260 | 1,113 | 1,821 | 1,133 | 590 | 1,311 | 532 | 1,917 | 1,252 |

* In 2011, Duncansby Head to Wick was not surveyed. Therefore the 15 grey seals given for the northern most area in 2011 include 7 counted in 2008.

† For years where only the main area was surveyed (i.e. Helmsdale to Findhorn), the most recent counts for the outlying areas are used to give a total for the Moray Firth Seal Management Area.

**Table 5. August counts of harbour seals in the Firth of Tay and Eden Estuary SAC, 1990-2016.** Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 12 for the 2016 distribution of seals within the SAC and Figure 13 for a histogram of these data.

| | Area | 1990 | 1991 | 1992 | 1994 | 1997 | 2000 | 2002 | 2003 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Survey method | 1fw | 1fw | 1fw | 1fw | 1ti | 1fw | 1fw | 1fw | 2fw ,1ti | 1fw | 1fw ,1ti | 2fw | 1fw | 1fw | 1fw | 1fw | 1ti | 1fw | 1fw | 1ti |
| (MEAN) COUNTS | Upper Tay | 27 | 73 | 148 | 89 | 113 | 115 | 51 | 83 | 91 | 91 | 63 | 49 | 45 | 41 | 16 | 40 | 36 | 21 | 51 | 41 |
| | Broughty Ferry | 77 | 83 | 97 | 64 | 35 | 52 | 0 | 90 | 51 | 31 | 27 | 13 | 28 | 15 | 18 | 16 | 3 | 0 | 2 | 4 |
| | Buddon Ness | 13 | 86 | 72 | 53 | 0 | 113 | 109 | 142 | 25 | 96 | 64 | 27 | 8 | 23 | 11 | 8 | 10 | 1 | 3 | 0 |
| | Abertay & Tentsmuir | 319 | 428 | 456 | 289 | 262 | 153 | 167 | 53 | 63 | 34 | 31 | 50 | 8 | 9 | 0 | 5 | 0 | 0 | 0 | 1 |
| | Eden Estuary | 31 | 0 | 0 | 80 | 223 | 267 | 341 | 93 | 105 | 90 | 90 | 83 | 22 | 36 | 32 | 19 | 1 | 7 | 4 | 5 |
| | SAC total | 467 | 670 | 773 | 575 | 633 | 700 | 668 | 461 | 335 | 342 | 275 | 222 | 111 | 124 | 77 | 88 | 50 | 29 | 60 | 51 |

fw, fixed-wing survey; ti, thermal imager helicopter survey; SAC, Special Area of Conservation

**Table 6. August counts of grey seals in the Firth of Tay and Eden Estuary SAC, 1990-2016.** Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 12 for the 2016 distribution of seals within the SAC and Figure 14 for a histogram of these data.

| | Area | 1990 | 1991 | 1992 | 1994 | 1997 | 2000 | 2002 | 2003 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Survey method | 1fw | 1fw | 1fw | 1fw | 1ti | 1fw | 1fw | 1fw | 2fw ,1ti | 1fw | 1fw ,1ti | 2fw | 1fw | 1fw | 1fw | 1fw | 1ti | 1fw | 1fw | 1ti |
| (MEAN) COUNTS | Upper Tay | 0 | 0 | 18 | 20 | 61 | 64 | 78 | 50 | 42 | 22 | 27 | 26 | 55 | 98 | 16 | 39 | 127 | 62 | 115 | 132 |
| | Broughty Ferry | 0 | 3 | 0 | 9 | 0 | 0 | 0 | 16 | 0 | 8 | 1 | 8 | 0 | 0 | 2 | 3 | 0 | 2 | 0 | 0 |
| | Buddon Ness | 0 | 0 | 1 | 104 | 0 | 101 | 0 | 33 | 11 | 25 | 85 | 7 | 0 | 12 | 22 | 13 | 18 | 0 | 2 | 0 |
| | Abertay & Tentsmuir | 912 | 1,546 | 1,191 | 1,335 | 1,820 | 2,088 | 1,490 | 1,560 | 763 | 1,267 | 1,375 | 483 | 395 | 1,406 | 1,265 | 1,111 | 323 | 531 | 687 | 738 |
| | Eden Estuary | 0 | 0 | 16 | 0 | 10 | 0 | 25 | 4 | 27 | 57 | 31 | 33 | 0 | 39 | 17 | 36 | 14 | 39 | 32 | 66 |
| | SAC total | 912 | 1,549 | 1,226 | 1,468 | 1,891 | 2,253 | 1,593 | 1,663 | 843 | 1,379 | 1,519 | 557 | 450 | 1,555 | 1,322 | 1,202 | 482 | 634 | 836 | 936 |

fw, fixed-wing survey; ti, thermal imager helicopter survey; SAC, Special Area of Conservation

**Table 7. August counts of harbour seals on the English east coast, 1988 to 2016.** In years when more than one survey was undertaken, values are means with the numbers of surveys in parentheses. Blank grey cells means that no survey was carried out.

| | Northeast England | | Southeast England | | | | |
|---|---|---|---|---|---|---|---|
| Year | N'umberland | The Tees | Donna Nook | The Wash | Blakeney Point | Scroby Sands | Essex & Kent |
| 1988 | | | 173 | 3,035 | 701 | | |
| 1989 | | 16 (31) | 126 | 1,556 (2) | 307 | | |
| 1990 | | 23 (31) | 57 | 1,543 | | | |
| 1991 | | 24 (31) | | 1,398 (2) | | | |
| 1992 | | 27 (31) | 32 (2) | 1,671 (2) | 217 | | |
| 1993 | | 30 (31) | 88 | 1,884 | 267 | | |
| 1994 | 13 | 35 | 103 (2) | 2,011 (2) | 196 | 61 | |
| 1995 | | 33 (31) | 115 | 2,084 (2) | 415 (2) | 49 | 130 |
| 1996 | | 42 (31) | 162 | 2,151 | 372 | 51 | |
| 1997 | 12 | 42 (31) | 251 (2) | 2,466 (2) | 311 (2) | 65 (2) | |
| 1998 | | 41 (31) | 248 (2) | 2,374 (2) | 637 (2) | 52 | |
| 1999 | | 36 (31) | 304 (2) | 2,392 (2) | 659 (2) | 72 (2) | |
| 2000 | 10 | 59 (31) | 390 (2) | 2,779 (2) | 895 | 47 (2) | |
| 2001 | | 59 (31) | 233 | 3,194 | 772 | 75 | |
| 2002 | | 52 (31) | 341 | 2,977 (2) | 489 (2) | | |
| 2003 | | 38 (31) | 231 | 2,513 (2) | 399 | 38 | 180 |
| 2004 | | 40 (31) | 294 (2) | 2,147 (2) | 646 (2) | 57 (2) | |
| 2005 | 17 | 50 (31) | 421 (2) | 1,946 (2) | 709 (2) | 56 (2) | 101 |
| 2006 | | 45 (31) | 299 | 1,695 | 719 | 71 | |
| 2007 | 7 | 43 (31) | 214 | 2,162 | 550 | | |
| 2008 | 9 | 41 (31) | 191 (2) | 2,011 (2) | 581 (2) | 81 (2) | 319 |
| 2009 | | 49 (31) | 267 (2) | 2,829 (2) | 372 | 165 (2) | |
| 2010 | | 53 (31) | 176 (2) | 2,586 (2) | 391 | 201 (2) | 379 |
| 2011 | | 57 (31) | 205 | 2,894 | 349 | 119 | |
| 2012 | | 63 (31) | 192 (2) | 3,372 (2) | 409 | 161 | |
| 2013 | | 74 (31) | 396 | 3,174 | 304 | 148 | 482 |
| 2014 | | 81 (31) | 353 | 3,086 | 468 | 285 | 489 |
| 2015 | 0 | 91 (31) | 228 (2) | 3,336 (2) | 455 | 270 (2) | 451 |
| 2016 | | 86 (31) | 369 (2) | 3,377 (2) | 424 (2) | 198 (2) | 694 |

SOURCE - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
**Northumberland** - One complete survey in 2008 (funded by DECC (previously DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015. Fixed-wing surveys of Holy Island only in 1994 & 2000.
**The Tees** - Ground counts by Industry Nature Conservation Agency (Bond & Gibson, 2016). Single SMRU fixed-wing count
**Southeast England** - All SMRU aerial surveys, except for Essex & Kent 2013-2016: data from surveys (aerial/by boat/from carried out by the Zoological Society of London (Barker & Obregon, 2015, and unpublished). The 130 for 1995 are an estimate based on a partial SMRU aerial survey.

**Table 8. August counts of grey seals on the English east coast, 1995 to 2016.** In years when more than one survey was undertaken, values are means with the numbers of surveys in parentheses. Blank grey cells means that no survey was carried out.

| | Northeast England | | Southeast England | | | | |
|---|---|---|---|---|---|---|---|
| Year | N'umberland | The Tees | Donna Nook | The Wash | Blakeney Point | Scroby Sands | Essex & Kent |
| 1988 | | | | 52 | 1 | | |
| 1989 | | 7 | | | | | |
| 1990 | | 9 | 115 | 10 | | | |
| 1991 | | 8 | | 48 (2) | | | |
| 1992 | | 9 | 235 | 35 (2) | 6 | | |
| 1993 | | 9 | 59 | 64 | 7 | | |
| 1994 | 100 | 6 | 100 (2) | 94 (2) | 40 (2) | 43 | |
| 1995 | | 10 | 123 | 66 (2) | 18 (2) | 32 | |
| 1996 | | 11 | 119 | 60 | 11 | 46 | |
| 1997 | 603 | 10 | 289 (2) | 49 (2) | 45 (2) | 34 (2) | |
| 1998 | | 11 | 174 (2) | 53 (2) | 33 (2) | 23 | |
| 1999 | | 12 | 317 (2) | 57 (2) | 14 (2) | 89 (2) | |
| 2000 | 568 | 11 | 390 | 40 (2) | 17 | 40 (2) | |
| 2001 | | 11 | 214 | 111 | 30 | 70 | |
| 2002 | | 12 | 291 | 75 (2) | 11 (2) | | |
| 2003 | | 11 | 232 (2) | 58 (2) | 18 | 36 | 96 |
| 2004 | | 13 | 609 (2) | 30 (2) | 10 (2) | 93 (2) | |
| 2005 | 1,092 | 12 (31) | 927 (2) | 49 (2) | 86 (2) | 106 (2) | |
| 2006 | | 8 (31) | 1,789 | 52 | 142 | 187 | |
| 2007 | 1,907 | 8 (31) | 1,834 | 42 | | | |
| 2008 | 2,338 | 12 (31) | 2,068 (2) | 68 (2) | 375 (2) | 137 (2) | 160 |
| 2009 | | 12 (31) | 1,329 (2) | 118 (2) | 22 | 157 (2) | |
| 2010 | | 14 (31) | 2,188 (2) | 240 (2) | 49 (2) | 292 (2) | 393 |
| 2011 | | 14 (31) | 1,930 | 142 | 300 | 323 | |
| 2012 | | 18 (31) | 4,978 | 258 (2) | 65 | 126 | |
| 2013 | | 16 (31) | 3,474 | 219 | 63 | 219 | 203 |
| 2014 | | 16 (31) | 4,437 | 223 | 445 | 509 | 449 |
| 2015 | 6,767 | 16 (31) | 3,766 (2) | 369 (2) | 528 | 520 (2) | 454 |
| 2016 | | 22 (31) | 3,964 (2) | 431 (2) | 355 (2) | 642 (2) | 481 |

SOURCE - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
**Northumberland** - One complete survey in 2008 (funded by DECC (previously DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015. Fixed-wing surveys of Holy Island only in 1994 & 2000.
**The Tees** - Ground counts by Industry Nature Conservation Agency (Bond & Gibson, 2016). For years prior to 2005, only monthly maximums are available for grey seals. For these years, the given values are estimates calculated using the mean relationship of mean to maximum counts from 2005-2013.
**Southeast England** - All SMRU aerial surveys, except for Essex & Kent 2013-2016: data from surveys (aerial/by boat/from carried out by the Zoological Society of London (Barker & Obregon, 2015, and unpublished).

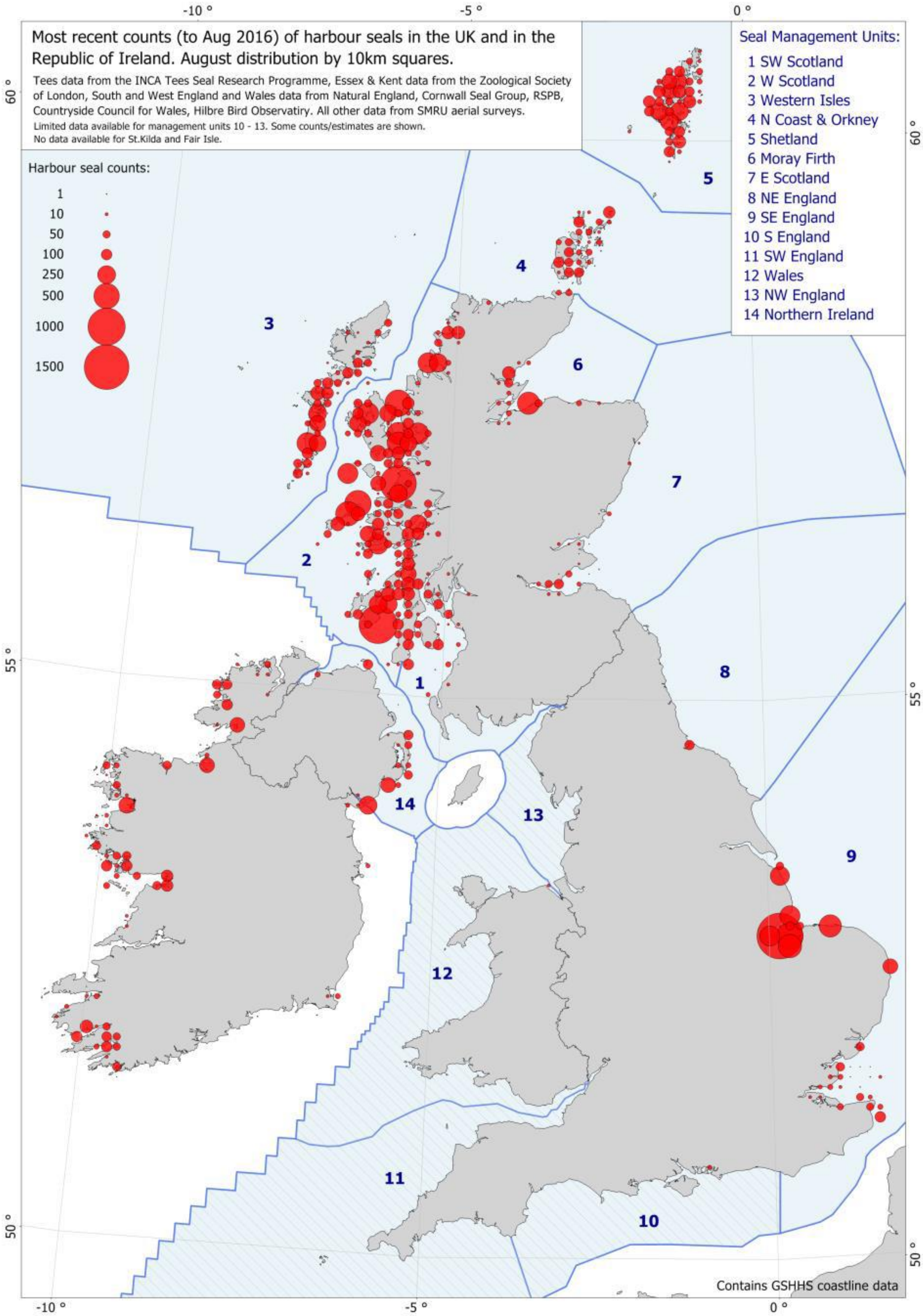



**Figure 1**. August distribution of harbour seals around the British Isles. Very small numbers of harbour seals (<50) are anecdotally but increasingly reported for the Management Units 10-13, but are not included on this map.

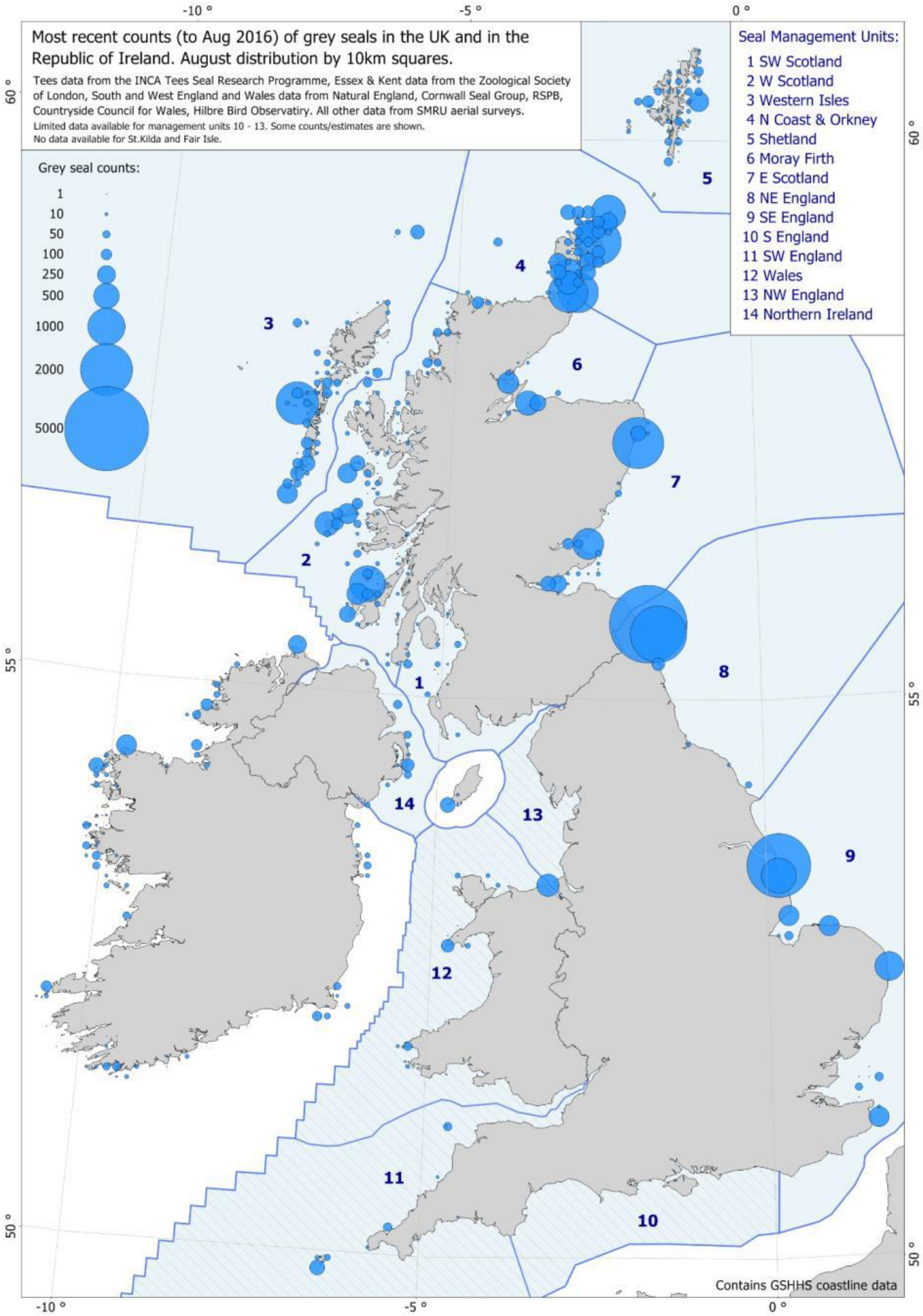



**Figure 2.** August distribution of grey seals around the British Isles. Only a few August counts are available for grey seals in the Management Units 10-13.

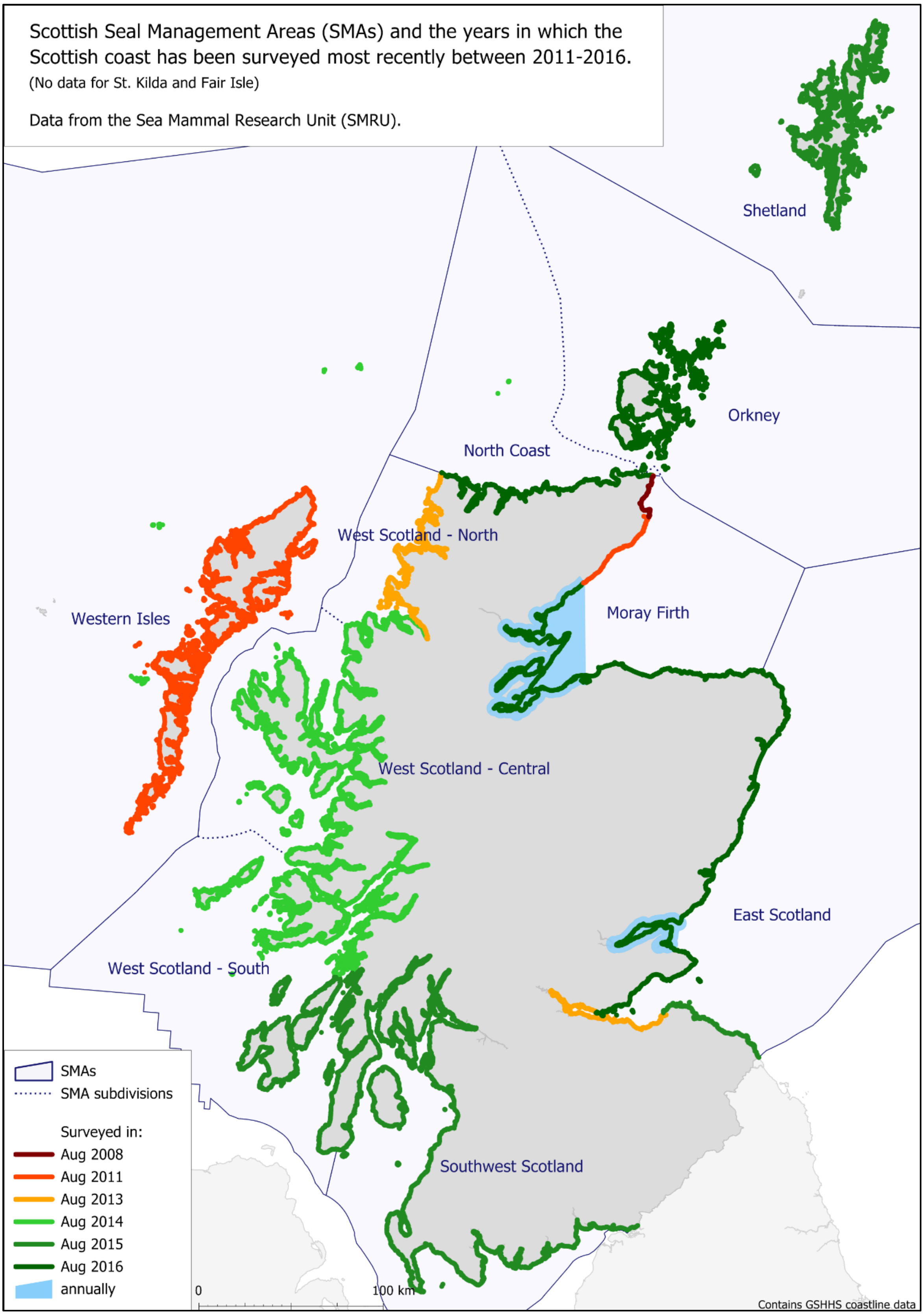



**Figure 3**. Years in which different parts of Scotland were surveyed most recently by helicopter using a thermal imaging camera. Most areas were surveyed between 2011 and 2015. The enclosed areas of the Firth of Tay and the Moray Firth (between Findhorn and Helmsdale) are surveyed every year, usually by fixed-wing aircraft.

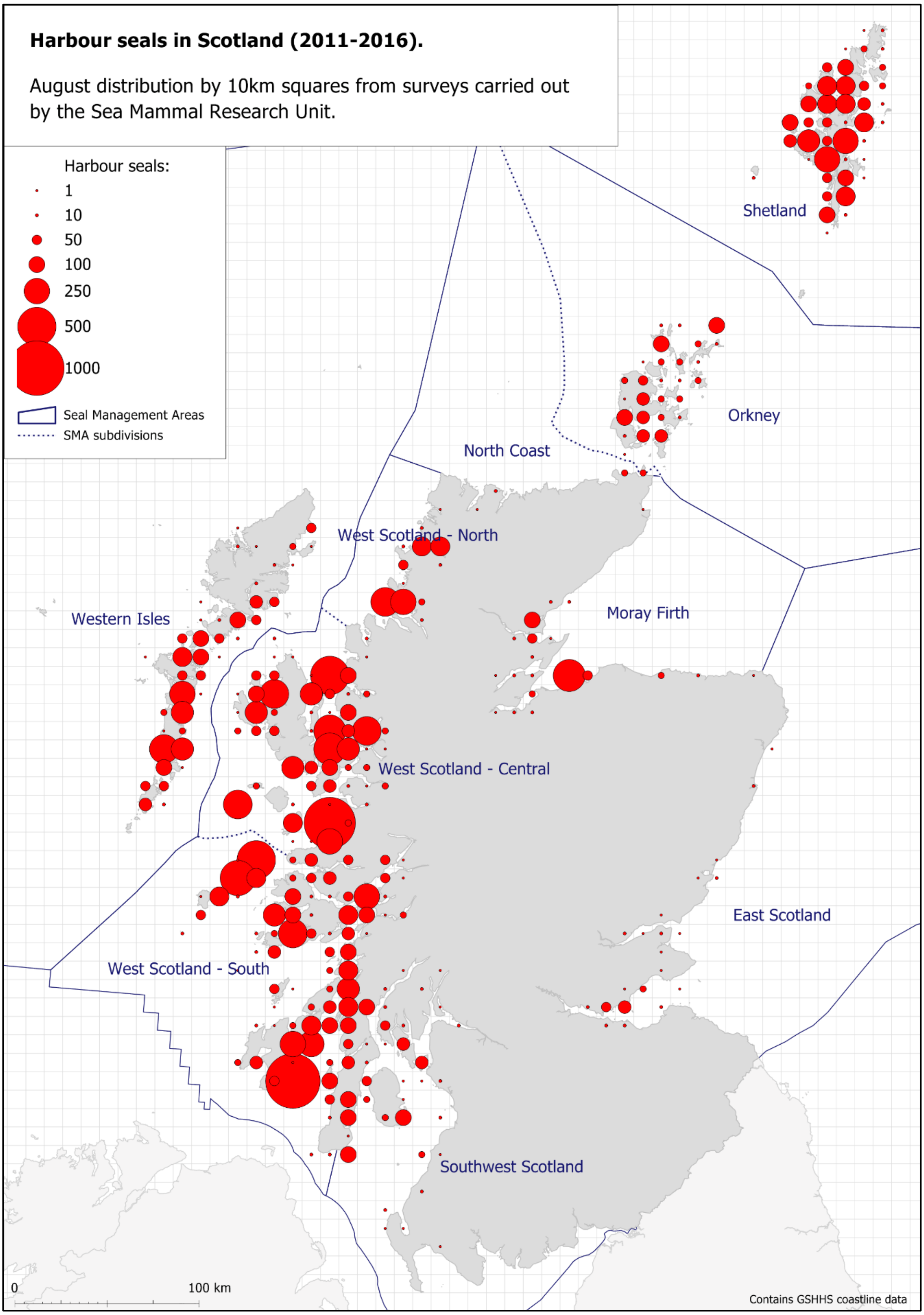



**Figure 4.** August distribution of harbour seals in Scotland. All areas were surveyed by helicopter using a thermal imaging camera, except for the Moray Firth area between Helmsdale and Findhorn, which was surveyed by fixed-wing aircraft without a thermal imager.

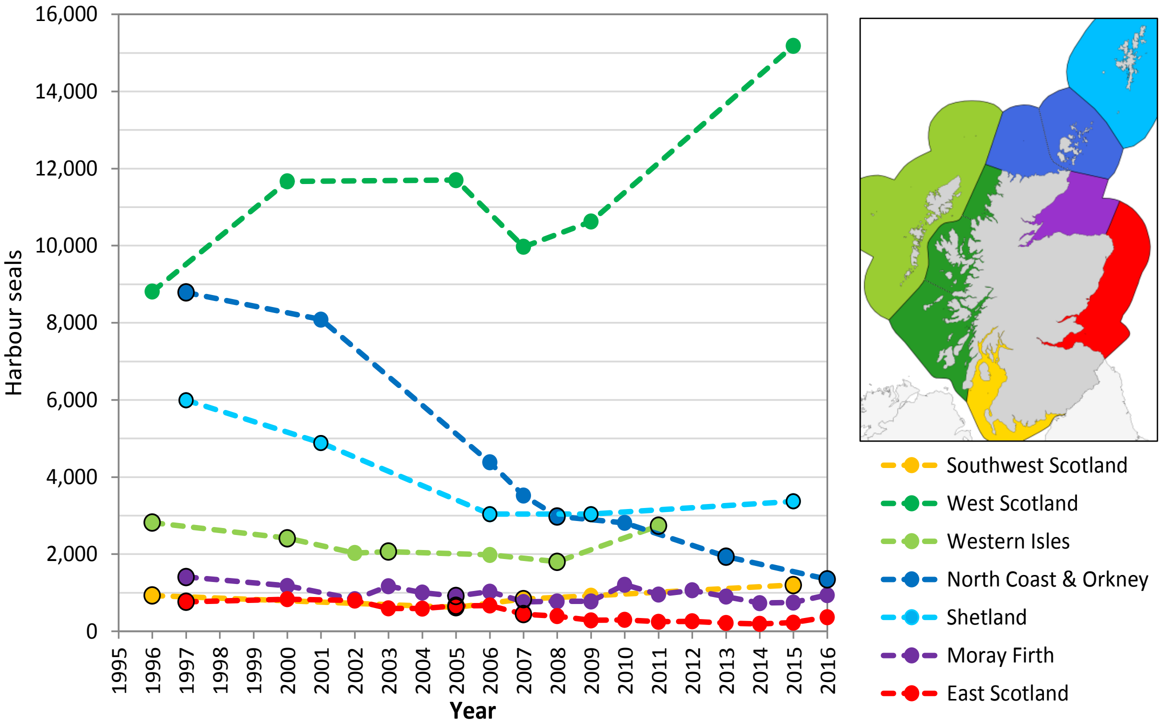



**Figure 5.** August counts of harbour seals in Scottish Seal Management Areas, 1996-2016. Data from the Sea Mammal Research Unit. Note that because these data points represent counts of harbour seals distributed over large areas, individual data points may not be from surveys from only one year. Points are only shown for years in which a significant part of the SMA was surveyed. Points with a black outline are counts obtained in a single year. Trajectories and Seal Management Areas are colour coordinated.

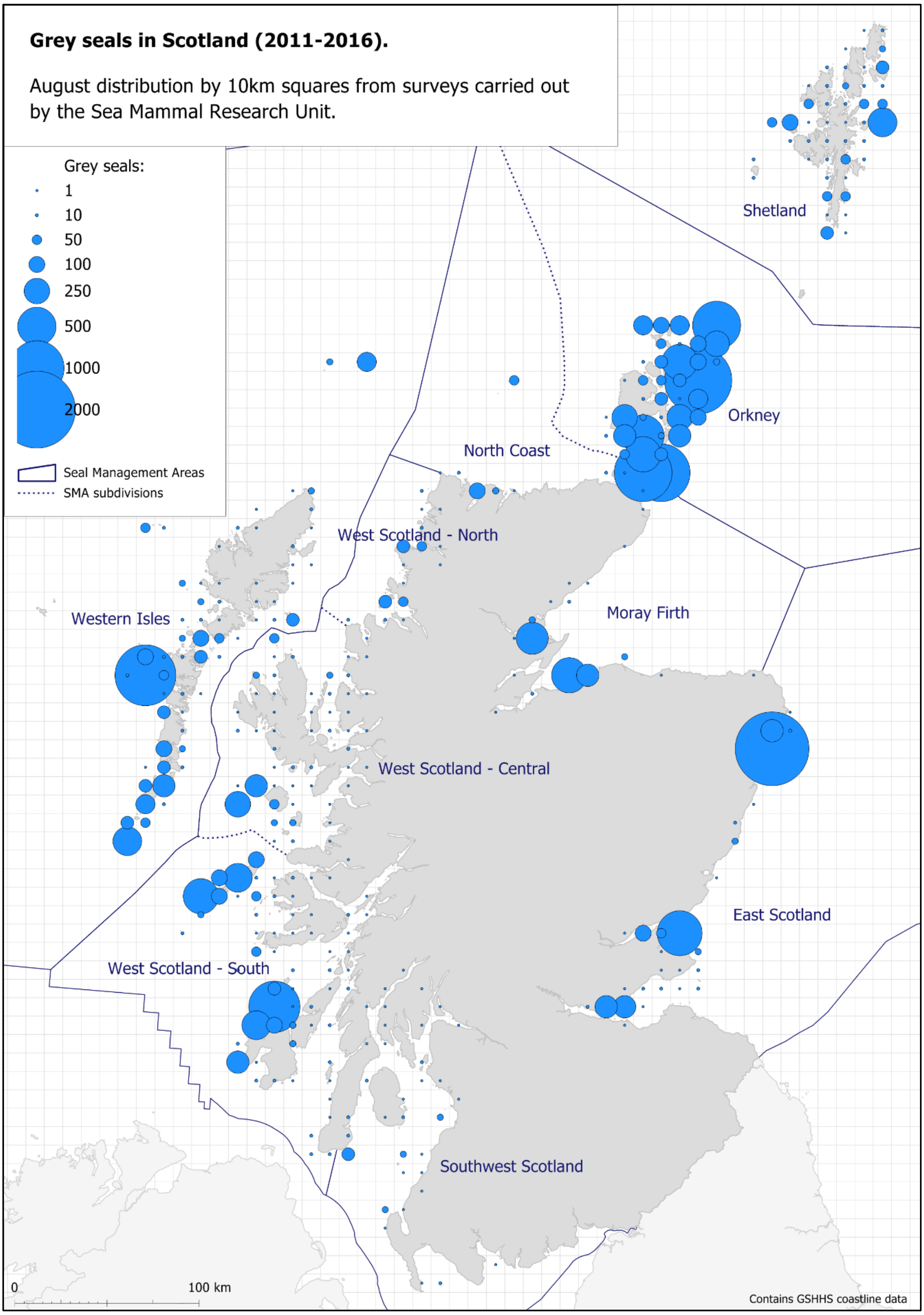



**Figure 6.** August distribution of grey seals in Scotland. All areas were surveyed by helicopter using a thermal imaging camera, except for the Moray Firth area between Helmsdale and Findhorn, which was surveyed by fixed-wing aircraft without a thermal imager.

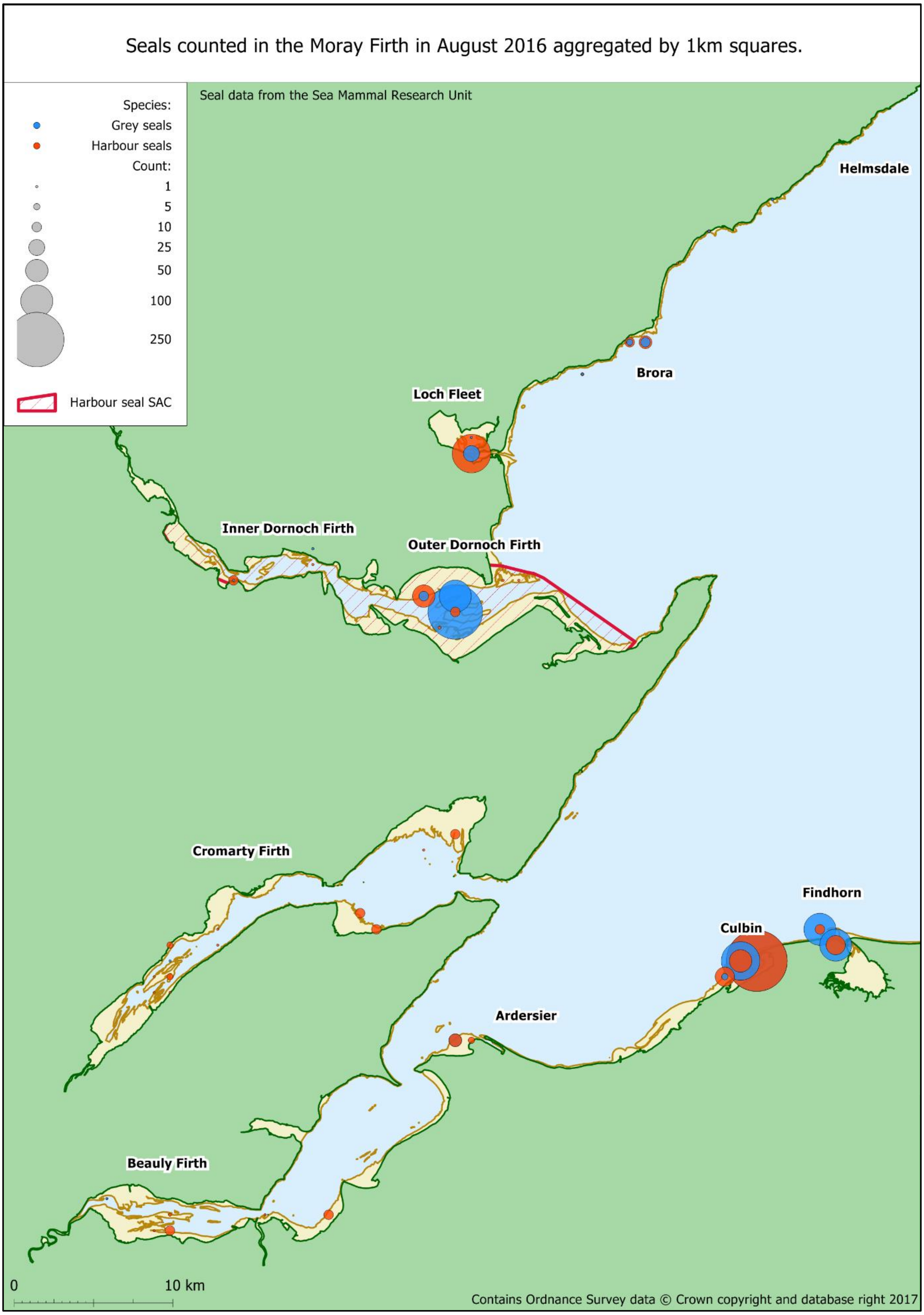



**Figure 7.** Distribution of harbour (red) and grey seals (blue) in the annually surveyed part of the Moray Firth, between Helmsdale and Findhorn, from an aerial survey carried out on 10th August 2016.

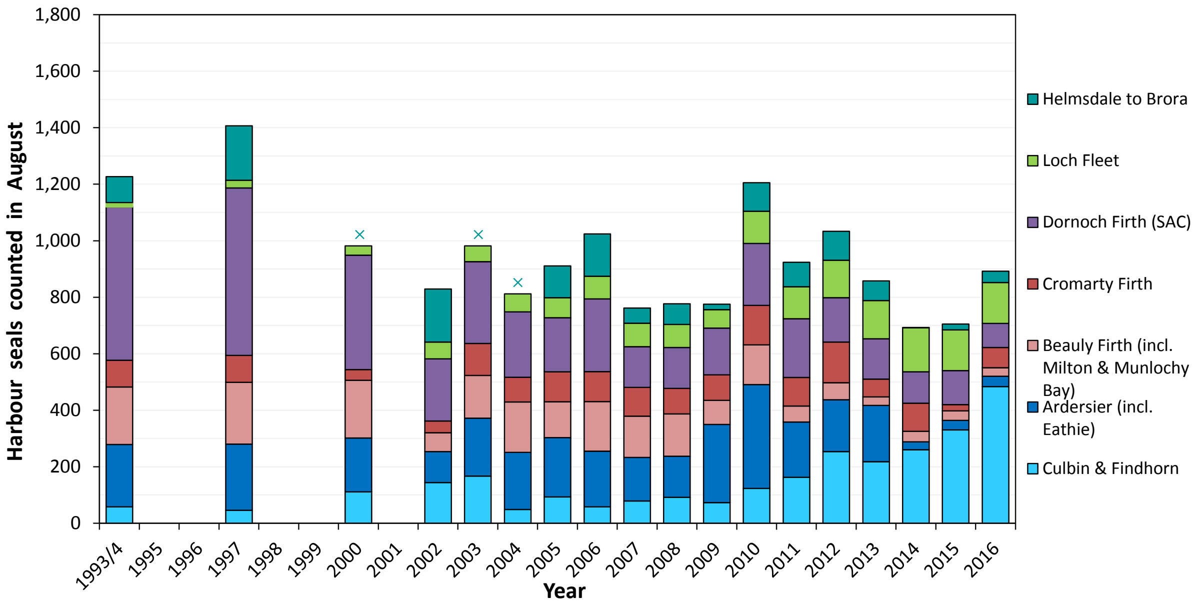



**Figure 8**. August counts of harbour seals in different areas of the Moray Firth, 1994-2016. Data are from the Sea Mammal Research Unit. x: Helmsdale to Brora not surveyed in 2000, 2003 or 2004.

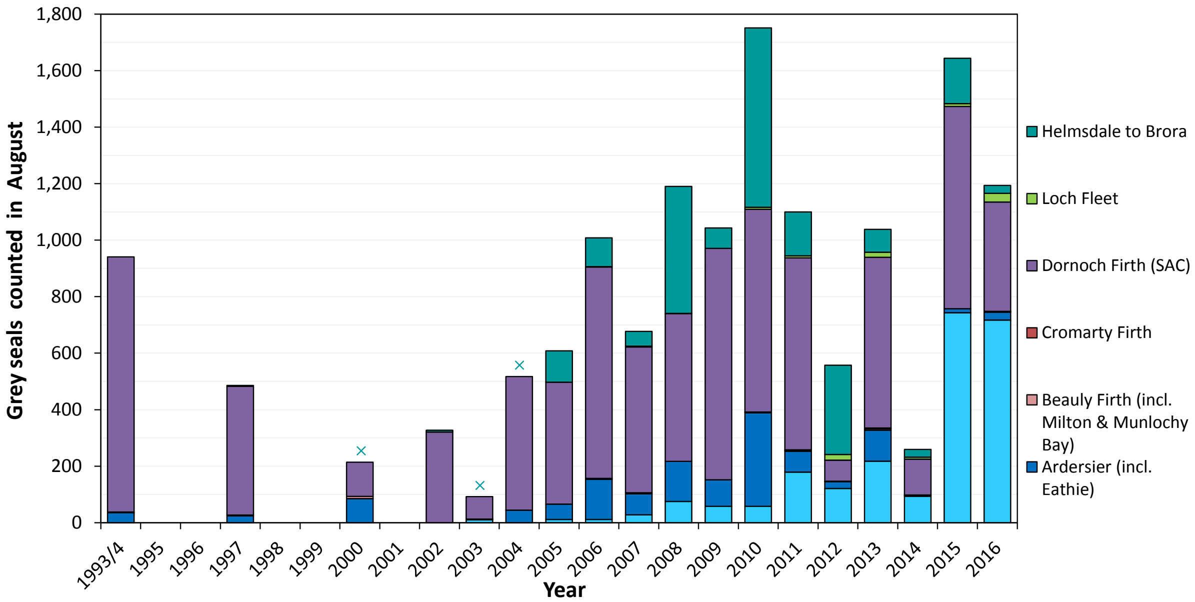



**Figure 9**. August counts of grey seals in different areas of the Moray Firth, 1994-2016. Data are from the Sea Mammal Research Unit. x: Helmsdale to Brora not surveyed in 2000, 2003 or 2004.

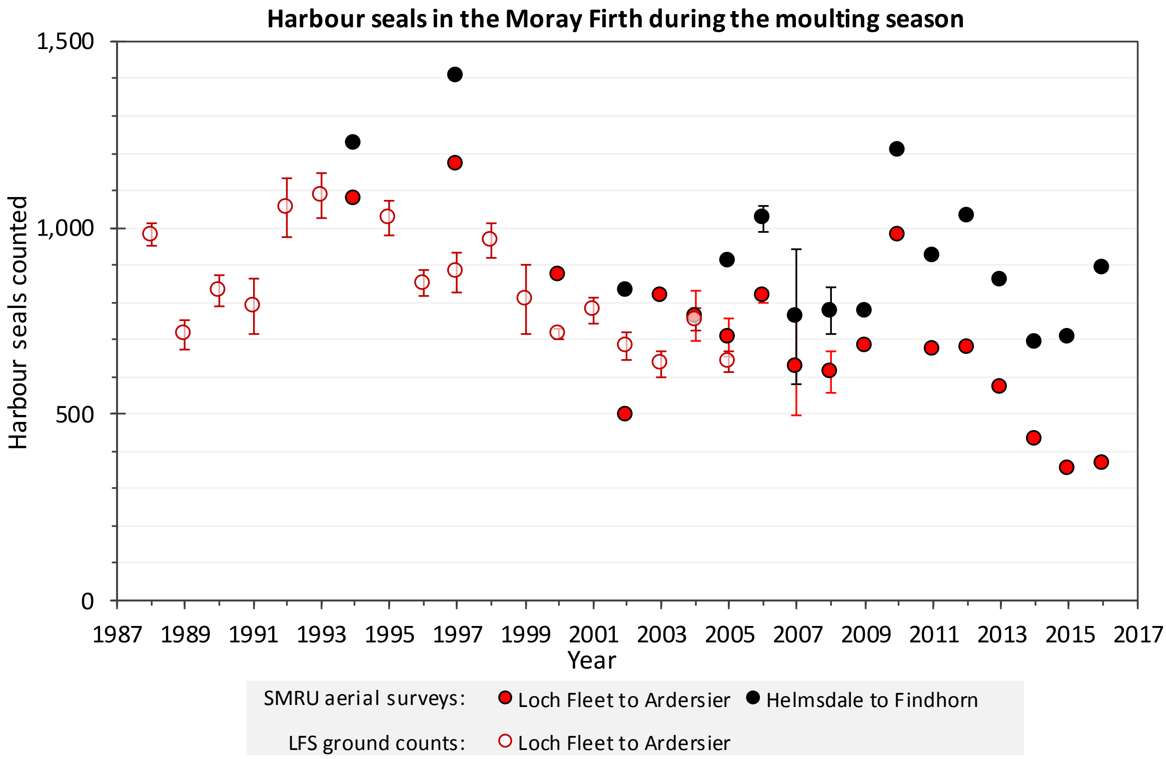



**Figure 10.** Counts of harbour seals in the Moray Firth during the moult season (August), 1988-2016. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

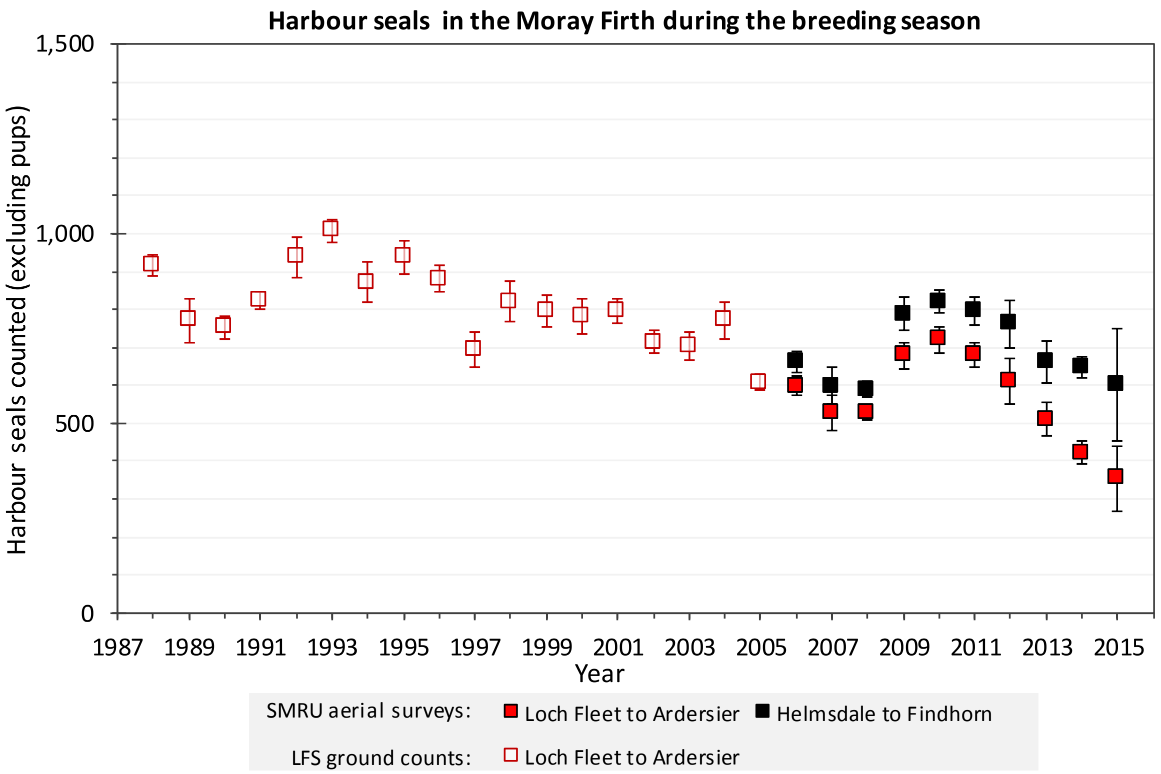



**Figure 11.** Counts of harbour seals in the Moray Firth during the breeding season (June/July), 1988-2016. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

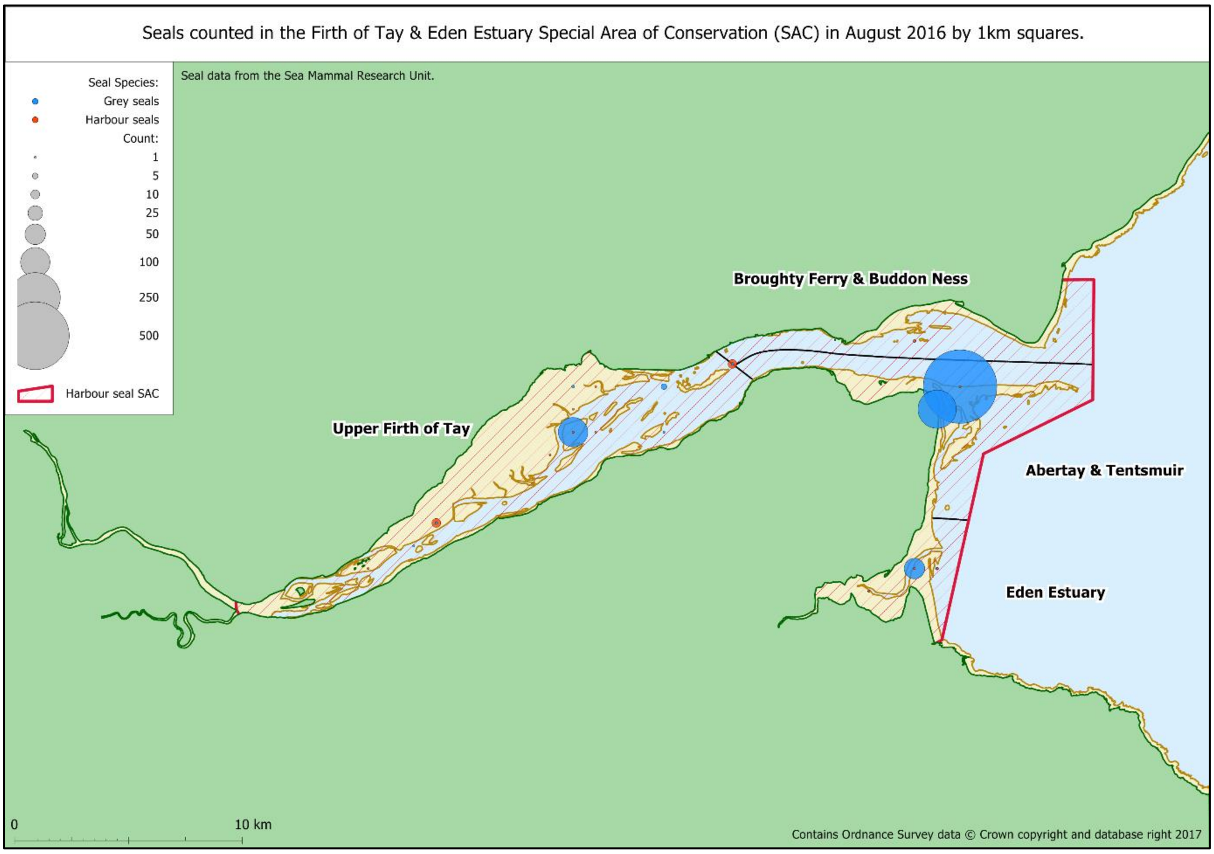



**Figure 12.** The distribution of harbour (red) and grey seals (blue) in the Firth of Tay and Eden Estuary on 9th August 2016.

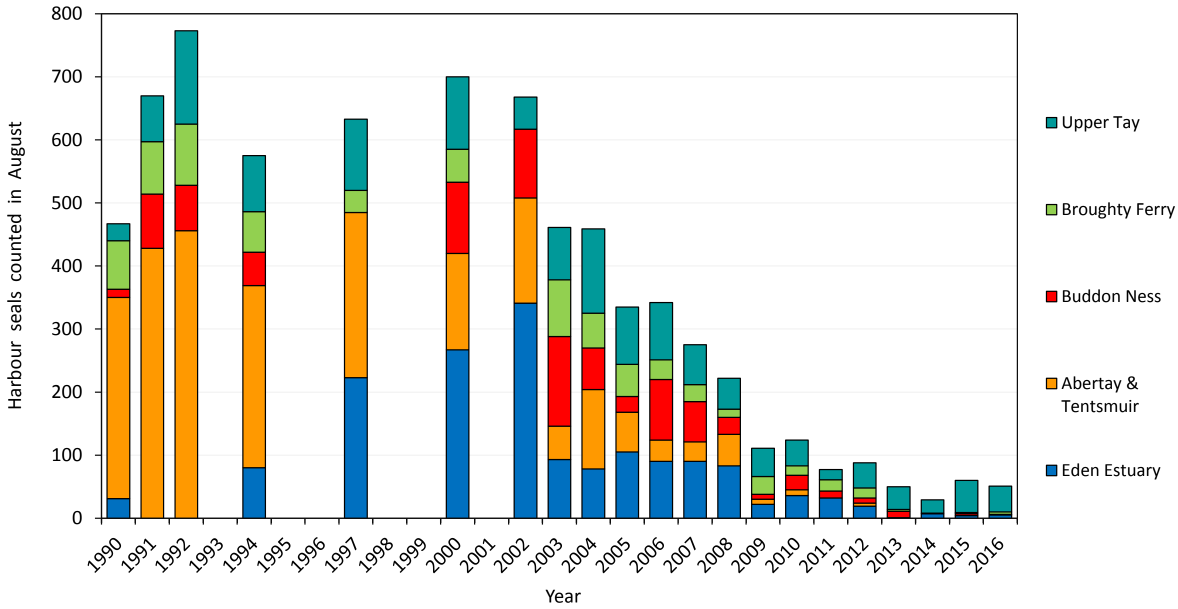



**Figure 13.** August counts of harbour seals in the Firth of Tay and Eden Estuary, 1990 to 2016.

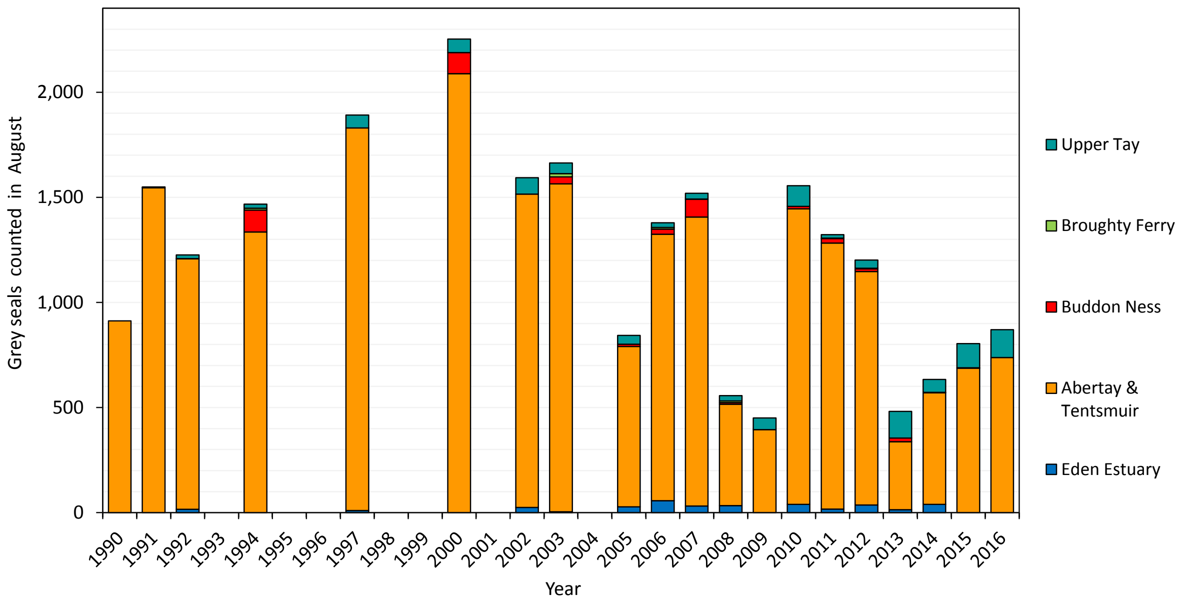
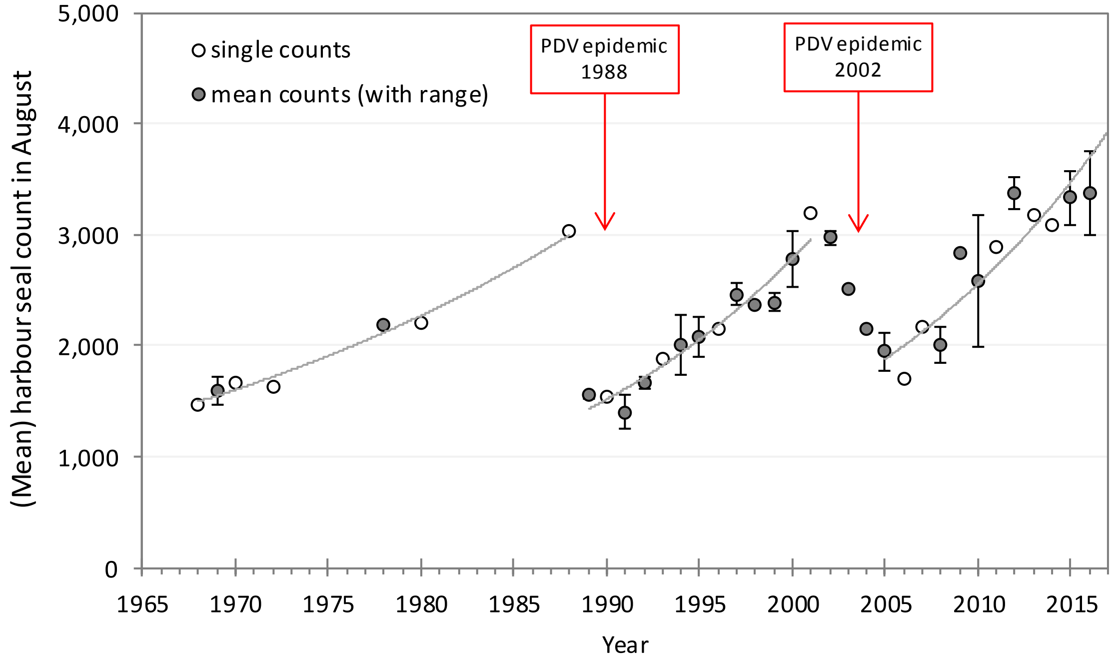



**Figure 14.** August counts of grey seals in the Firth of Tay and Eden Estuary, 1990 to 2016.




NOTE - vertical bars indicate the range of the counts used to calculate the mean.

**Figure 15.** Counts of harbour seals in The Wash between 1967 and 2016 from surveys by the Sea Mammal Research Unit.

# Harbour seal decline - vital rates and drivers

## A progress report on Year 2

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**Abstract**

Numbers of harbour seals (*Phoca vitulina*) have dramatically declined in parts of Scotland over the last 15 years. This report provides a summary of the work conducted under year two of the 'harbour seal decline – vital rates and drivers' task (Marine Mammal Scientific Support Research Programme MMSS/02/15), which aims to identify, understand and assess the relative contribution of various factors in this decline.

A simplified version of the population model previously built for the Moray Firth has been re-coded in JAGS language, and a decision support tool has been developed to include a biologically realistic simulation model and a model-fitting step that attempts to recover the parameters used in the simulation. The fitting software is able to estimate parameters from historical count data containing data gaps and when no pup count data are available.

Live capture-release studies were conducted in Orkney in April and May 2016, to collect individual covariates and deploy telemetry tags to inform the photo-identification effort. Blubber concentrations of progesterone may be a much more reliable indicator of pregnancy than levels in plasma. The proportion of the live-captured adult females (n=13) that were pregnant was 61.5% (95% CI 35% - 88%), which is lower than would have been expected. 88% of the urine and faecal samples collected showed domoic acid above the limit of detection, indicating some low level exposure. Fish viscera (n=85, 4 different species) sampled off the west coast of Orkney mainland were all positive for domoic acid although concentrations in all fish sampled were at low levels.

In addition to the moult aerial surveys conducted in August 2016 in Orkney as part of the SMRU annual survey programme, breeding aerial surveys were conducted in Scapa Flow (Orkney), Kintyre and Isle of Arran, and Loch Dunvegan, using a fix-wing aircraft and digital photography. The difficulty of locating the seals at haulout sites from the aircraft and the impossibility of identifying age classes in the photographs led to the decision of excluding such data from the population model.

A total of 92 seal carcasses (both species) were reported to SMASS between June 2016 and March 2017 in the three study areas. However, no obvious consistent causes of death were identified among the harbour seals that were examined post-mortem.

**Introduction**

A decline in Scottish harbour seals (*Phoca vitulina*) was detected in the early 2000s (Lonergan *et al.*, 2007) and has continued in some of the surveyed regions, with the decline in numbers being more apparent for the east and north coasts of Scotland and in the Northern Isles (SCOS, 2015). In order to determine the management and mitigation options to address this situation, the relative contributions of various factors potentially involved in the declines need to be identified, understood and assessed. Potential drivers include changes in prey quality and/or availability, increasing grey seal population size which may be influencing harbour seal populations through direct predation or competition for resources, and the occurrence and exposure of seals to toxins from harmful algae. Irrespective of the factor or factors driving the decline, changes observed at the population level must result from changes in vital rates (i.e. survival and fecundity rates). Obtaining information on such life history parameters from long-term studies (e.g. Bowen *et al.*, 2003) in regions with contrasting population trajectories (declining compared to stable or increasing populations) will help to identify the causal factors and determine how and where the potentially important natural and/or anthropogenic factors are acting. At present, life history information for harbour seals in Scotland is available only from Loch Fleet and the Moray Firth (Mackey *et al.*, 2008; Cordes and Thompson, 2013), but is completely lacking for other regions in Scotland. In complex ecosystems, populations may experience pressure from multiple causes (e.g. food shortage, predation, toxin exposure and anthropogenic mortality). Causes of mortality or poor condition may impact different parts of the population in different ways (e.g. young or pregnant animals might be especially vulnerable to nutritional stress). Also, for long-lived animals such as harbour seals, considerable time lags may also be seen between cause and consequence in terms of population numbers. Consequently, the outcomes of combined effects at the level of population abundance may be difficult to predict intuitively.

This paper presents a summary of the progress on each of the six approaches included in the task 'habour seal decline – vital rates and drivers' under the Marine Mammal Scientific Support Research Programme MMSS/02/15: (1) integrated population model; (2) harbour seal vital rates using mark-recapture photo-identification data (this approach will not start until the end of photo-ID data collection on Year 5 and is thus not reported here); (3) live capture-release of harbour seals at the photo-ID study sites; (4) aerial survey counts of harbour and grey seals at and adjacent to the study sites; (5) improving the understanding of potential drivers of population change; and (6) seal carcass collection.

**Methods**

1. <u>Integrated population model</u>

The integrated population model is based on original Moray Firth study of local harbour seal population dynamics and subsequent developments of that model (Matthiopoulos *et al*., 2014; Caillat and Smout, 2015). A decision support tool (DST) has been developed to include an age-structured population model coded in R to produce simulated data, and a model-fitting step coded in JAGS package to recover the parameters used in the simulation, using the Bayesian hidden-process modelling approach (Newman *et al*., 2006). The simulation tool provides a framework to test out possible hypothesis about population decline, such as the imposition of 'external' sources of mortality (e.g. shooting, toxic algal blooms, or predation by grey seals). The simulation can show the effects of changes that may affect all the population or only certain age/sex classes.

The simulation approach can also suggest how well model-fitting will inform our understanding of local seal populations, including where data are limited (i.e. sparse data or moult count only data). The DST was first applied to data sets including pup and moult count data and then excluding the pup count data. For the model fitted to moult-only data, a single value representing pup recruitment (i.e. the average number of yearling seals produced in year *t+1* by female pupping in year *t)* was calculated as the product of female fecundity with first year survival. For ease of comparison between models, this is the quantity that has been estimated for all results reported here.

The DST was then used to investigate whether this modelling approach would be suitable for limited data sets, such as those from Scapa Flow (Orkney). The fitted model was modified to include the change in 'external' mortality as a logistic function of time rather than as a step function, and simplified by excluding the density dependent processes, calculating male survival rate as a simple multiplier (*0.9 X female survival*), and fixing female fecundity at 0.9.

2. Live capture-release at the photo-ID study sites

Two separate trips were conducted in Orkney to carry out live capture-release studies of harbour seals in April and May 2017, focussing on capturing adult females where possible. Seals were captured in South Burray and in Widewall Bay (South Ronaldsay), at haulout sites where photo-ID studies were to be carried during the breeding season. During both trips adult and juvenile harbour seals were captured, individual covariate data were collected from each seal and telemetry tags (GSM/GPS and LO tags) were deployed on adult seals, primarily on females. Pictures of their pelage were taken for photo-identification purposes.

Urine and faecal samples were analysed for domoic acid concentrations using the validated and published ELISA method (Hall and Frame, 2010). The growth layer groups in the collected teeth were counted to determine the age of the individuals (Dietz *et al*., 1991). Blood samples were analysed for progesterone and 17 beta-oestradiol to determine the pregnancy status of the adult females, using commercially available ELISA assays (Gardiner *et al*., 1996). Progesterone was determined in the blubber samples using the same assay following solvent extraction of the steroids (Kellar *et al*., 2006). In addition, all serum and plasma samples collected in 2016 and 2017 will in future be analysed for specific clinical chemistry parameters to determine health condition.

3. Breeding aerial survey counts of harbour seals

The annual moult surveys conducted by SMRU in August covered the Orkney coastline in August 2016. Results of those surveys are reported in SCOS-BP 17/03. Additionally, breeding aerial surveys were conducted in Scapa Flow (Orkney), Kintyre and Isle of Arran, and in Loch Dunvegan (Isle of Skye) using a small fixed-wind aircraft and digital photography. Due to the extent and complexity of the coast line, the west end of Scapa Flow could not be surveyed in a single tide cycle.

4. Improving the understanding of potential drivers of population change

In addition to the excreta samples collected during the live captures, a further six scats were collected at the capture haulout sites in Widewall Bay (n=5 scats) and West Burray (n=2 scats, n=13 in total) during May and June. One scat was also collected at Rubh nan Sgarbh, in Kintyre, west coast of mainland. It was not possible to collect scat at the Isle of Skye study site as it was not possible to land during the photo-ID trips.

Two fishing trips to collect prey samples were undertaken in the waters off Scapa Flow on the west coast of Orkney mainland. A total of 85 fish guts were sampled for domoic acid analysis, using the same method as for the urine and faecal samples. 35 cod, 12 haddock, 36 ling and two torsk were sampled, classified by species and stored in bags containing between 1 and 7 guts, with details on the length of the sampled fish contained in each bag (all fish were measured except for 11).

5. Seal carcass collection

A total of 92 seal carcasses were reported to SMASS between June 2016 and March 2017 in the three study areas (Orkney, Isle of Skye and Kintyre and the Clyde). No carcasses were reported for these areas in April and May 2016.

**Results and Discussion**

1. Integrated population model

Data including both pup and moult count data sub-sampled from a 30 year time interval were fitted in about 15 minutes using 100,000 MCMC iterations on a standard I7 laptop using JAGS. The 'recovered' values of the parameters (marginal posterior distributions estimated by the fitting process, black curves, (Figure 1) were fairly close to the 'known' values (prior distributions, red curves). The fitted model recovers the 'known' population (i.e. known values from the simulated data set, red curve) trajectory well, and approximates the change point year (Figure 2). The 'known' population trajectory lied within the 95% confidence intervals (dashed curves) of the estimated population trajectory based on the fitted model (black curve).

When only moult count data were made available for model fitting, results showed refined male and female survival rates, compared with the priors, but male survival was not estimated well (Figure 3). This is perhaps not surprising as moult count data do not distinguish adult males from females. Where pup count data are available this may put some constraints on numbers of breeding females and inform estimates of female numbers overall, thus indirectly informing estimates of male numbers and survival rates. It is thus recommended that in all future model-fitting, the approach used in the original Moray Firth model is adopted, and male survival is assumed to be (*0.9 X female survival*). The year in which mortality changes occurred was considerably refined from the broad prior and it was close to the true value, but the estimates' 95% confidence intervals did not include the true value i.e. they were too 'tight', therefore giving artificial confidence in the estimated result (Figure 4). This may be due to poor mixing within the MCMC for this parameter, a technical issue which should be further explored. The estimated population trajectory based on the fitted model compared fairly closely with the 'known' trajectory though there was some deviation associated with imperfect estimation of the change point year (Figure 4).

Fitting a simplified population model to the historical data from Scapa Flow (Orkney) resulted in the MCMC converging and reasonable-seeming parameter values estimated. Total population size model estimates and original data appeared consistent (Figure 5), suggesting that some of the observed patterns in the data could be explained by a change in 'externally forced' mortality starting around 1999. However, resulting estimated pup recruitment (the product of female fecundity with first year survival) was very low compared with results for the previous simulation-based models (Figure 6). This is because the previous models had density-dependence in this quantity so that the reported parameter for those models represents a maximum possible level of pup recruitment, not typically seen except in years of very low population size. For 'typical' years under the density-dependent model, pup recruitment would be reduced well below the level indicated by this parameter, due to intraspecific competition.

2. <u>Live capture-release at the photo-ID study sites</u>

A total of 24 seals were captured (14 females and 10 males) (Table 1). There was no significant difference in the mean age of the males compared to the females (males = 8.6 y, females = 9.3 y, p>0.05). Unfortunately, some of the teeth could not be aged because of they were inadvertently stored in ethanol in the field which caused them to split during the sectioning stage of the process (marked with 'x' in Table 1). In addition there was no significant difference in the age of the pregnant compared to the non-pregnant females (not-pregnant = 10.8, pregnant = 8.3, p>0.05).

Concentrations of plasma progesterone and 17 beta-oestradiol are shown in Table 1, together with assignment of their pregnancy status based on the progesterone concentrations (n=13, see Table 1) and using the threshold established by Gardiner *et al*. (1996) of 18.9 ng $ml^{-1}$. Concentrations of plasma 17 beta-oestradiol showed considerable overlap between pregnant and non-pregnant animals (p=0.09, non-pregnant 117.8 pg $ml^{-1}$, pregnant 297.5 pg $ml^{-1}$). Two females that had been assigned as not pregnant from their blood results were seen with a pup during photo-ID observations (highlighted in green in Table 1). However, when the blubber samples were analysed for progesterone concentration, the degree of agreement with the observations carried out during the photo-ID study were entirely consistent with the assignments from the blubber hormones. Concentrations in blubber samples were significantly different between the two groups (p=0.0012, mean concentration in non-pregnant females = 17.16 ng $g^{-1}$, mean concentration in pregnant females = 198.11 ng $g^{-1}$). It appears therefore that the blubber concentrations may be a much more reliable indicator of pregnancy than plasma levels. Using these final assignments, the proportion of the live-captured adult females that were pregnant was 61.5% (95% CI 35% - 88%). This is lower than would have been expected as other studies in harbour seals (including those carried out in the Moray Firth in the early 1990s) reported between 79% (95% CI 60% - 89%, Gardiner *et al*. (1996)) and 82% (95% CI 67% – 91%, Greig (2002)) of live captured animals as being pregnant (using the above respective concentrations as thresholds). However, the sample size was small, leading to wide confidence intervals compared to the other studies.

Domoic acid concentrations in the urine and faecal samples collected from the live capture-release animals showed that the majority (88%) were above the limit of detection, indicating some low level exposure. Only one pregnant female had a reasonably high level of DA in her urine (>60,000 pg $ml^{-1}$). Unfortunately, it was not possible to collect samples from all individuals. There was no difference in concentrations between pregnant and non-pregnant females (p=0.9) or between males and females (p=0.5). It should be noted that it is not possible to say whether the concentrations measured in the excreta are due to low level, recent exposure or previous higher level exposure. Nevertheless, these animals have been consuming fish contaminated with DA and since the half-life of DA is short, the levels represent a minimum exposure.

Ten adult harbour seals (7 females and 3 males) were equipped with GSM/GPS telemetry tags (GSM) during in the April trip. These tags were funded by Vodafone UK, and their support is gratefully acknowledged. A further five adult females were equipped with low-cost, GPS haulout site location-only (LO) tags, designed at SMRU to provide low-cost tracking of the haulout sites visited . The seals showed a variety of movement patterns as well as individual preferences for certain areas (Figure 7). Some seals showed very restricted movements (e.g. females 263 and 265) while others travelled greater distances (e.g. females 256, 259, 264). The design life for the SMRU LO tags was initially three months, but this was foreshortened due to a programming error that made the tags attempt a GPS location fix once every hour, rather than once every four hours. The durations of the five tags were thus only 6, 13, 18, 21 and 21 days.

3. Aerial survey counts of harbour and grey seals

The search for haulout sites along the coast was guided by previous knowledge from the historical data collected during August moult aerial surveys. Despite this, it was difficult to detect all seals hauled out as they were well camouflaged among the rocky and seaweed-covered shores, meaning some might not have been photographed. During the processing of photographs it also became obvious that it was impossible to distinguish age classes (e.g. harbour seal pup versus yearling or juvenile) from the digital photographs taken, even in the best quality photographs. Given the uncertainty around the resulting pup count data and the ability of the population model to perform without these data, it was decided that harbour seal pup counts would be excluded from the population model.

4. Improving the understanding of potential drivers of population change

Three scat samples from Orkney (two from West Burray and one from Widewall Bay) were positive for domoic acid (12,600 – 23,500 pg $g^{-1}$) but the remainder were either below the limit of detection or the samples were too small for analysis.

All fish gut samples were positive for domoic acid at or above the limit of detection (Figure 8). Interestingly, all the levels in the samples of ling were very low (at the limit of detection). However, in general, concentrations in all fish sampled were at low levels. Samples of fish viscera are also being analysed for the presence of PSP toxins (saxitoxin and its derivatives) at the Marine Scotland Science Laboratory in Aberdeen. Results will be reported as soon as they are available.

5. Seal carcass collection

Most of the reported seal carcasses were found in Orkney (n=72) and on the North Coast (n=1). Of these, 53 were grey seals (6 adults, 7 juveniles, 17 pups, 7 unknown age, and 16 to be determined), 10 were harbour seals (2 adults, 3 juveniles, 3 pups, 2 unknown age) and 9 carcasses could not be identified to the species level. Proximate causes of death for harbour seals in Orkney included entanglement (n=2), possible grey seal predation (n=2) and starvation/hypothermia (n=2). For the remaining 4 carcasses proximate cause of death could not be determined as there was insufficient data or the carcasses had advanced autolysis preventing any determination.

A total of 7 seal carcasses were reported in Isle of Skye, of which 5 were harbour seals (2 juveniles and 3 pups) and 3 were grey seals. Of these, 6 do not have an associated cause of death as they could not be examined, and one harbour seal pup was frozen for a future post-mortem examination.

In the Kintyre and Clyde area, 12 seal carcasses were reported, of which 5 were harbour seals (1 adult, 3 juveniles and 1 pup), 6 were grey seals (3 juveniles and 3 unknown age) and one carcass could not be identified to the species level. Only two of the carcasses were recovered (2 juvenile harbour seals) and are pending a post-mortem examination.

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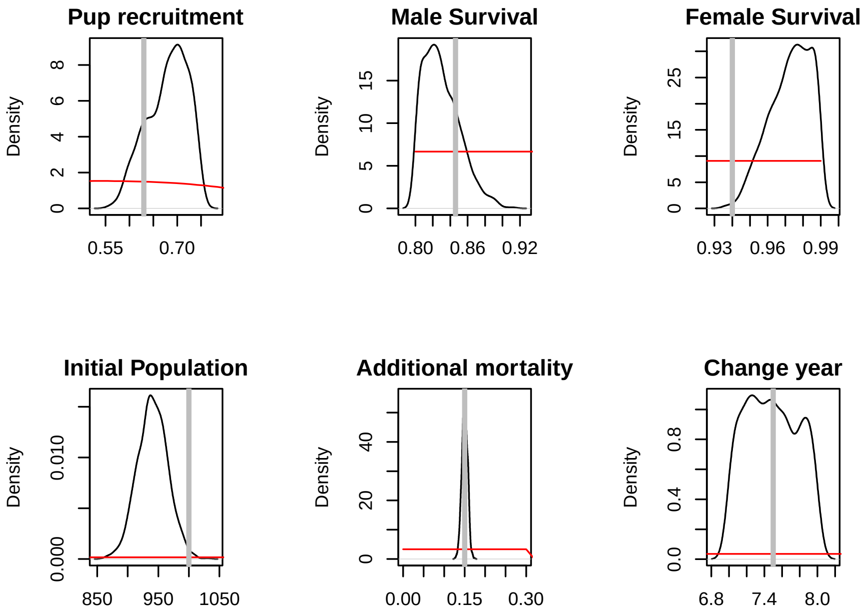


**Figure 1.** Posterior parameter distributions (black curves) compared with prior distributions (red curves) for the DST run with simulated pup and moult count data both included for model fitting. The vertical grey lines represent the ‘true’ values of the parameters i.e. those that were used in the simulations that produced the simulated data. The most probable estimate of the parameter corresponds to the location (on the x axis) of the peak of the black curve.

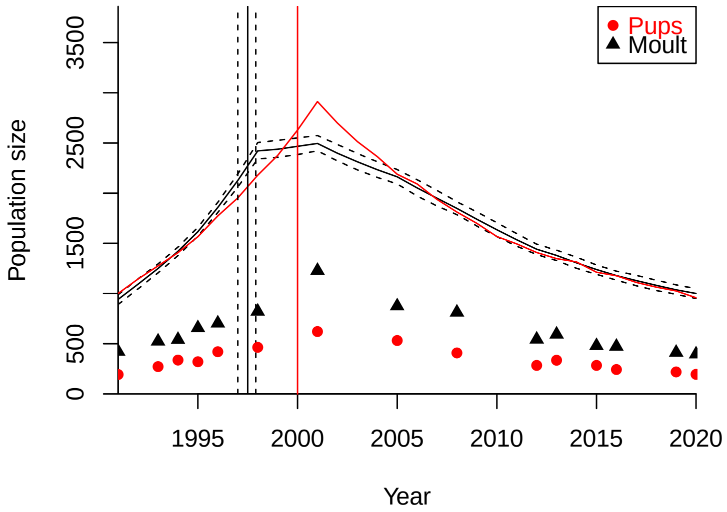


**Figure 2**. Estimated population trajectory (black curve) compared with known population trajectory (red curve) and simulated data for pup counts during breeding (red dots), and seals hauled out during moult (black triangles) (which are mainly adults). The estimated change-point year is shown as a vertical black line and confidence intervals around it are shown with dashed lines. The ‘true’ value for this change-point is represented by the red vertical line.

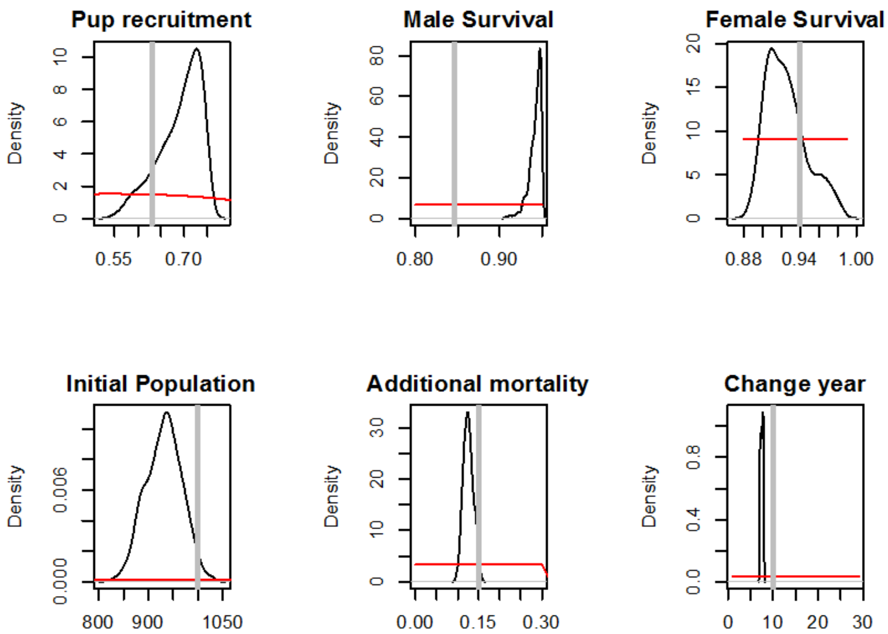


**Figure 3**. Posterior parameter distributions (black curves) compared with prior distributions (red curves) for the DST run with moult count data only included for model fitting. The vertical grey lines represent the 'true' values of the parameters i.e. those that were used in the simulations that produced the simulated data.

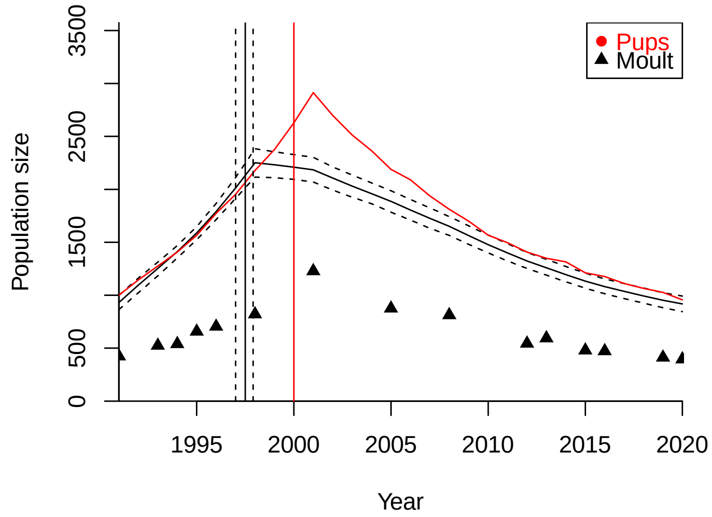


**Figure 4**. Estimated population trajectory (black curve) compared with known population trajectory (red curve) and counts of seals hauled out during moult (which are mainly adults). There are no pup count data. The estimated change-point year is shown as a vertical black line and confidence intervals around it are shown with dashed lines. The 'true' value for this change-point is represented by the dotted vertical line which coincides with the lower confidence limit on the estimate (2000).

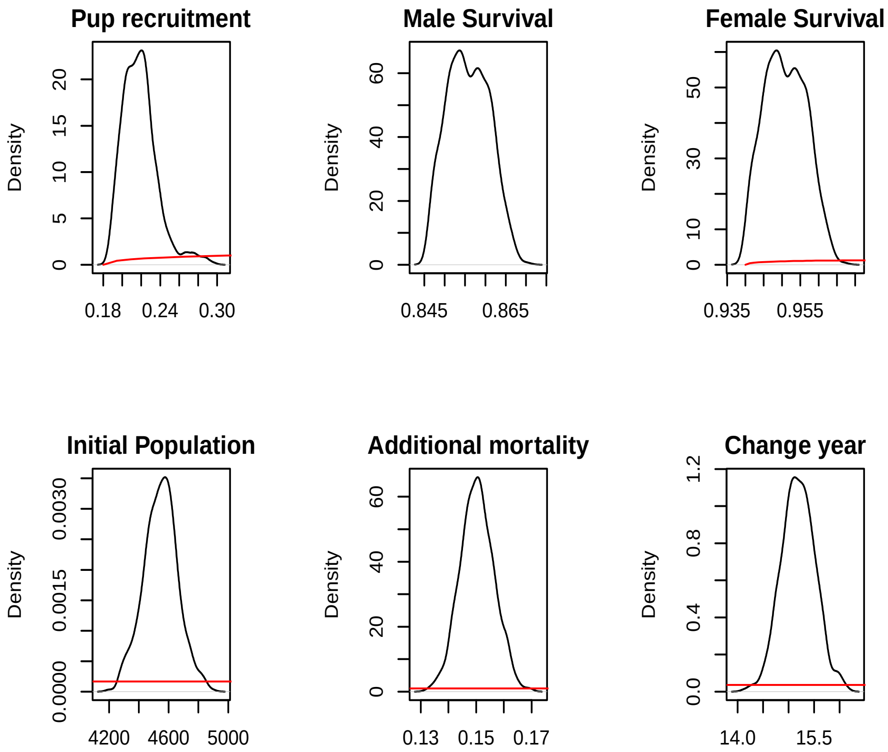


**Figure 6**. Posterior parameter distributions (black curves) compared with prior distributions (red curves) for the historical moult count data at Scapa Flow. No prior is shown for adult male survival, which was modelled using a simple multiplier on female survival (0.9): the posterior distribution is shown here for information only

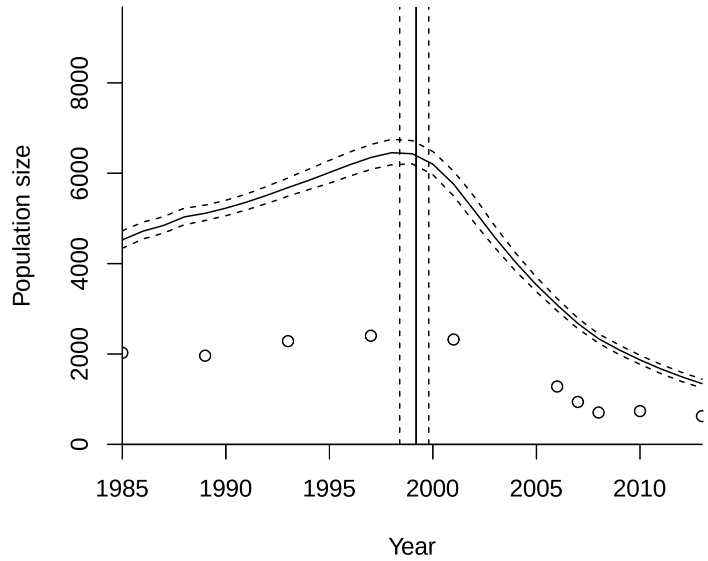


**Figure 5.** Estimated population trajectory (black curve) compared with counts of seals hauled out during moult (which are mainly adults). The estimated change-point year, when mortality increases across the whole population, is shown as a vertical black line, and confidence intervals around it are shown with dashed lines.

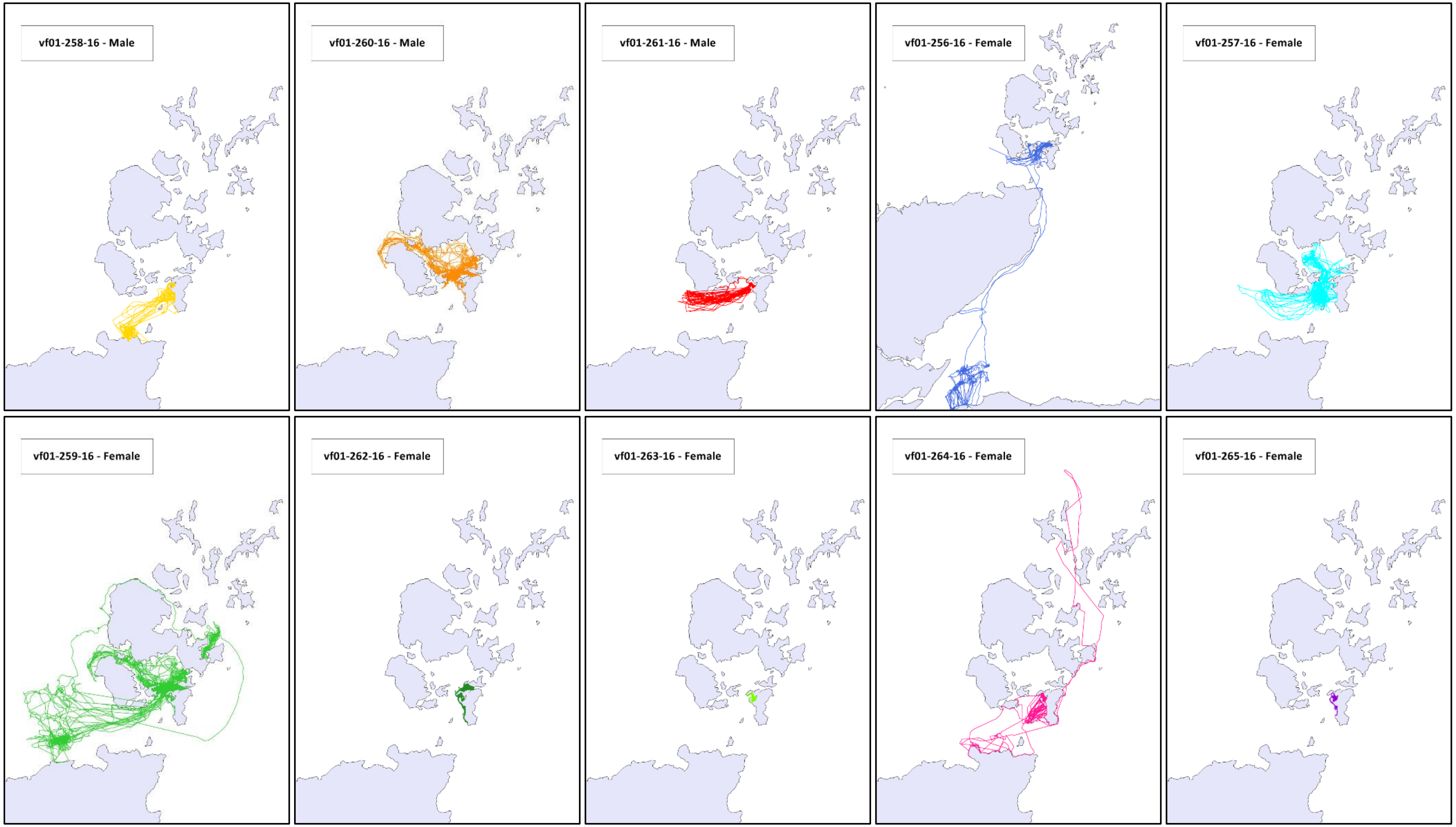


**Figure 7**. Individual tracks from adult harbour seals tagged in Orkney in 2016 with GSM-GPS telemetry devices.

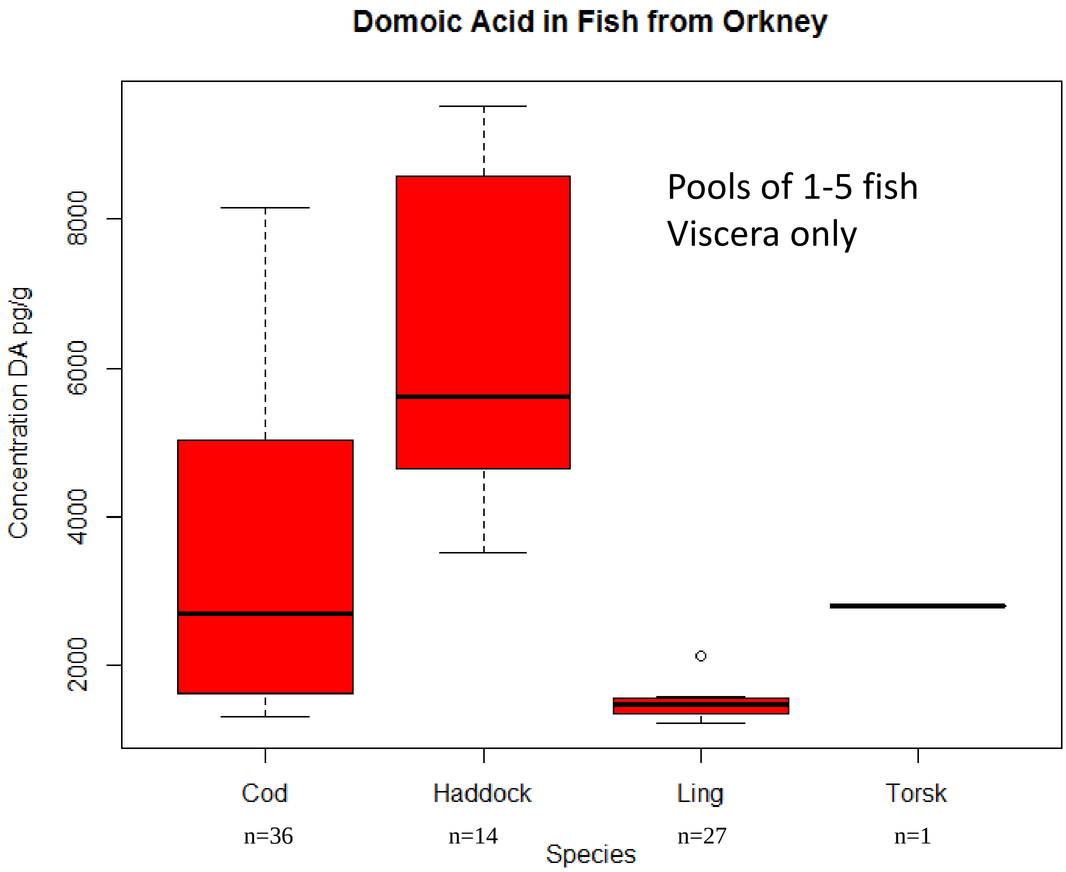


**Figure 8.** Concentration of DA (pg/g) in viscera by species of fish sampled off Scapa Flow in Orkney in 2016. Each data sample contained between 1 and 5 viscera. The black lines show the median, the red boxes the interquartile range and the dashed lines the value range of concentrations of DA.

Table 1. Summary of results from the analysis of samples collected in Orkney in 2016

| Flipper tag | Tag label | Age | Tooth Age (y) | Sex | Progesterone Blood (ng/ml) | 17 beta oestradiol (pg/ml) | Pregnant-Blood | Progesterone Blubber (ng/mg) | Pregnant-Blubber | With Pup | Seen Pregnant | Agreement in pregnancy from blubber progesterone | Urinary Domoic Acid pg/ml | Faecal Domoic Acid pg/g |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55187 | FA-B-389 | Adult | - | F | 141.70 | 569.40 | Pregnant | 223.02 | Pregnant | yes | | yes | 62937 | |
| 55189 | vf01-264-16 | Adult | 11 | F | 3.94 | 790.70 | Not Pregnant | 61.24 | Pregnant | yes | | yes | 1227 | |
| 00590 | FA-B-666 | Adult | 4 | F | 3.05 | 73.90 | Not Pregnant | 352.78 | Pregnant | yes | | yes | | |
| 55196 | vf01-256-16 | Adult | x | F | 55.57 | 293.90 | Pregnant | 225.46 | Pregnant | yes | | yes | | |
| 00584 | vf01-259-16 | Adult | 5 | F | 85.51 | 225.60 | Pregnant | 113.34 | Pregnant | | yes | yes | | |
| 00600 | FA-B-128 | Adult | 8 | F | 152.25 | 232.50 | Pregnant | 117.01 | Pregnant | | | | 27557 | |
| 55127 | vf01-257-16 | Adult | 12.5 | F | 99.81 | 77.90 | Pregnant | 196.28 | Pregnant | | | | <LOD | |
| 55197 | | Adult | 9.5 | F | 73.47 | 115.80 | Pregnant | 295.74 | Pregnant | yes | | | | 18728 |
| 00591 | FA-B-787 | Adult | 14 | F | 45.52 | 132.10 | Possibly Pregnant | 8.91 | Not Pregnant | | | | 27352 | |
| 00585 | vf01-263-16 | Adult | x | F | 1.40 | 82.50 | Not Pregnant | 15.73 | Not Pregnant | no | | yes | 2803 | |
| 55192 | vf01-262-16 | Adult | 12 | F | 2.39 | 241.90 | Not Pregnant | 23.13 | Not Pregnant | no | no | yes | 2297 | |
| 55186 | FA-B-155 | Adult | 9 | F | 2.00 | 90.70 | Not Pregnant | 23.21 | Not Pregnant | | | | | |
| 55191 | vf01-265-16 | Adult | 8 | F | 1.33 | 41.70 | Not Pregnant | 14.82 | Not Pregnant | | | | | |
| 55188 | | Juvenile | - | F | 2.07 | | | | | | | | | |
| 00583 | | Adult | - | M | 1.21 | | | | | | | | 5184 | |
| 00586 | vf01-261-16 | Adult | x | M | 1.79 | | | | | | | | 1695 | |
| 55126 | vf01-260-16 | Adult | 5.5 | M | 1.08 | | | | | | | | 3453 | |
| 55128 | vf01-258-16 | Adult | 7.5 | M | 1.14 | | | | | | | | <LOD | |
| 55129 | | Adult | 9.5 | M | 1.06 | | | | | | | | 2083 | |
| 55190 | | Juvenile | - | M | 1.17 | | | | | | | | 16596 | |
| 55193 | | Juvenile | x | M | 1.61 | | | | | | | | | 28191 |
| 55198 | | Adult | 4.5 | M | 2.37 | | | | | | | | 6977 | |
| 55199 | | Adult | 5 | M | 1.09 | | | | | | | | 15566 | |
| 73349 | | Adult | 19.5 | M | 1.86 | | | | | | | | 4134 | |

# Provisional Regional PBR values for Scottish seals in 2018

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## Abstract

This document estimates PBR values for the grey and harbour seal “populations” that haul out in each of the ten Seal Management Areas in Scotland. Sets of possible values are tabulated for each area using the equation in Wade (1998) with different values of that equation’s recovery factor. A value is suggested for this parameter in each population, the resulting PBR is highlighted, and a rationale is provided for each suggestion. The PBR values are calculated using the latest confirmed counts in each management area.

Changes since last year: The latest survey counts for Orkney and North Coast management region was 30% lower than the previous estimate, resulting in a 30% lower PBR for that management region. A revised estimate of the ratio between grey seal summer counts and the local populations in all areas has increased the PBR by approximately 50% in all regions and together with higher counts in Orkney and North coast region pushed the overall PBR for Scottish grey seals up by 67%.

Recovery factors have been held constant in all management regions.

## Introduction

Potential Biological Removal is a widely used way of calculating whether current levels of anthropogenic mortality are consistent with reaching or exceeding a specific target population, chosen to be the Optimum Sustainable Population. It is explicitly given, in an amendment to the US Marine Mammal Protection Act, as the method to be used for assessing anthropogenic impacts in the waters around that country. The method has been supported by simulations demonstrating its performance under certain assumptions (Wade 1998). The formulation of the equation allows for small anthropogenic takes from any population, however much it is depleted or fast it is declining.

Scottish Government uses PBR to estimate permissible anthropogenic takes for each of the ten seal management regions and uses this information to assess licence applications for seal control and for other licensable marine activities.

## Materials and Methods

### The PBR calculation:

PBR = Nmin.(Rmax/2).FR

where:

PBR is a number of animals considered safely removable from the population.

Nmin is a minimum population estimate (usually the 20th percentile of a distribution)

Rmax is the population growth rate at low densities (by default set 0.12 for pinnipeds), this is halved to give an estimate of the growth rate at higher populations. This estimate should be conservative for most populations at their OSP.

FR is a recovery factor, usually in the range 0.1 to 1. Low recovery factors give some protection from stochastic effects and overestimation of the other parameters. They also increase the expected equilibrium population size under the PBR.

The approach and calculation is discussed in detail in Wade (1998).

Data used in these calculations

Nmin values used in these calculations are from the most recent summer surveys of each area, for both species:

- Harbour seals: The surveys took place during the harbour seal moult, when the majority of this species will be hauled out, so the counts are used directly as values for Nmin. (An alternative approach, closer to that suggested by Wade (1998), would be to rescale these counts into abundance estimates and take the 20th centile of the resulting distributions. Results of a recent telemetry study in Orkney (Lonergan et al., 2012) suggest that would increase the PBRs by between 8%, if the populations are predominantly female, and 37%, if most of the animals are male.)

- Grey seals: Analysis of telemetry data from 107 grey seals tagged by SMRU between 1998 and 2016 shows that around 23.9% (95% CI: 19.2 - 28.6%) were hauled out during the survey windows (Russell et al. 2016 SCOS-BP 16/03). The 20th centile of the distribution of multipliers from counts to abundances implied by that data is 3.86. This represents a 50% increase over previous estimates due to a revised estimate of the proportion of time seals spend hauled out and available to be counted during the aerial survey window that is substantially lower than previous estimates and has narrower confidence intervals.

**Rmax** is set at 0.12, the default value for pinnipeds, since very little information relevant to this parameter is available for Scottish seals. A lower value could be argued for, on the basis that the fastest recorded growth rate for the East Anglian harbour seal population has been below 10% (Lonergan et al. 2007), though that in the Wadden Sea has been consistently growing at slightly over 12% p.a. (Reijnders et al. 2010). Regional pup production estimates for the UK grey seal population have also had maximum growth rates in the range 5-10% p.a. (Lonergan et al. 2011b). However the large grey seal population at Sable Island in Canada has grown at nearly 13% p.a. (Bowen et al. 2003).

$\mathbf{F_R}$ needs to be chosen from the range [0.1, 1]. Estimated PBR values for the entire range of $F_R$ values are presented. A recommended $F_R$ value is indicated for each species in each region, together with a justification for the recommended value.

## Areas used in the calculations

Figure 1 and Table 1 shows the boundaries of the Seal Management Areas.

Particularly for grey seals, there will probably be substantial movement of animals between these areas. The division is a pragmatic compromise that attempts to balance: current biological knowledge; distances between major haul-outs; environmental conditions; the spatial structure of existing data; practical constraints on future data collection; and management requirements

Table 1: Boundaries of the Seal Management Areas in Scotland.

| Seal Management Area | | Area Covered |
|---|---|---|
| 1 | Southwest Scotland | English border to Mull of Kintyre |
| 2 | West Scotland | Mull of Kintyre to Cape Wrath |
| 3 | Western Isles | Western Isles incl. Flannan Isles, North Rona |
| 4 | North Coast & Orkney | North mainland coast & Orkney |
| 5 | Shetland | Shetland incl. Foula & Fair Isle |
| 6 | Moray Firth | Duncansby Head to Fraserburgh |
| 7 | East Scotland | Fraserburgh to English border |

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## Results

PBR values for grey and harbour seals for each Seal Management Area. Recommended $F_R$ values are highlighted in grey cells.

**Table 1.** Potential Biological Removal (PBR) values for harbour seals in Scotland by Seal Management Unit for the year 2018

| Seal Management Area | 2008-2016 count | Survey years | $N_{min}$ | PBRs based on recovery factors $F_R$ ranging from 0.1 to 1.0: 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | selected $F_R$ | PBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Southwest Scotland | 1,200 | (2015) | 1,200 | 7 | 14 | 21 | 28 | 36 | 43 | 50 | 57 | 64 | 72 | 0.7 | 50 |
| 2 West Scotland | 15,184 | (2013-2015) | 15,184 | 91 | 182 | 273 | 364 | 455 | 546 | 637 | 728 | 819 | 911 | 0.7 | 637 |
| 3 Western Isles | 2,739 | (2011; 2014) | 2,739 | 16 | 32 | 49 | 65 | 82 | 98 | 115 | 131 | 147 | 164 | 0.5 | 82 |
| 4 North Coast & Orkney | 1,349 | (2014; 2016) | 1,349 | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 0.1 | 8 |
| 5 Shetland | 3,369 | (2015) | 3,369 | 20 | 40 | 60 | 80 | 101 | 121 | 141 | 161 | 181 | 202 | 0.1 | 20 |
| 6 Moray Firth | 940 | (2008; 2011; 2016) | 940 | 5 | 11 | 16 | 22 | 28 | 33 | 39 | 45 | 50 | 56 | 0.1 | 5 |
| 7 East Scotland | 368 | (2013; 2015-2016) | 368 | 2 | 4 | 6 | 8 | 11 | 13 | 15 | 17 | 19 | 22 | 0.1 | 2 |
| **SCOTLAND TOTAL** | **25,149** | (2008; 2011; 2013-2016) | **25,149** | **149** | **299** | **449** | **599** | **753** | **902** | **1,053** | **1,203** | **1,352** | **1,507** | | **804** |

$PBR = N_{min} \cdot (R_{max}/2) \cdot F_R$

where: **PBR** is a number of animals considered safely removable from the population.

**$N_{min}$** is a minimum population estimate (counts were used directly as values for $N_{min}$).

**$R_{max}$** is the population growth rate at low densities (by default set 0.12 for pinnipeds), this is halved to give an estimate of the growth rate at higher populations. This estimate should be conservative for most populations at their OSP.

**$F_R$** is a recovery factor, usually in the range 0.1 to 1. Low recovery factors give some protection from stochastic effects and overestimation of the other parameters. They also increase the expected equilibrium population size under the PBR.

**Table 2.** Potential Biological Removal (PBR) values for grey seals in Scotland by Seal Management Unit for the year 2018

| | **2008-2016** | | | **PBRs based on recovery factors $F_R$ ranging from 0.1 to 1.0** | | | | | | | | | | **selected** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Seal Management Area** | **count** | **Survey years** | **$N_{min}$** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** | **1.0** | **$F_R$** | **PBR** |
| 1 Southwest Scotland | 374 | (2015) | 1,444 | 8 | 17 | 25 | 34 | 43 | 51 | 60 | 69 | 77 | 86 | 1.0 | 86 |
| 2 West Scotland | 5,064 | (2013-2015) | 19,547 | 117 | 234 | 351 | 469 | 586 | 703 | 820 | 938 | 1,055 | 1,172 | 1.0 | 1,172 |
| 3 Western Isles | 4,065 | (2011; 2014) | 15,691 | 94 | 188 | 282 | 376 | 470 | 564 | 659 | 753 | 847 | 941 | 1.0 | 941 |
| 4 North Coast & Orkney | 9,714 | (2014; 2016) | 37,496 | 224 | 449 | 674 | 899 | 1,124 | 1,349 | 1,574 | 1,799 | 2,024 | 2,249 | 1.0 | 2,249 |
| 5 Shetland | 1,558 | (2015) | 6,014 | 36 | 72 | 108 | 144 | 180 | 216 | 252 | 288 | 324 | 360 | 1.0 | 360 |
| 6 Moray Firth | 1,252 | (2008; 2011; 2016) | 4,833 | 28 | 57 | 86 | 115 | 144 | 173 | 202 | 231 | 260 | 289 | 1.0 | 289 |
| 7 East Scotland | 3,812 | (2013; 2015-2016) | 14,714 | 88 | 176 | 264 | 353 | 441 | 529 | 618 | 706 | 794 | 882 | 1.0 | 882 |
| **SCOTLAND TOTAL** | **25,839** | (2008; 2011; 2013-2016) | **99,739** | **595** | **1,193** | **1,790** | **2,390** | **2,988** | **3,585** | **4,185** | **4,784** | **5,381** | **5,979** | | **5,979** |

PBR = $N_{min} \cdot (R_{max}/2) \cdot F_R$

where: **PBR** is a number of animals considered safely removable from the population.

**$N_{min}$** is a minimum population estimate. Analysis of SMRU tagging data shows that around 23.9% of grey seals were hauled out during the survey windows (Russell et al., 2016). The 20th centile of the distribution of multipliers from counts to abundances implied by that data is 3.86.

**$R_{max}$** is the population growth rate at low densities (by default set 0.12 for pinnipeds), this is halved to give an estimate of the growth rate at higher populations. This estimate should be conservative for most populations at their OSP.

**$F_R$** is a recovery factor, usually in the range 0.1 to 1. Low recovery factors give some protection from stochastic effects and overestimation of the other parameters. They also increase the expected equilibrium population size under the PBR.

## Rationale for the suggested recovery factors

The original PBR methodology leaves the setting of the recovery factor as a subjective choice for managers. Factors such as the amount of information available about the population (and in particular its maximum annual growth rate), recent trends in local abundance, and the connections to neighbouring populations are relevant to setting this. The main factors affecting the value suggested for each species in each area are given below:

## Harbour seals

1) Shetland, Orkney + North Coast and Eastern Scotland ($F_R$= 0.1)

$F_R$ set to minimum because populations are experiencing prolonged declines.

2) Outer Hebrides ($F_R$ = 0.5)

Population was undergoing a protracted but gradual decline but the most recent count was close to the pre-decline numbers. The population is only partly closed being close to the relatively much larger population in the Western Scotland region, and the $R_{max}$ parameter is derived from other seal populations. Suggested recovery factor to be revised when new survey data become available for 2017.

4) Western Scotland ($F_R$ = 0.7)

The population is largely closed, likely to have limited interchange with much smaller adjacent populations. The population is apparently stable and the intrinsic population growth rate is taken from other similar populations.

4) South West Scotland ($F_R$ = 0.7)

The population is apparently stable, is closed to the south and the adjacent population to the north is apparently stable. The intrinsic population growth rate is taken from other similar populations.

5) Moray Firth ($F_R$= 0.1)

Counts for 2016 in the Moray Firth were 26% higher than in 2015 which was one of the lowest counts ever in the Moray Firth. This continues a pattern of large inter annual fluctuations with no overall trend over the past 15 years. The neighbouring Orkney and Tay populations are continuing to undergo unexplained rapid and catastrophic declines in abundance. Data available from electronic telemetry tags suggest there is movement between these three areas. In the absence of a significant increase in the Moray Firth counts it is recommended that the $F_R$ should be left at its previously recommended value of 0.1.

## Grey seals

All regions ($F_R$ = 1.0)

There has been sustained growth in the numbers of pups born in all areas over the last 30 years, with some now appearing to be at or close to their carrying capacities (Lonergan et al. 2011b). Available telemetry data and the differences in the regional patterns of pup production and summer haul-out counts (Lonergan et al. 2011a) also suggest substantial long-distance movements of individuals.

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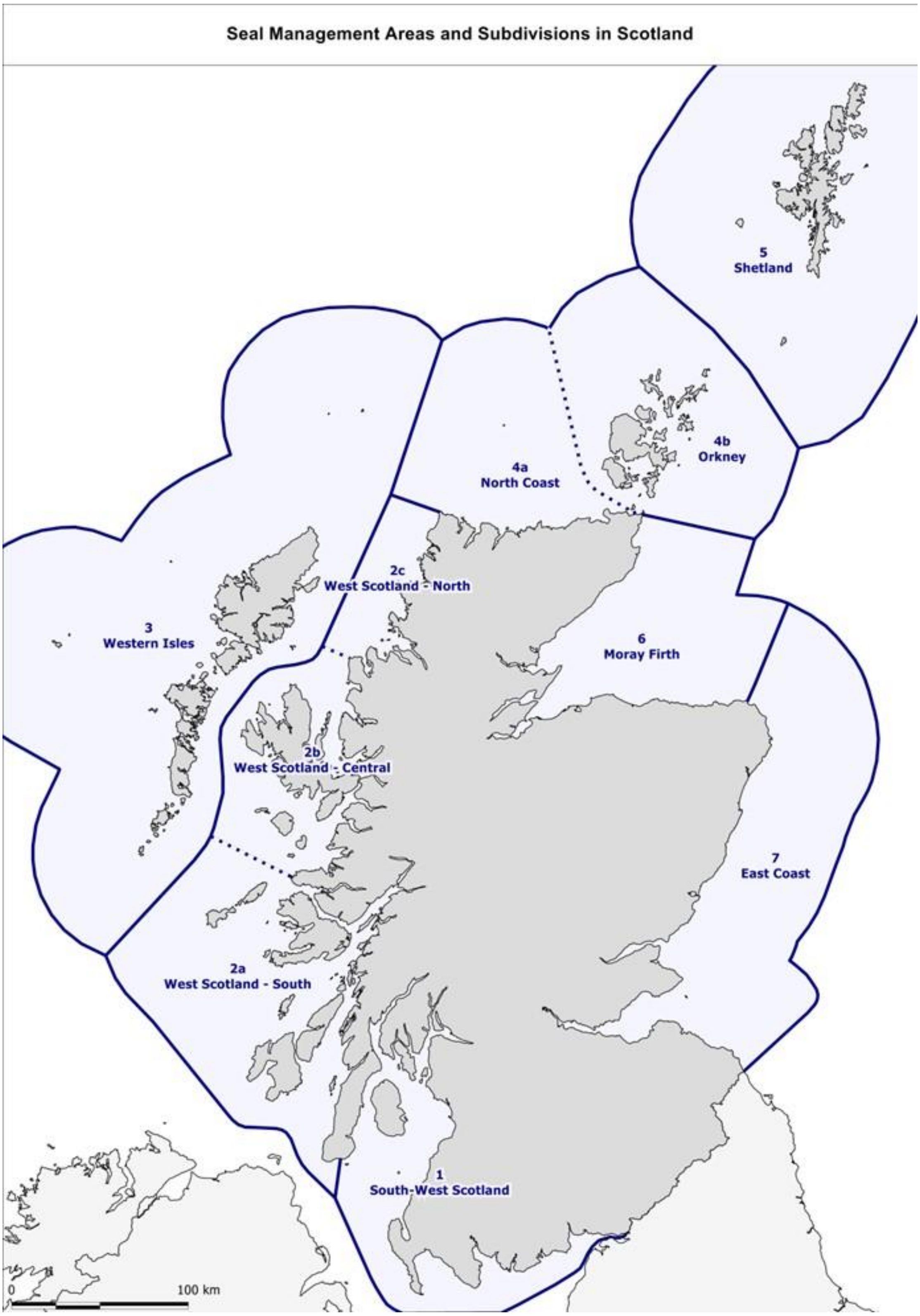


**Figure 1**.Seal management areas in Scotland.

# Persistent organic pollutant concentrations in grey seal weaned pups from the Isle of May, 2015 compared to 2002.

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**Abstract**

Persistent organic pollutants (POPs) remain a major risk to marine mammal health. They accumulate in fat tissue and biomagnify up the food chain, such that seals have high levels in their blubber. Regulation of PCB manufacture and release caused a reduction of these compounds in the marine environment and in marine mammals during the late 1990s, but the reduction seems to have slowed more recently. Here we present a preliminary comparison of PCB and DDT concentrations in blubber tissue of grey seal pups sampled in 2002 and 2015 to investigate whether these compounds have changed in seal tissues since the early 2000s. Our data suggest a modest but significant decrease in PCBs has occurred, whereas DDT levels have increased over the same period. In both cases, the concentrations measured are well below the limits that cause immediate negative health effects in seals. Cross laboratory comparisons will be undertaken to establish whether small methodological differences in the analysis process may be responsible for observed differences in concentrations. Differences in concentration between years were not due to mass or sex differences in the pups sampled, but may reflect parity and/ or age of the pups' mothers. Higher variation in PCB and DDT levels in 2002 could have been caused by a greater range in the time of sampling relative to weaning compared with 2015. The consequences of the observed changes in POP loads are unknown. Investigation of the impact of PCBs, PBDEs and DDTs on measures of energy balance are underway.

## Introduction

The impact of persistent organic pollutants (POPs) on the health and survival of phocid seals continues to be a concern (Hitchcock *et al.* 2017), particularly the risk they pose in combination with other stressors (National Academies of Sciences & Medicine 2017). Of the so-called 'legacy' POPs, polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethanes (DDTs) are of particular interest as they can alter thyroid hormone homeostasis and impact on immunity, energy regulation and reproduction (Weijs & Zaccaroni 2016). Indeed these compounds may also be a factor in determining the probability of first year survival in UK grey seals (Hall *et al.* 2009).

The Sea Mammal Research Unit (SMRU) has been studying the effect of these pollutants on grey seals from the Isle of May, Firth of Forth, since the early 1990s (Pomeroy *et al.* 1996). More recently the University of Abertay, in conjunction with SMRU, have been investigating the link between fat metabolism and POP exposure in grey seal pups during development and fasting. As part of this project, blubber biopsy samples were taken from pups during the post-weaning fast and analysed for the presence of a range of POPs, particularly the PCBs and DDTs that make up the majority of the contaminant burden in this species. These compounds were also measured in Isle of May post-weaned pups in 2002 as part of a survivorship study (Hall et al. 2009), allowing a comparison between concentrations over the intervening 13 year period to be carried out. Since the ban on the production and use of both PCBs and DDTs in the mid-1980s, concentrations in the environment have declined. However, in many marine mammals although blubber levels declined during the 1990s, since then they have shown no further reduction (Law 2014, Law *et al.* 2012). Concentrations in weaned pups reflect the contaminant concentrations in the adult females as the only source of POPs in animals at this life stage is through gestation and lactational transfer. This briefing paper summarises initial comparisons of PCB and DDT concentrations in the blubber of Isle of May grey seal weaned pups.

**Methods**

Blubber samples were taken from individually identified pups during the post-weaning period using a sterile biopsy punch (Acupunch, Acuderm, Fort Lauderdale, US), following an intravenous 0.01 ml dose of $Zoletil_{100}$ (Virbac, Carros, France) and 2 ml 2% w/v subcutaneous dose lignocaine (Lignol, Dechra, Northwich, UK) in the dorsal midpelvic region.

*Blubber contaminant analysis methods*

Samples collected in 2002 were analysed at the University of Lancaster and details of the method can be found in Hall et al. (2009). In brief, samples were mixed with anhydrous sodium sulfate, extracted with dichloromethane (DCM) using an accelerated solvent extraction system (Soxhlet). An aliquot was taken for gravimetric lipid determination, and the remaining sample was transferred to hexane. All samples were spiked with seven 13C-labeled PCBs and 13C-labeled BDE 209 before extraction. Samples were then cleaned by chromatography using silica gel treated with concentrated sulphuric acid, eluted with hexane. All samples received a secondary cleanup using gel permeation chromatography before being concentrated to a small volume with internal standards added. Samples were analysed for 7 PCB congeners (namely PCB 28, 52, 101, 138, 153, 170 and 180) using a GC-MS system (Finnigan TRACE) in SIM mode using an EIC source. The concentration of organochlorine pesticides was also determined. Four of these (namely, *p*,*p*′-DDD, *p*,*p*′-DDE, *o*,*p*′-DDT and *p*,*p*′-DDT) were also analysed using the Finnigan TRACE GC-MS in EI mode.
A set of seven calibration standards, containing all of the internal standards, recovery standards, and analytes, was run on the instrument before and after a batch of up to 24 samples. Within the batch, after every 6 samples, a specially prepared “QC” standard was run. Samples were quantified using the Thermo “Xcaliber”’ instrument software, and calibration and quantification was achieved using an internal standards method. Recoveries averaged 67-81% for each of the 13C labelled standards.

Samples collected in 2015 were analysed at the University of Liege using the same methods as above with the exception that the purified extracts were analysed using a Thermo Quest Trace, 2000 (Thermo Quest, Milan, Italy). Before the extraction, 100 ml of a hexanic solution of PCB congener 112 (Dr. Ehrenstorfer, Augsburg, Germany) was added to the samples as a surrogate internal standard at a concentration of 50 pg/ml. The PCB and the pesticide concentrations in each sample and in the QC were corrected for initial sample weight, and the percentage recovery of the surrogate PCB 112 (Damseaux *et al.* 2017).

Statistical analysis was carried out using the statistical package R (R Core Team, 2016) using linear modelling and analysis of variance to investigate differences between years.

**Results and Discussion**

A summary of the pup mass data for all the study animals sampled by year and sex is shown in Table 1. A total of 90 animals were included in the analysis, 60 sampled in 2002 and 30 in 2015. There was no significant difference in the mean mass of the pups by year or sex ($p > 0.05$).

**Table 1.** Summary of post-weaned pup masses by year and sex.

| Year | n | Sex | Mean mass (kg) | SD |
|---|---|---|---|---|
| 2002 | 31 | F | 39.19 | 5.38 |
| | 29 | M | 42.24 | 6.25 |
| 2015 | 18 | F | 42.40 | 3.79 |
| | 12 | M | 40.92 | 5.42 |

*Polychlorinated biphenyls (PCBs)*

The distribution of the total of the seven PCB congeners (sum PCBs, ng/g lipid weight) analysed in both years is shown in Figure 1. The concentrations were log-normally distributed. Further analysis was performed on the log-transformed data and mean concentrations are reported as geometric means and standard deviations.

The geometric mean concentration of sum PCBs in the blubber samples collected in 2002 = 763.9 ± 1.88 and in 2015 = 558.3 ± 1.63 ng/g lipid wt. The concentrations were significantly lower in 2015 than 2002 ($p = 0.019$, Figure 2). There was no difference between the sexes and no interaction between sex and year.

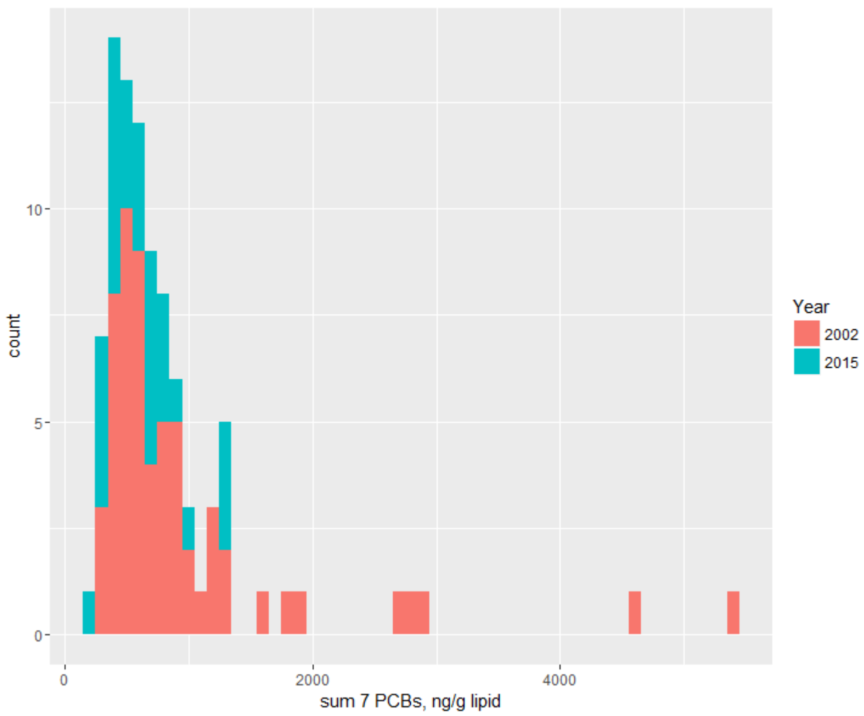


**Figure 1**. Distribution of sum PCBs in post-weaned pups by year

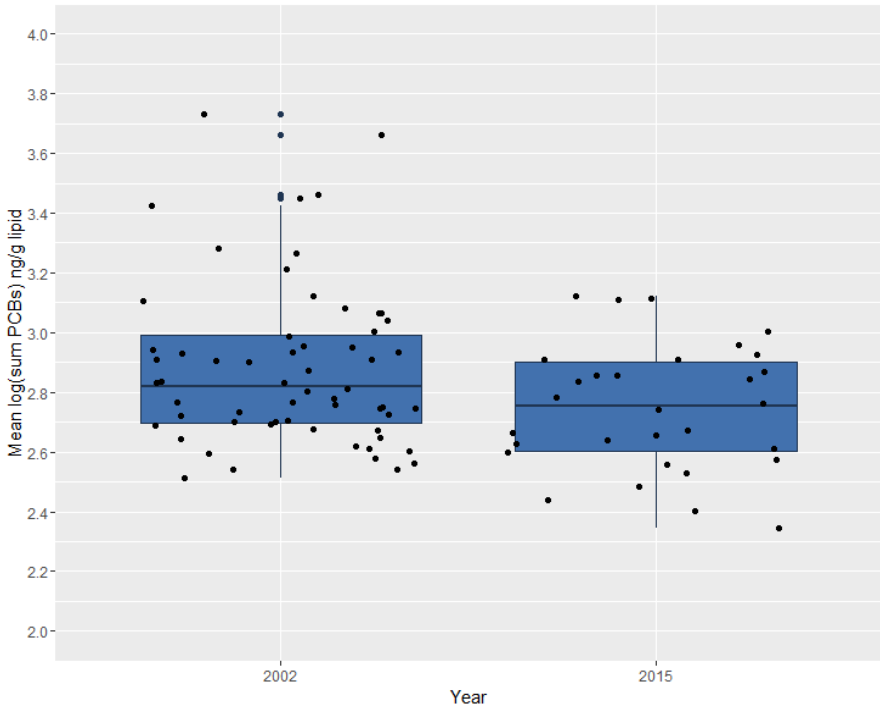


**Figure 2.** Log(sum PCBs) in post-weaned pups by year

*Dichlorodiphenyltrichloroethanes (DDTs)*

Concentrations of DDTs (sum of four DDT congeners) were significantly positively correlated with concentrations of PCBs (Figure 3) in both datasets. The intercept was significantly higher in 2015 than in 2002. Thus, in contrast to the PCBs, the concentrations of DDTs were significantly higher in 2015

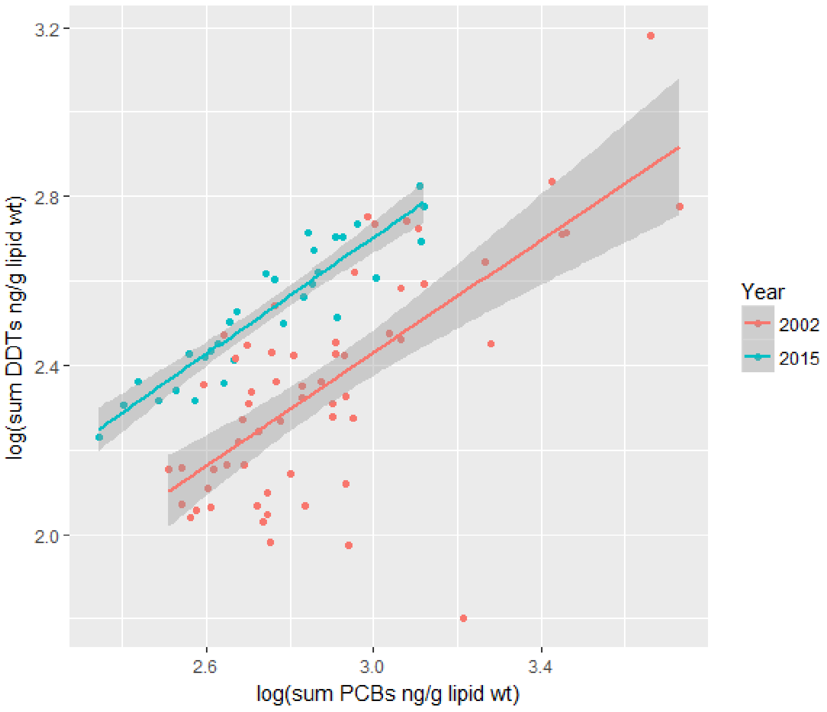


**Figure 3**. Relationship between sum PCBs and sum DDTs in post-weaned pups by year

than in 2002 (geometric mean concentration of sum DDTs in 2002 = 224.9 ± 1.84 and in 2015 = 337.5 ± 1.44 ng/g lipid wt., p=0.001, Figure 4).

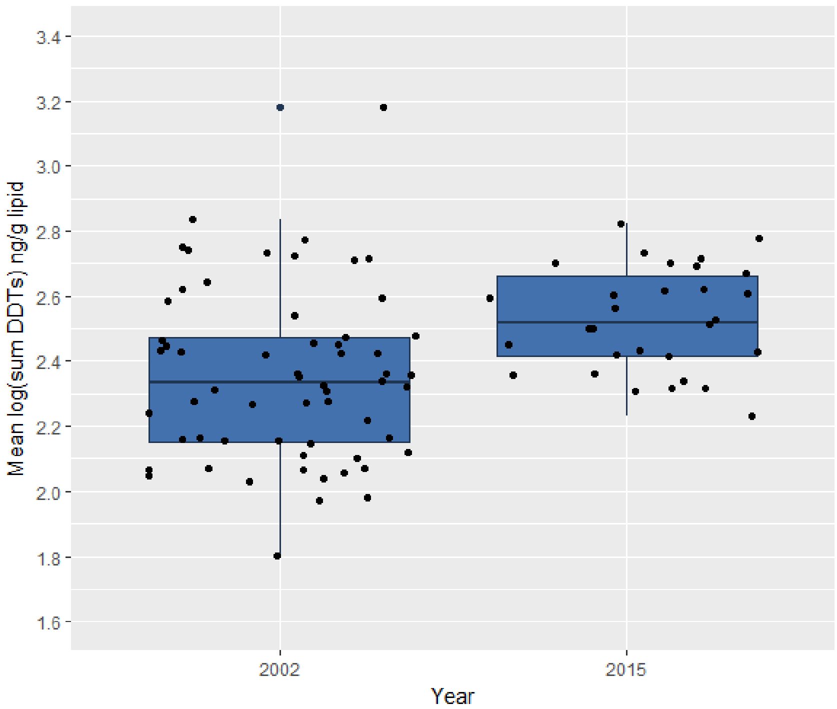


**Figure 4**. Log(sum DDTs) in post-weaned pups by year.

**Discussion**

This initial investigation comparing the concentration of selected PCB and DDT congeners in post-weaned grey seal pups from the Isle of May found that concentrations of PCBs were lower in recently collected samples compared with those collected 13 years earlier. However, DDT concentrations were higher. A number of factors could account for these findings.

1. The analysis has been carried out in two different laboratories using essentially the same methods. Without an inter-laboratory comparison it is not possible to determine whether any differences reported are due to measurement variation. This should be borne in mind when interpreting these findings and further inter-laboratory comparisons will be carried out in future.

2. Samples were collected from fasting post-weaned pups at different stages in their fast. Despite no differences in the mass of the animals, differences in body composition may account for some of the variation reported. As animals lose body fat and increase body protein, contaminants will concentrate in the remaining blubber, resulting in an increase in concentrations (Hall *et al.* 2008, Hall *et al.* 2003). This may account for the higher variability in the 2002 data as the pups sampled included a range of post-weaned stages whereas in 2015 were very closely matched by days post weaning.

3. The concentrations in the pups will reflect the concentrations in the females. If the cohort sampled in either year was biased towards either primiparous females, which will have higher concentrations of POPs in their blubber (Iwata *et al.* 2004), or older females, which may have depurated a large proportion of their burdens depending on reproductive history. The pups sampled

in 2002 were randomly selected from the animals on the colony and data on their mothers' ages and parity is not available.

With these caveats in mind, it is interesting that whilst the concentrations of PCBs have declined, those of DDTs have not, and may even have increased over time. It should be noted that the PCB concentrations measured here are an order of magnitude *below* those considered to pose a health risk. Kannan *et al.* (2000) assessed the blubber threshold level for effects for seals to be ~17,000 ng/g lipid wt. Thus, any changes in concentration between the years seen here are well within the limits of immediate risk. However, studies on factors affecting the survival of pups in 2002 indicated that higher contaminant concentrations, particularly the polybrominated diphenyl ethers in the blubber, together with sex and mass at weaning, were significant predictors of first year survival probability (Hall et al. 2009) and effects on energy balance may occur well below the estimated threshold for effects. It may be that the main risks following uptake of these compounds in grey seal pups from the Isle of May occur in conjunction with other energetic stressors during their early development.

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# Potential Future Global Distributions of Grey and Harbour Seals Under Different Climate Change Scenarios.

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**Abstract**

Most research on the impact of climate change on marine mammals has been focussed on arctic species that are threatened by shrinking suitable habitats. Here we present an exploration of potential habitat shifts of two temperate pinniped species, the harbour and grey seal, in two scenarios of climate change, using seal telemetry data and environmental grids. Core habitat, determined through telemetry locations, was projected on the lowest and highest scenarios of warming as determined for the Intergovernmental Panel on Climate Chante's 2014 report.

The low warming scenario predicted an overall compression of core habitat, with loss of habitat in the northern and southern edges of distribution for both species in the North Atlantic. In the high warming scenario, there was a general northward shift in predicted core habitat in the North Atlantic with substantial loss at low latitudes but substantial increase in available habitat in high Arctic regions.

The present methodology seems to be a useful tool for an initial exploration of a species' potential climate-related changes in habitat. However, explicit consideration of prey species' responses to climate change will be needed to improve predictions. As demonstrated in this study, the methods are easily applicable to other species, and provide the opportunity to use in-situ location data from telemetry studies to explore potential changes in habitat use.

**Introduction**

Recent IPCC projections based on a range of greenhouse gas production trajectories all suggest significant increases in global surface temperatures (IPCC, 2014) leading to rising sea levels, changes in water temperatures and reduced seasonal sea-ice cover, all of which could influence marine mammal distributions both locally and globally (Ferguson *et al*., 2005; IPCC, 2014; Learmonth *et al*., 2006). Future changes in environmental conditions could impact populations, so understanding the interactions between species distributions and climatic shifts will be needed to inform both conservation and management strategies (Kaschner *et al*., 2011).

To date, most of the focus on future marine mammal habitat predictions has been on polar species as the ecosystems in the Arctic where the loss of sea ice may lead directly to the loss of a critical habitat for many species in higher trophic levels (Kovacs *et al*. 2011; Laidre *et al*. 2015) but may benefit other species by opening up foraging habitats (Ragen *et al*. 2008).

To date little attention has been paid to temperate marine habitats. Boehme *et al*. (2012) suggested that the population size of grey seals changed dramatically over time due to the lack of available shelf areas during the Last Glacial Maximum about 20,000 years ago. This postglacial population expansion was confirmed by Klimova *et al*. (2014) based on DNA extraction showing how grey seal populations are affected by habitat availability. Such results from temperate ecosystems might appear less spectacular compared to the rapid changes in the Arctic ecosystems, but understanding these drivers will help us to understand the likely pressures on temperate species and ecosystems.

Here we present a preliminary study using the methods of Boehme *et al*. (2012) to make predictions concerning potential habitat shifts for harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) over the next century in response to climate change.

**Methods**

**1. Telemetry data**

Our data comprise the dive records of 131 harbour seals and 128 grey seals. The harbour seal tags were deployed between 2005 and 2014 and covered most areas of the British Isles, as well as north-east Ireland. The grey seal deployments spanned 2003 to 2007 and covered the east and western sides of the North Atlantic (Table 1). Two types of tags were used in this study: satellite-relay data loggers (SRDL) (Fedak *et al*. 2002) and GPS-GSM tags (Cronin & McConnell 2008), both of which provided detailed depth and temperature profiles as well as location fixes.

**2. Current habitat definitions**

Boehme *et al*. (2012) showed that a combination of a depth range based on locations and dive profiles from tracked seals in combination with a temperature range based on the annual mean SST for areas visited by tracked seals was a reliable indicator of suitable habitat for grey seals.

For the current analysis the frequency distribution of observed maximum dive depths were used to define suitable water depths used by the seals. For each species a cut-off at the 99th percentile of maximum dive depth distribution was used as the boundary of suitable habitat.

As the location data for harbour seals were limited to areas around the British Isles, which represents only a small part of the animals' distribution it was likely that the annual mean SST range would not be representative of the species' range. Consequently, local in-situ mean SSTs across the harbour seal's current range (south-east Greenland, Iceland and west Svalbard in the north down to the North coast of France) were used in conjunction with the actual observed SST records from the tracked seals to define the range of temperatures potentially encountered by harbour seals.

**3. Environmental data for future habitat estimation**

*3.1. Present conditions*

Following Boehme *et al*. (2012) three environmental variables were chosen to describe the present habitat of seals: bathymetry (ETOPO1), annual mean sea surface temperature climatology (WOA13), and climatological summer (September) sea ice concentration (National Ice Center). All data were interpolated onto a common 5 minute grid spanning the northern hemisphere as a compromise between calculation time and a reasonably fine spatial scale. Suitable habitat based on bathymetry and temperature was defined using in-situ tag measurements (see above) for each species. Summer sea ice was chosen as another constraint to limit the use of high-latitude areas. Both species frequent pack ice but do not inhabit fast ice areas. For harbour seals, the maximum "suitable" ice concentration was set at 50% based on telemetry studies in Svalbard (Blanchet *et al*. 2014) but as grey seals breed on sea ice in Canada and the Baltic, the limit of ice concentration for this species was set at 90%.

*3.2. Future conditions*

The environment experienced by seals for the year 2,100 was estimated using gridded field outputs from the series of CMIP5 experiments, commissioned for the IPCC reports on Climate Change (IPCC 2014) using outputs from NOAA's isopycnal Earth System Model (ESM2G) (Delworth *et al*. 2006). Grids of monthly SST and monthly sea level change as well as the September sea ice area fraction were chosen from scenarios of carbon emissions at either end of the spectrum: the highest (RCP 8.5) and the lowest (RCP 2.6). The monthly values for temperature and sea level were averaged for the year 2,100 to calculate annual mean values. Global annual sea level rise was subtracted from the reference bathymetry for the present, to estimate the water depth in the future. All data were interpolated onto a common 5-minute grid for each carbon emission scenario.

**4. Core habitat calculations**

For each cell of the reference 5-minute grid, suitable habitat status was achieved if depth, temperature and sea ice concentration were within the ranges described earlier. Core habitat extent was the sum of the areas of "suitable" grid cells. Those areas were calculated for current, RCP 2.6 and RCP 8.5 scenarios at the global level, as well as for each coast of the Atlantic and Pacific.

## Results

### Present habitat

*Harbour seals*

A total of 2,170,000 dives by 125 seals were included in the analysis. Maximum dive depths ranged between 1.2 m and 248.6 m, with a 99$^{th}$ percentile of 96.9 m. The interpolated bathymetry under each seal location fix gave similar results, with maximum bottom depth of 224.3 m and 99% of bottom depths of 101.8 m. The dive limit for harbour seals was therefore set at 97 m depth (fig.1).

480,000 temperature profiles were included, with surface temperatures ranging from 0.5° to 31.4°C. Restricting those data to the central 99% generated temperature limits of 2.8° and 13.9°C (fig.1).

Under those limits for habitat, the present core habitat (PCH) covered $1.97 \times 10^6$ km$^2$ (fig. 2).

*Grey Seals*

A total of 90 tags contributed 800,000 dive profiles to the analysis. Maximum dive depths ranged from 2 to 445 m, with the 99$^{th}$ percentile at 171 m (fig. 1). 87 tags contributed to the surface temperature datasets with almost 30,000 temperature profiles. Consistent with the methodology of Boehme *et al*. (2012) the SST limits were generated using the interpolated average annual SST. There was no need to use in situ recordings as a proxy as the deployments spanned most of the species' distribution. The limits for suitable SST were 1.7° to 12.5°C.

PCH for the Atlantic region was estimated to be $3.21 \times 10^6$ km², (fig. 3)

- $1.85 \times 10^6$ km² in the eastern North Atlantic,
- $1.36 \times 10^6$ km² and western North Atlantic.

### Future habitat – low warming scenario

*Harbour seals*

Under the low emission (RCP2.6) scenario the FCH was estimated to be 1,74 $\times 10^6$ km², representing an overall loss of habitat for Atlantic harbour seals in the future. The global future core habitat (FCH) covered 88% of PCH. There was a substantial increase in suitable habitat in Hudson Bay more than discounted by a minor loss of habitat at the southern edge of the range on both sides of the Atlantic and the loss of significant amounts of habitat in the White Sea and northern coasts of Hudson Bay (fig. 2).

*Grey seals*

Using the grey seal habitat limits in the low warming scenario RCP 2.6 resulted in an overall decrease of core habitat. FCH extent for the Atlantic in 2100 was $2.61 \times 10^6$ km², representing 81% of PCH (fig. 3). The southern boundary of suitable habitat was predicted to move north on both sides of the

Atlantic, to a greater extent than for harbour seals. A large area of Hudson's Bay becomes suitable but at present this is an area not frequented by grey seals. More surprisingly, large areas of PCH in the northern part of their current range will be excluded from the FCH mainly due to decreases in SST under the low impact scenario (fig. 3a).

**Future habitat – high warming scenario**

*Harbour seals*

Overall, the FCH for harbour seals under the high emission RCP 8.5 scenario was estimated at $2.38x10^6$ km², representing a 21% increase over the PCH estimate. As expected there was increased area loss in lower latitude areas of the species' distribution on both sides of the Atlantic, leaving no suitable habitat along the USA and French coasts. However, these losses were more than compensated for by a large increase in suitable habitat in the high Arctic in Canada, Svalbard and along the Arctic coast of Russia (fig 2b).

*Grey seals*

In RCP 8.5 scenario, the total area of suitable habitat was $3.68x10^6$ km², 14% larger than the present PCH. The southern boundaries of suitable habitat for grey seals were pushed northwards, resulting in a loss of 10% and 17% of the present suitable habitat in the East and West Atlantic respectively (fig 3b,). Importantly this predicted shift incorporates the Scotian shelf and waters off New England in the west. These areas currently hold the majority of the NW Atlantic grey seal population. However, the habitat loss in the south is more than compensated by a dramatic increase in available habitat in the high Arctic. Although the northern coast of Iceland was lost, large areas of Arctic Canada and Russia as well as Svalbard are identified as part of the FCH.

**Discussion**

This paper presents a preliminary examination of potential range shifts in distribution of grey and harbour seals in the Atlantic as a result of predicted climate change scenarios. It is not meant to provide an accurate description of the fine scale distribution pattern within the available habitat but does provide a methods for defining the limits of suitable range under different predicted conditions. As shown previously by Boehme *et al.* (2012) the use of simple metrics such as depth of dives and in-situ temperature range effectively delimits the current range of the two species allowing examination of future range shifts for any scenario where those simple metrics can be predicted.

Predicted PCH for both species corresponded well with species distribution maps (such as Burns 2009) and incorporated all known breeding areas. For grey seals this included the peripheral breeding sites in France and on the Murman coast of Russia as well as the recently established colonies in Maine and Massachusetts in the US (Wood, Brault and Gilbert 2007).

For both species, the PCH included some areas that are not currently occupied. In most cases these correspond to areas known to have had breeding populations relatively recently (Mikkelsen 2010; Hassani *et al*. 2010; Rosing-Asvid *et al*. 2010 & Haug, Hammill and Olafsdóttir 2007). Exceptions are the absences of grey seals from Hudson Bay, the Grand Banks and Svalbard, all of which were identified as PCH for both species. It is not known whether these absences are due to extinction in prehistory or failure to colonise them at any time since the LGM.

Relative to PCH, FCH in the low warming scenario tended to show contraction of the habitat available to grey and harbour seals in the Atlantic. In the high warming scenario, FCH showed a continued and enhanced loss of southernmost habitat, compensated for by an increase in habitat in arctic latitudes in North-Eastern Canada and the Barents Sea.

It appears that southernmost populations of both species could be at risk of habitat loss in both scenarios. Southern edges of FCH were pushed northwards compared to the present, due to the warming ocean.

Loss of core habitat has implications for the harbour seal colonies on the US east coast and in the southern North Sea. Additional factors such as reduced productivity (Hoegh-guldberg & Bruno 2010) and therefore increased intra and interspecific competition might increase the pressures of a changing environment. These populations thus might warrant additional conservation efforts in the near future.

The range contraction observed in 2100 for the low carbon emission scenario is interesting. Aside from warmer southern waters pushing the boundaries of FCH northward, warming is also at the source of loss of FCH in high latitudes: the influx of cold melted glacial ice from Greenland and other ice sheets caused an influx of cold fresher meltwater into areas such as Hudson Bay and Labrador in Canada, Greenland, Iceland and the Barents Sea area. Additionally, though not illustrated in the FCH because of the use of summer sea ice for the study, this meltwater might result in a higher production of winter sea ice despite the annual warming (Nummelin *et al*. 2016; Bintanja *et al*. 2015). The cooling of high latitude waters would affect a large number of harbour and grey seal populations, though the timing and extent is as yet unclear in this exploratory study.

The high warming scenario produced very different results for high latitude areas, where new habitat was gained by both species. Warming in high latitude waters, and the associated receding summer sea ice extent is thought to result in a northward shift of pagophilic pinnipeds (Kovacs *et al*. 2011). It is possible that such shifts will make some areas available to harbour and grey seals, enabling expansion in northern Canada, and Barents area. However, it is unclear whether arctic species will all shift northwards or if temperate seals will move northward to fill these new habitats.

Current emission levels (404ppm in December 2016) are similar (if not worse) than in the high warming scenario RCP8.5 (404ppm for 2016) (https://www.co2.earth/), making its FCH more likely than that of scenario RCP 2.6. To some extent, the conditions predicted in the low warming scenario will necessarily happen en-route to the high warming scenario.

To estimate FCH we used 3 abiotic variables, but there are more factors determining habitat suitability, such as substrate of haul-outs and foraging areas (Bailey *et al*. 2014) and most importantly the presence and availability of suitable prey. Climate change is predicted to negatively impact primary productivity (Hoegh-guldberg & Bruno 2010) and prey species distributions may not change in favourable ways. This could result in parts of FCH becoming more difficult or even unsuitable and reduce the carrying capacity compared to the present. Additionally, anthropogenic pressures can also impact seals whether directly or indirectly and potentially exacerbate problems.

**Conclusion**

This study investigated the current habitat of harbour seals and grey seals using depth and SST from a large dataset of telemetry. Despite a simple approach to environmental grids, with a need for interpolation and a limited resolution to bathymetry, the use of depth and annual SST limits to delineate core habitat appears to be a useful method to represent possible habitat extent in the present and possibly the future.

Although the methodology would need refining to supply more quantitative results, it provides an easy and fast tool for initial exploration of a species' potential climate-related changes in distribution.

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Table 2 - Deployments used in the study

| Species | Deployment name | Country | Location | Start Date | Tag type | No. seals |
|---|---|---|---|---|---|---|
| Phoca vitulina | pv11 | UK | Dornoch | March 2005 | Argos SRDL | 5 |
| Phoca vitulina | pv15 | UK | Wash | March 2005 | Argos SRDL | 8 |
| Phoca vitulina | pv23 | UK | Eden | May 2008 | GPS/GSM | 7 |
| Phoca vitulina | pv24 | UK | Pentland Firth | September 2010 - March 2011 | GPS/GSM | 14 |
| Phoca vitulina | pv24e | UK | Eden | February 2011 | GPS/GSM | 5 |
| Phoca vitulina | pv33 | UK | Strangford Lough | April 2010 | GPS/GSM | 12 |
| Phoca vitulina | pv40 | UK | Thames | January 2012 | GPS/GSM | 10 |
| Phoca vitulina | pv41 | UK | Islay | September 2012 | GPS/GSM | 17 |
| Phoca vitulina | pv42 | UK | Wash | January 2012 | GPS/GSM | 25 |
| Phoca vitulina | pv44 | UK | Eden | August 2012 | GPS/GSM | 21 |
| Phoca vitulina | pv47 | UK | Orkney | July 2012 | GPS/GSM | 7 |
| Phoca vitulina | pv50 | UK | Kirkaldy/St Andrews | March2013 - May 2013 | GPS/GSM | 21 |
| Phoca vitulina | pv55 | UK | Islay | April 2014 | GPS/GSM | 10 |
| Halichoerus grypus | hg4 | Canada | Sable Island | February 2004 | Argos SRDL | 45 |
| Halichoerus grypus | hg7 | UK | Wales | June 2004 | Argos SRDL | 19 |
| Halichoerus grypus | hg5 | Canada | Gulf of St Lawrence? | June 2004 | Argos SRDL | 20 |
| Halichoerus grypus | hg9 | Canada | Sable Island | January 2007 | Argos SRDL | 6 |
| Halichoerus grypus | hg1 | UK | Oronsay, Colonsay | May 2003 | Argos SRDL | 12 |
| Halichoerus grypus | hg3 | UK | Oronsay | September 2003 | Argos SRDL | 10 |
| Halichoerus grypus | hg6 | UK | Tiree, Coll | April 2004 | Argos SRDL | 12 |
| Halichoerus grypus | hg11 | UK | Donna Nook | July 2005 | Argos SRDL | 10 |

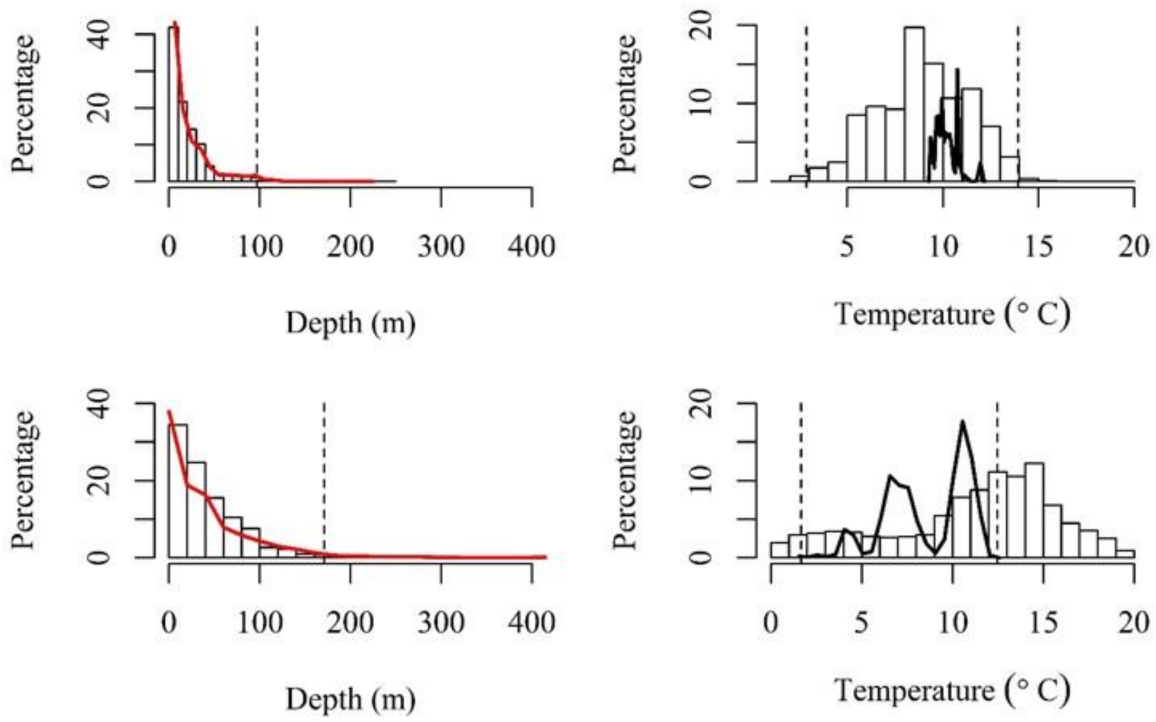


**Figure 1.** Histograms of tag-recorded depths and temperatures for harbour (top) and grey seals (bottom). Interpolated bottom depths (bold red) and annual SST (bold black) are overlaid, and the limits for maximum depth and temperatures are represented as dashed lines.

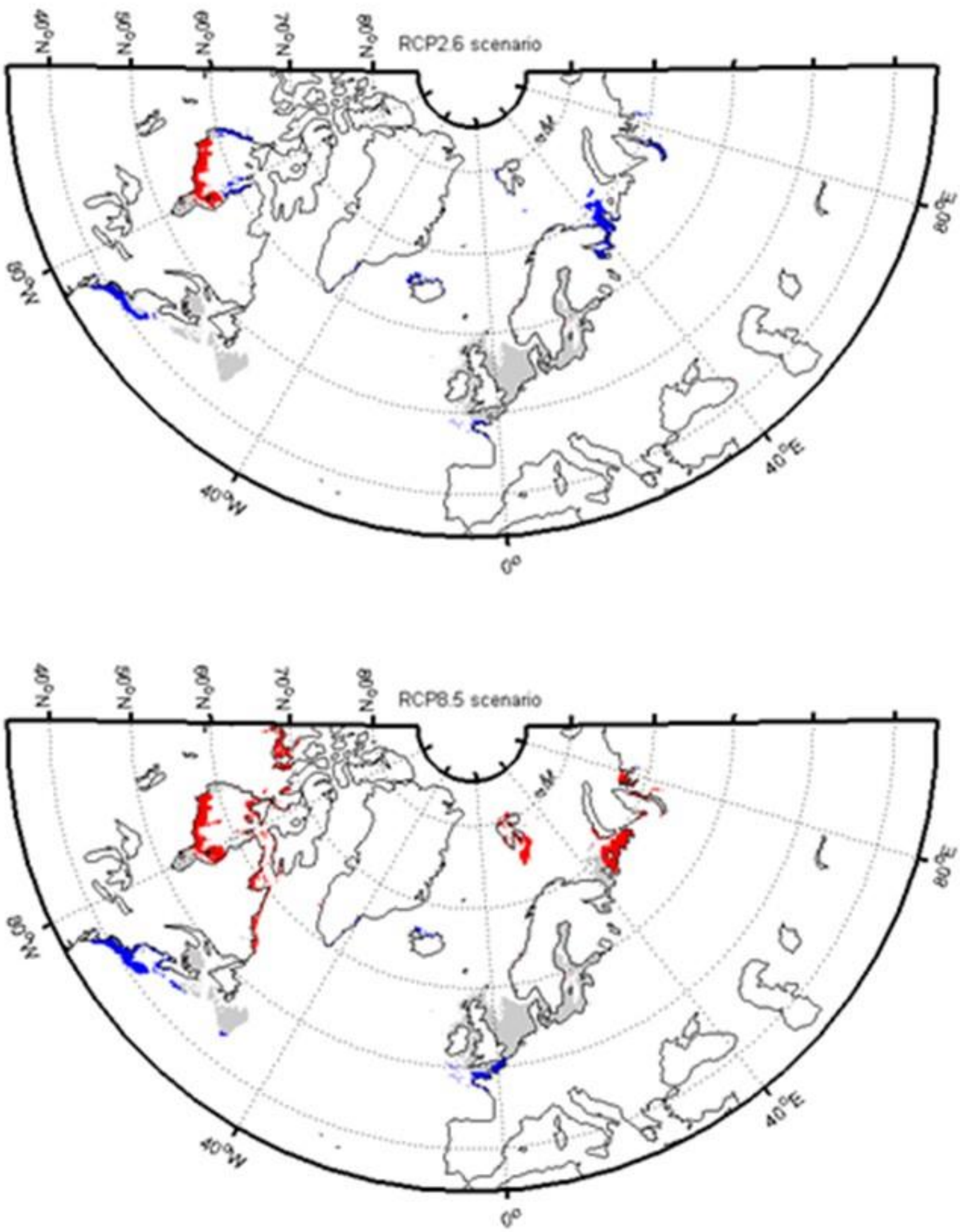


**Figure 2.** Future core habitat (FCH) for harbour seals in the year 2100 under low emission scenario RCP 2.6 (a) and high emission scenario RCP 8.5 (b). Grey represents or areas of habitat common to the present core habitat (PCH) and FCH. Blue and red represent habitat loss and gain (respectively) relative to the PCH. PCH: is the combination of areas common to the present and future scenario (red) and those lost in the FCH (blue).

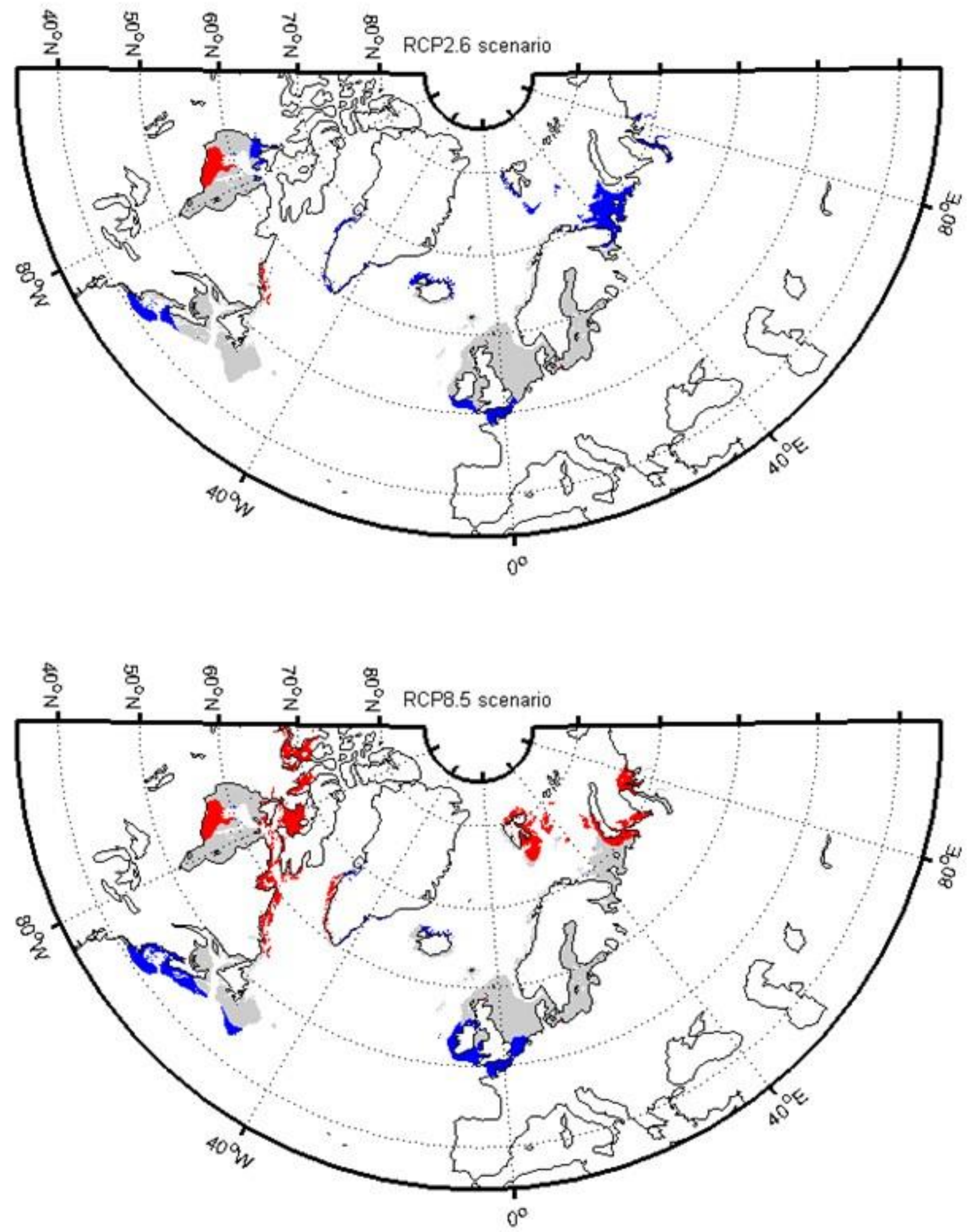


**Figure 3.** Future core habitat (FCH) for grey seals in the year 2100 under low emission scenario RCP 2.6 (a) and high emission scenario RCP 8.5 (b). Only the Atlantic is shown. Grey represents or areas of habitat common to the present core habitat (PCH) and FCH. Blue and red represent habitat loss and gain (respectively) relative to the PCH. PCH: is the combination of areas common to the present and future scenario (red) and those lost in the FCH (blue).

# Protein and metabolite changes in seal milk from birth to desertion.

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**Summary**

True seals, such as the two species that occur around the British Isles, have uniquely short lactation periods, and then desert their pups. We periodically collected milk samples from grey seals throughout lactation and submitted them to proteomic and metabolomic analyses. These seals were found to exhibit a more rapid transition between colostrum and mature milk than yet found in any other mammal. This may be a general character of all true seals. Immune factors such as immunoglobulin G were unusually persistent in milk throughout lactation, whereas anti-microbial oligosaccharides were found only early in the lactation cycle. Taurine levels fell with time, suggesting that taurine-dependency in seals, and depletion of maternal stores during their fast, should be investigated. Indicators of progressive changes in fat metabolism of the mothers were found, indicating that markers of metabolic strain could be used to predict when a mother seal will desert her pup, or is under premature metabolic stress.

## Introduction

True seals have the shortest lactation periods of any species group of mammals. Nursing females may fast while transferring a substantial proportion of their body reserves to their pups, which they then desert, and there is no period of mixed feeding. Post-desertion survival of the pups in breeding colonies, and subsequently at sea, will be heavily influenced by the body condition and physiology of nursing mothers, and what immune factors she can provide. Detrimental changes in food resources and environment of pre-parturtion females may therefore have both short- and long-term effects on their own and their pup's survival, and both their subsequent abilities to reproduce. Long term reproductive potential of seal populations, and hence population recovery from, for instance, disease epidemics will be affected by the starting quality of pups. We have begun an analysis of the proteins, micronutrients and metabolites in grey seal (*Halichoerus grypus*) milk from birth to desertion to address the following questions.

1. Given the unusually abbreviated lactation periods of seals, how rapid is the transition from colostrum (first milk) to main phase milk?

2. What agents of innate and acquired immunity are transferred from mother to young? And how do these change in kind and quantity from birth to desertion?

3. As the mothers fast and their fat reserves deplete to criticality, their fat metabolism is likely to change change. What signals of this can be detected in their milk?

4. Are there signs of encroaching metabolic stress detectable in seal milk as desertion approaches? Can we find a metabolic indicator of when a mother is about to desert?

These questions were aimed at both increasing our understanding of seal reproductive biology, and to provide signs of deterioration in maternal condition that may be caused by changes in food resources, build-up of pollutants, and predicted alterations in climate and sea conditions.

**Methods**

Milk samples were collected from the colony of Atlantic grey seals on the Isle of May, Scotland, during October and November 2013, and stored frozen until processed. A further collection was made in November 2016 to obtain samples as close after birth as possible without risking adverse maternal behaviour or survival of pups. The samples were centrifuged at 4°C, and the water soluble layer below the fat layer collected for analysis. For protein analysis and proteomics, samples were separated on 1- and 2-dimensional protein electrophoresis gels. Gel bands or spots were excised and submitted to proteomics. There is no genome database for grey seals, so the identification of the isolated proteins was obtained by interrogation of the collective databases for the Caniformia subset of the Carnivora, which includes genome data for Weddell seals. Metabolomics was carried out by liquid chromatography-high resolution mass spectrometry analysis and peak extraction and alignment were calculated by integration of the area under the curve, using MZMine 2.14 software.

**Results**

**Proteins.** The visual appearance of milk samples after initial processing by centrifugation in the cold illustrated the degree to which grey seal milk changes with time after birth (Figure 1). When these samples were subjected to protein gel electrophoresis, it was seen that the protein profiles mature extremely rapidly, such that the putative colostrum phase is over within a day (Figure 2). As expected, immunoglobulins (antibodies) were present at higher levels early in lactation (IgG in addition to IgA and IgM in particular). These are likely to be transferred across the neonate's gut to provide systemic immunity, and directly protect against pathogen colonisation of both the neonate's gut and the mother's mammary gland. Unexpectedly, immunoglobulin G (IgG) was found at relatively high levels until soon before desertion.

**Oligosaccharides.** These complex sugars in milk are thought not to be to support a neonates energy metabolism , but instead to be important in preventing the establishment of pathogens in the gut of infant animals. We found two major oligosaccharides, fucosyllactose and sialyllactose in grey seal milk, each of which is thought to have anti-microbial activities. Unexpectedly, however, these putatively protective complex sugars were apparent for only a few days after birth (See Figure 3 for sialyllactose).

**Taurine.** This compound is essential to a range of cellular and developmental processes, including membrane stabilisation, modulation of calcium signalling, and it is essential for cardiovascular function, development and function of skeletal muscle, the retina, and the central nervous system. Taurine is also a component of bile acids that are crucial for the processing of fats in the intestine – which is likely to be of particular importance in seal pups given the extremely high fat content of seal milk. Most mammals can synthesise their own taurine, but some hypercarrnivores (such as cats, and possibly also polar bears) cannot, and are therefore dependent on carnivory to maintain a supply. We found that the level of taurine in grey seal milk was initially at high relative levels, and fell with time after birth (Figure 3).

**Indicators of metabolic activity?** We sought for potential indicators of changes in maternal fat metabolism with time as lactation proceeds, concentrating on nicotinamide and its derivatives. We found substantial changes in these with time, such that nicotinamide itself (Figure 3) increased in concentration, whereas acetlycarnitine fell. These changes do suggest that there are substantial changes in maternal fat metabolism as lactation proceeds.

A point of note is that while the general trends in the levels of the above metabolites are clear, there is nevertheless considerable variation in the levels between mothers, possibly indicative of diversity in pre-parturition body stores, or individual variation in metabolism and lactation.

**Discussion, conclusions and prospective**

The following points and questions arise.

1. The transition from colostrum to mature phase lactation is faster in seals than has been observed in any other group of mammals.

2. The persistence of IgG may indicate that there is prolonged direct transfer of immunity from mother to the circulation of their pups through delayed closure of the gaps between the enterocytes of the gut, or that there are mechanisms for trans-enterocyte transfer of IgG from milk to blood circulation in seals.

3. Is there trans-placental transfer of immunoglobulins? This could investigated by examination of the blood plasma of pups before first suckle. Collecting such samples is unethical because of the risk to maternal acceptance of a newborn pup, but opportunistic collection could be done on, for example, a pup that dies accidentally soon after birth or is stillborn.

4. The milks of some mammals contain large quantities of oligosaccharides of many different types. This applies to humans, but not to mice or cows, in which other innate protective mechanisms presumably suffice. The abbreviated appearance of oligosaccharides in the first half of lactation in grey seal milk is therefore puzzling? Is it to protect the neonate's gut and the mother's mammary gland from new exposure to a host of microbes, or to assist the establishment of a then persistent microbiota?

5. What is the initial gut microbiome of seal pups and how does it change with time?

6. Are seals taurine-dependent? If so, then pups will be particularly vulnerable to limitations in supply. Is the fall in taurine levels in milk with time due to an increase in milk volume or depletion in maternal reserves? If the latter, and if seals are taurine-dependent, then fasting seal mothers may become dangerously depleted towards the end of lactation, and their milk will be of reduced value to a taurine-dependent offspring. Further metabolomics, or genomics of grey seals or related seals (already available for Weddell seals) could show whether the taurine synthetic pathway is intact.

7. There appear to be indicators of changes in fat metabolism of mother seals as lactation proceeds. Is it therefore possible that seal mothers reach a stage in the depletion of their fat reserves that is not metabolically sustainable for lactation to continue, or for survival upon return to sea through loss of insulation? This raises the possibility that there exist detectable indicators of when females are about to desert in addition to those found here. If so, then they may be more evident in blood samples than in milk.

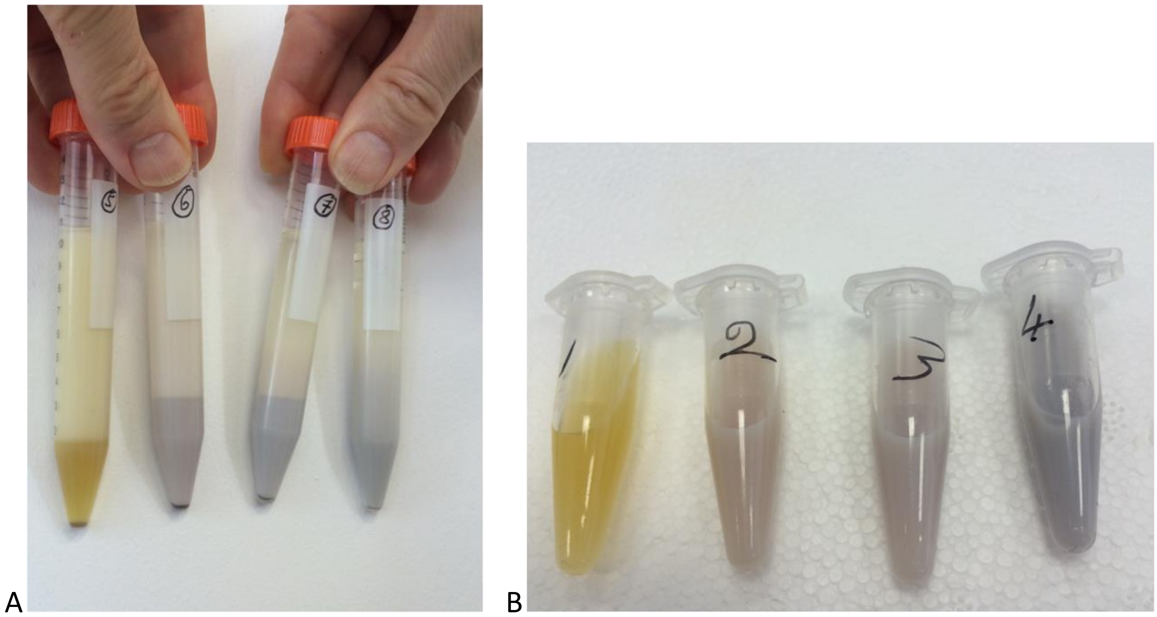


**Figure 1.** Change in appearance of grey seal milks with time after birth. Ten ml of each milk sample were centrifuged at 4°C. Panel A shows the resulting separation between the upper fat layers and the lower water soluble layer below. The latter layer was removed from the tubes in A to provide samples such as in B. The samples in panel A are from days 2, 7, 13, and 18 of an18-day lactation of an individual seal. The samples in panel B are, in numerical order, from days 1, 7, 13, and 18 of a 21-day lactation by another seal.

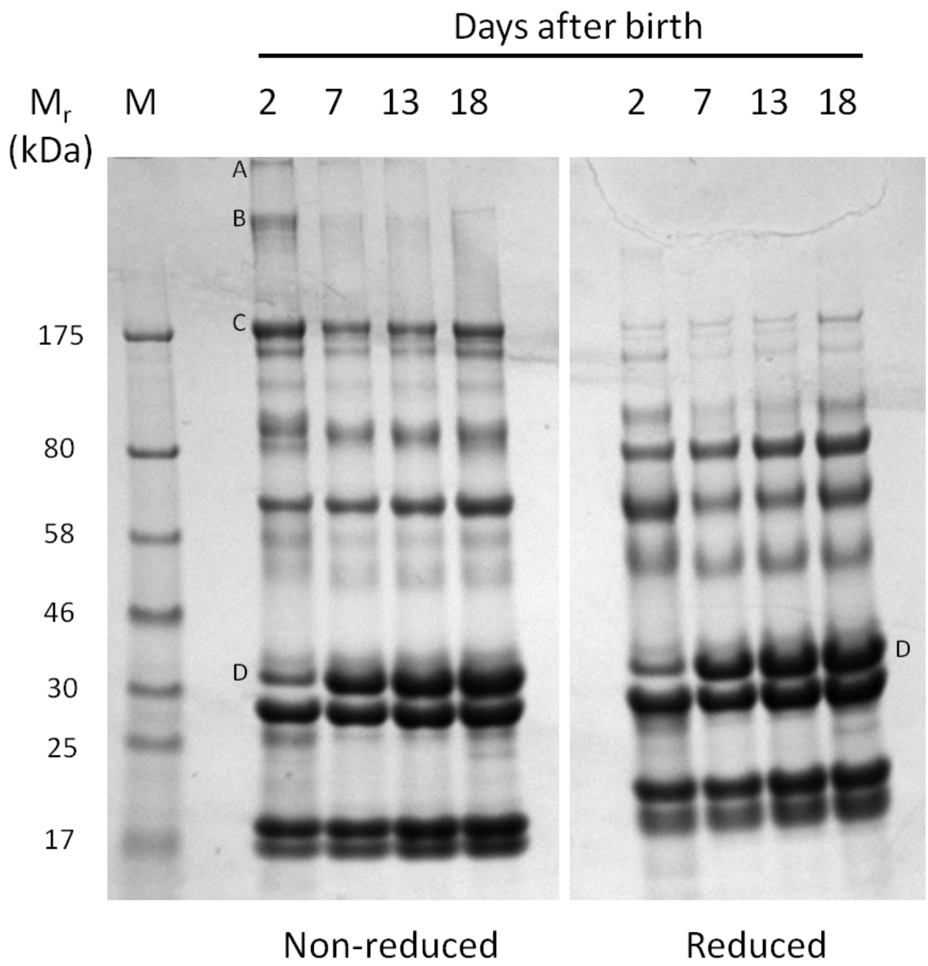


**Figure 2.** Changing protein profiles of grey seal milk with time after birth. Gradient SDS-PAGE of milk samples obtained from a single mother seal on the days indicated. Gels were stained for protein with Coomassie blue. Note the rapid fall in the amounts of immunoglobulins IgM (band A) and IgA (band B), but the persistence of IgG (band C). Also, the low level of one of the milk caseins at an early stage(band D). Samples taken between 10 and 19 hours after birth show the same effects. Most of the other bands were identified by proteomics. Overall, the time taken for the maturation of the protein profile after birth is remarkably short. M – size standard proteins.

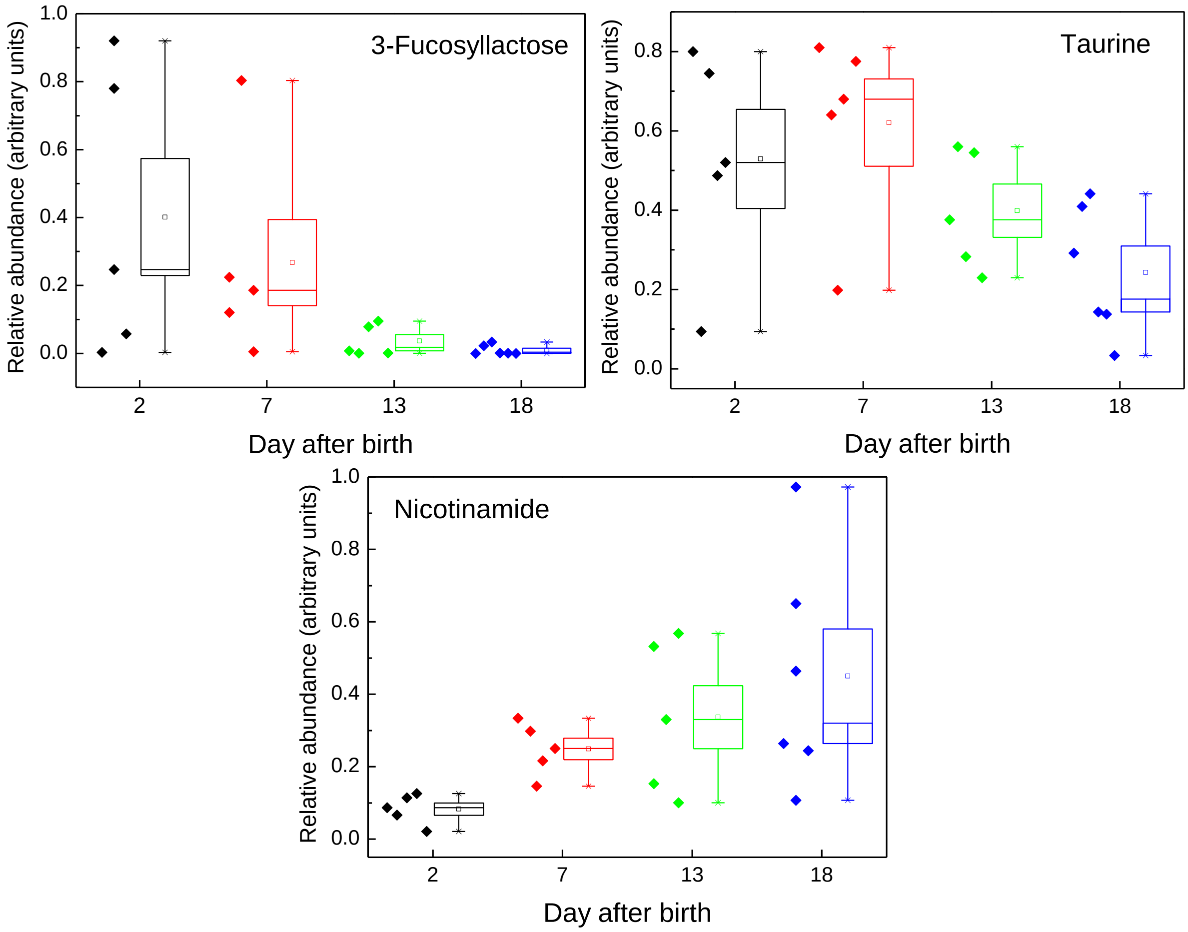


**Figure 3.** Changes in grey seal milk small molecules/metabolites with time after birth. Selection of three compounds illustrating distinctive patterns of change. Fucosyllactose is an oligosaccharide that has known inhibitory effects on microbial colonisation of the gut in some species. Taurine is an essential dietary requirement in some species of hyperpredator (such as cats) – seals are piscovorous hyperpredators. Nicotinamide is associated with fat metabolism, which is likely to be particularly important in seals in terms of mobilisation of maternal body reserve lipids, and lipids required for rapid growth and maintenance of pups that need to accumulate large fat reserves for the forthcoming starvation period and for thermal insulation at sea. The square symbol in a box is the mean; the band in the box is the median; the box extends to the standard error of the mean; the whiskers indicate the range.