Scientific Advice on Matters Related to the Management of Seal Populations: 2016

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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 2016, 20 questions were addressed by SCOS.

Current status of British grey seals

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. The most recent surveys of the principal Scottish grey seal breeding sites flown in 2014, produced a pup production estimate of 54,900. Adding in an additional 5,500 pups estimated to have been born at the 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 pups (95% CI 53,900-66,900, rounded to the nearest 100). The pup production estimates are then converted to estimates of total population size (1+ aged population) using a mathematical model and projected forward to 2015.

The population model provided an estimate of 139,800 (approximate 95% CI 116,500-167,100) UK grey seals (1+ aged population).

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 (2011-2015) gives a total of 31,200 counted in the UK. 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 2015 of 43,300 (approximate 95% CI: 35,500-59,000). 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 2015, 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 78% between 1997-2013), the East coast (down 70% between 1997 and 2015, but primarily driven by the decline in the Firth of Tay, down 92% between 2000-2015) 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 very similar to those reported for 2013 and 2014.

SCOS recommended that the measure to protect vulnerable harbour seal populations should remain in place.

Causes of the recent decline in common/harbour seals

A wide range of potential causes of the decline in Scottish harbour seals in some regions continues to be discussed. Although the causal mechanisms have not yet been identified, several factors can now be ruled out as primary causes for the decrease in numbers (for example by-catch in fishing nets, pollution and phocine distemper virus) and research efforts are currently focussed on two of the remaining potential mechanisms: interactions with grey seals (both direct and indirect competition and direct predation) and exposure to toxins from harmful algae.

Potential Biological Removals (PBRs) in relation to the seal licence system

SCOS considered it important to recognise that the setting of management objectives is primarily a societal issue and that scientists can only recommend methods for achieving such objectives. A report of a workshop convened by Marine Scotland Science to discuss the available methods for achieving management goals is appended (SCOS-BP 16/07). The workshop participants clearly felt that there was a need to improve or move on from using PBR for some of Scottish Government's licensing requirements. Several options were discussed, including tests to demonstrate the effectiveness of PBR, as well as methods by which assessments may be undertaken in the future. This is an area for development as questions remain.

Use of PBR for setting long term management goals in situations where the level of mortality is unknown and the structure, and therefore potential effect, is likely to remain in the long-term, was identified as a specific problem. Several lines of research leading to possible solutions were identified at the workshop. Although no formal comparisons were made between population tools, Population Viability Analysis (PVA) was agreed to have potential for assessments relating to marine renewable energy developments in part because it is widely used in seabird assessments. However, PVA does not set levels of acceptable effect/take; what is considered acceptable is a societal decision.

Provisional regional PBR values for Scottish seals for 2017 for use in issuing seal licences were endorsed by SCOS.

Anthropogenic mortality in relation to PBR

Any anthropogenic take, including bycatch, is included in the PBR value. Subtracting bycatch from the PBR estimate does not represent 'double-counting'. PBR provides an estimate of the number of animals that can be removed from that population in the following 12 months while still allowing it to tend towards its Maximum Net Productivity Level (MNPL). The method is designed to ensure that the population will be at or above its MNPL after 100 years. The value of $N_{min,}$used in the calculation of PBR, is recommended to be the lower 20th percentile of the current population estimate. It is implicit in the calculation of the PBR that N_{min} is correct.

Seals and Marine Renewables

Since reporting in 2015, there have been a number of published updates on the interactions between seals and marine renewable energy 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. Sound exposure estimates during piling operations suggested that approximately half of the tagged harbour seals were subjected to levels likely to cause hearing damage. Tests of Acoustic Deterrent Devices (ADDs) as mitigation methods for pile driving showed that seals exhibited behavioural responses out to a range of 1km. Thus, 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 (e.g. rotor speed reductions).

Seals and River Fisheries

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 also been developed.

Seals and Fish Farms

A full review of this issue is beyond the scope of the SCOS. Underwater cameras have been deployed on salmon cages for 96 days, but low predation levels meant no predation was observed. Captive seals were trained to push against simulated cage net walls. Forces measured suggest that medium sized seals can push net in by 30cm or more. Captive seals found it difficult to feed on salmon presented to them in a model of a salmon pen. When seals had access to fish overnight they recreated the damage characteristics typically seen at fish farms. Trials with various ADD devices suggest that predation can be reduced without disturbance of non-target harbour porpoises. Trials of low voltage pulsed electric field showed potential to deter seals from pushing against nets. A field trial of an electric cage defence system has been carried out but no results are available yet.

Marine Strategy Framework Directive

SCOS discussed the work carried out by SMRU on the MSFD seal indicators. Data and analyses for indicators M3 and M5 have fed into the Intermediate Assessment 2017 (IA2017), prior to the August 2016 deadline. The latest available data from the UK were used to perform an assessment of MSFD indicators M-3 and M-5, describing changes in grey seal and harbour seal population abundance and distribution. It was necessary to arbitrarily subdivide UK Assessment Units into smaller subareas to calculate distribution metrics for harbour seals. The distribution metrics showed no catastrophic contraction or shift in distribution has occurred for either grey or harbour seals in any Assessment Unit. In 2016 an extended version of the UK grey seal population assessment model incorporating a movement model to allow recruitment to new regions was applied to the NE Atlantic grey seal population. Results indicate that the overall population is clearly increasing.

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 2016. 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.

As with most publicly funded bodies in the UK, SMRU's long-term funding prospects involve a reduction in spending in cash terms that represents a substantial reduction in real terms into the foreseeable future. This is will have an impact on the frequency and types of advice that SMRU will be able to deliver, although prioritization of research activities will mitigate some of these impacts.

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.

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, typically 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. 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 recovery from the 2002 epidemic until 2009 but have increased dramatically in the past four years. In contrast, the adjacent European colonies in the Wadden Sea have experienced continuous rapid growth since 2002 but that increase may be slowing.

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 declined by 50% before 2005 remained reasonably stable for 4 years then increased by 40% in 2010 and has fluctuated since. 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 the main concentrations of 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. In Northern Ireland 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 2016 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. A

1. What are the latest estimates of the number of seals in UK waters?	MS Q1; Defra Q1; NRW Q1

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

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 flown in 2014, produced a pup production estimate of 54,900. Adding in an additional 5,500 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 pups (95% CI 53,900-66,900, rounded to the nearest 100, Table 1). The pup production estimates are then converted to estimates of total population size (1+ aged population) using a mathematical model and projected forward to 2015.

The population model provided an estimate of 139,800 (approximate 95% CI 116,500-167,100) UK grey seals (1+ aged population).

Pup production is then converted to total population size (1+ aged population) using a mathematical model. The stages in the process (pup production → mathematical model → total population size) and the trends observed at each stage are given below and presented in detail in SCOS-BP 16/01 and SCOS-BP 16/02.

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

Aerial surveys to estimate grey seal pup production were carried out in Scotland in 2014, using a digital camera system for the second time. Major colonies in Scotland are now surveyed biennially (see SCOS-BP 14/01). The total number of pups born in 2014 at all UK colonies was estimated to be 60,500 (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. 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 never bred in significant numbers. 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. 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. Interestingly, the Farne Islands estimate increased by approximately 18% last year after a period of little change since 2000.

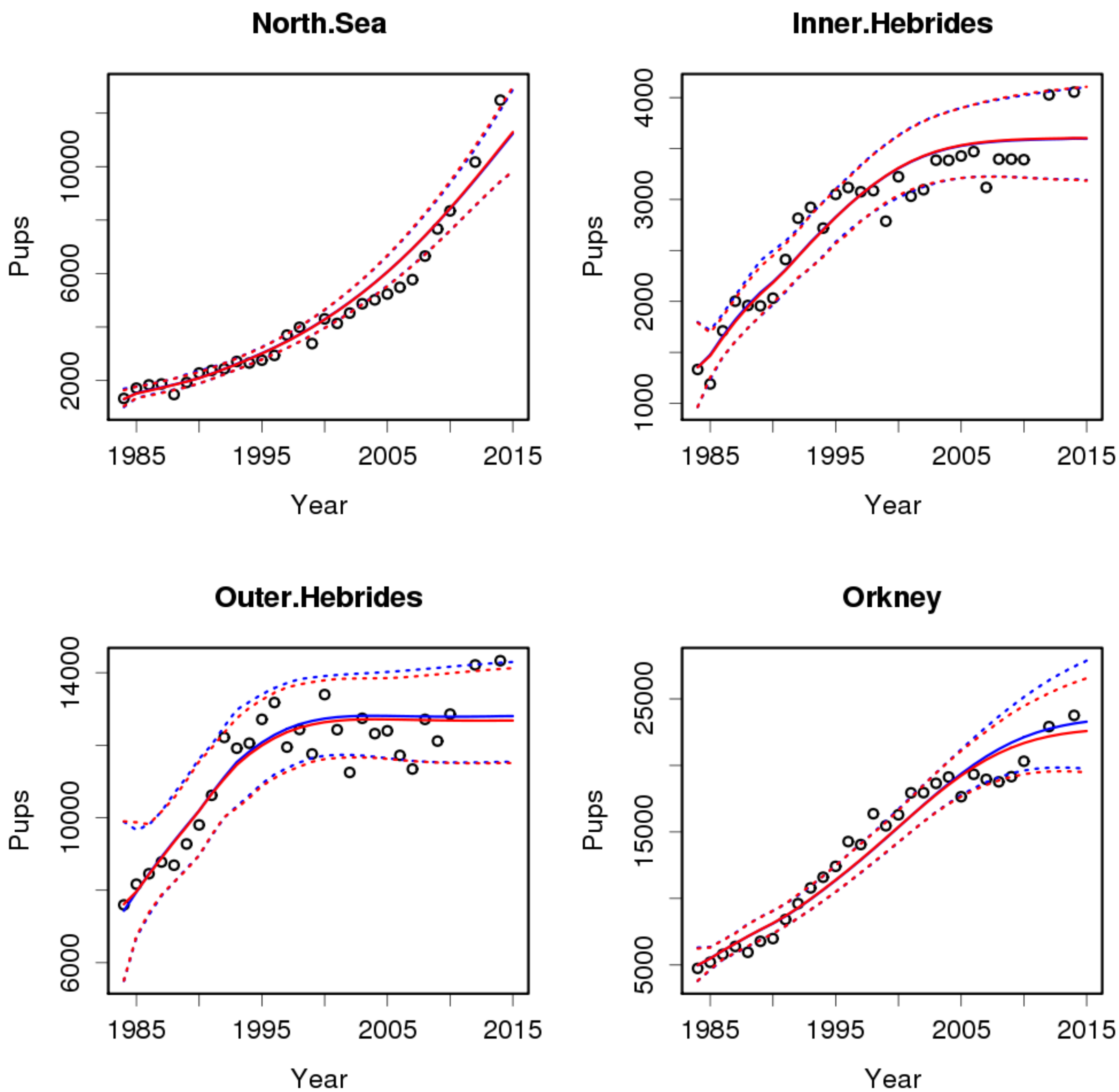


Figure 1. ***Mean estimates of pup production (solid lines) and 95% Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 (circles) and two independent total population estimates from 2008 and 2015. Blue lines show the fit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

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] http://wtswwcdn.8a1bc20d.cdn.memsites.com/wp-content/uploads/2014/07/Seal-Report-2015-final-.pdf

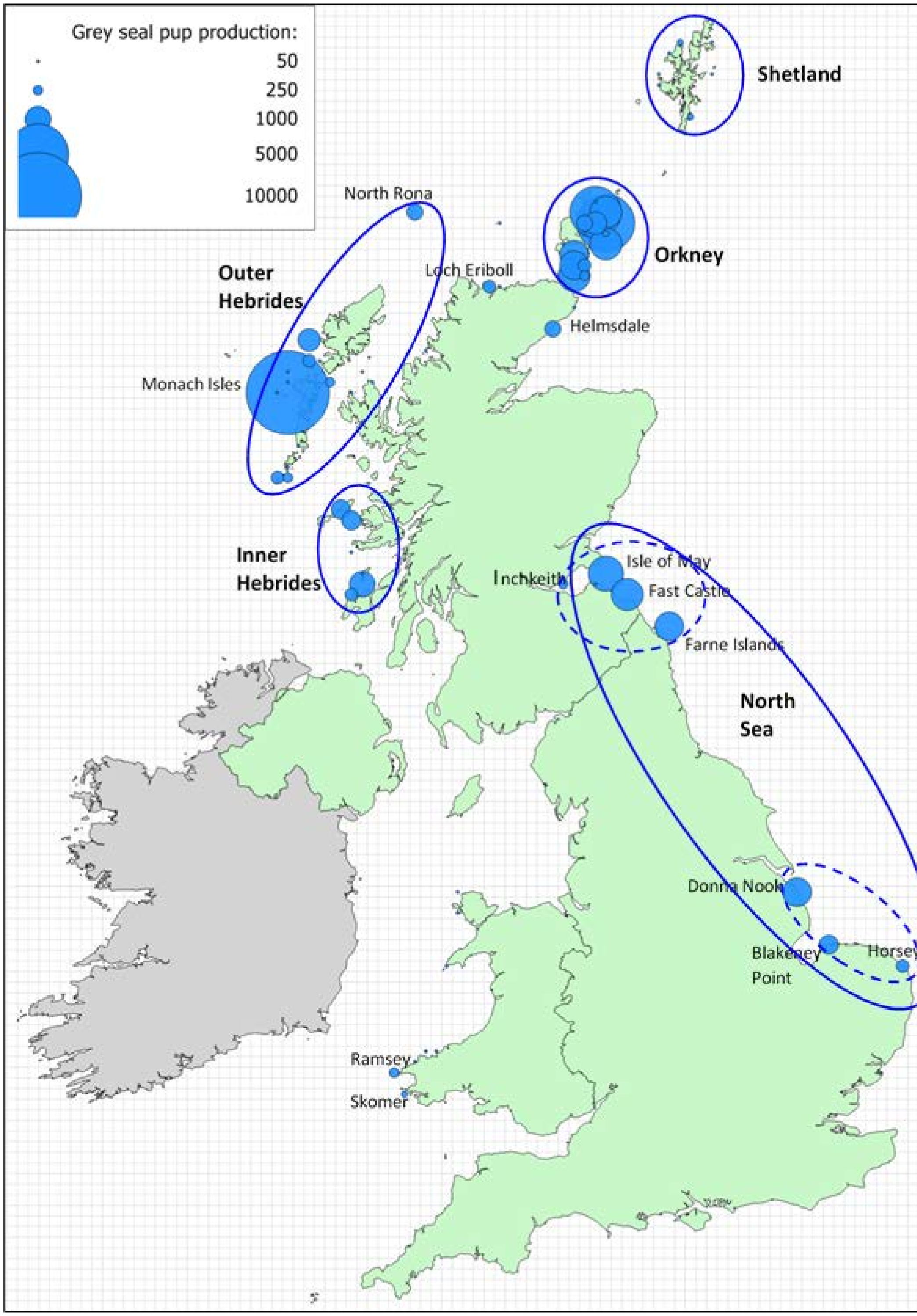


Figure 2. ***Distribution and size of grey seal breeding colonies. Blue ovals indicate groups of colonies within each region.***

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.

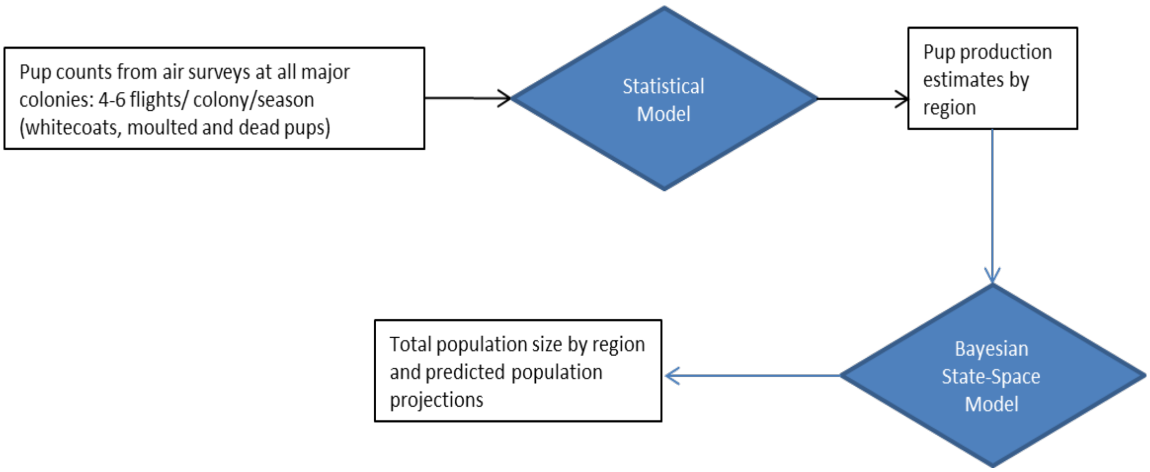


Figure 3. ***Schematic diagram of steps involved in estimating total population size from pup counts*** *(see also SCOS BP-09/02, SCOS BP-10/02).*

Using appropriate estimates of fecundity rates and both pup and non-pup survival rates 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 individuals were counted 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.

This year, 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 are presented in SCOS-BP 03/16.

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, 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.

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 last year'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 prior distributions were used on model parameters, including a prior on sex ratio and a constraint on adult survival to the range 0.80-0.97.

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

[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.

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).

This estimated population in 2015 is approximately 20% higher than that reported last year and the trajectory overall has increased by the same amount. An initial investigation showed that a difference of 14% can be attributed to changes in the independent estimate resulting from the new estimate of the proportion of animals hauled out during the survey window; the other 6% is presumably caused by the high 2014 pup count (SCOS-BP 16/02).

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.

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 a new set of surveys planned for 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 annually monitored colonies have increased by approximately 1% p.a. (SCOS-BP 16/02) between 2012 and 2015. 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.

In the southern North Sea the rates of increase in pup production since 2010 (>22% p.a.) suggests that there must be some immigration from colonies further north.

UK grey seal population in a world context

The UK grey seal population represents approximately 36% 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	1,100	2015[2]	Increasing
Norway	1,300	2008[3]	Increasing
Russia	800	1994	Unknown
Iceland	1,200	2002	Declining
Baltic	6,400	2013[4,5]	Increasing
Europe excluding UK	**12,900**		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	**169,400**		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_2016.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

<u>Current status of British harbour seals</u>

Harbour seals are counted while they are on land during their August moult, giving a <u>minimum</u> 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 (2011-2015) gives a total of 31,200 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 2015 of 43,300 (approximate 95% CI: 35,500-59,000). 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 2015, 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 78% between 1997-2013), the East coast (down 70% between 1997 and 2015, but primarily driven by the decline in the Firth of Tay, down 92% between 2000-2015) 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 very similar to those reported for 2013 and 2014.

Table 4. ***UK harbour seal counts.***

Location	Most recent count (2007-2014)
England	4,850
Wales	<50[1]
Scotland	25,400[2]
Northern Ireland	950
Total UK	**31,200[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 16/04. 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 photography 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 the moult counts to total population was derived from flipper mounted ARGOS tags applied to harbour seals 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 2015 are described in more detail in SCOS-BP 16/04. 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 (2007-2015) at all sites, approximately 31,200 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 ~34,700 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 relatively stable, increasing by an average of 1% p.a.

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. The east Anglian coast surveys were carried out throughout the breeding season in June and July (SCOS-BP 16/05). The maximum count in 2015 was approximately 18% lower than the 2014 count which was the highest ever recorded. Despite apparently wide inter-annual variation, the maximum annual pup count in The Wash has increased at around 8.2% p.a. since regular pupping season surveys began in 2001. As noted previously, the ratio of pups to the moult counts remained high in 2015, more than double the same ratio in 2001. This can be seen as an index of the productivity of the population and is referred to here as apparent fecundity. Interestingly, a similar trend of 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.

Table 5. ***The most recent August counts of harbour seals at haul-out 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 16/04.

Seal Management Unit / Country		Harbour seal counts			
		2008-2015	**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	1,938	2,979	4,384	8,787
5	Shetland	3,369	3,039	3,038	5,994
6	Moray Firth	745	776	1,028	1,409
7	East Scotland	224	283	667	764
SCOTLAND TOTAL		**25,399**	**20,430**	**23,423**	**29,514**
8	Northeast England	91	58	62	54
9	Southeast England	4,740	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		**4,869**	**4,032**	**3,048**	**3,280**
BRITAIN TOTAL		**30,268**	**24,462**	**26,471**	**32,794**
NORTHERN IRELAND TOTAL		**948**	**1,101**	**1,176**	
UK TOTAL		**31,216**	**25,563**	**27,648**	
REPUBLIC OF IRELAND TOTAL		**3,489**	**2,955**	**2,955**	
BRITAIN & IRELAND TOTAL		**34,705**	**28,518**	**30,603**	

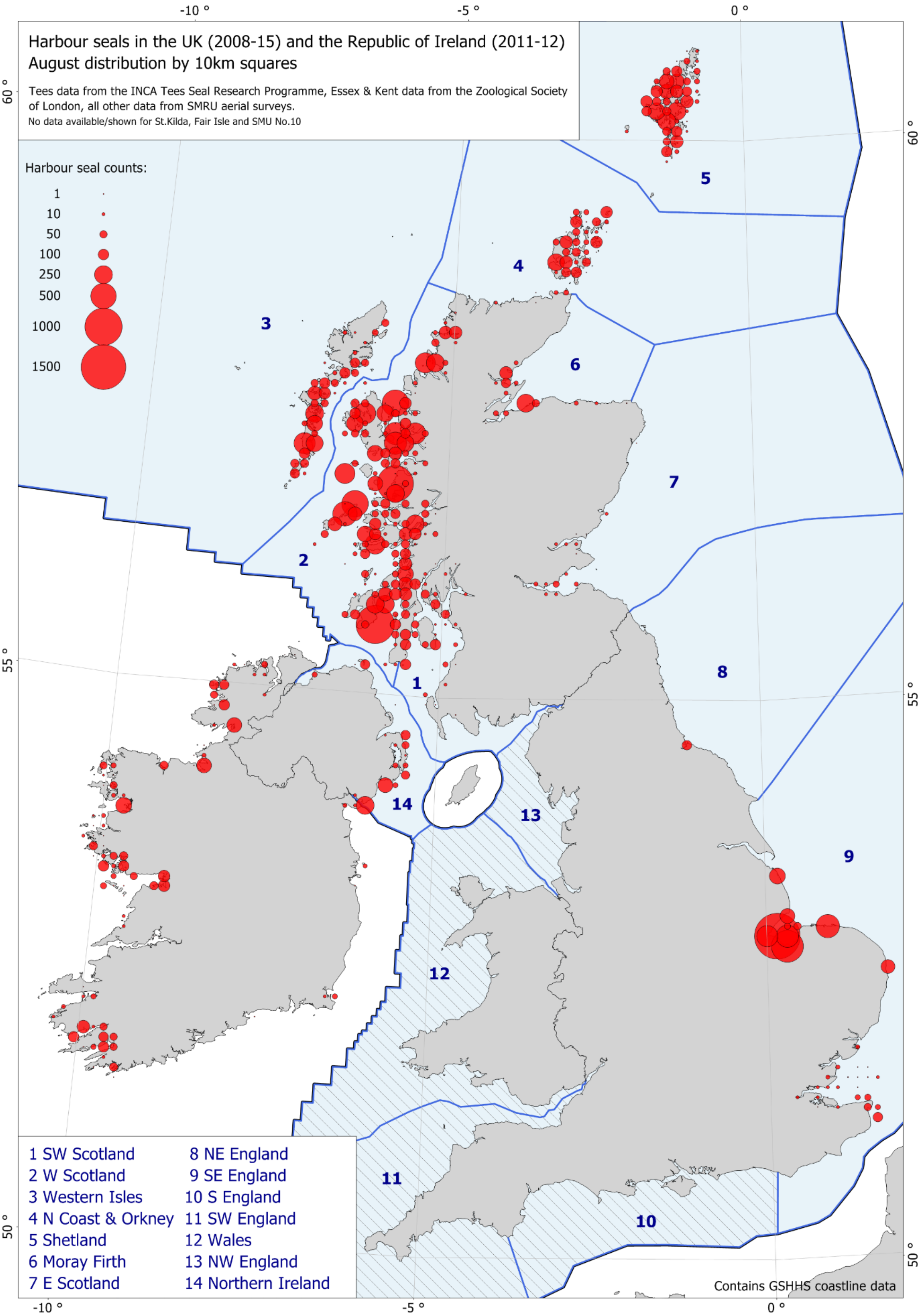


Figure 4. ***August distribution of harbour seals around the British Isles. Very small numbers of harbour seals (<50) are anecdotally but increasingly reported for the West England & Wales management unit, but are not included on this map. Estimates are composites of the most recent survey counts in each region between 2008 and 2015.***

Population trends

Overall, the harbour seal population has increased from 24,500 (rounded to the nearest 100) in the 2007-09 period to 30,300 animals during the 2011-2015 period, but remain slightly below the pre-epidemic 1996-97 levels of 32,800 (Table 5). However, as reported in SCOS 2008 to 2015, changes in abundance have not been universal, with declines being observed in several regions around Scotland but with some populations either stable or increasing. Details are given in (Figure 5, SCOS-BP 16/04).

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) (SCOS-BP 16/04). 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 is of particular interest as it shows the first increase since 1993 following a period of decline[6].

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 surveys in the 1996 and 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%.

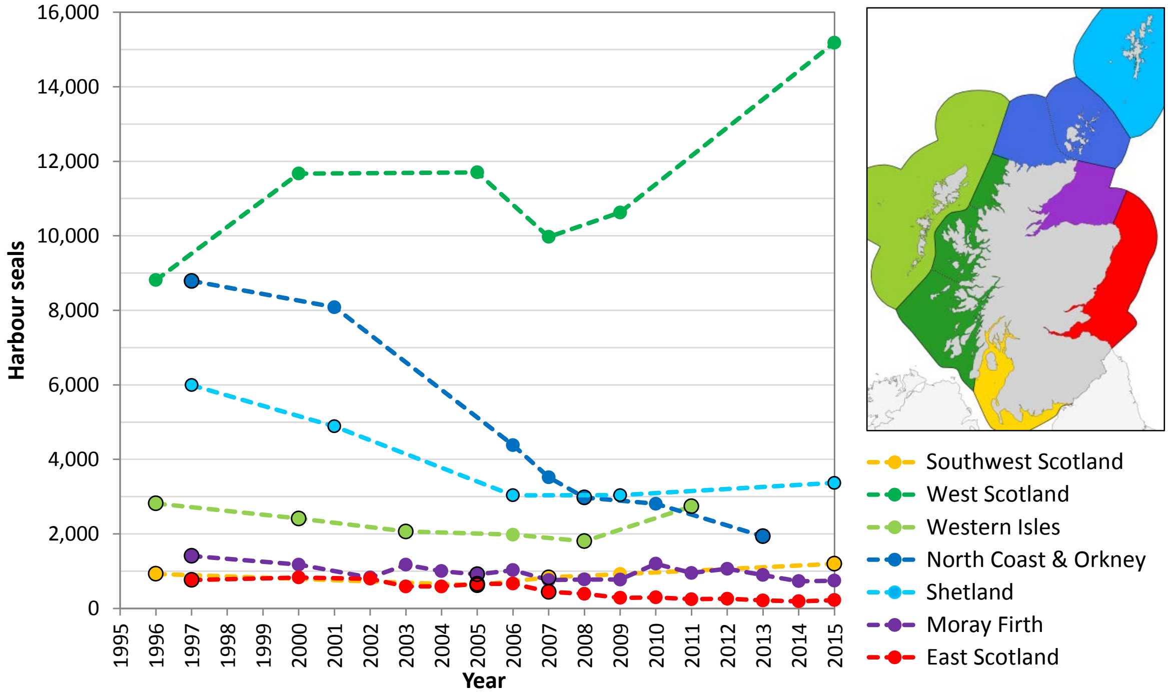
In the Moray Firth, the overall total counts in August were similar to those in 2007-2009, but showed a 50% decline since the 1996-97 counts. Within the Moray Firth, the count between Loch Fleet and Findhorn was similar to the 2014 count which was the lowest in the time series. Counts at Culbin Sands and Findhorn have continued to increase rapidly, suggesting substantial re-distribution within the area.

The 2015 harbour seal moult count for the Firth of Tay and Eden Estuary Special Area of Conservation (SAC) (60) was double that in 2014 (SCOS-BP 16/04). The 2014 count was the lowest count ever for the SAC population and although the 2015 count was higher, it still 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 2015 (4,740) was very similar to the 2014 count (4,681). 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 and 2015 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.

[6] 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.



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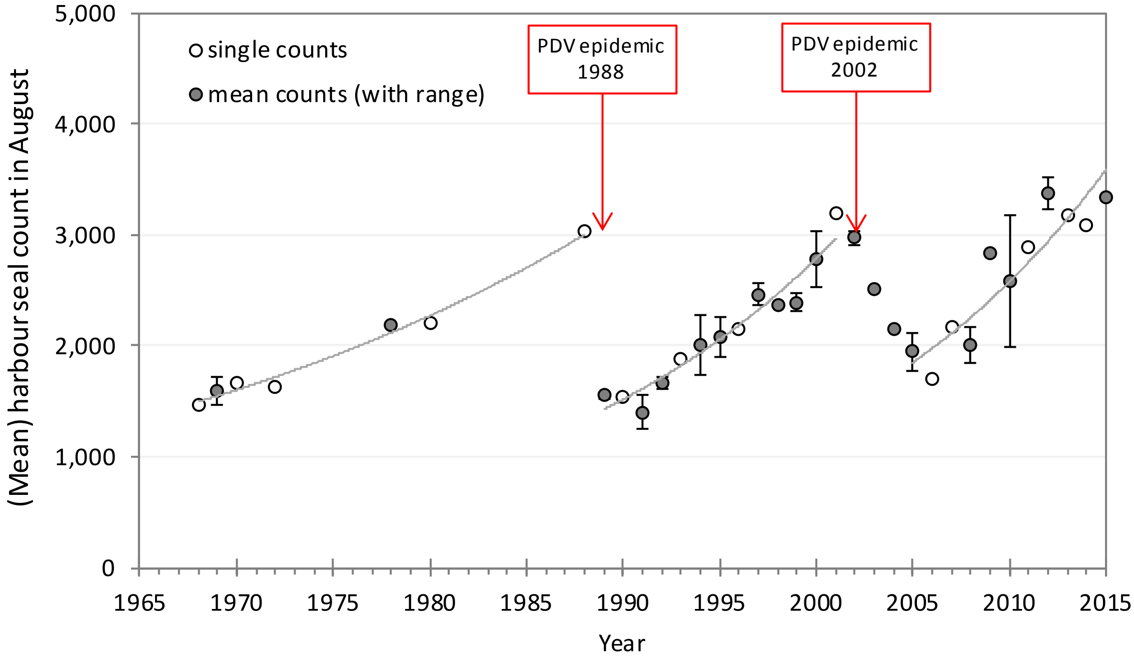

Figure 5. ***Recent trends in numbers of harbour seals:*** *a.* ***counted in different Scottish seal management areas, 1996-2015 (black circled points indicate a single count in that year, plain points represent means of multiple counts);*** *b.* ***counted in The Wash, southeast England, 1967-2015 (grey filled points indicate means of multiple counts) (SCOS-BP 16/04).***

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	**25,400**	2007-2015
England	**4,900**	2015
Northern Ireland	**900**	2011
UK	**31,200**	
Ireland	3,500	2011-12
Wadden Sea-Germany	15,900	2015
Wadden Sea-NL	7,700	2015
Wadden Sea-Denmark	2,800	2015
Limfjorden	1,400	2013
Kattegat	9,500	2013
Skagerrak	2,600	2007
Baltic proper	1,000	2013
Baltic Southwestern	900	2013
Norway	7,100	2013
Iceland	11,000	2011
Barents Sea	1,900	2010
Europe excluding UK	**65,300**	
Total	**96,500**	

[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.

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, 2014, Aerial surveys of harbour seals in the Wadden Sea in 2014, 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
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 common seals in UK and European waters? Is there any new evidence of populations or sub-populations specific to local areas?	MS Q2; Defra Q2;

Grey seals

There is evidence for regional differences in grey seal demographics but information on vital rates would improve our ability to provide advice on population status. This includes the requirement for a time series of fecundity and survival rates on a regional basis.

The only contemporary data that we have on fecundity and adult survival has been estimated for adult females at the two breeding colonies which constitute the long term studies (see survival and fecundity rates below).

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 and generates posterior distributions for the main demographic parameters; fecundity, pup survival and estimates of adult female (1+ age classes) and sex ratio. 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.

Survival and fecundity rates

In the model used to generate the 2015 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 sex ratio prior of 1.7 (SE 0.02), i.e. seven males to every ten females.

Survival rates and fecundity estimates for adult females breeding at North Rona and the Isle of May have been estimated from re-sightings of permanently marked animals. This work is ongoing and will be reported to SCOS 2017.

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[7] and within Scotland, there are significant differences between

[7] 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.

grey seals breeding on the Isle of May and on North Rona[8]. Recent telemetry data suggest that there may be significant mixing between these populations outwith the breeding season[9] e.g. observed movements of adult seals between summer haulout sites in Northern France and both the Scottish east coast and Inner Hebrides.

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 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[10,11]. 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[12].

Genetics

Genetic data from a study directed toward resolving patterns of population structure of harbour seals from around the UK and adjacent European sites[13] has recently been added to and more thoroughly analysed (with funding from Scottish Natural Heritage) to investigate fine-scale population structure and gene flow in harbour seal populations. This work will be presented to SCOS 2017.

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[8]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.

[9] 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.

[10]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.

[11]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

[12]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.

[13] Olsen, M.T., V. Islas, J.A. Graves, A. Onoufriou, C. Vincent, S. Brasseur, A.K. Frie & A.J. Hall (in press). Genetic population structure of harbour seals in the United Kingdom. Aquatic Conservation: Marine and Freshwater Ecosystems

Seal Policy

3. What additional research is considered most necessary by the Committee to improve our knowledge and understanding of seal ecology in Scotland to help inform management and thus sustainable harbour seal populations for the future?	MS Q3;

SCOS discussed the briefing paper that was drafted in response to this question. A revised briefing paper will be drafted and discussed inter-sessionally by members of the SCOS and a response to this question will be tabled at the 2017 meeting.

Harbour Seal Population

4. 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 Q4

The status of the local harbour seal population varies around the UK. Declines are continuing in Orkney and along the East coast of Scotland. Counts appear stable in the Western Isles, Shetland and the East coast of England. Counts on the West coast of Scotland indicate a large increase over the last decade.

As reported in SCOS 2008 to 2015, 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 16/04.

In some areas recent counts indicate a potential recovery. 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 2015 count of 60 represents a 90% decrease from the mean counts before 2002, and in Orkney where the 2013 count of 1,938 represents a 78% decrease since 1997. In the Moray Firth there is considerable variability in the August total counts for the entire region, but the most recent counts for the inner Moray Forth coast between Loch Fleet and Findhorn are the lowest in the time series.

The combined count for the Southeast England management unit in 2015 (4,740) was very similar to the 2014 count (4,681). The Southeast England population has returned to its pre-2002 epidemic levels.

5. What is the latest understanding of the causes of the recent decline in common/harbour seals?	MS Q5

A wide range of potential causes of the decline in Scottish harbour seals in some regions has been discussed at previous SCOS meetings. Although the causal mechanisms have not yet been identified, 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. A workshop identified an extensive list of potential causal factors that required investigation[14]. Although no factors have been reliably identified as the causal mechanism, various factors can now be ruled out as **primary** causes for the decrease in numbers (such as persistent organic pollutants, phocine distemper virus and bycatch in fishing gear). Other factors may be involved secondarily (such as changes in body condition, primary and secondary infection) and the causes of the decline may not be the same in all regions. At present research efforts are concentrating on two of the remaining potential mechanisms: interactions with grey seals (both indirect, such as competition for resources and habitat, and direct, such as predation) and exposure to toxins from harmful algae.

A major issue identified at the harbour seal declines workshop was the need for more demographic data for populations with differing trajectories. A study designed to estimate demographic parameters from pelage i.d. photographs and seal population monitoring, to examine site fidelity by tracking seal movements from telemetry studies and to obtain representative measures of individual and environmental covariates began in 2015 and will report to SCOS annually. The University of Aberdeen have continued their long-term monitoring and photo i.d. studies in Loch Fleet providing additional information for estimating demographic parameters for that population. A series of GPS telemetry deployments is providing at-sea behaviour and movement data for study animals with known reproductive histories.

6. In the light of the latest reports, should the Scottish Government consider additional conservation measures to protect vulnerable local harbour seal populations in any additional areas to those already covered by sea conservation areas or should it consider removing existing conservation measure in any areas?	MS Q6

The measures to protect vulnerable harbour seal populations should remain in place. Conservation orders are currently in place for the Outer Hebrides, 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 Advice 2015). The potential biological removal (PBR) is calculated for each region for each year (SCOS-BP 15/08) and the recovery factor is reviewed annually based on the latest survey data.

[14] http://www.smru.st-andrews.ac.uk/files/2015/10/CSD1-2_and_CSD2_Workshop_report_on_decline_in_abundance_of_harbour_seals.pdf

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

The declines in Orkney and at sites on the East coast suggest strongly that the conservation orders should remain in place. The Moray Firth Management Plan will continue to operate and provide specific management actions for that population.

Recent surveys in the Western Isles indicate that the population has increased since the 2007-09 surveys and is now close to the 1996-97 levels. The adjacent and much larger West coast population is at an all-time high since surveys began. Changes to policy with respect to the Outer Hebrides should be deferred until the results of the next survey are available.

Unusual seal mortalities

7. MS: What is the latest information on unusual seal mortalities? Can these mortalities now be solely or largely attributed to grey seal predation? **NRW: Grey seal predation is now considered the main cause of 'corkscrew injuries' in grey seals and common seals (and possibly harbour porpoise).** **a. To what extent do you think that grey seal predation might be a factor in common seal declines and** **b. If predation was included as a parameter in the population models, might that provide a better prediction of common seal status?**	MS Q7; NRW Q2

The latest understanding of the cause of the recent unusual spiral seal mortalities is that this is likely to be due to predation by male grey seals rather than ducted propellers. A study funded by Scottish Government is being carried out by SMRU to determine whether collisions with vessels remain a plausible explanation for some cases.

(a) Recent studies have described a series of observations of predation by adult male grey seals on weaned grey seal pups and harbour seals[15,16,17]. The pathology associated with the attacks is in some cases indistinguishable from that seen in stranded carcasses previously ascribed to interactions with ship propellers. Brownlow *et al*.[18] argue that grey seal predation is sufficient to explain all of the recorded examples of corkscrew mortalities in the UK. It is not possible to entirely discount seal/ship interactions as the cause of some of the injuries and research into potential interactions with shipping is ongoing.. However, the existence of a directly observed cause that is present at all locations where the corkscrew events have been recorded means that it is reasonable to assume that grey seal predation is the primary cause.

There are limited data on the extent and intensity of predation by grey seals on harbour seals. In the UK over the last year there have been observations of male grey seals killing grey seal pups in Orkney, the Firth of Forth, East Anglia and Wales[18]. There are anecdotal reports of previous observations of grey seals eating harbour seals in East Anglia and killing harbour seal pups in Orkney as well as the detailed observations from Germany.

Over recent years corkscrew injury has been a major cause of death in the relatively small number of harbour seals recorded by the Scottish Marine Animal Stranding Scheme (SMASS). Given the

[15] van Neer, A., L. F. Jensen, & U. Siebert. (2015). Grey seal (*Halichoerus grypus*) predation on harbour seals (*Phoca vitulina*) on the island of Helgoland, Germany. *Journal of Sea Research* 97:1-4.
[16] Bishop, A. M., J. Onoufriou, S. Moss, P. P. Pomeroy, and S. D. Twiss. (2016). Cannibalism by a Male Grey Seal (*Halichoerus grypus*) in the North Sea. *Aquatic Mammals* 42 (2):137-143.
[17] Brownlow, A., J. Onoufriou, A. Bishop, N. Davison, & D. Thompson. (2016). Corkscrew Seals: Grey Seal (*Halichoerus grypus*) Infanticide and Cannibalism May Indicate the Cause of Spiral Lacerations in Seals. *Plos One* 11 (6):e0156464.
[18] Boyle, D. (2011). Grey Seal Breeding Census: Skomer Island 2011. Countryside Council for Wales Regional Report CCW/WW/11/1.

observed rates of predation by individual male seals it is likely that single predatory grey seals can cause substantial mortality in local seal populations. The number of predatory seals is unknown, but the temporal and spatial pattern of corkscrew carcasses recorded in the SMASS database and reported from the German coast (van Neer pers. com.) suggests that at least six individuals are currently active around UK and German coasts.

Reports from Blakeney in 2010 indicate that at least 38 female harbour seals were killed in one location over one summer. Many of these were either pregnant or lactating so there would have been some associated loss of pups. Blakeney is not considered to be a breeding site, few pups are recorded there during breeding surveys, so the seals that were killed would have been part of the breeding population in The Wash. The Wash population produced around 1,500 pups in 2010. We do not know what component of the Wash population was involved, so it is not possible to estimate an appropriate mortality rate. However, if the mortalities were applied to the entire Wash, they would represent approximately 2 to 2.5% of the estimated adult female population, depending upon the assumed fecundity rate used to estimate adult female population from observed pup production. Associated pup mortality may have removed approximately 2.5% of that year’s pup production. Although there have been regular reports of predation on grey seal pups at Blakeney since 2010 there has not been a recurrence of the large scale harbour seal mortality.

The Firth of Tay and Eden harbour seal population has declined by more than 90% since 2000 (SCOS-BP 16/04). Corkscrew injured harbour seals have been recorded in this area each summer since 2008. The scale of mortality due to corkscrew injuries is considered to be unsustainable and is thought to be a major contributor to the continuing decline in that population. It is not clear to what extent this type of mortality contributed to the initial stages of the 90% decline.

Only small numbers of corkscrew injuries have been recorded in either the Moray Firth or Orkney, and to date none have been recorded in Shetland. It is therefore not possible to relate the large scale population reductions in these populations to grey seal predation. It is not known if this is an under-reporting issue or an absence of such mortality events.

If the predation at Blakeney in 2010 were due to an individual grey seal it would suggest that one predatory male could remove 38+ seals from a population in one year. The decline in Orkney since the late 1990s represents the removal of approximately 10,000 seals over and above background natural mortality. Equivalent to removing around 600 seals per year for 16 years. At predation levels seen at Blakeney the Orkney decline could be due to as few as 17 adult male grey seals. Using current demographic parameter and population estimates (SCOS-BP 16/02) produces an adult male grey seal population of approximately 7,500 for Orkney. The observed reduction could therefore be achieved if as few as 0.3% of the adult male grey seals in Orkney preyed on harbour seals.

(b) Counts of grey seals during the summer have been included in the Moray Firth harbour seal population model as explanatory variables. SCOS-BP 15/07 presented results suggesting a significant relationship between the number of grey seals and the population trajectory; acting through an effect on pup survival. Including grey seal abundance as a covariate improved the fit of the model and the projected near-future population trend was different to the one in the baseline model. The population was projected to decrease due to a reduced pup survival rate, which was linked to a projected continuing increase in the overall grey seal population size. The mechanism of this effect is not explicit in the model, so it is not currently possible to differentiate between competition effects and direct predation.

Seal Licensing and PBRs

8. MS: What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system? **NRW: Based on the outputs on the Seal population management workshop in 2016, which looked at PBR and other approaches to managing/predicting anthropogenic impacts on UK seals (see page 3 of main advice SCOS 2015), what approach does SCOS recommend for determining levels of acceptable effect/take and setting thresholds in marine renewable impact management?**	MS Q8; NRW Q5

SCOS considered it important to recognise that the setting of management objectives is primarily a societal issue and that scientists can only recommend methods for achieving such objectives. A report of a workshop convened by Marine Scotland Science to discuss the available methods for achieving management goals is presented as SCOS-BP 16/07. The workshop participants clearly felt that there was a need to improve or move on from using PBR for some of Scottish Government's licensing requirements. Several options were discussed, including tests to demonstrate the effectiveness of PBR, as well as methods by which assessments may be undertaken in the future. This is an area for development as questions remain.

Use of PBR for setting long term management goals in situations where the level of mortality is unknown and the structure, and therefore potential effect is likely to remain in the long-term, was identified as a specific problem. Several lines of research leading to possible solutions were identified at the workshop. Although no formal comparisons were made between population tools, Population Viability Analysis (PVA) was agreed to have potential for assessments relating to marine renewable energy developments in part because it is widely used in seabird assessments. However, PVA does not set levels of acceptable effect/take; what is considered acceptable is a societal decision[19].

Provisional regional PBR values for Scottish seals for 2017 are given in SCOS-BP 16/08. A separate PBR for the Welsh grey seal population is presented below (Question 9).

9. NRW have used PBR of grey seals in the consenting process for marine renewable developments in Wales. What are the current PBR values for grey seals in the West England and Wales Management Unit (MU) and what N_{min} is used?	NRW Q3

Until recently, PBR estimates for the Welsh grey seal population and specific sub sections of that population were generated in-house by the Countryside Council for Wales (CCW). Current PBR estimate is 138 and N_{min} is calculated based on pup production.

In recognition of the fact there are limited data on the distribution and abundance of seals in Wales outside the breeding season, the estimated pup production was used to generate a total population estimate based on a multiplier derived from the pup production and total population estimates for

[19] Green, R.E., Langston, R.H.W., McCluskie, A., Sutherland, R and Wilson J. D. 2016. Lack of sound science in assessing wind-farm impacts on seabirds. *Journal of Applied Ecology* 53()6), 1635-1641.

the regularly monitored population in Scotland and the North Sea[20]. The lower 2.5% of the estimate, based on the confidence intervals of the pup production, was used as a conservative alternative to the lower 20th percentile recommended by Wade[21].

There are as yet no comprehensive survey data for the Welsh and SW English grey seal population in summer, so the method applied to estimate N_{min} for Scotland is not applicable here. An alternative approach that produces results comparable to the Scottish method is to derive a multiplier to scale pup production to the independent estimate (SCOS-BP 16/04) for the rest of the UK grey seal population and apply that to the estimated pup production in Wales and South West England. Variability in the telemetry data can then be used to derive the lower 20th percentile of the multiplier and generate an estimate of N_{min}.

The most recent nationwide estimate for pup production in Wales and SW England is 1,949 pups, derived from counts/estimates at indicator sites and a scaling factor (approximately 2) to convert the sum of these indices to total pup production (SCOS-BP 16/09). This assumes that observed trends at the monitored sites are representative of the entire Welsh population.

The ratio of pup production to independent estimate for the rest of the UK grey seal population was used to generate a conversion factor for N_{min} (i.e. the upper 20th percentile of the ratio of pup production to independent estimate). Based on an analysis of the patterns in the telemetry haulout data (SCOS-BP 16/03) to estimate the upper 80th percentile of the distribution of the proportion of time spent hauled out this conversion factor is 2.30.

Although the Welsh population is increasing slowly, CCW recommended setting the F_R to 0.5 based on uncertainty in population status and the use of parameter estimates from other populations. SCOS have used this value. In combination, these parameter values produce a PBR for the grey seal population of Wales and South West England of 134.

Previously CCW produced PBR estimates for small subsections of the Welsh population. This is not well supported by the analyses used to derive PBR. The models were tested on what were assumed to be total or closed populations. The large scale movements of grey seals between breeding and foraging sites, as well as potential recruitment to breeding sites other than the natal site, means that the assumptions of closed populations are likely to be violated. As a consequence, removal of seals in one area in summer may have an impact on breeding populations in other areas and may not be accounted for in the "local" PBR. SCOS recommends that alternative methods are used to allocate potential takes to activities in specific areas using information on seasonal distribution patterns.

10. In EIA and HRA scenarios where a baseline population size is used (eg abundance in relevant MU), that baseline population is usually considered to have already been subject to existing anthropogenic pressures. In other words, the baseline population will have been estimated in any one year with a certain level of existing anthropogenic pressures (e.g. bycatch) in that year and represents the population already affected. In the case of using N_{min} in PBR for grey seals in the West England and Wales MU, can SCOS justify why anthropogenic mortality, i.e. bycatch, should be subtracted from the PBR value rather than considered already present in the population baseline (N_{min})? Can it be argued that subtracting bycatch from the PBR value is 'double-counting'?	NRW Q3

[20] Hewer, H. R. 1964. The determination of age, sexual maturity, longevity and a life-table in the grey seal (*Halichoerus grypus*). *Proceedings of the Royal Society B: Biological Sciences* 142:593-624.

[21] Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Marine Mammal Science* 14 (1):1-37.

Any anthropogenic take, including bycatch, is included in the PBR value. Subtracting bycatch from the PBR estimate does not represent 'double-counting'. PBR is calculated using the most recent estimate of N_{min} and provides an estimate of the number of animals that can be removed from that population in the following 12 months while still allowing it to tend towards its Maximum Net Productivity Level (MNPL). The method is designed to ensure that the population will be at or above its MNPL after 100 years. The value of N_{min} is recommended to be the lower 20th percentile of the current population estimate. It is implicit in the calculation of the PBR that N_{min} is correct.

The method of calculation does not take into account any mortality that has occurred between the estimation of population size and the calculation of the PBR. If it is suspected that a major source of anthropogenic mortality is acting on the population between the estimation of N_{min} and the calculation of PBR, then N_{min} should be recalculated accordingly. If this is not feasible, e.g. if the level of that extra mortality is unknown, a partial solution would be to reduce the value of F_R to reflect the reduced confidence in the N_{min} value.

The PBR estimate should be compared to the sum of all anthropogenic removals over the following year. Any bycatch mortality occurring in the following 12 months should be counted against the PBR. This would not be 'double-counting'.

This interpretation of what should be included in the estimated take for comparison with the PBR is particularly important in SW Britain. Estimates of by-catch mortality for grey seals are high. SCOS 2015 noted an estimate of 340 grey seals per annum killed in UK fishing operations in the region. This exceeds the current PBR of 134 by a factor of 2.5. SCOS is concerned that additional and potentially higher bycatch mortality in Irish fishing operations is also likely to be impacting this region.

Seals and Marine Renewables

11. What is the current state of knowledge of interactions actual or potential between seals and marine renewable devices and possible mitigation measures?	MS Q10; Defra Q10; NRW Q6

Since reporting in 2015 (see SCOS Advice 2015), 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. Sound exposure estimates during piling operations suggested that approximately half of the tagged harbour seals were subjected to levels likely to cause hearing damage. 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 (e.g. rotor speed reductions).

Wind

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 suggests that seals were not excluded from the vicinity of the windfarm during the overall construction phase[22]. A comparison of historical, pre-construction movement patterns with similar data during construction again showed no overall exclusion. However, 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[23]. 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.

Combining information on individual piling blows, a propagation loss model and individual seal movement and dive behaviour records allowed estimation of sound exposure levels. The results suggested that half of the seals exceeded published auditory damage thresholds despite showing this pronounced avoidance behaviour during piling.

Additional tag deployments on harbour seals are planned to coincide with piling activity at wind farm developments in both East Anglia and the Moray Firth in 2016 and 2017.

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. In comparison to 2005, it appears that offshore usage emanating from Donna Nook in 2015 was not restricted to discrete patches. The dispersed foraging areas, and the greater maximum extent, may be a result of an increasing grey seal population and thus a depletion of prey resources or an increase in competition at key foraging areas since 2005. This finding highlights the importance of updating at-sea usage maps with recent telemetry data especially when changes in population have occurred.

Grey seals have been tracked in the vicinity of pile driving activity in the Netherlands coastal zone[24]. 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[25].

Mitigation

Operational protocols to minimise the likelihood of harm to seals during pile driving operations (published by the JNCC in 2010[26]) 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 were reported to SCOS 2015[27]. 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

[22] Hastie G.D., Russell D.J.F., McConnell, B.J., 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.

[23] Russell, D. J. F., G. D. Hastie, D. Thompson, V. M. Janik, P. S. Hammond, L. A. S. Scott-Hayward, J. Matthiopoulos, E. L. Jones, & B. J. McConnell. 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology*: early view.

[24] Kirkwood R., Aarts, G. and Brasseur, S. 2014. Seal monitoring and evaluation for the Luchterduinen offshore wind farm : 2 . T construction – 201 4 report number : C 152/14

[25] McConnell, B., Lonergan, M ., and Dietz, R . 2012. Interactions between seals and offshore wind farms . The Crown Estate, 41 pages. ISBN: 978-1-906410-34-6 .

[26] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/50006/jncc-pprotocol.pdf

[27] Gordon, J., Blight, C., Bryant, E., & Thompson, D. (2015). Tests of acoustic signals for aversive sound mitigation with harbour seals . Sea Mammal Research Unit, University of St Andrews, Report to Scottish Government, no. MR 8.1 , St Andrews , 35 pp. http://www.smru.st-andrews.ac.uk/documents/scotgov/MR8-1_ADD_mitigation_VF2.pdf

experiment and probably the motivation and status of the subjects. No further trials with seals and ADDs have been carried out. However, during deliberations on research priorities for an Offshore Renewable Joint Industry Programme (ORJIP) funded study of the effectiveness of ADDs as piling mitigation, the steering group, comprising representatives of Statutory Nature Conservation Bodies and regulators determined that results from harbour seals would likely suffice as a proxy for other phocid seals.

Wave

Data on the interactions between seals and wave energy devices remain lacking and no commercial scale developments are planned to date.

Tidal

The only direct information on interactions between seals and tidal stream energy devices (turbines) remains that collected in Strangford Narrows in Northern Ireland where a long term study of seal populations and seal foraging movements has been carried out during the development and deployment stage of SeaGen, a large twin rotor tidal turbine.

Telemetry data shows harbour seals used Strangford Narrows throughout periods of turbine operation and SeaGen is not an overt barrier to their movements. Analysis of all of the tagged seals showed no statistically significant change during operation and non-operation of SeaGen; however, this was likely to be partly due to high inter-individual variation in transit rates. There was an apparent change in movement patterns with transits concentrated in the middle of the channel before the turbine installation and less so afterwards.

A series of acoustic playbacks of tidal turbine sounds were carried out as part of the NERC funded RESPONSE project. A programme of land based visual observations of harbour seal activity during signal playbacks (simulated turbine signal based on SeaGen) plus equivalent control signals were made in a narrow, tidally energetic channel on the west coast of Scotland (Kyle Rhea: 57°14'8.10"N, 5°39'15.25"W). Furthermore, the behaviour of ten individual seals was monitored through swimming tracks of high resolution UHF/GPS telemetry tagged seals were collected in conjunction with the playback trials. Results of this study showed that there was no significant difference in the numbers of seals sighted within the channel between playback and silent control periods. However analysis of the GPS telemetry derived locations of seal surfacings showed a significant avoidance of the area around the sound source during playback compared to silent control periods[28].

Mitigation

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 (e.g. rotor speed reductions).

Work is currently being carried out at SMRU 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 ms^{-1}). 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.

[28] Hastie, G. D., D. J. F. Russell, Lepper, P., Elliott, J., Wilson, B., Benjamins, S. & Thompson, D. (in review) Harbour seals (*Phoca vitulina*) avoid tidal turbine noise; implications for collision risk. *Journal of Applied Ecology*.

Additional trials with a redesigned simulated turbine blade are ongoing to identify damaging impact speed thresholds.

In terms of operational mitigation, the only mitigation method that has been attempted for tidal turbines at this stage is the shutdown protocol at Strangford Lough; this requires observers to monitor the outputs of a series of active sonar systems 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 are currently being developed and may prove an effective alternative in the future. Impending turbine deployments in the Pentland Firth and in Ramsey sound will not shut down in the event of a marine mammal approach and sonar systems will be used to identify and quantify any collisions.

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.

12. In light of the February workshop, can the Committee suggest a preferred method for assessing seal population impacts arising from marine renewable energy developments?	MS Q9;

See question 8 above.

13. In light of ongoing research, what are the questions that still need to be addressed with respect to interactions between seals and marine renewables?	MS Q11;

A report detailing the current state of knowledge and identifying the priority areas for research was drafted by SMRU for Scottish Government. That report was updated in January 2016 and is available through the SMRU website at http://www.smru.st-and.ac.uk/pageset.aspx?psr=152

SCOS will defer answering this question at this stage as various studies to investigate interactions are currently underway.

Seals and River Fisheries

14. 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?	MS Q13 ; Defra Q3

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.

At present we are aware that ADDs have been deployed by several District Salmon Fishery Boards (DSFB) to try to prevent seals from swimming up salmon rivers. Details are provided in annual research reports by SMRU to Marine Scotland, (the most recent of which can be found at www.smru.st-andrews.ac.uk/documents/scotgov/SSI_seals_and_salmon_VF1.pdf (See Annex 1)). Collaboration with Dee DSFB personnel, who have installed two Lofitech seal scarers in the river Dee, has shown that seals are still able to swim upriver past these devices. This work has highlighted the difficulties in using ADDs in salmon rivers, in particular maintaining sound head position / orientation and delivering an adequate power supply, which are possibly the two most difficult and critical issues. A very similar series of events occurred in the North Esk; seals were found to have swum upriver past a Lofitech device, which was found to have power supply problems and a misplaced sound head on the river bed.

Once seals have learned to bypass ADDs within rivers, other measures need to be adopted. One approach has been to attempt to 'sweep' seals back to the sea using a boat fitted with an ADD, a method that proved successful in the Kyle of Sutherland. SMRU have provided the loan of an ADD to the Dee DSFB for this purpose and it has been used successfully by the fishery board to return seals downriver.

Other than lethal removal, and acoustic sweeping, it would be possible though difficult to capture seals alive and return them to the sea, in the hope that they would not then return past a properly functioning ADD (or changing to an ADD that utilises different sound characteristics), though there are obvious risks to this approach.

A better understanding of how seals are utilising rivers and a method to detect their presence might enable a triggered response to their presence, using ADDs or even electric field gradients to prevent them moving up river. It may be worth noting that considerable research has been devoted to trying to deter pinnipeds from predating wild salmonids in several western US rivers, with mixed success. In such instances, which mainly involve California Sea Lions, the use of ADDs has not been effective[29], but physical exclusion and trapping and removing animals have been more so.

An electrical deterrent system has been tested as an effective and safe method to deter Pacific harbour seals preying on pacific salmon (*Oncorhynchus* sp.) in a Fraser River gillnet test fishery. Seals were deterred using a pulsed, low-voltage DC electrical gradient. Salmon catch (CPUE) was significantly higher in protected sections of net and there were no apparent injuries to any animals during the study[30]. A complete river barrier system using the same electric field gradients has been tested in a British Columbian river system and shown to deter seals from passing the electrode array.

As part of a project funded by Marine Scotland to develop seal control or removal methods as alternatives to shooting, a robust and portable seal trap has been built and tested under field conditions. It is intended to deploy the trap in east Scottish river systems when problem seals are identified. Captured seals will then be translocated and fitted with high resolution tracking devices to monitor their subsequent movements.

[29] Stansell, R.J., Gibbons, K.M. & Nagy, W. T. (2010). Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2008-2010. US Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, OR. October 14, 2010.
[30] Forrest, K. W., J. D. Cave, C. G. J. Michielsens, M. Haulena, & D. V. Smith. (2009). Evaluation of an Electric Gradient to Deter Seal Predation on Salmon Caught in Gill-Net Test Fisheries. *North American Journal of Fisheries Management* 29 (4):885-894.

Seals and Fish Farms

15. What is the latest understanding of interactions between seals and fin fish farms and possible mitigation measures?	MS Q14; Defra Q3

A full review of this issue is beyond the scope of the SCOS, so this represents a brief summary of recent work and current understanding of the issue. Underwater cameras have been deployed on salmon cages for 96 days, but low predation levels meant no predation was observed. Captive seals were trained to push against simulated cage net walls. Forces measured suggest that medium sized seals can push net in by 30cm or more. Captive seals found it difficult to feed on salmon presented to them in a model of a salmon pen. When seals had access to fish overnight they recreated the damage characteristics typically seen at fish farms. Trials with various ADD devices suggest that predation can be reduced without disturbance of non-target porpoises. Trials of low voltage pulsed electric field showed potential to deter seals from pushing against nets. A field trial of an electric cage defence system has been carried out but no results are available yet.

The recent development of a Technical Standard for Scottish Finfish Aquaculture has focused attention on the lack of information on seal depredation and its role in enabling caged salmon to escape. A project funded by SARF[31] was carried out to address several knowledge gaps identified in a previous SARF Report[32] on issues relating to containment of salmon in marine fish farms and interactions with seals.

Four overall objectives were: to use underwater video systems to observe how seals attack salmon pens; to investigate net deformation in tidal currents using motion data loggers; to review existing literature and other sources to better understand predator attacks; and to use trained captive seals to better understand the forces they are able to generate underwater to push against nets, and their behaviour associated with taking fish from net enclosures.

An underwater camera system was deployed at four sites over 96 days in total, however seal depredation rates were low at all sites, and no seal depredation event was recorded. Farm operators were unwilling to deploy motion sensors on any aquaculture pens, although suitable attachment methods and software tools for visualisation and analysis of data were developed.

Three grey and three harbour seals of a range of sizes were trained to push against a stretched piece of nylon salmon cage netting to establish how much force they would be able or willing to exert against such netting for a food reward. Results suggest a tight relationship between seal size (mass) and maximum force, and extrapolations suggest a large 300 kg grey seal might be able to exert a force of over 800 N. Estimates of the amount of net deformation for samples of nylon cage netting under load were used to calculate the maximal deformation of a typical bottom net panel from a 100 m diameter circular pen. An incursion of at least 30 cm would be expected from even a medium sized seal.

Newer netting materials such as High Density Polyethylene (HDPE) are currently being trialled at farm sites in Scotland. These will have a lower extensibility than nylon and may therefore make seal incursions more difficult. Controlled tests of HDPE netting in the context of seal predation would be useful.

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[31] Coram, A., Mazilu, M. and Northridge, S. 2016. Plugging the Gaps Improving Our Knowledge of How Predators Impact Salmon Farms. SARF 097. A study commissioned by the Scottish Aquaculture Research Forum (SARF). http://www.sarf.org.uk/. ISBN:978-1-907266-73-7

[32] A report presenting proposals for a Scottish Technical Standard for Containment at Marine and Freshwater Finfish Farms. SARF 071. ISBN: 978-1-907266-45-4 available at: http://www.sarf.org.uk

All seals tested found it very difficult to feed on salmon presented to them in a model of a salmon pen. When seals had access to fish over long periods, e.g. when fish were left overnight in the net, they recreated the damage characteristics typically seen at fish farms by chewing much of the flesh from the carcass, but leaving the spine, head and tail intact.

The stereotypical gashes and abdominal bite-marks sometimes seen on large numbers of salmon at fish farms were not recreated, and are probably therefore indicative of fish being live at the point of attack. Only dead fish could be fed as part of our experiments. Further work is needed to explore seal behaviour and net configurations in the real world. This will need the active participation of fish farming companies. Pool and laboratory based results need to be compared and followed up with observations and tests made in the wild and on fish farm sites.

A review evaluating the effectiveness of acoustic deterrents and other-non lethal measures to mitigate marine mammal conflicts especially with fish farms was published by Marine Scotland in late 2014[33]. Suggestions for further research into resolving conflicts between seals and fish farms included:

1) Improving baseline data on factors associated with greatest levels of seal damage
2) Experimental or analytical approaches to quantify efficacy of existing mitigation measures
3) Exploration of factors that may or may not make anti-predator nets effective in Scotland
4) Examination of unintended environmental consequences of the use of Acoustic Deterrent Devices on
    a. the hearing of target species (seals)
    b. the disturbance and consequent ecological consequences for non-target species notably harbour porpoises
5) Further work on electric field deterrents and / or conditioned taste aversion

A startle response ADD device[34], marketed by Genuswave[35], has been found to significantly decrease seal predation on a farm without habituation effects over a one year period. It has also been used successfully to reduce acute seal attacks at several farms on the West coast and in Orkney and Shetland. Trials of the commonly used Terecos ADD also suggested little or no effect on the detection rate of porpoise vocalisations[36]. Other flexible systems with signals tailored to particular target species are being developed, for example the FaunaGuard system, developed by Van Oord and SEAMARCO has been tested on a wide range of species including fish, turtles and porpoises.

Additional work on deterrence effects of low voltage electric fields was carried out at SMRU's captive facility. Trials with a single electrode at the food source and a remote (3m distant) second electrode showed similar results to the original effect[37]. A trial system of electric net defence based on these results was field tested by a seal deterrent manufacturer, in Orkney. No results have been published to date.

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[33] Coram, A., J. Gordon, D. Thompson & S. Northridge. 2014. Evaluating and assessing the relative effectiveness of non-lethal measure including acoustic deterrent devices on marine mammals. Report to Scottish Government, Sea Mammal Research Unit, University of St Andrews, St Andrews.

[34] Gotz, T. & Janik, V.M. 2014. Target-specific acoustic predator deterrence in the marine environment. *Animal Conservation*, 18(1), 102-111.

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

[36] Northridge, S., Coram, A. & Gordon, J. 2013. Investigations on seal depredation at Scottish fish farms. Edinburgh: Scottish Government. 79pp.

[37] Milne, R., Line, G., Moss, S. & Thompson, D. 2013. Behavioural responses of seals to pulsed, low-voltage electric fields in sea water (preliminary tests).SARF 071. A study commissioned by the Scottish Aquaculture Research Forum (SARF). http://www.sarf.org.uk/ ISBN: 978-1-907266-55-3

Use of Acoustic Deterrents

16. What is the latest 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)?	MS Q15 ; Defra Q3; NRW Q6

To our knowledge, no research specifically to compare the relative effectiveness of different acoustic deterrent devices has been carried out.

Apart from the trial conducted by Janik and Gotz[38] (reported at SCOS 2014), which showed a reduction in seal depredation after a 'startle response' ADD was deployed at three farm sites, we are not aware of any independent studies on the effectiveness of ADDs at farms sites.

SMRU have shown that the Lofitech device does increase salmon CPUE, reduce the proportion of damaged fish, and also reduces the frequency of seal sightings, at salmon bag net stations. Preliminary data also suggest that the Airmar device can also reduce the frequency of seal visits to bag nets as well as the proportion of damaged fish in the nets[39]. Previous work has also shown the effectiveness of the Lofitech in reducing seal ingress up salmon rivers[40].

The Lofitech device has also been tested as a potential longer range deterrent to act as part of a mitigation method for avoiding damage to seals from pile driving and other potentially harmful anthropogenic activity. In a series of at-sea behavioural response trials with telemetry tagged harbour seals, the Lofitech ADD caused avoidance behaviour at ranges up to 1km[41].

It is important to note throughout, however, that the use of ADDs bears the risk of damaging hearing in seals and other marine mammals[29]. They can also deter cetaceans from an area. This is to be considered especially when using several ADDs for example on bag nets within a small area. Harbour seals can experience compromised hearing when spending as little as 3 min within 10 m of a high-powered ADD. This effect is reversible, but will have a more permanent effect on hearing if this threshold is exceeded repeatedly. Effects on cetaceans occur more easily. For example, temporary effects on porpoise hearing can occur at ranges of 89 to 345 m when spending 3 min within that range. Permanent threshold shift* is predicted to occur in porpoises when spending between 4 and 21 hours within 76 to 345 m of an ADD (depending on whether Lofitech or Airmar is used and on the selected duty cycle). Effects on killer whales occur at even lower exposures. However, effects in cetaceans are likely mediated by a deterrence effect on some species. This effect has been most dramatic when using a Lofitech device with harbour porpoises avoiding an area of at least 7.5 km around the device. This kind of habitat avoidance can be problematic if devices were used around Scotland on a large scale. The presence of cetaceans will not alter the efficacy of the device, though clearly where disturbance of cetaceans is a concern, then one of the 'cetacean friendly' ADDs may be a preferred management option (see comments on ADD effects on cetaceans in Question 17 below)[39].

SCOS recommends that a standardised testing protocol should be developed to assess the relative effectiveness of different ADDs. Protocols should address deterrence of seals and non-target species. To avoid cetacean disturbance, certain devices have been designed to have a lower impact on cetaceans and could be used where there are concerns about disturbance to porpoises as has been

[38]Götz, T. & Janik, V.M. (2013). Acoustic deterrent devices to prevent pinniped depredation: Efficiency, conservation concerns and possible solutions. *Marine Ecology Progress Series* 492, 285–302.
[39] Harris, R.N. & Northridge, S. (2015) Seals and wild salmon fisheries. Sea Mammal Research Unit, University of St Andrews, Report to Scottish Government, no. SS1, St Andrews, 28pp.
[40] Graham, I. M., Harris, R. N., Denny, B., Fowden, D., and Pullan, D. 2009. Testing the effectiveness of an acoustic deterrent device for excluding seals from Atlantic salmon rivers in Scotland. – *ICES Journal of Marine Science*, 66: 860–864.
[41]Gordon, J., Blight, C., Bryant, E., & Thompson, D. (2015). Tests of acoustic signals for aversive sound mitigation with harbour seals. Sea Mammal Research Unit, University of St Andrews, Report to Scottish Government, no. MR 8.1, St Andrews, 35pp
* a permanent reduction in hearing sensitivity at particular frequencies

shown for high frequency, high amplitude devices[35]. SCOS recognised that comparative testing of ADD signals was likely to involve large numbers of behavioural response trials and would probably require new trials for each new ADD design. Such extensive testing of signals on wild or captive seals may not be desirable. SCOS recommend that testing programmes should be designed to identify, where possible, the characteristics of signals causing aversive responses.

In a recent report to Marine Scotland[34], recommendations for research on ADDs in relation to disturbance and its ecological consequences for porpoises were identified. These could involve controlled experimental exposure of porpoises to the full suite of ADDs currently available to be able to make robust comparisons regarding disturbance, while also looking at porpoise densities at sites with and without active ADDs.

17. Can current knowledge on common seals and their behaviour around ADDs be effectively applied to grey seals knowing they have different behaviours? We would welcome views from SCOS on the use of ADDs as a mitigation technique to deter grey seals from marine renewable devices (tidal stream/tidal range structures) in Wales. Could ADDs be used as the sole mitigation approach in such situations?	NRW Q6

In the absence of direct comparative studies SCOS cannot assess the likelihood that grey seals' reactions to ADDs will be the same as harbour seals'.

In the absence of information on the audibility of ADDs in high flow noise environments, on the reactions of seals to ADDs in high tidal currents and on the likelihood of habituation, SCOS cannot assess the effectiveness of ADDs as mitigation for tidal energy devices.

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 were reported to SCOS 2015[42]. All seals tested out to a range of 1km showed an identifiable change in behaviour. No further trials with seals and ADDs have been carried out. However, when setting research priorities for assessing the effectiveness of ADDs as a piling mitigation tool, the ORJIP steering group, comprising representatives of SNCBs and regulators concluded that results from harbour seals would suffice as a proxy for other phocid seals. SCOS noted that there is no direct evidence to support that assumption.

SCOS is unable to provide a direct answer to the last part of the question. There have, as yet, been no direct tests of the effectiveness of ADDs at preventing seal collisions with tidal turbines. The potential use of ADDs at tidal turbine sites and relevant knowledge gaps were discussed by Coram *et al*.[34] They pointed out that devices must be audible at appropriate ranges in high flow-noise environments and must elicit an appropriate response that continues throughout the life of the turbine, i.e. must not illicit habituation. To date there is a lack of information on all of these aspects of the use of ADDs at tidal energy sites. In addition, the use of multiple ADDs in large scale arrays will need to be investigated both in terms of their efficacy as a mitigation method and their potential to cause habitat exclusion and/or hearing damage.

[42] Gordon, J., Blight, C., Bryant, E., & Thompson, D. (2015). Tests of acoustic signals for aversive sound mitigation with harbour seals . Sea Mammal Research Unit, University of St Andrews, Report to Scottish Government, no. MR 8.1 , St Andrews , 35 pp. http://www.smru.st-andrews.ac.uk/documents/scotgov/MR8-1_ADD_mitigation_VF2.pdf

18. Is it possible to provide specific recommendations about which models of acoustic deterrents might be more effective in the situations outlined above?	MS Q16; Defra Q3

SCOS does not recommend any specific devices as there has not been any experimental work to test their respective efficacy at fisheries or fish farms. Research into effectiveness of devices and their effects on non-target species should be focussed on the characteristics of the signal and not on particular commercial systems.

See answers to Questions 15 and 16 above

Seals and their Non-lethal Management

19. Further to your 2015 advice regarding non-lethal mitigation measures to minimise seal interactions with salmon netting stations, river fisheries, fish farms and marine renewable devises, do you have any additional information to add, which would facilitate the development of non-lethal conflict resolution advice?	Defra Q3

See answers to Questions 15 and 16 above

Marine Strategy Framework Directive

20. The UK has agreed, under its obligations to the OSPAR Commission, to lead on the delivery of assessments of seal populations for the OSPAR Intermediate Assessment in 2017 (IA2017). Building on the work SCOS has already undertaken on Marine Strategy Framework Directive (MSFD) indicators can you provide the latest available data for the UK and where possible other countries in the region to feed into the IA2017 by August 2016 (initial draft due Nov 2015): M3 – seal abundance and distribution; M5 – Grey seal pup production?	Defra Q4

SCOS does not work directly on MSFD indicators but has discussed the work carried out by SMRU on the MSFD seal indicators. Data and analyses for indicators M3 and M5 have fed into the Intermediate Assessment 2017 (IA2017), prior to the August 2016 deadline. The latest available data from the UK were used to perform an assessment of MSFD indicators M-3 and M-5, describing changes in grey seal and harbour seal population abundance and distribution. Preliminary results were given in SCOS-BP 15/09. It was necessary to arbitrarily subdivide UK Assessment Units into smaller subareas to calculate distribution metrics for harbour seals. The distribution metrics showed no catastrophic contraction or shift in distribution has occurred for either grey or harbour seals in any Assessment Unit. In 2016 an extended version of the UK grey seal population assessment model incorporating a movement model to allow recruitment to new regions was applied to the NE Atlantic grey seal population (SCOS-BP 16/09). Results indicate that the overall population is clearly increasing.

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

In the UK, pup production estimates and prior knowledge of life history parameters are incorporated into a Bayesian state-space model to estimate total population size. This model is fitted to pup production data from four regions: Inner Hebrides, Outer Hebrides, Orkney and the North Sea. This population model was extended to incorporate four additional regions and an initial run of the model was conducted to estimate the population of grey seals in the North-east Atlantic (excluding Norway) between 1991 and 2015. In addition to regional pup production data, an independent estimate of total North-east Atlantic population size in 2008 was included in the model. Details are presented in SCOS-BP 16/09 and (SCOS-BP 16/02).

The rapid increase in Netherland's grey seal population was driven by recruitment of females born in the UK. Thus, a movement model was included here. With the exception of the movement model, the priors used in the population model were consistent with those used in the UK model in 2015 (SCOS-BP 16/02).

An update to the model results is currently under review as part of OSPAR's Intermediate Assessment 2017. For this update, a revised independent summer population estimate was used; this was derived from an updated estimate of the proportion of time hauled out during the survey window (SCOS-BP 16/03).

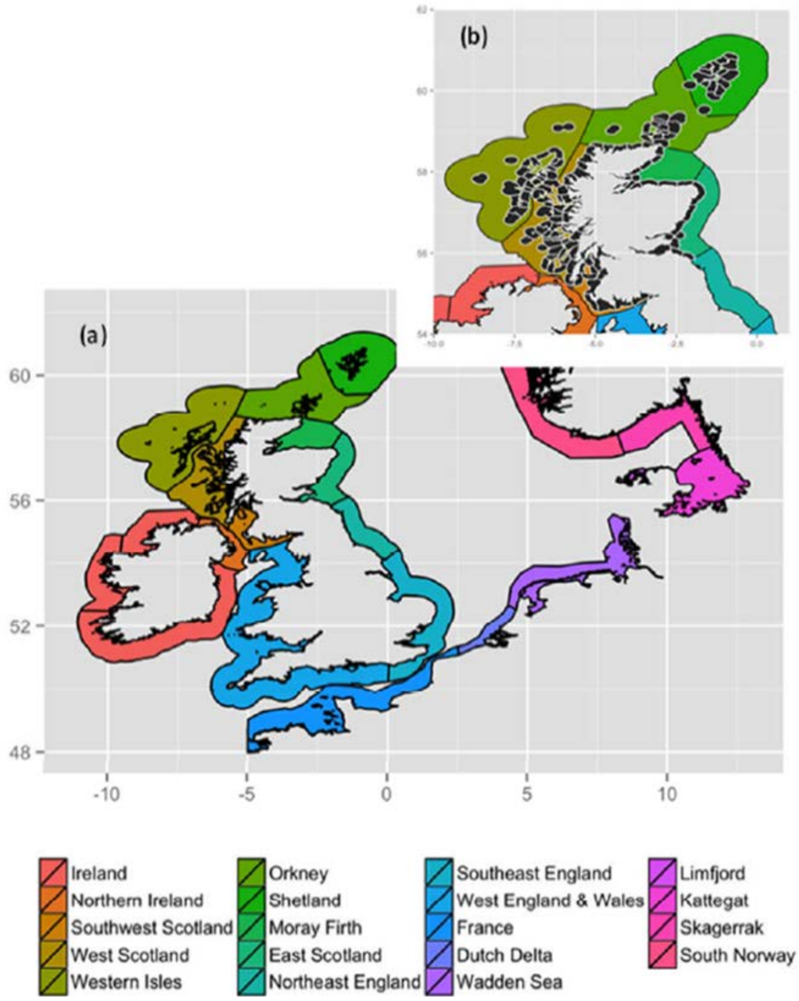

Figure 6. ***Proposed Marine Strategy Framework Direct (MSFD) Assessment Units (a) and detail of Assessment Unit subdivisions in Scotland (b)***

As expected, the results suggest that the North-east Atlantic grey seal population is increasing; there was no evidence of a decline (SCOS-BP 16/09). Further work is required to refine the population estimates and regional trend predictions. In a particular, a review of the movement model and associated priors is required to ensure they are biologically plausible.

As reported in 2015, simple models were also fitted to count data and 95% confidence intervals of the specified metrics were calculated from bootstrap resamples of the data to provide estimates of the uncertainty surrounding each metric. In some cases, wide confidence intervals that include target values indicate that confidence in the assessment is low. Targets that use both rolling and stationary baselines were presented and gave added information about (nonlinear) population trends.

In general, the results of the target assessments were unsurprising; for grey seals, nearly all populations are experiencing positive growth rates and thus meet the proposed targets for abundance. Harbour seal populations experiencing well-characterised long-term declines ‘fail’ to meet targets as expected (East Coast, Shetland, Orkney), but three other Assessment Units stand out. The Moray Firth ‘passed’ abundance target 1 with a rolling baseline but ‘failed’ to meet abundance target 2 which used a fixed baseline population reference level from 1992. This reflects the nonlinear pattern of growth in this population, which was negative until ~2003 and thereafter appeared to stabilise[43] and highlights the potential for drawing erroneous conclusions about a population based on comparison with only one type of baseline. The bootstrapped confidence intervals calculated for change in abundance for the West Coast and Western Isles harbour seal populations were wide, spanning negative and positive growth. This reflects the fact that counts in these areas are fairly stable, but variable.

The distribution metrics showed no catastrophic contraction or shift in distribution has occurred for either grey or harbour seals in any Assessment Unit (Figure 6) . These simple metrics – with added information about uncertainty and number of surveys – should prove applicable to other European datasets, as well as being understandable and useful to policy-makers. Further details of the targets and results from each Assessment Unit were presented in SCOS-BP-15/09.

It should be noted that agreements for data sharing are not yet in place for the Irish data sets because the Irish Assessment Units are not yet fixed.

[43] Matthiopoulos J., Cordes L., Mackey B., Thompson D., Duck C., Smout S., Caillat M. & Thompson P. 2014. State-space modelling reveals proximate causes of harbour seal population declines. *Oecologia* 174, 151-62.

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

Dr M. Hammill (Chair)	Maurice Lamontage Institute, Canada;
Dr 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

Dear Mrs Mason

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

Thank you for your letter of 29 April concerning the next meeting of the Special Committee on Seals on 14 and 15 September 2016 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:-

Seal Policy

3. What additional research is considered most necessary by the Committee to improve our knowledge and understanding of seal ecology in Scotland to help inform management and thus sustainable harbour seal populations for the future?

We hope, if possible, to initiate a more wide-ranging Committee discussion around this broad question.

Harbour Seal Population

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

5. What is the latest understanding of the causes of the recent decline in harbour seals?

6. 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?

Unusual Seal Mortalities

7. What is the latest information on unusual seal mortalities? Can these mortalities now be solely or largely attributed to grey seal predation?

Seal Licensing and PBRs

8. What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system?

Seals and Marine Renewables

10. What is the latest understanding of interactions actual or potential between seals and marine renewable devices and possible mitigation measures?

9. In light of the February workshop, can the Committee suggest a preferred method for assessing seal population impacts arising from marine renewable energy developments?

11. In light of ongoing research, what are the questions that still need to be addressed with respect to interactions between seals and marine renewables?

Seals and River Fisheries

13. 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?

Seals and Fish Farms

14. What is the latest understanding of interactions between seals and fin fish farms and possible mitigation measures?

Use of Acoustic Deterrents

15. What is the latest 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)?

16. Is it possible to provide specific recommendations about which models of acoustic deterrents might be more effective in the circumstances outlined above?

17. What research questions still need to be addressed regarding the use of ADDs in avoiding potential collisions between seals and tidal turbines?

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 2015 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/2011/2015

I am copying this letter to Defra colleagues for information.

Yours sincerely

IAN WALKER

Marine Conservation

Questions from Defra

CONSERVATION OF SEALS ACT 1970: ANNUAL REVIEW OF MANAGEMENT ADVICE

Thank you for your email letter of 29 April 2016, 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

What are the latest estimates of the number of seals in English waters?

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?

Specific questions about improving seal management:-

Seals and their non-lethal management

3. Further to your 2015 advice regarding non-lethal mitigation measures to minimise seal interactions with salmon netting stations, river fisheries, fish farms and marine renewable devises, do you have any additional information to add, which would facilitate the development of non-lethal conflict resolution advice?

I hope this satisfies your requirements. If you have any queries about this letter please contact me.

Marine Strategy Framework Directive (MSFD) indicators

4. The UK has agreed, under its obligations to the OSPAR Commission, to lead on the delivery of assessments of seal populations for the OSPAR Intermediate Assessment in 2017 (IA2017).

Building on the work SCOS has already undertaken on Marine Strategy Framework Directive (MSFD) indicators can you provide the latest available data for the UK and where possible other countries in the region on M3 – Seal abundance and distribution; M5 – Grey seal pup production?

It would useful to include this information as annexes to the assessments for each indicator in the OSPAR format. This would fit with the timing of the meeting and would mean SMRU do not have to produce the results in two different formats – one for SCOS and one for OSPAR.

Yours sincerely

Simon Liebert

Wildlife Management Policy Officer

Questions from Natural Resources, Wales

Dear Mrs Mason

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

Thank you for your email of 29 April 2016 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 current status of grey seal populations in UK?

2. Grey seal predation is now considered the main cause of 'corkscrew injuries' in grey seals and common seals (and possibly harbour porpoise). To what extent do you think that grey seal predation might be a factor in common seal declines and if predation was included as a parameter in the population models, might that provide a better prediction of common seal status?

3. NRW have used PBR of grey seals in the consenting process for marine renewable developments in Wales. What are the current PBR values for grey seals in the West England and Wales Management Unit (MU) and what N_{min} is used?

4. In EIA and HRA scenarios where a baseline population size is used (eg abundance in relevant MU), that baseline population is usually considered to have already been subject to existing anthropogenic pressures. In other words, the baseline population will have been estimated in any one year with a certain level of existing anthropogenic pressures (eg bycatch) in that year and represents the population already affected. In the case of using N_{min} in PBR for grey seals in the West England and Wales MU, can SCOS justify why anthropogenic mortality, ie bycatch, should be subtracted from the PBR value rather than considered already present in the population baseline (N_{min})? Can it be argued that subtracting bycatch from the PBR value is 'double-counting'?

5. Based on the outputs on the Seal population management workshop in 2016, which looked at PBR and other approaches to managing/predicting anthropogenic impacts on UK seals (see page 3 of main advice SCOS 2015), what approach does SCOS recommend for determining levels of acceptable effect/take and setting thresholds in marine renewable impact management? We would welcome a comparative view of population tools - PBR, IWC, ASCOBANS, PVA etc.

6. Can current knowledge on common seals and their behaviour around ADDs be effectively applied to grey seals knowing they have different behaviours? We would welcome views from SCOS on the use of ADDs as a mitigation technique to deter grey seals from marine renewable devices (tidal stream/tidal range structures) in Wales. Could ADDs be used as the sole mitigation approach in such situations?

Many thanks for your consideration, it is very much appreciated.

Sincerely,

Dr Tom Stringell

Senior Marine Mammal Ecologist

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 meeting of SCOS.

List of Briefing Papers

16/01 Grey seal pup production in Britain in 2014. Duck, C and Morris C.

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

16/03 Independent estimates of grey seal population size: 2008 and 2014. Russell, D., Duck, D., Morris, C. and Thompson, D.

16/04 The status of UK harbour seal populations in 2015, including summer counts of grey seals. Duck, C., Morris C. and Thompson, D.

16/05 Distribution and abundance of harbour seals (*Phoca vitulina*) during the 2015 breeding season in The Wash. Thompson, D., Onoufriou J. and Patterson, W.

16/06 Additional research requirements to improve knowledge and understanding of seal ecology in Scotland. Sea Mammal Research Unit.

16/07 Seal Impact Assessment Methods Workshop. Brookes, K.

16/08 Provisional Regional PBR values for Scottish seals in 2017. Thompson, D., Morris, C. and Duck, C.

16/09 Marine Strategy Framework Directive. Estimating the European grey seal population. Russell, D., Hanson, N. and Thomas, L.

Appendix 2016 Annual review of priors for grey seal population model. Russell, D.

Grey seal pup production in Britain in 2014

Callan D. Duck and Chris D. Morris

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Abstract

In the 2014 grey seal breeding season, SMRU successfully surveyed the 67 main grey seal breeding colonies in Scotland. Grey seal pups born at four colonies in England were ground-counted by staff from the National Trust, Lincolnshire Wildlife Trust and Natural England.

In Scotland, each main colony was surveyed 4 or 5 times during the breeding season and 111,181 pups were counted in total from 317 aerial surveys of 67 breeding colonies.

Using the standard pup production model run (0.9 for proportion of moulters correctly classified, 23.0 days for mean time to fully moulted and 31.5 days for mean time to leave), pup production at the Inner Hebrides colonies was estimated to be **4,054**, slightly lower than the 2012 estimate of 4,088. Pup production at colonies in the Outer Hebrides was **14,316** (14,136 in 2012), in Orkney production was **23,758** (22,926 in 2012), in the Firth of Forth production was **5,860** (5,210 in 2012). Total pup production at the main biennially monitored colonies in Scotland was **47,988.**

At the four main English North Sea colonies, pup production in 2014 was **6,627** compared with 4,963 in 2012 and 5,539 in 2013. There was a very considerable increase in the number of pups born at Blakeney Point (**2,425** pups born in 2014 and 1,560 in 2013, an increase of 55%) which is now the biggest grey seal breeding colony in England, overtaking Donna Nook (**1,799** pups in 2014) for the first time.

Combining with an estimated additional **3,875** pups born at other colonies in Scotland (including **2,350** born on north mainland Scotland), an estimated 250 pups born in south-west England, an estimated 1,650 pups born in Wales and an estimated 100 pups born in Northern Ireland, the total grey seal pup production for the UK in 2014 was estimated to be **60,490**.

Introduction

Grey seals breed at traditional colonies, with females frequently returning to the same colony to breed in successive years (Pomeroy *et al*. 2001). Some females return to breed at the colony at which they were born. Habitual use by grey seals of specific breeding colonies, combined with knowledge of the location of those colonies, provides opportunity for the numbers of pups born at the colonies to be monitored.

While grey seals breed all around the UK coast, most (approximately 85%) breed at colonies in Scotland (Figure 1). Other main breeding colonies are along the east coast of England, in south-west England and in Wales. Most colonies in Scotland and east England are on remote coasts or remote off-lying islands. Breeding colonies in south-west England and in Wales are either at the foot of steep cliffs or in caves and are therefore extremely difficult to monitor.

Until 2010, SMRU conducted annual aerial surveys of the major grey seal breeding colonies in Scotland to determine the number of pups born. Reductions in funding, combined with increasing aerial survey costs, have resulted in SMRU reducing monitoring the main Scottish grey seal breeding colonies from an annual to a biennial regime. No grey seal pup surveys were carried out by SMRU in 2011, 2013 and 2015. The number of pups born at colonies along the east coast of England is monitored annually through ground counting by different organisations: National Trust staff count pups born at the Farne Islands (Northumberland) and at Blakeney Point (Norfolk); staff from Lincolnshire Wildlife Trust count pups born at Donna Nook and staff from Natural England (plus volunteers) count pups born at Horsey/Winterton, on the east Norfolk coast. Scottish Natural Heritage (SNH) staff ground counted grey seal pups born in Shetland.

In 2012, SMRU replaced the film-based large-format Linhof AeroTechnika system used since 1985 with a new digital camera system, funded by NERC. Increased numbers of images acquired during a full aerial survey season (approx. 30,000 digital images compared with 6,000 frames) resulted in a delay in completing estimating pup production at all 60 Scottish colonies.

This Briefing Paper reports on the estimated pup production in 2014 at the main grey seal breeding colonies in the UK.

Materials and Methods

SMRU aerially surveys the main breeding colonies around Scotland. Grey seal pups born at colonies in England and Shetland are counted from the ground annually by staff from the National Trust (Farne Islands and Blakeney Point), Lincolnshire Wildlife Trust (Donna Nook) and Natural England (Horsey/Winterton) and by SNH (Shetland).

The numbers of pups born (pup production) at the aerially surveyed colonies in Scotland is estimated from a series of 3 to 5 counts derived from aerial images, using a model of the birth process and the development of pups. The method used to obtain pup production estimates for 2014 was similar to that used in previous years. A lognormal distribution was fitted to colonies surveyed four or more times and a normal distribution to colonies surveyed three times. Investigation of the effect of changing the time-to-leave parameter and of the proportion of correctly classified pups is under way (Russell *et al*. 2015 SCOS-BP 15/03)

SMRU successfully surveyed all the main grey seal breeding colonies between September and December 2014. Four or five surveys of all colonies in the Inner Hebrides, Outer Hebrides, the north coast of Scotland, Orkney, north-east mainland Scotland, and the Firth of Forth were completed. A late (sixth) survey of Fast Castle in the Firth of Forth was completed in December.

Paired digital images were obtained from two Hasselblad H4D 40MP cameras mounted at opposing angles of 12 degrees from vertical in SMRU's modified Image Motion Compensating cradle (Figure 2). As previously, a series of transects were flown over each breeding colony, ensuring that all areas used by pups were photographed (Figures 3 and 4). Images were recorded directly onto hard drives, one for each camera. Images on hard drives were downloaded and backed up after each day's survey.

All images were first adjusted for brightness and sharpness using Hasselblad's image processing software, Phocus®. Individual images were then stretched from rectangular to trapezoid to closely match the ground area covered by oblique photographs taken at an angle of 12 degrees (Figure 3). All perspective-corrected images covering one survey of a particular colony were then stitched together to create a single digital image of the entire colony up to 15GB in size. Images were stitched and exported as PSB files using Microsoft's Image Composite Editor v1.4.4. In a few cases where the stitching software could not stitch all images, such as with images of areas with large differences in ground elevation, images were stitched or adjusted manually using Adobe Photoshop CS5. The final composites were then saved as LZW compressed TIFF files (large images were split if TIFF's 4GB maximum file size was exceeded) and imported into Manifold GIS 8.0 for counting. The imported images were compressed within Manifold to reduce file size without losing too much image detail. Separate layers were created for marking whitecoat, moulted and dead pups (Figures 5 and 6).

The pup production model allows different misclassification proportions to be incorporated. Previously, because there was a significant risk of misclassifying moulted pups as whitecoats, the pup production model used a fixed value of 50% for the proportion of correctly classified moulted pups. Pups spend a lot of time lying on their back or side and, depending on light conditions during a survey, it is possible to misclassify a moulted pup exposing its white belly as a whitecoat. Misclassification of a whitecoat as a moulted pup is considerably less likely.

In Shetland, where pups are counted from the tops of cliffs and misclassification of moulted pups is likely to be low, a correctly classified proportion of 90% was used (SCOS-BP 05/01). Since 2012, the digital images were of sufficient quality to reduce the probability of misclassification, so a proportion of 90% was used as standard for all production estimates. In line with previous years, the standard mean time to moult of 23.0 days and mean time to leave of 31.5 days were also incorporated into the pup production model.

Results & Discussion

The locations of the main grey seal breeding colonies in the UK are shown in Figure 1. In 2014, pup production at the main biennially monitored breeding colonies in Scotland was estimated to be **47,988** compared with 46,360 in 2012, an average annual increase of 1.7% (Table 1; Figure 7). The contribution of different island groups to the pup production at the annually monitored colonies is shown in Figure 8. Pup production trajectories of the main island groups in Scotland, with 95% confidence intervals, are in Figure 9.

In 2014, pup production at the annually monitored colonies in England was estimated to be **6,627** compared with 4,963 in 2012, an average annual increase of 15.6% (Table 1). Pup production trajectories for individual colonies in the North Sea are in Figure 10, including 95% confidence intervals where available. Pup production estimates for the four annually monitored, main island groups since 1960 are in Table 2.

Including **3,875** pups born at other colonies in Scotland (Table 3), an estimated **250** pups born in south-west England, an estimated **1,650** pup born in Wales and an estimated **100** pups born in Northern Ireland, the total grey seal pup production for the UK in 2014 was estimated to be **60,490** (Table 1).

Pup production at colonies in the Inner Hebrides

In 2014, grey seal pup production at 13 colonies the Inner Hebrides was estimated to be **4,054** compared with 4,088 in 2012, an average annual decline of -0.4% (Table 1; Figure 9). Grouped colonies from different parts of the Inner Hebrides show slightly different production trajectories (Figure 11). Breeding colonies in the Inner Hebrides have only been surveyed since the late 1980s, so it is not possible to group them by age of colony.

Pup production at colonies in the Outer Hebrides

At 16 colonies in the Outer Hebrides, pup production in 2014 was **14,316** compared with 14,136 in 2012, an average annual increase of 0.6% (Table 1; Figure 9). Grouping colonies in the Outer Hebrides by location and age, reveals different pup production trajectories (Figure 12). Production at older, long established colonies around the Sound of Harris is declining while production at colonies in the Monach Isles and new colonies at the southern end of the Outer Hebrides slightly increased.

Pup production at colonies in Orkney

At 28 colonies in Orkney, pup production was **23,758** in 2014 compared with 22,926 in 2012, an average annual increase of 1.8% (Table 1; Figure 9). Grouping colonies of similar ages showed that production at the long established colonies is slowly declining, but not as constantly as at old colonies in the Outer Hebrides (Figure 13). Overall production at colonies formed since the 1970s is slightly increasing (Figure 13).

Pup production at colonies in the Firth of Forth

At 4 colonies in the Firth of Forth, pup production in 2014 was **5,860** compared with 5,210 in 2012, an average annual increase of 6.1% (Table 1; Figure 9 combined and Figure 10 individual).

Production at Fast Castle continues to increase and it is now the biggest colony in the North Sea (Figure 10). This increase is due to expansion to the south-east towards St Abbs Head and westwards towards Siccar Point.

Pup production at colonies on the north and north-east coast of Scotland

At 6 colonies on the north mainland coast of Scotland, pup production in 2014 was 2,350, compared with an estimated 2,145 born in 2012. These colonies lie between Helmsdale and Duncansby head and at Loch Eriboll and Eilean nan Ron on the north coast of Scotland (Figure 1). The latter two are very close to an active RAF bombing range and access for aerial survey can be restricted when the range is busy.

Pup production at colonies in east England

In England, **6,627** pups were born at the annually monitored colonies on the east coast compared with 4,963 born in 2012, an average annual increase of 15.6% (Table 1; Figure 10). Most of this increase was at the three colonies in Lincolnshire and Norfolk (Table 1). A big increase in the number of pups born at Blakeney Point saw it become the biggest grey seal breeding colony in England, overtaking the Farne Islands and Donna Nook (Figure 10).

References

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Duck, C.D. and Mackey, B.L. 2005. Grey seal pup production in Britain in 2004. SCOS Briefing Paper 05/01. pp 22-33 in: Scientific advice on matters related to the scientific management of seal populations: 2005. Unpublished Report to the Special Committee on Seals: 2005. Url: http://www.smru.st-andrews.ac.uk/documents/SCOS_05_v2f.pdf.

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Russell, D.J.F., Duck, C.D., Morris, C.D. & Thompson, D. 2015 Review of parameters of the grey seal pup production model. SCOS Briefing Paper 2015/03. Available at: http://www.smru.st-andrews.ac.uk/documents/scos/SCOS_2015.pdf pp 84-91.

Table 1. Grey seal pup production estimates from 2014 compared with production estimates from 2012 and preceding six-year intervals. The average annual change for the multi-year intervals are the slope of the regression of the $\log_{10}$ (pup production) over the relevant period, for annually monitored colonies only.

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

Table 2. Estimates of grey seal pup production from annually surveyed colonies in the Inner and Outer Hebrides, Orkney and in the North Sea between 1960 and 2014.

YEAR	Inner Hebrides	Outer Hebrides	Orkney	North Sea	Total
1960			2048	1020	
1961		3142	1846	1141	
1962				1118	
1963				1259	
1964			2048	1439	
1965			2191	1404	
1966		3311	2287	1728	7326
1967		3265	2390	1779	7434
1968		3421	2570	1800	7791
1969			2316	1919	
1970		5070	2535	2002	9607
1971			2766	2042	
1972		4933		1617	
1973			2581	1678	
1974		6173	2700	1668	10541
1975		6946	2679	1617	11242
1976		7147	3247	1426	11820
1977			3364	1243	
1978		6243	3778	1162	11183
1979		6670	3971	1620	12261
1980		8026	4476	1617	14119
1981		8086	5064	1531	14681
1982		7763	5241	1637	
1983				1238	
1984	1332	7594	4741	1325	14992
1985	1190	8165	5199	1711	16265
1986	1711	8455	5796	1834	17796
1987	2002	8777	6389	1867	19035
1988	1960	8689	5948	1474	18071
1989	1956	9275	6773	1922	19926
1990	2032	9801	6982	2278	21093
1991	2411	10617	8412	2375	23815
1992	2816	12215	9608	2437	27075
1993	2923	11915	10790	2710	28338
1994	2719	12054	11593	2652	29018
1995	3050	12713	12412	2757	30932
1996	3117	13176	14273[1]	2938	33504
1997	3076	11946	14051	3698	32771
1998	3087	12434[2]	16367	3989	35877
1999	2787	11759	15462	3380	33388
2000	3223	13396	16281	4303	37210
2001	3032[3]	12427	17938	4134	37531
2002	3096	11248	17942[4]	4520[4]	36816
2003	3386	12741[5]	18652[5]	4805[5]	39584
2004	3385	12319	19123	4921	39748
2005	3387	12297[6]	17644[6]	5132	38460

YEAR	Inner Hebrides	Outer Hebrides	Orkney	North Sea	Total
2006	3461	11719	19332	5322	39727
2007	3071	11342	18952	5560	38772
2008	3396	12712	18765[7]	6617	41450
2009	3396[8]	12113[8]	19150	7637[8]	42296
2010	3391	12857	20312	8314	44874
2011					
2012	4088[9]	14136	22926	10143	51293
2013					
2014	4054	14316	23758	12435	54615

[1]Calf of Flotta included with Orkney total from 1996

[2]Berneray and Fiaray (off Barra) included in the Outer Hebrides total from 1998

[3]Oronsay included with Inner Hebrides from 2001

[4]South Ronaldsay included in the Orkney total; Blakeney Point and Horsey (both Norfolk) included with North Sea from 2002

[5]North Flotta, South Westray, Sule Skerry included with Orkney; Mingulay included with Outer Hebrides from 2003

[6]Pabbay included with Outer Hebrides; Rothiesholm (Stronsay) included with Orkney from 2005

[7]East Hoy included with Orkney from 2008

[8]2008 production estimates were used as a proxy for all colonies in the Inner Hebrides and for 7 colonies in the Outer Hebrides for which new production estimates could not be derived in 2009. Oronsay Strand included with Inner Hebrides; Inchkeith included with North Sea

[9] Soa, Coll included with Inner Hebrides from 2012

Table 3. Estimates of grey seal pup production from irregularly surveyed colonies around Scotland.

Island group	Location	Survey type	Last surveyed	Last surveyed	Recent pup counts	Most recent count
Inner Hebrides	LochTarbert, Jura	SMRU visual	2007	2003, 2007	10,**4**	4
	West coast Islay	SMRU visual	2008	1998, every 3-4 years	None seen	0
	Ross of Mull, south coast	SMRU visual	2005	1998, infrequent	None seen	0
	Treshnish small islands	SMRU photo & vis	2010	annual	~**20** in total	20
	Staffa	SMRU visual	2008	1998, every other year	~**5**	5
	Little Colonsay, by Ulva	SMRU visual	2008	1998, every 3-4 years	**6**	6
	Meisgeir, Mull	SMRU visual	2008	1998, every 3-4 years	**1**	1
	Craig Inish, Tiree	SMRU photo	2005	1998, every 2-3 years	**2**	2
	Cairns of Coll	SMRU photo	2008	2003, 2007	22, **10**	10
annual	Soa, Coll	SMRU photo		2010	annual, with Inner Hebrides	
	Muck	SMRU photo	2005	1998, 2005	36, **18**	18
	Rum	SNH ground	2013	2005, annual	10-15	15
	Canna	SMRU photo	2005	2002, 2005	54, **25**	25
	Rona (Skye)	SMRU visual	2003	1989, infrequent	None seen	0
	Ascrib Islands, Skye	SMRU photo	2008	2002, 2005, 2007, 2008	60, 64, 42,**64**	64
	Fladda Chuain, North Skye	SMRU photo	2008	2005, 2007, 2008	73, 43,**129**	129
	Trodday, NE Skye	SMRU photo	2008	2008new	**55**	55
	Heisgeir, Dubh Artach, Skerryvore	SMRU visual	2003	1995, 1989, infrequent	None	0
Outer Hebrides	Sound of Harris islands	SMRU photo	2008	2002, 2005, 2007, 2008	358, 396, (194), **296**	296
annual	Sandray, S of Barra	SMRU photo		2010	annual , with Ohebs	0
	St Kilda	NTS reports	rare	Infrequent	Few pups are born	5
	Shiants	SMRU visual	2008	1998, every other year	None	0
	Flannans	SMRU visual	2000	1994, every 2-3 years	None	0
	Bernera, Lewis	SMRU visual	1991	1991, infrequent	None seen	0
	Summer Isles	SMRU photo	2010	2002, 2003, 2005-2008. 2010	50, 58, 67, 69,25, **73** . 29	73
	Islands close to Handa	SMRU visual	2009	2002	**10**	10
	Faraid Head	SMRU visual	1998	1989, infrequent	None seen	0
	Eilean Hoan, Loch Eriboll	SMRU visual	2006	1998, annual	None	0
	Rabbit Island, Tongue	SMRU visual	2006	2002, every other year	None seen	0
Orkney	Sanday, Point of Spurness	digicam	2013	2002, 2004, 2005-2008, 2010	10, 27,34, 21,8,17 **0**	15
	Sanday, east and north	SMRU visual	2003	1994, every 2-3 years	None seen	0
	Papa Stronsay	SMRU visual	2009	1993, every 3-4 years	None seen	0
	Holm of Papa, Westray	SMRU visual	2009	1993, every 3-4 years	None seen	0
	North Ronaldsay	SMRU visual	2006	1994, every 2-3 years	None seen	0
	Eday mainland	SMRU photo	2010	2000, 2002	8, **2**	2
Others	Small Firth of Forth islands	Fife Seal Group	2014	Infrequent, 1997	<10, 4	9
Total	Small colonies (above)	Various			868	**764**
	Mainland Scotland	SMRU annual	2014			**2,350**
	Shetland	SNH ground	2012			**761**
Total	**Other Scottish colonies**		**to 2014**			**3,875**

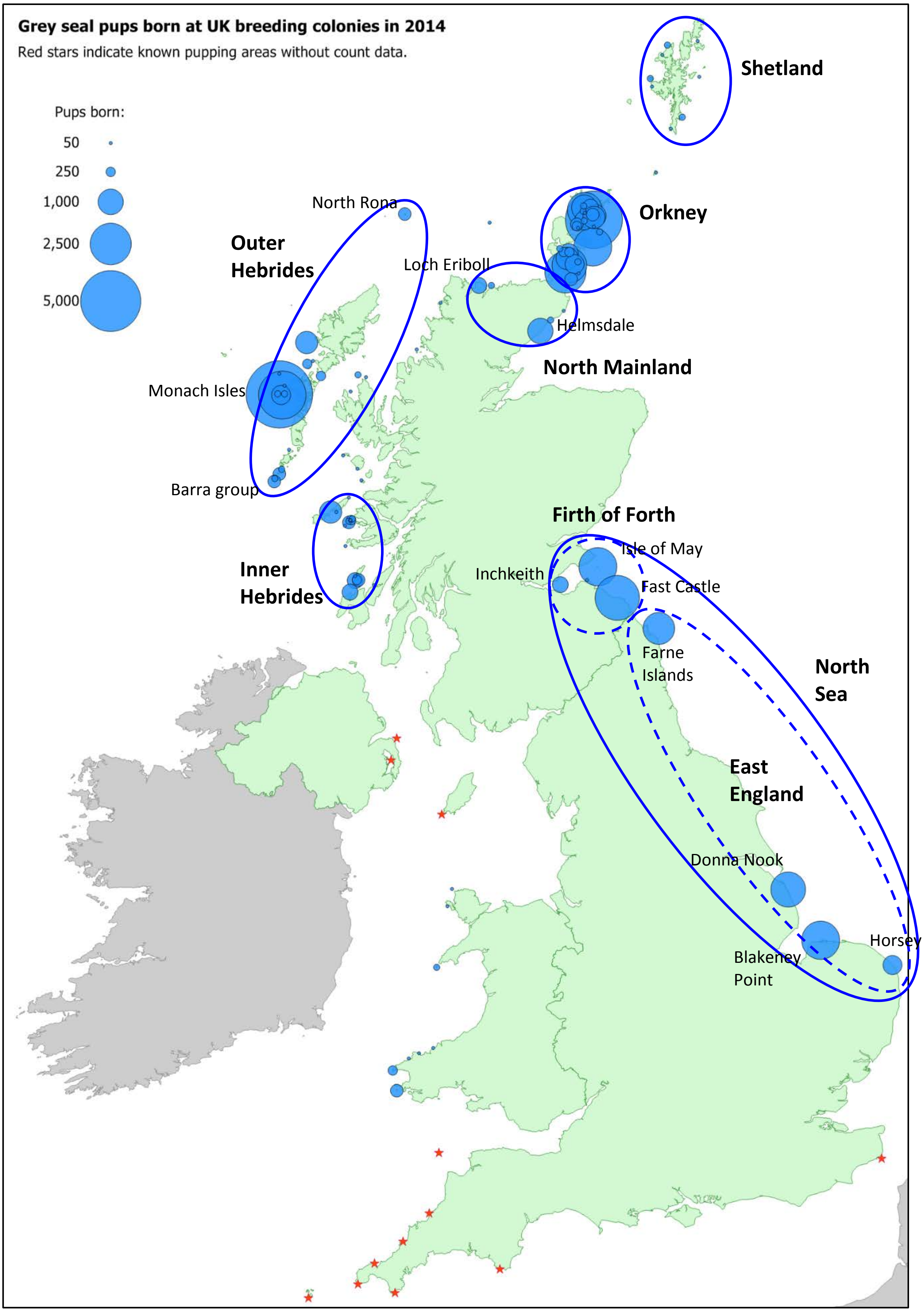

Figure 1. Pup production at the main grey seal breeding colonies in the UK in 2014. Smaller numbers of grey seals will breed at locations other than those indicated here, including in caves.

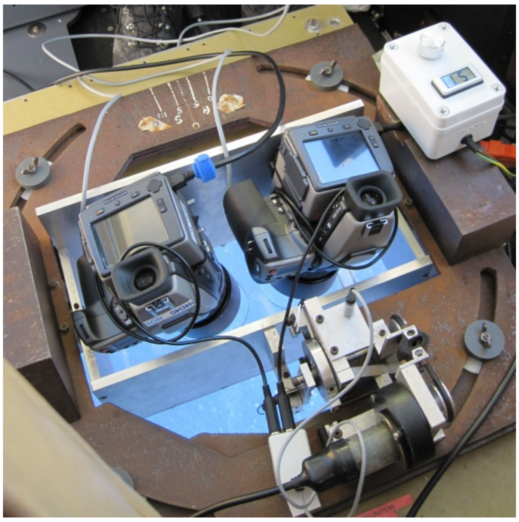

Figure 2. Two Hasselblad H4D-40 medium format cameras fitted in SMRU's Image Motion Compensation (IMC) mount. Each camera is set at an angle of 12 degrees to increase strip width. The cradle holding the cameras rocks backwards and forwards during photo runs. Rocking speed is set depending on the altitude and the ground speed of the aircraft. The camera shutters are automatically triggered and an image captured every time the cameras pass through the vertical position on each front-to-back pass. Images are saved directly to a computer as 60MB Hasselblad raw files and can be instantly viewed and checked using a small LED screen. The H4D-40 can take up to 40 frames per minute allowing for ground speeds of up to 140kts at 1100ft (providing 20% overlap between consecutive frames). The resulting ground sampling distance is approximately 2.5 cm/pixel.

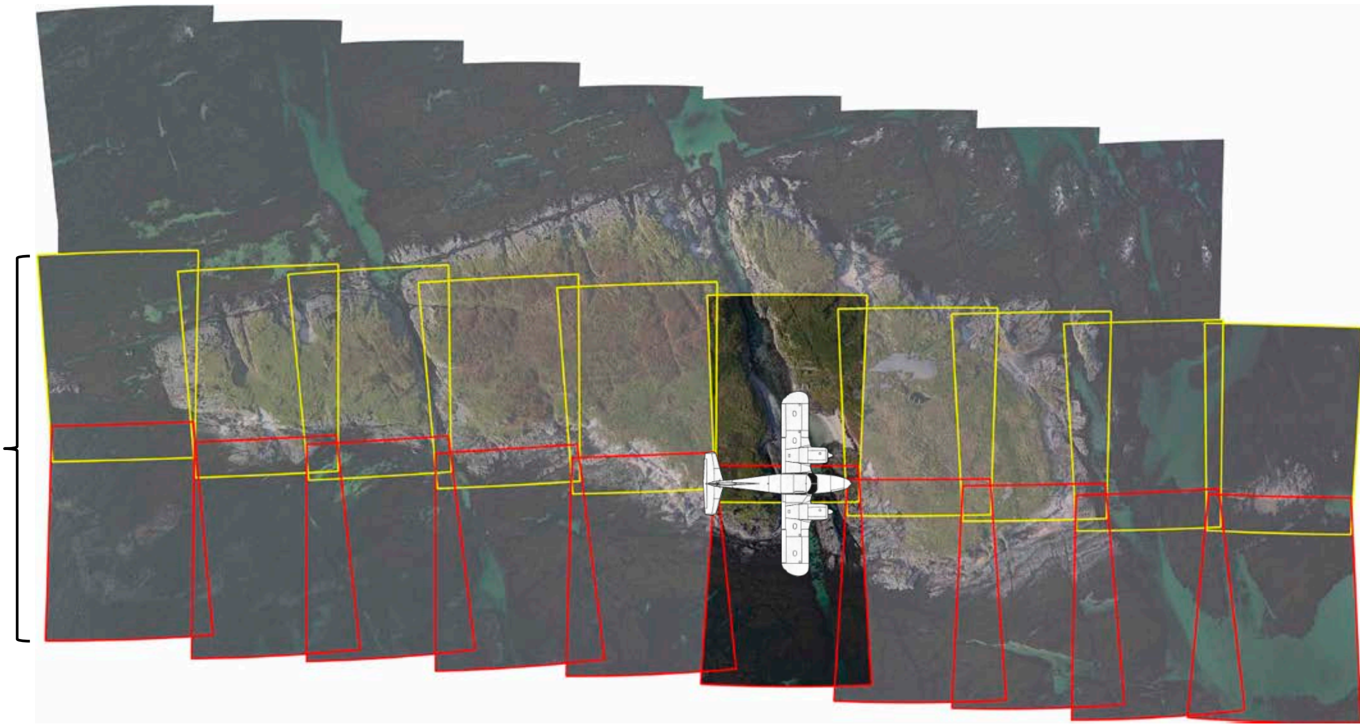

Figure 3. The individual footprints of each pair of photographs taken on a run over Eilean nan Ron, off Oronsay in the Inner Hebrides, flying at 1,100ft (red: left-hand camera; yellow: right-hand camera).

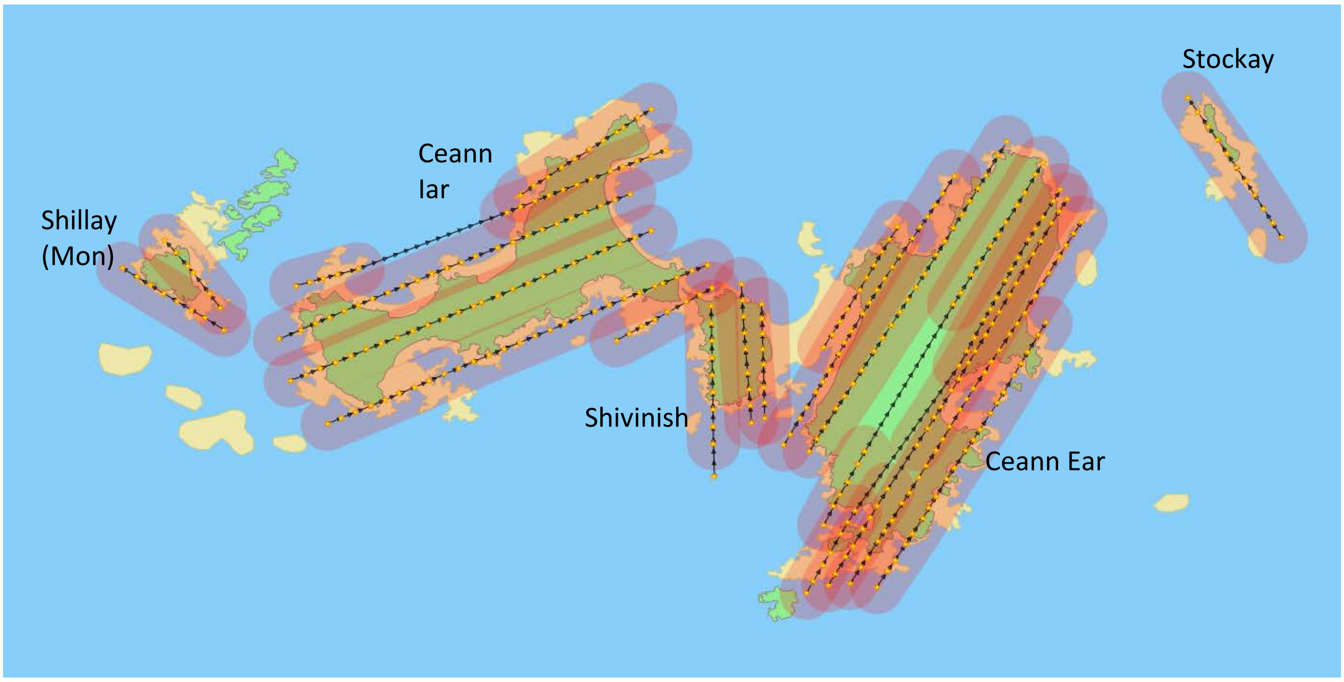

Figure 4. Survey runs and approximate camera trigger locations (yellow dots) for five colonies in the Monach Isles in the Outer Hebrides on 26 October 2012.

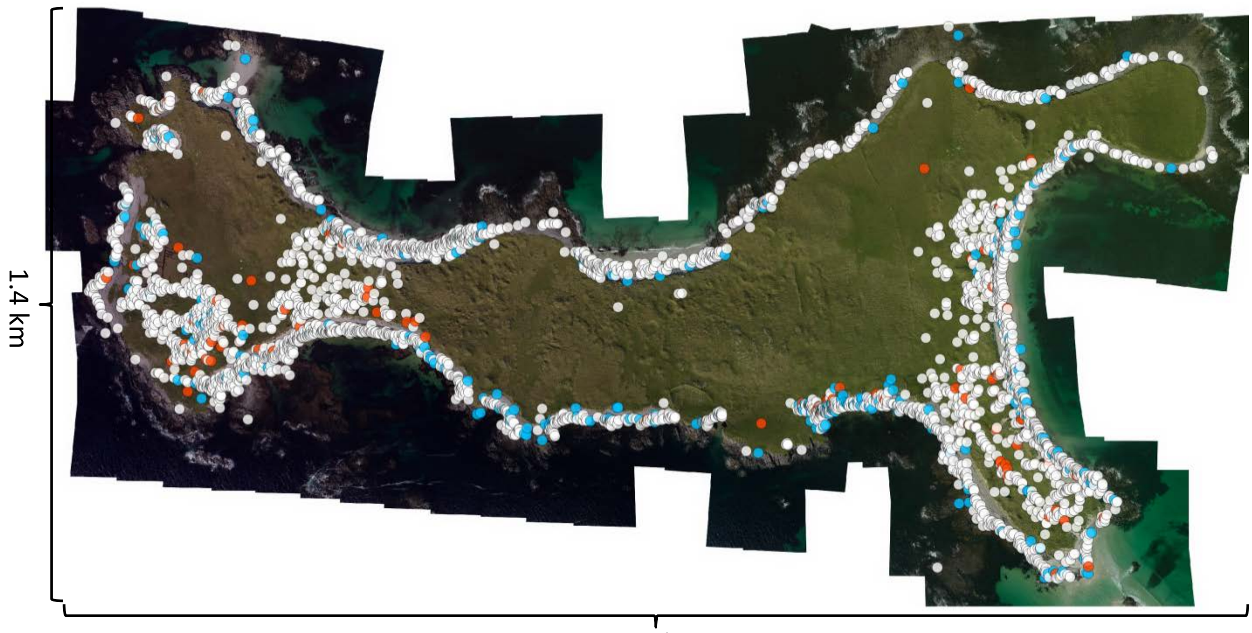

Figure 5. Ceann Iar, the second biggest of the Monach Isles in the Outer Hebrides, is the largest grey seal breeding colony in Europe (ca. 6,000 pups are born each year). This screenshot shows white-coated (white), moulted (blue) and dead pups (red) counted from approximately 200 stitched photographs taken on 7 October 2012. The composite image was stitched together and exported using Microsoft's Image Composite Editor v1.4.4®. The resulting 7.2 gigapixel PSB file (15 GB) was split into 30,000x30,000 pix TIFF tiles using Adobe Photoshop CS5®. These were then imported into Manifold GIS 8.0® for counting.

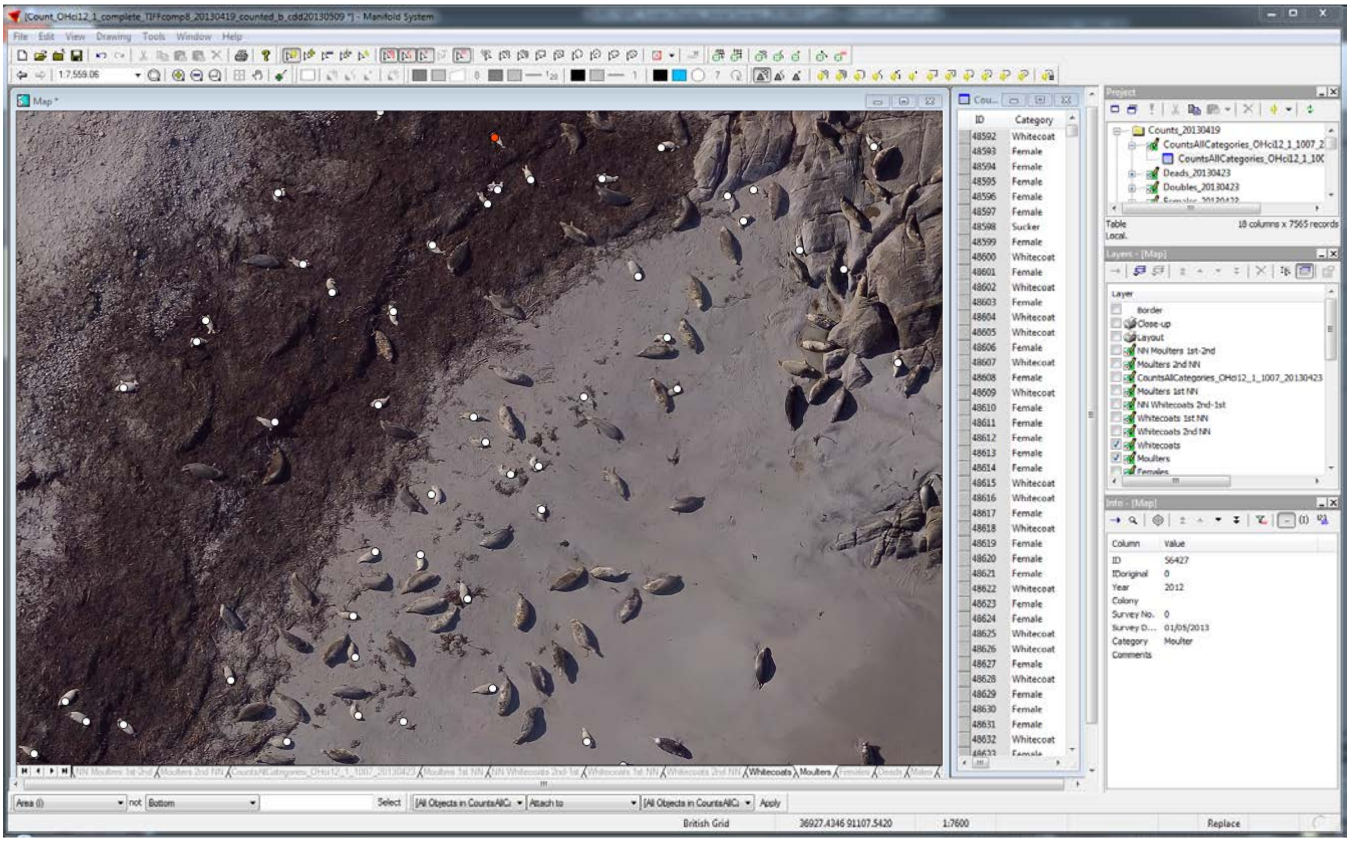

Figure 6. Manifold GIS 8.0® screenshot showing grey seal pups counted on Ceann Iar. Pups of each category (whitecoat, moulted, dead) are counted on a separate layer. The images are not currently geo-referenced but there is the potential for further processing, thus obtaining approximate coordinates for every pup counted.

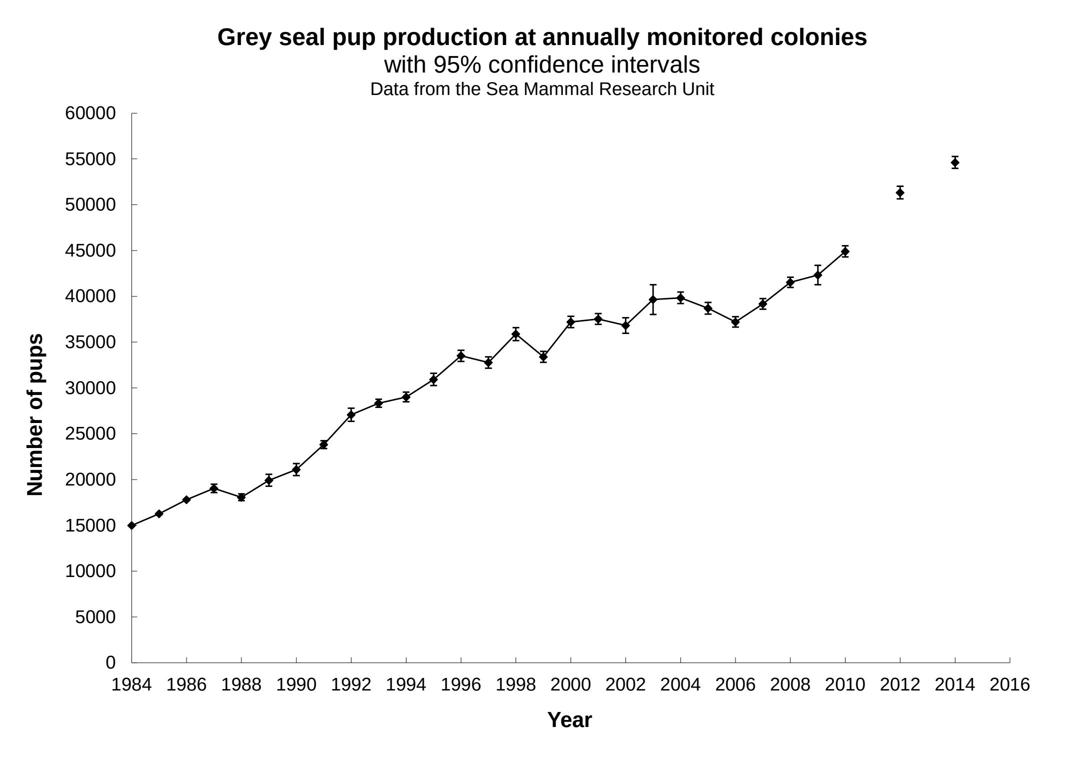

Figure 7. Grey seal pup production at all the major annually monitored colonies in Scotland and England, with 95% confidence intervals from 1984 to 2014.

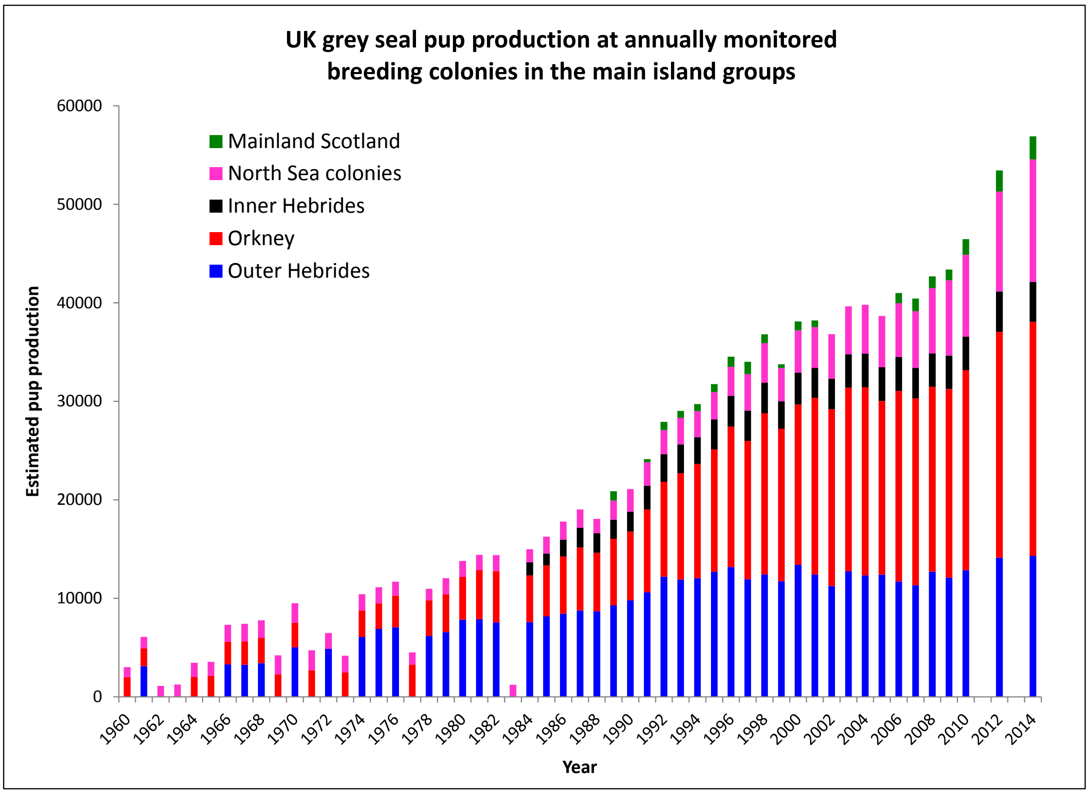

Figure 8. Grey seal pup production at the main ‘island’ groups between 1960 and 2014.

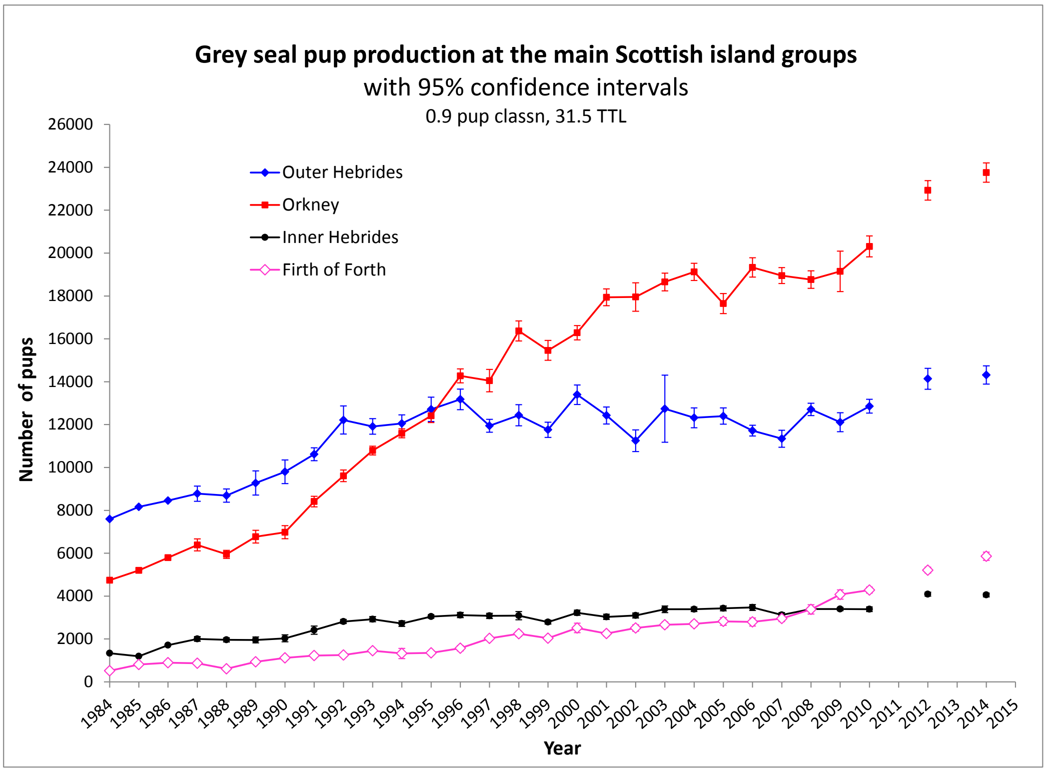

Figure 9. Grey seal pup production at the four main island groups in Scotland, with 95% confidence intervals, calculated using the standard Time to Leave of 31.5 days.

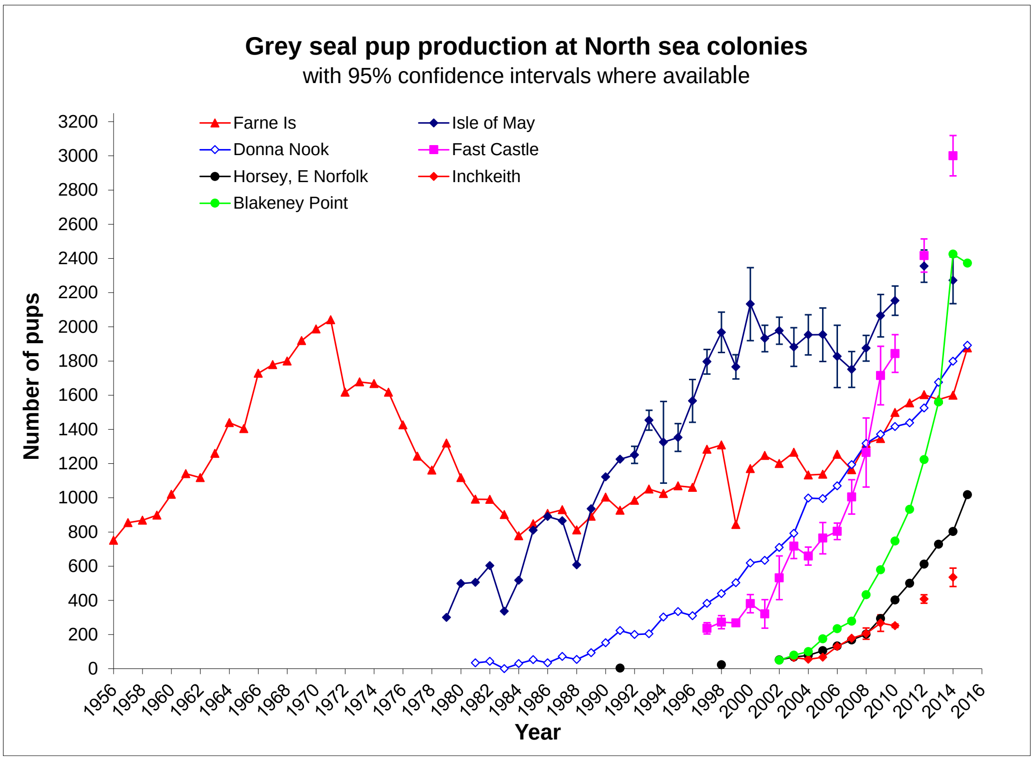

Figure 10. Grey seal pup production at the North Sea colonies. In 2014, Fast Castle became the biggest colony in the North Sea and Blakeney Point became the biggest grey seal breeding colony in England, overtaking the Farne Islands and Donna Nook.

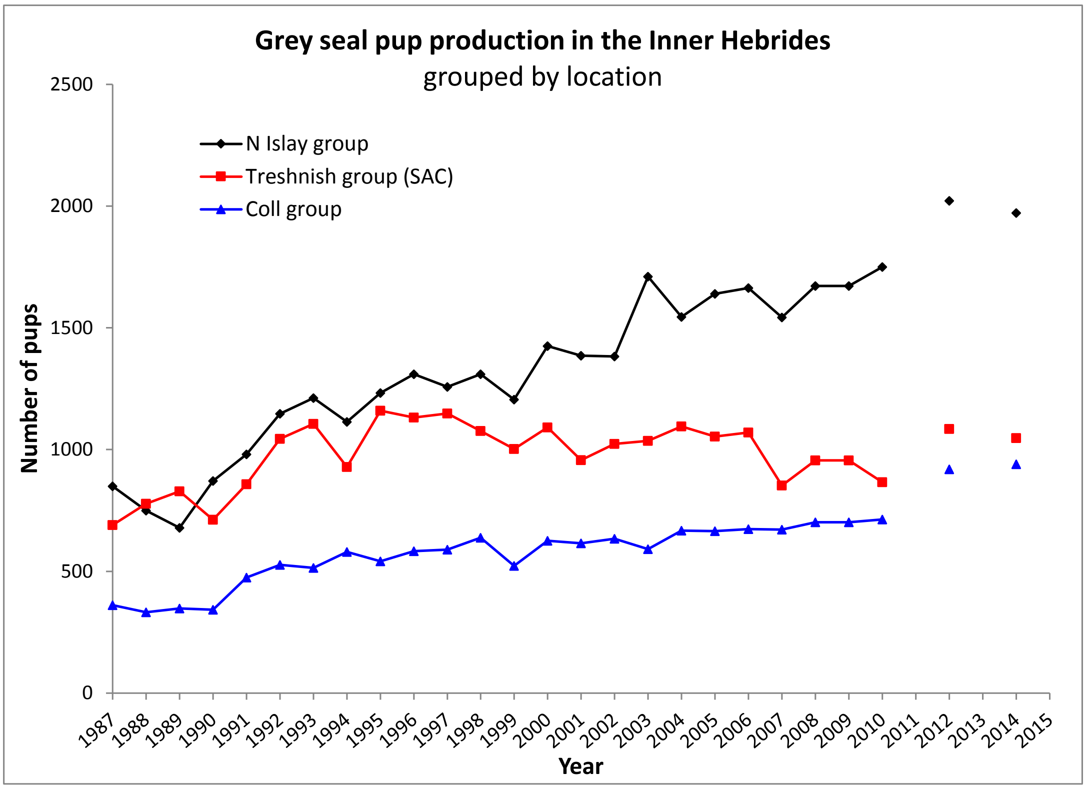

Figure 11. Grey seal pup production at colonies in the Inner Hebrides, grouped by location. Regular surveys of grey seals breeding in the Inner Hebrides only started in the 1980s.

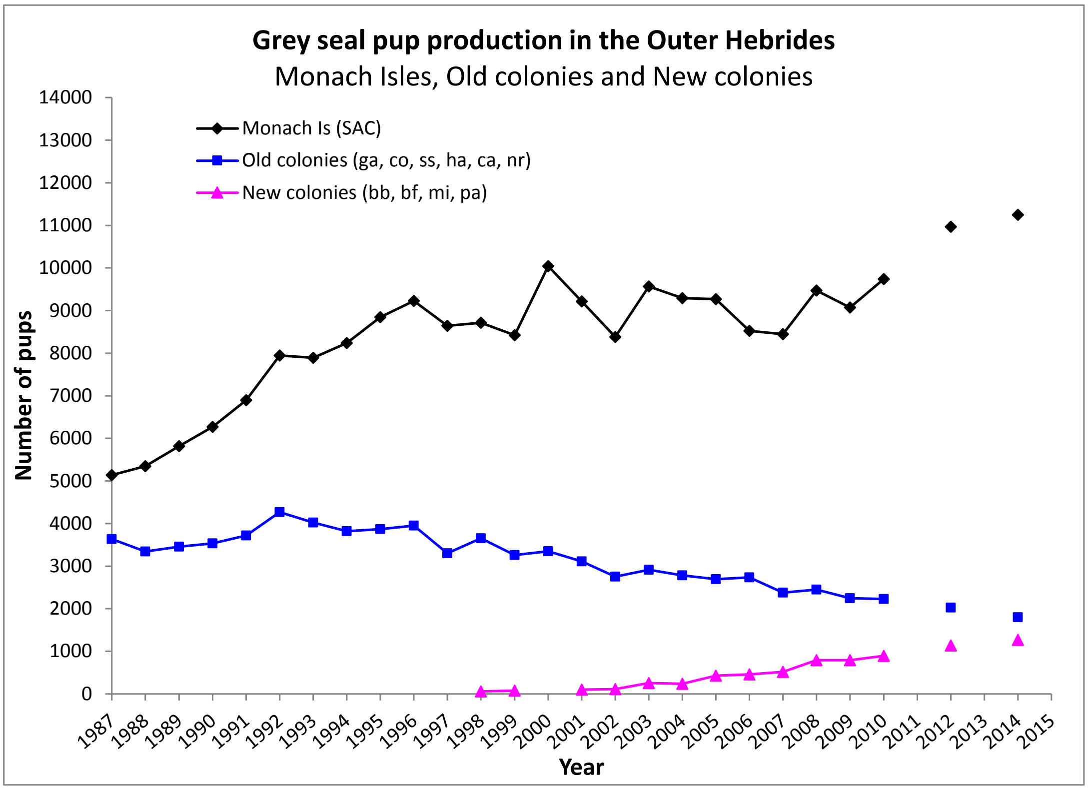

Figure 12. Grey seal pup production in the Outer Hebrides, comparing breeding colonies on the Monach Isles, long established (old) colonies and newly established colonies.

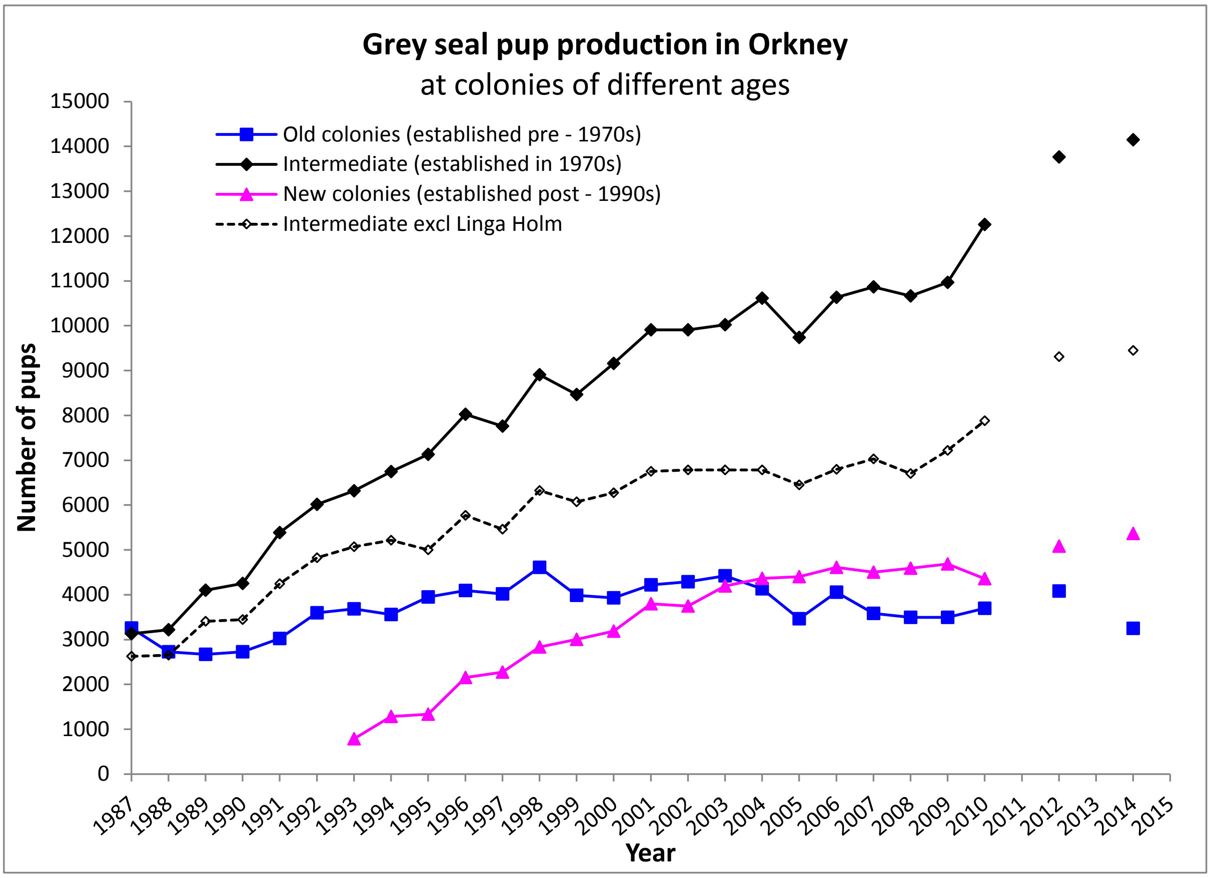

Figure 13. Grey seal pup production at colonies in Orkney, comparing colonies well established before the 1970s (Old), colonies established during the 1970s (Intermediate) and colonies established during or after the 1990s (New).

Estimating the size of the UK grey seal population between 1984 and 2015

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Abstract

We fitted a Bayesian state-space model of British grey seal population dynamics 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. This model is identical to that used to provide last year's advice; the same prior distributions were used on model parameters, including a prior on sex ratio and a constraint on adult survival to the range 0.8-0.97.

The 2014 pup production data had not been used in any previous modelling. Like the 2012 estimate, which was the first produced with new survey equipment and revised analysis assumptions, pup production estimates were noticeably higher than what might be expected given the trajectory from 1984-2010. The independent estimate for 2014 was also new; an estimate for 2008 had been used previously but a re-analysis of the data underlying the independent estimates meant the 2008 value was approximately 14% higher than the value used previously, and had a slightly larger coefficient of variation. The estimates used adjust for the fact that the population model is based only on regularly monitored breeding colonies (approx. 94% of the total population).

Estimated adult population size in regularly monitored colonies in 2015 was 127,100 (95% CI 105,900-151,900). The estimated population trajectory is approximately 20% higher than that reported last year. An initial investigation showed that a difference of 14% can be attributed to changes in the independent estimate (the presence of the 2014 estimate and the revised 2008 estimate); the other 6% is presumably caused by the high 2014 pup count.

Introduction

This paper presents estimates of British grey seal population size and related demographic parameters, using identical models and fitting methods to Thomas (2015, and previous years), but incorporating new data in the form of a pup production estimate from 2014, a revised independent estimate of adult population size in 2008 and a new independent estimate from 2014. We project the model forward from the last available data to provide estimates of population size in 2015.

As with past briefing papers, the data are fitted to a population dynamics model within a Bayesian statistical framework using an algorithm called a Monte Carlo particle filter. Previously, multiple models of the population dynamics have been fitted and compared, representing differing hypotheses about the demographic parameter subject to density dependent regulation and about movement of recruiting females between regions. The model where density dependence affects pup survival, and where recruiting females do not move between regions was found to be better supported by the data than one where density dependence affects female fecundity (Thomas 2012); hence only this model is used here. A revised set of priors were suggested by Lonergan (2012), based on updated information and discussions within the Sea Mammal Research Unit; these were further modified in Thomas (2015) to constrain adult female survival to a maximum of 0.97 and the modified priors were used in the SCOS advice in 2015. This set of priors were used here. Hence the only differences in models and methods from Thomas (2015) are the new data.

Materials and Methods

Process model

The population dynamics model is described fully in Thomas and Harwood (2008) and papers cited therein (it is referred to there as the EDDSNM model), except that those models assumed a fixed adult sex ratio. The model was extended to allow estimation of adult sex ratio by Thomas (2012). In summary, the model tracks seal population numbers in 8 age and sex groups (pups, age 1-5 females, which do not pup, and age 6+ females, which may produce a single pup, and age 1+ males) in each of four regions (North Sea, Inner Hebrides, Outer Hebrides and Orkney). There are three population sub-processes: (1) survival, (2) ageing and pup sexing and (3) breeding. (The models of Thomas and Harwood 2008 also included movement of age 5 females between regions, but we assume no movement in the current model.) Age 1+ ("adult") males are not tracked explicitly, but instead are linked to the number of females by a sex ratio parameter. The model has 9 parameters: adult (i.e., age 1 and older) female survival, ϕ_a, maximum pup survival, $\phi_{j\max}$, one carrying capacity parameter-related parameter for each region, β_1 - β_4, a parameter, ρ, that dictates the shape of the density-dependent response, fecundity (i.e., probability that an age 6+ female will birth a pup), α, and adult sex ratio ω.

Data, observation models, and priors

One source of input data was the pup production estimates for 1984-2010, 2012 and 2014 from Duck (2016) covering the regularly surveyed colonies, aggregated into regions. These estimates were assumed to be normally distributed with mean equal to the true pup production in each region and year, and constant coefficient of variation (CV). This CV was estimated from an initial run of the model by Thomas (2014), and for the runs performed here was fixed to this value (10.5%).

The second source of input data was two estimates of adult population size obtained by Russell et al. (2016) from summer haulout counts and telemetry data. Although these data were collected over multiple years, we assumed they were estimates of population size just before the start of the 2008 and 2014 breeding seasons. We scaled the estimates of Russell et al. to account for the fact that their estimate is of the total adult UK population of seals while the pup production model covers only the breeding colonies regularly surveyed – estimated to be 92.34% of total pup production in 2008 (Duck 2009) and 93.40% in 2014 (Russell pers. comm). Uncertainty in the estimates was represented using a right-shifted gamma distribution that was fitted to the nonparametric bootstrap distribution produced by Russel et al., after scaling, using maximum likelihood. We assumed the two estimates were independent of one another, when in fact they are derived partly from the same data (telemetry data used to derive the correction factor turning counts of hauled-out animals to a total population size) – see Discussion.

Prior distributions for the process model parameters were the same as the "revised priors" used in Thomas (2014); these in turn are those suggested by Lonergan (2012, Table 1), except for the prior on adult sex ratio, which was first suggested by Thomas (2014), and the prior on adult female survival, which was constrained to lie between 0.8 and 0.97 as suggested by Thomas (2015). We followed Thomas and Harwood (2005) in using a re-parameterization of the model to set priors on the numbers of pups at carrying capacity in each region, denoted χ_r for region r, rather than directly on the β s. Prior distributions for the states were generated using the 1984 data, as described by Thomas and Harwood (2008).

Fitting method

The fitting method was identical to that of Thomas (2015), again using the particle filtering algorithm of Thomas and Harwood (2008). This involves simulating samples ("particles") from the prior distributions, projecting them forward in time according to the population model, and then resampling and/or reweighting them (i.e., "filtering") according to their likelihood given the data. An identical algorithm to that of Thomas and Harwood (2008) was used for the pup production data, and the additional adult data was included by reweighting the final output according to the likelihood of the estimated 2008 and 2014 population sizes, using the method described by Thomas (2010).

The final output is a weighted sample from the posterior distribution. Many samples are required for accurate estimation of the posterior, and we generated 2,000 replicate runs of 1,000,000 samples. A technique called rejection control was used to reduce the number of samples from the posterior that were required to be stored, and the effective sample size of unique initial samples was calculated to assess the level of Monte Carlo error, as detailed in Thomas and Harwood (2008). The rejection control threshold used was w_c=1000.

Additional investigation: effect of new total population size estimates

An estimate of total population size in 2008, derived by Lonergan et al. (2010) was used in previous year's analyses. However, the value used here for this year, derived by Russell et al. (2016) from a re-analysis of the data, is higher than the value used previously; the variance is also larger. To determine the effect of this change, and of the new 2014 population size estimate, we re-ran the analysis using the same pup production data, but only the total population estimate for 2008 from Lonergan et al. (2010).

Results

Total population estimates for 2008 and 2014

The bootstrap estimates of total population size from Russell et al. (2016) were well approximated by right-shifted gamma distributions (Figure 1). The mean and SD of the bootstrap data were, after scaling, 94,390 (SD 9,787) for 2008 and 137,639 (SD 14,271) for 2014 (note that these are not identical to the numbers provided by Russell et al. because those are before scaling, have an additional 4% included to account for the proportion of the population in the South-west UK, and are medians not means); the equivalent values from the fitted gamma distributions were 94,399 (SD 9,788) and 137,650 (SD 14,273). (For the record, the right-shifted gamma distribution parameters were 59167.8, 12.9441 and 2719.38 (shift, shape and scale respectively) for 2008 and 86360.5, 12.9136 and 3971.20 for 2014.)

Monte Carlo accuracy

The effective sample size (ESS) of unique particles is a useful measure of the accuracy of the simulation. The ESS based on pup production data alone was 427.8 (Table 2, 1st row), and after inclusion of the independent population estimate was 97.5. ESSs smaller than this have been shown in previous briefing papers to produce population and parameter estimates accurate to around 2-3 significant figures, so we should expect the estimates reported here to be accurate to at least this level.

This latter ESS is larger than in previous briefing papers, likely because the independent population estimates had larger variance and so did not exert such a strong selection effect on the particles. This is confirmed by the fact that the additional investigation ESS (Table 2, 2nd row), which is from the analysis re-run using the Lonergan et al. (2010) total population estimate from 2008 (and excluding the total estimate for 2014) had a much smaller ESS of 7.6. Although population size estimates from this analysis are likely to be less accurate, they were only produced for the purposes of the additional investigation.

Parameter and population estimates

Model fits to pup production estimates are shown in Figure 2. Modelled pup production estimates are almost unchanged by the addition of the two total population size estimates to the model (cf. blue and red lines in Figure 2). The two most recent pup production estimates are higher than expected under the model in all four regions, but the effect is by far stronger in the Hebrides regions than North Sea or Orkney. Nevertheless, in Orkney the two most recent estimates are high, coming after 5 previous estimates that are relatively stable. In North Sea the estimates are somewhat consistent with a strongly increasing pattern, although the modelled pup production is not increasing as strongly as the pup production estimates indicate.

Estimated adult population size is shown in Figure 3. The estimates are significantly affected by the two total population size estimates: the 2015 estimate is 155,300 (95%CI 113,200-215,800) based on the pup production data alone, but is reduced to 127,100 (95%CI 105,900-151,900) with the addition of the total population estimates. Note that of the two estimates, the 2008 estimate is lower than the modelled adult population size in that year while the 2014 estimate is higher, and that in both cases the confidence intervals from the total population size estimates overlap the modelled credible intervals. Prior and posterior parameter estimates are shown in Figure 4. Estimated adult population size by region for 2015 is given in Table 2, and for all years is given in the Appendix. Posterior distributions on demographic parameters are not strongly affected by the addition of the total population size estimates (cf. Figures 4a and 4b).

Additional investigation: effect of new total population size estimates

The estimate of total population size in 2008 from Lonergan et al. (2010) was 14% lower than the estimate from Russell et al. (2016); the variance was also smaller (coefficient of variation, CV, 8.5% as opposed to 10.2%). Using the Lonergan et al. value for 2008 resulted in an estimated adult population size in 2015 that was 14% lower than the one reported above (109,000 with 95%CI 94,000-132,300). Note that this is the effect both of the different estimate for 2008 and of using no total population size estimate for 2014.

Discussion

The revised total population estimate for 2008 more closely matches the modelled population trajectory from pup production data, although the total estimate is still rather lower than that predicted by the model (cf. estimate with 2008 with blue line in Figure 3). The 2014 total estimate is also lower than that predicted by the model, but not as much. When pup production data and total population estimates are combined, the joint trajectory matches both datasets reasonably well. One area of concern, however, is the two most recent pup production estimates, which seem unexpectedly high given previous pup production numbers, especially in the Hebrides. The two most recent pup production estimates were produced after a change in survey methodology (and some analysis assumptions); further investigation of this is warranted. It should be noted that pup production in the North Sea region is partly estimated from ground counts, so these counts will need to be separated out in any statistical investigation.

The estimated population trajectory is somewhat higher than that reported last year: the 2014 estimated adult population size for the same model and priors was 105,200 (95% CI 87,000-128,800), compared with 2014 estimates in this report (Appendix) of 125,800 (95% CI 105,500-149,700) – about 20% higher. Our additional investigation showed that the difference in trajectory caused by the revised and new total population size estimate was 14%; therefore, the difference due to the additional pup count estimate is approximately 6%.

In using the total population estimates, we have assumed the two estimates are statistically independent, when in fact they both used the same multiplier to account for proportion of animals hauled out. It may be possible to account for this correlation in a revised analysis (although we also note that aspects of pup production estimation are the same across years, potentially inducing correlation there also).

The model assumes a fixed CV for 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 aerial pup count data; we plan to investigate this in the coming year. One factor that will require consideration is how to incorporate uncertainty on the ground counts made in some North Sea colonies.

Previous briefing papers (e.g., Thomas 2014, 2015) discussed other aspects of the model that could be improved, including a re-examination of the sex ratio prior and the movement of recruiting females between regions.

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Thomas, L. and J. Harwood. 2008. Estimating the size of the UK grey seal population between 1984 and 2007. SCOS Briefing Paper 08/03.

Table 1. Prior parameter distributions and summary of posterior distributions. (The two parameters of the gamma distribution specified here are shape and scale respectively.) Posterior summaries are all from analyses that use both 1984-2014 pup production estimates, and the 2008 and 2014 total population estimates.

	Main analysis		
Parameter	Prior distribution	Prior mean (SD)	Posterior mean (SD)
adult survival ϕ_a	0.8+0.17*Be(1.6,1.2)	0.90 (0.04)	0.95 (0.01)
pup survival ϕ_j	Be(2.87,1.78)	0.62 (0.20)	0.51 (0.08)
fecundity $\alpha_{\max}$	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.90 (0.06)
dens. dep. ρ	Ga(4,2.5)	10 (5)	3.47 (0.79)
NS carrying cap. χ_1	Ga(4,2500)	10000 (5000)	1700 (3900)
IH carrying cap. χ_2	Ga(4,1250)	5000 (2500)	3620 (277)
OH carrying cap. χ_3	Ga(4,3750)	15000 (7500)	12700 (693)
Ork carrying cap. χ_4	Ga(4,10000)	40000 (20000)	23000 (2470)
observation CV ψ	Fixed	0.89 (0)	-
sex ratio ω	1.6+Ga(28.08, 3.70E-3)	1.7 (0.02)	1.7 (0.02)

Table 2. Number of particles simulated (K), number saved after final rejection control step (K*), number of unique ancestral particles (U), effective sample size of unique particles from pup count data alone(ESS_{u1}), and with pup production data and the independent total population estimates (ESS_{u2}). For the second row, the last part of the analysis, where the independent population size is introduced, was re-run with only the 2008 estimate from Lonergan et al. (2010).

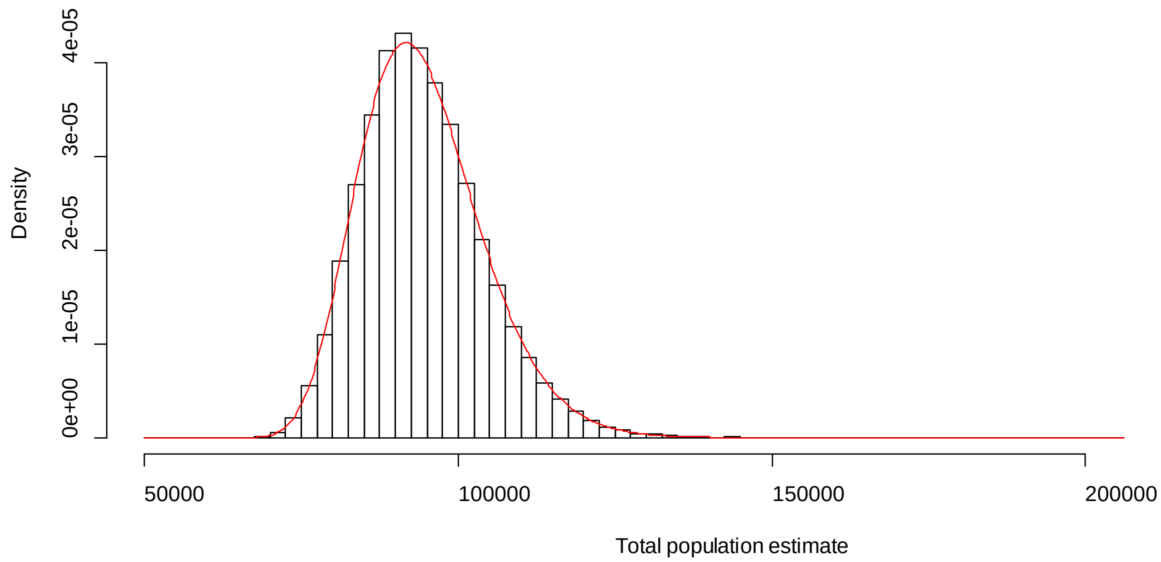
Model	*K* (x10^7)	*K** (x10^6)	*U* (x10^4)	ESS_{u1}	ESS_{u2}
EDDSNM All data	2000	28.5	32.3	427.8	97.5
EDDSNM Old 2014 total pop size estimate	.	.	.	.	7.6

Table 3. Estimated size, in thousands, of the British grey seal population at the start of the 2015 breeding season, derived from models fit to pup production data from 1984-2014 and the additional total population estimates from 2008 and 2014, using the revised parameter priors. Numbers are posterior means with 95% credible intervals in brackets.

	Estimated population size in thousands (95% CI)
North Sea	33.7 (26.2 41.4)
Inner Hebrides	8.7 (7.3 10.3)
Outer Hebrides	30.4 (26.3 35.2)
Orkney	4.3 (46.1 65.1)
Total	127.1 (105.9 151.9)

Figure 1. Histograms of total population estimates from Russell et al. (2016) (scaled to account for colonies not regularly surveyed) with fitted right-shifted gamma distributions (line).

(a) 2008



(b) 2014

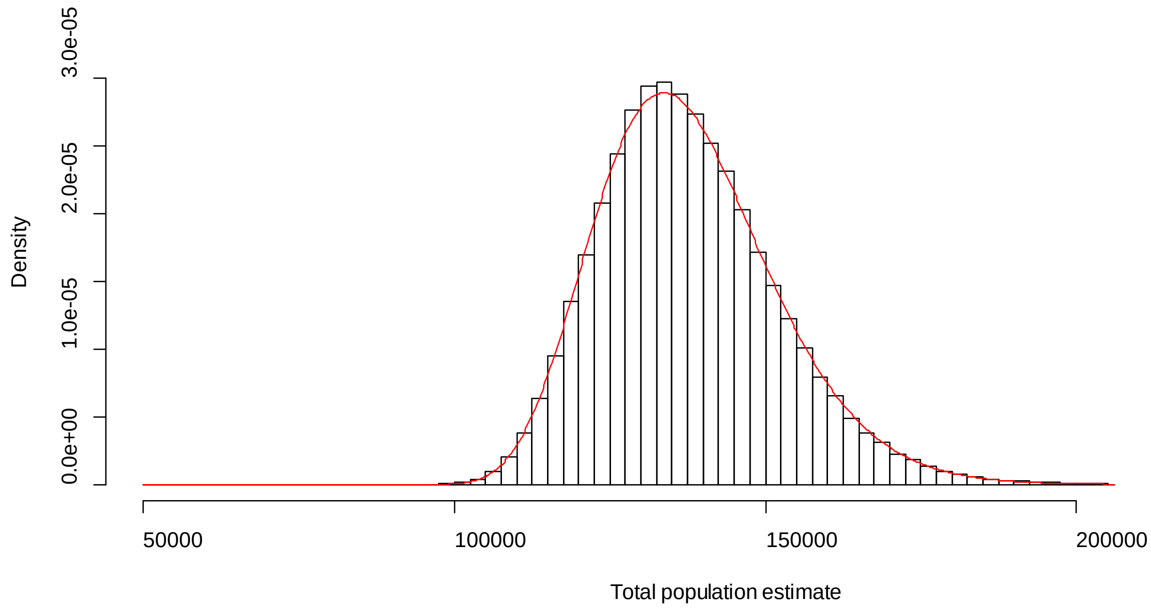


Figure 2. Posterior mean estimates of pup production (solid lines) and 95%CI (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 (circles) and the total population estimates from 2008 and 2014. Blue lines show the fit to pup production estimates alone; red lines show the fit to pup production estimates plus the total population estimate.

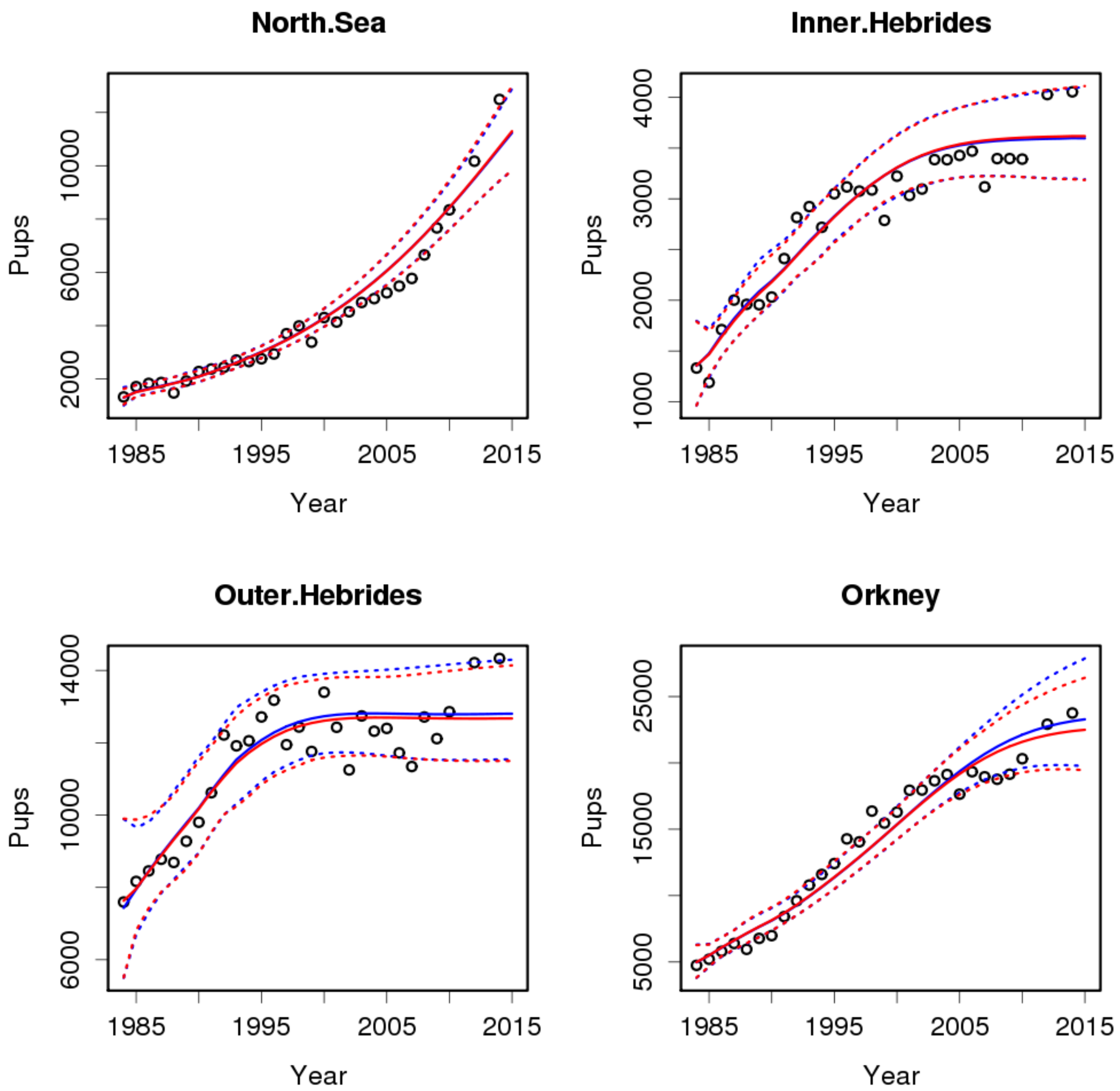


Figure 3. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2015 from the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 and total population estimates from 2008 and 2014 (circles, with vertical lines indicating 95% confidence interval on the estimates). Blue lines show the fit to pup production estimates alone; red lines show the fit to pup production estimates plus the total population estimates.

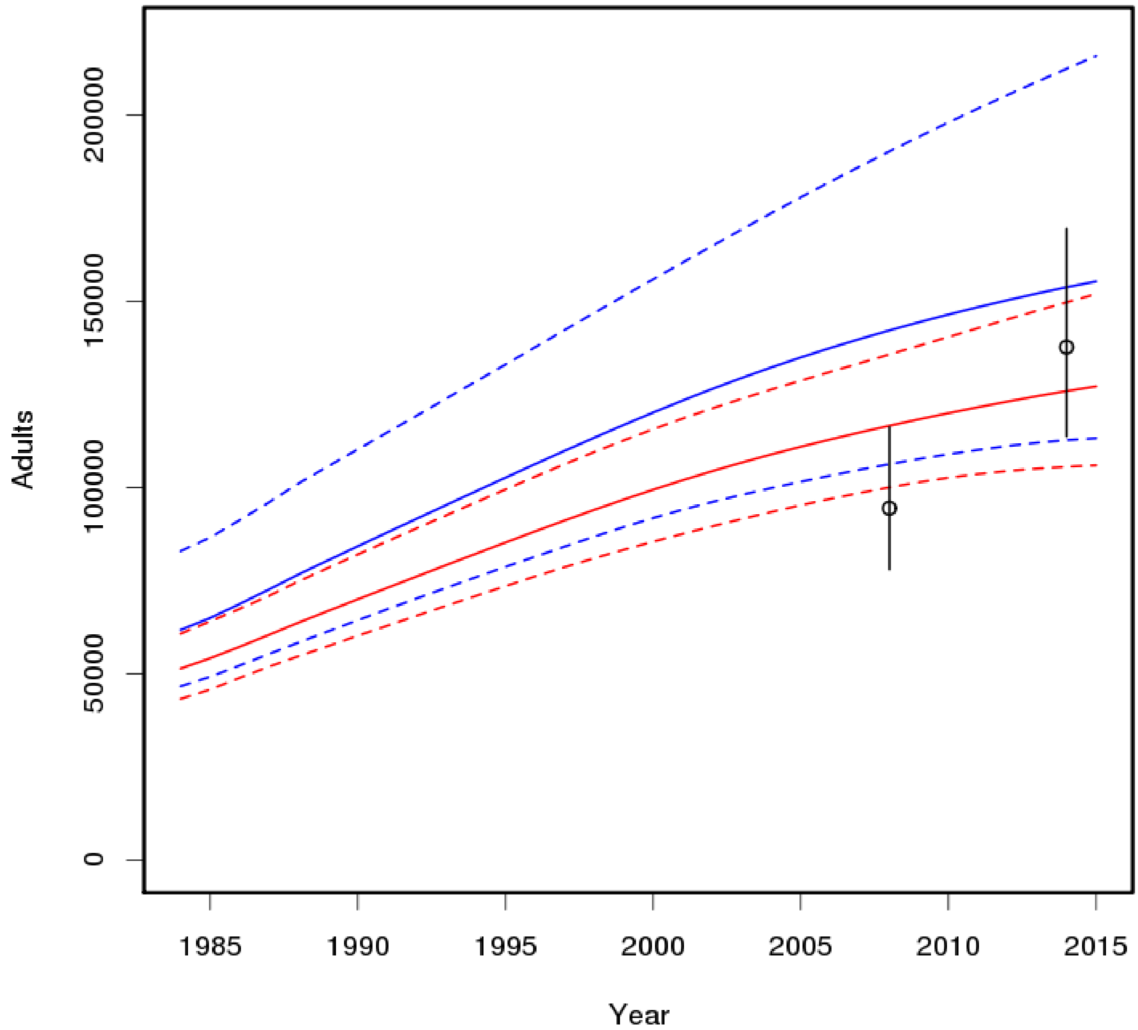
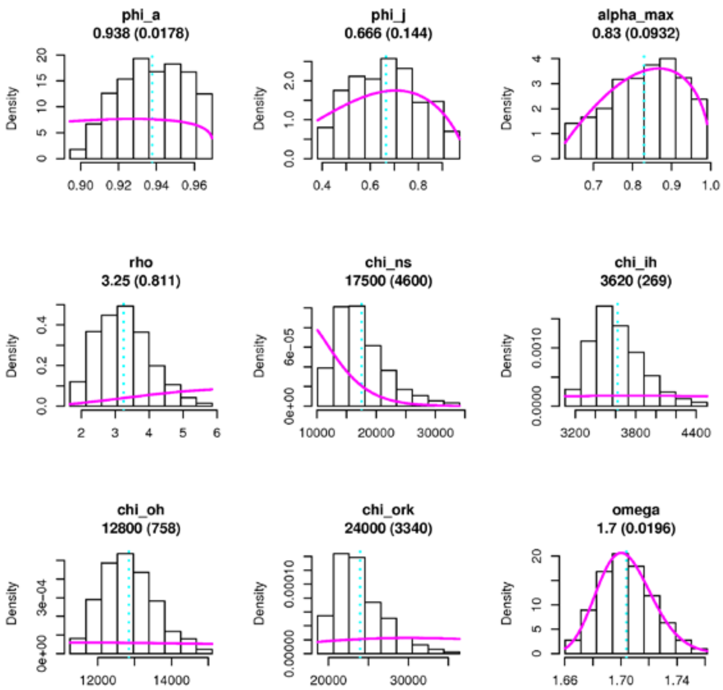
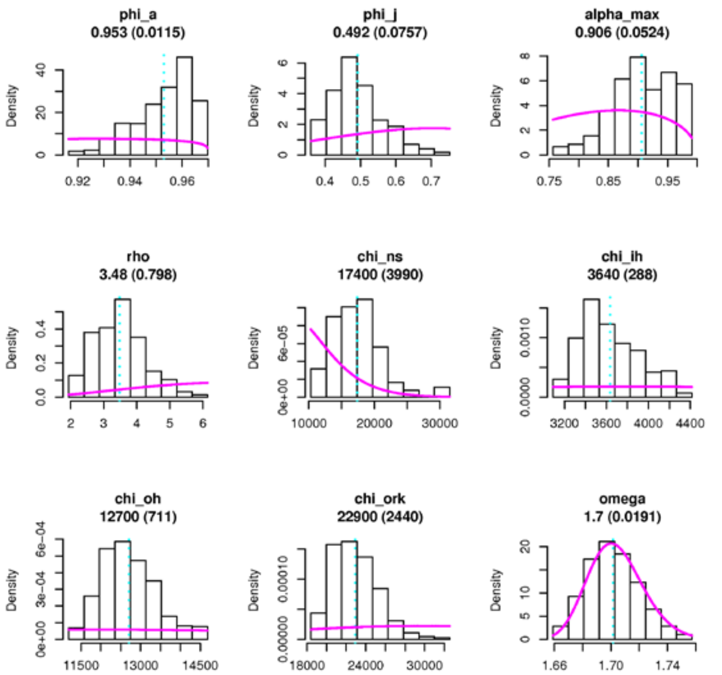


Figure 4. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 and total populations estimate from 2008 and 2014. The vertical dashed line shows the posterior mean; its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses.

(a) Pup production data alone



(b) Pup production data and 2008 and 2014 population estimates



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.

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)

Independent estimates of grey seal population size: 2008 and 2014

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Abstract

Aerial surveys of grey seal haul-out sites are conducted in August during the harbour seal moult, two hours either side of low tide. In conjunction with estimates of the proportion of the population hauled out from telemetry data, such counts can be used to provide an estimate of grey seal population size, independent of the estimates produced using a Bayesian age-structured model into which pup production estimates are input (Thomas 2016).

In a previous analysis, Lonergan *et al*. (2011) used telemetry data to estimate that 31% (95% CIs: 15 - 50%) of the population was hauled out during the survey window and thus available to count. This was combined with a count of 26,699 individuals from aerial surveys (mostly conducted between 2007 and 2009) across the UK (excluding South-west UK). Assuming 4% of the population were in South-west UK, this resulted to a UK independent population estimate in 2008 of 91,800 (95% CI: 78,400 - 109,900; Lonergan *et al.* 2011).

Here, the approach by which the telemetry data were used to calculate the proportion of the population available to count during the aerial surveys was reviewed. This resulted in a revised scalar of 23.9% (95% CI: 19.2 - 28.6%). As per the analyses of the previous scalar, no effect of region, length of individual, sex or time of day was found.

Between 2013 and 2015, another round of aerial surveys covered the UK grey seal haulout sites (excluding South-west UK); 34,817 individuals were counted. To maximise comparability between population estimates in 2008 and 2014, the counts used for the 2008 population estimate were recalculated using the same approach as used for count data underlying the 2014 population estimate, resulting in a total 2008 count of 24,151. Using these counts with the revised scalar, the total population estimates were 105,245 (95% CI: 87,797 – 130,856) and 151,725 (95% CI: 126,571 – 188,647) for 2008 and 2014, respectively. These estimates assume (as per Lonergan *et al.* 2011) that 4% of the population is in the South-west UK.

Additional work is required to ensure that as much uncertainty as possible in the estimated proportion of time hauled out is reflected in the variance of the scalar, and thus in the population estimate. Furthermore, although the analysis conducted by Lonergan *et al.* (2011) revealed no effect of environmental covariates, it would be prudent to re-examine this in light of the new estimate of the proportion of time hauled out.

Introduction

Aerial surveys are conducted in August during the harbour seal moult, two hours either side of low tide. These surveys were extended to cover additional grey seal haulout sites resulting in a comprehensive count of all grey seal haulout sites in the UK (excluding South-west UK). A small number of sites in Scotland and the NE coast of England were not counted, but the total for these sites is thought to be less than 200 seals. Surveys were largely carried out over a period of three years (2007-2009). Using telemetry data, Lonergan *et al.* (2011) calculated that 31% (95% CI: 15 - 50%) of seals would be hauled out during the survey window and thus available to count, resulting in a population estimate for the surveyed area of 88,300 (95% CI: 75,400 – 105,700). A multiplier of 1.04 was used to scale this up to the UK resulting in a total population estimate of 91,800 (95% CI: 78,400 – 109,900).

This independent estimate for 2008 is much lower than would be expected given the estimated UK pup production which (excluding South-west UK) was 44,931 in 2008 (Duck 2009). The pup production estimates were generated using multiple aerial survey counts or directly from ground counts (Duck & Morris 2016). Although, recent evidence suggests that pup production estimates resulting from aerial survey counts may be too high (Russell *et al.* 2015a), the ratio of pups counted to the total population estimate cast some doubt on the independent estimate. Here the methods used to calculate the proportion of the population hauled out and available to count during the aerial survey are reviewed and updated. In addition, recent tagging predominantly funded by the Department of Energy and Climate Change has led to telemetry data being available from an additional 20 individuals. Between 2013 and 2015, a comprehensive count of the grey seal haulout sites in the UK was conducted (excluding South-west UK) allowing generation of a new independent estimate of population size in 2014.

Materials and Methods

<u>Survey Data</u>

Surveys were conducted within two hours either side of low tide, for low tides which fell between 12:00 and 19:00 BST. Predominantly the surveys were conducted within the first three weeks of August. Seals were only counted if they are hauled out on land, i.e. seals visible in the water were not counted. The east coast of England, the Tay & Eden estuaries, and parts of the Moray Firth were surveyed using a fixed-wing airplane with oblique photography using a hand-held digital SLR. The rest of Scotland was surveyed in a helicopter at an altitude of around 250m, 300-500m offshore. In the helicopter surveys, seals were located using a thermal imager, and oblique photographs were taken using a hand-held DSLR (see Thompson, Lonergan & Duck 2005 and Lonergan *et al.* 2011 for more details). No uncertainty surrounding the counts was considered, as previous work (Thompson, Lonergan & Duck 2005) has suggested that the variability introduced by errors in the counting of animals is likely to be negligible compared to the variation in the proportion of seals hauled out.

Complete UK counts (excluding South-west UK) result from surveys conducted over multiple years; most of the counts are from a block of three years (survey block), from which the population estimate is assigned to the middle year (focal year). For the 2008 population estimate 97% of seals were counted between 2007 and 2009; the remaining 3% were counted in 2005 and 2006. For 2014 estimate, 93% were counted between 2013 and 2015; with the remaining 7% counted in 2011 and 2016.

In order to generate counts for 2014, the coast was split into up to five sub-regions or haulouts within nine management units (Southwest Scotland, West Scotland, Western Isles, North Coast & Orkney, Shetland, Moray Firth, East Scotland, North-east England and South-east England). These splits represented sub-regions which were, for the most part, completely counted on one survey. For example, South-east England was split into Donna Nook, The Wash, Blakeney Point, Scroby Sands and Essex & Kent. At this sub-region scale, if there was more than one complete survey conducted within August then the mean count was assigned to that sub-region for that year. For each sub-region a count was assigned to 2014, using a sequential process dependent on data availability (Table 1). Finally total counts were assigned to four regions, aggregates of the Management Units: Western Scotland, Western Isles, North Coast (including Orkney & Shetland) and the North Sea (Table 2). These regions match the regions considered in the population model (Thomas 2016), with the exception of North Coast as Shetland is not considered in the population model. They also match the regions considered in Lonergan *et al.* 2011, except that here the Moray Firth is included in North Sea rather than North Coast, and Shetland is included in North Coast. To maximise comparability between the two focal years, the count for 2008 was recalculated using the method described above.

<u>Telemetry data preparation</u>

Data from two types of telemetry tag were considered in this study: Argos SRDL (Satellite Relay Data Logger) tags and GPS/GSM phone tags that used Fastloc GPS. Telemetry data were used to estimate the proportion of time tagged individuals spent hauled out during the survey window, i.e. the proportion of the population available to count (Lonergan *et al.* 2011). On a telemetry tag, a haul out event is triggered once the wet/dry sensor on the tag has been dry for ten minutes. The haul out duration is then adjusted to include this ten minute period. All haul out events are recorded but not all are transmitted, although almost all haul out events recorded on GPS/GSM tags are transmitted. Haul out events are numbered sequentially starting at 0 and ending at a maximum number (dictated by the tag parameters); the number then restarts at 0. This numbering system allows missing haul out events to be detected: e.g. if haul outs 6, 7, 9, 10, 11 are present - haul out event 8 is missing. This essentially means that the respective time spent hauled out and at-sea between the 7 and 9 is unknown. If only that period of time was flagged as unknown then a bias would result because two at-sea events but only one haul out event would have been flagged. Thus the time spent in the next haul out event (in this case haul out 9) is also flagged as unknown. In effect two at-sea and haul out cycles are flagged as unknown. Thus for each individual, the time spent hauled out, at-sea, and flagged as unknown during the survey window can be used to calculate the proportion of population available to count.

Here the methods previously used are reviewed and updated – focussing on explaining the key differences between the previous methods (Lonergan *et al.* 2011) and those used here. All data preparation and analyses were conducted in R (R Core Team 2014).

Survey window

For the analyses of telemetry data, Lonergan *et al.* (2011) considered low tides that occurred between 08:00 and 18:00 BST, and associated survey windows within the same period. Thus entire survey windows were not always included - i.e. for low tides at 08:00, the survey window would only span 08:00 to 10:00, and for low tides at 18:00, the survey period would span 16:00 to 18:00. Thus the duration of the window considered varied (and the proportion of time hauled out within such windows was weighted evenly).

Investigation of the survey data revealed that surveys were conducted in association with low tides that fell between 12:00 and 19:00 BST with the survey windows falling between 10:00 and 21:00 BST. For the current analysis the above limits were used, and thus the survey windows were always 4 hours in duration. Low tide data was extracted from Poltips (The Proudman Oceanographic Laboratory, National Oceanography Centre).

Individuals considered

Here telemetry data were restricted to only include data from individuals for which there were data during the whole of August (cf. Lonergan *et al.* 2011). Seals can exhibit anomalous behaviour in the first week after tagging (McKnight 2011). Tags stop transmitting data for numerous reasons including animal death; an individual may exhibit anomalous behaviour near death. Thus tags which were deployed in or failed in August were excluded. Since Lonergan *et al.* (2011), there was one Argos tag and 19 GPS tags deployed for which there were data throughout August. This resulted in a total of 81

Argos tags (cf. 99 in Lonergan *et al.* 2011) and 25 GPS GSM tags (cf. 8 in Lonergan *et al.* 2011) available for analyses.

Temporal extent of data

Here and in Lonergan *et al.* (2011) the proportion of time spent hauled out during the survey window was considered for the whole of August. Due to the fact some haul out events are not transmitted, the difference in numbers between sequential transmitted haul out events was required to identify whether there were any haul outs between them. Thus the last haul out event in July and first in September is required to determine whether the time between these and the first and last haul out in August, respectively, was at-sea or unknown. In Lonergan *et al.* (2011) haul out events for August and the surrounding two days were retained at the start of the analysis. Grey seal trips can last up to a month and thus for many individuals the two day buffer on either side of August did not include a haul out. As a consequence the time to the first haul out in August and/or since the last haul out in August was often assigned as unknown. This resulted in at-sea time being wrongly assigned as unknown and thus an overestimate of the proportion of time hauled out and an underestimate of the population size. Here the last haul out prior to August and the first haul out after August was considered to allow accurate categorisation of at-sea, haul out, and unknown time.

Erroneous haul outs

The numbering of some haul outs is out of sequence (e.g. 6, 7, **16**, 8, 9). Such haul outs (e.g. 16) were thought to depict transmitted haul out events that were erroneously numbered (Lonergan *et al.* 2011). In the above example haul out 16 (erroneous) and haul out 8 (genuine) would have been flagged as unknown resulting in unknown time between the end of haul out 7 and the end of haul out 8. However, it has recently become apparent that such haul outs are actually erroneous – they have an error in the end time sent and should simply be removed. In the above example this would result in haul outs 6, 7, 8, and 9 being retained. Although in theory the previous approach should not have caused any bias as it simply resulted in the removal of an at-sea/haul out cycle, analyses suggests these erroneous haul outs did contribute to an overestimate of the proportion of time hauled out.

Haul outs that are out of sequence can occur due to non-transmitted or erroneous haul outs. Thus additional telemetry data were used to identify erroneous haul outs. The summary table (which provide data on the proportion of time hauled out, at-surface and diving at an interval of 2-6 hours), the dive table and the cruise table, were used to determine if any other activities had occurred during a potentially erroneous haul out. Due to the check sums in places, it is virtually impossible that an erroneous haul out record could have been transmitted more than once, thus the number of transmissions was also used to identify erroneous haul outs. In Argos tags, on average 1 in 230 haul out events were erroneous but their frequency of occurrence varied greatly with tag. Such erroneous haul outs are very rare in the GPS data.

At-sea haul outs

A telemetry tag records haul out events at sea if the tag is dry for over 10 minutes (Russell & Lonergan 2012). Such haul outs are particularly common if a tag is deployed on the head – such placement is sometimes preferred on large males due to scaring on the neck or to increase the frequency of locations at-sea. It is rarely possible to identify offshore haul outs in the Argos data due to the relatively low frequency of locations and the degree of error associated with locations (Vincent *et al.* 2002). In contrast, GPS locations are recorded more frequently than Argos and after cleaning, tests on land revealed that 95% of locations were accurate to within 50 m. A low tide map (Crown Copyright/SeaZone Solutions. All Rights Reserved. 1st April 2016) was generated and buffers around low tide of 1, 5 and 10 km were generated. The characteristics of GPS haul outs in these buffers were examined - rate of movement and haul out duration - rate of movement would be expected to be greater in the water compared to on land due to currents and duration would expected to be shorter on average as an individual on the surface of the sea may occasionally dive. This examination revealed that GPS haul outs located outside the 1 km buffer of the tidal zone were not the result of location error surrounding haul outs on land but the result of at-sea haul outs. Thus for GPS data, such haul outs were excluded if there was a location during the haul out. For GPS tags, 15% of haul outs were excluded; this percentage is likely to be particularly high because some GPS tags were deployed on the head. The previous inclusion of at-sea haul outs in Lonergan *et al.* (2011) likely contributed to an overestimate of the proportion of time hauled out.

Haul out adjustment

It was previously accepted that for SMRU SRDL and GPS telemetry tags, haul out events ended when the wet-dry sensor was wet for 40 seconds. However, thorough investigation of the telemetry data revealed that this is not the case. An issue in the tag programming means that an end time is not attributed to a haul out until a new event is started – a dive, haul out or a cruise (extended surface interval). A tag is defined as being at the surface if the wet/dry sensor is wet but the tag is above the dive threshold (1.5 to 6 m depending on tag parameters). A cruise is triggered once a tag has been at the surface for a specified period of time - for Argos tags, a cruise is triggered after 9-10 minutes but most GPS tags do not record cruises. Thus for GPS tags, a haul out can comprise haul out plus substantial at-surface time. This contributed to the overestimate of the proportion of time hauled out.

The proportion of time a tag is hauled out, at-surface and diving is recorded in the summary tables so the summary data can be used to correct haul out end times to remove the at-surface time. However due to the ten minute trigger for haul out events to be registered, if a haul out starts in the last ten minutes of a summary period, that haul-out time will be incorrectly assigned to the next summary period. For GPS tags, the proportion of time hauled out in the summary periods was adjusted so the first ten minutes of a haul out was assigned to the correct summary period. Location frequency decreases during a haul out event. Thus location frequency and adjusted summary tables were used to identify and adjust artificially long haul out events. This process could not be fully automated and thus was only undertaken for haul outs which spanned the survey window. Of the 172 haul outs which spanned the survey window, 37% required adjustment, with a median deduction of 28 minutes and a maximum deduction of 5 hours, 23 minutes. These adjustments were not conducted for Argos data due to the lack of haul out data (many haul out events are not transmitted) and the limited period of at-surface time before a cruise was triggered.

Duration of survey window

As a result of non-transmitted haul outs, some survey windows contain some unknown time. The proportion of time hauled out was previously calculated using the known time (at-sea and haul out combined; Lonergan *et al.* 2011). However, this resulted in varying survey window durations. Thus to ensure the survey window was constant (4 hours), here any survey window for which any time was flagged as unknown was excluded.

<u>Analysis of covariates</u>

The effect of covariates on the proportion of each low tide (day) hauled out was investigated using a generalised estimating equation (GEE) framework within the package geepack (Højsgaard, Halekoh & Yan 2006). The GEE framework allows the non-independence within individuals to be accounted for in the standard errors. The covariates included were timing of low tide (smooth), animal length (smooth), tag type (factor), region (factor), sex (factor), and day in August (smooth). The significance of terms was investigated through hypothesis testing within a backwards selection process.

<u>Estimating the Proportion of time hauled out</u>

The GPS data were almost entirely from one region (North Sea) and thus Argos data were required to investigate whether there were significant regional differences in the proportion of time hauled out. Once it had been demonstrated that there were no significant differences between regions, the Argos data were excluded. This was because, using the Argos data it was not possible to identify at-sea haul outs or to adjust haul outs to remove time at-sea on the surface (up to ten minutes for Argos tags), thus the proportion of time hauled out estimated for Argos data was likely to be an overestimate.

Using only GPS data, a non-parametric block bootstrap with replacement (100,000 samples) was conducted by individual, including all days containing a survey window, to estimate the mean and variance of the proportion of time hauled out. The bootstrap samples were also used to scale the total counts for 2008 and 2014 to population size. To account for seal population in South-west UK, these population estimates were multiplied by 1.04 (Lonergan *et al.* 2011) to obtain estimates for the UK population.

Results and Discussion

Timing of low tide, animal length, region, sex, tag type and day of August had no significant effect ($P>0.05$) on the proportion of time hauled out in the survey window. Considering GPS data only, the mean proportion of time hauled out was 23.9% (95% CI: 19.2 - 28.6%).

Using the methods described in 'Survey Data', a revised UK count (excluding southwest UK) of 24,151 grey seals was generated for 2008; this was approximately 2,500 seals less than reported by Lonergan *et al.* 2011. In the same way, a count of 34,817 was generated for 2014 (Table 2); a 44% increase compared to the total in 2008. Little change in numbers was observed in the Western Isles or the North Coast with changes of less than 10%. A large percentage increase occurred in West Scotland (96%) but this only represented a change of 2,665 individuals. The largest increase (8,141) occurred in the North Sea representing a 108% increase compared to 2008.

Using the revised scalar, the estimated population size for the surveyed area was 101,197 in 2008 (95% CI: 84,420 – 125,823) and 145,889 (95% CI: 121,703 - 181,391) in 2014 (Table 2). As per Lonergan *et al.* (2011), to account for seals in South-west UK which was not surveyed, the population estimates were multiplied by 1.04 to give a total UK estimate of 105,245(95% CI: 87,797 – 130,856) in 2008 and 151,725 (95% CI: 126,571– 188,647) in 2014.

Further work

Further work is required to ensure that as much uncertainty as possible in the estimated proportion of time hauled out is reflected in the variance of the scalar and thus in the population estimate. Preliminary investigations revealed that slight changes in the analytical method could result in considerable changes in the proportion of time hauled out. For example, the number of survey windows that are available when an individual is at-sea depends upon the timing of low tide and thus is dependent on a location. Currently, the last location at which the individual hauled out is used to determine the timing of low tide when they are at sea. However, it would be just as appropriate to use the next haul out location. The variation in the proportion of time hauled out resulting from changing whether the previous or next haul out was used should ideally be propagated into the variance surrounding the proportion of time hauled out.

The analysis conducted by Lonergan *et al.* (2011) revealed no effect of environmental covariates on the proportion of time hauled out. However, in light of the revised estimate it would be prudent to re-examine the effects of such covariates.

Using data from both Argos and GPS tags, there was no significant effect of region on the proportion of time hauled out. However, the Argos data had some potential biases (see above), the extent of which may have varied with region. Furthermore, the substantial proportion of missing haul outs resulted in a limited number of survey windows for which there were data, and consequentially a high variance surrounding the proportion of time hauled out (Lonergan *et al.* 2011). The GPS data are almost entirely based in the North Sea; tagging in the North Sea was conducted on sandy tidal beaches. Such habitat is in contrast to majority of haulout sites in other regions which are on rocky sites; haulout site habitat may affect the proportion of time hauled out during the survey window. The total time spent hauled out varies between North Sea and the other regions (Russell *et al.*

2015b), thus it would be sensible to deploy GPS tags on grey seals outwith the North Sea, to investigate any regional effect on the proportion of time hauled out during the survey window. In addition, although GPS location data could be used to identify haul outs which were likely to be at-sea (outwith a 1 km buffer of tidal zone), haul outs at-sea may also occur near shore, especially while individuals are waiting for tidal haulout sites to become exposed (although such behaviour would be limited within the survey window, 2 hours of low tide). Such at-sea haul outs cannot easily be identified due to the resolution of the low tide map, the changing extent of the tidal zone that is exposed and the error in GPS locations. It may be possible to attach a small device with a wet/dry sensor to the back of the seals with a Bluetooth connection to a GPS-GSM tag on the back of the neck. Alternatively, if accelerometry data were collected by the tags, there may be a distinguishable signal between haul outs on land and at sea. These methods would allow the frequency of which haul outs are wrongly assigned to being on land to be determined.

Finally, the proportion of the UK population in the non-surveyed South-West UK should be reviewed using available data.

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Table 1. The process undertaken to assign counts to the focal year (2008 or 2014).

Sequence	Definition of count
1	The mean of counts from complete surveys in all three years of the survey block
2	The count from a complete survey in the focal year (2008 or 2014)
3	The count from a complete survey in a year within the survey block
4	Combined complete counts from part-surveys from two years within survey block
5	Combined complete counts from part-surveys from one year within the survey block and one outwith the survey block (as close in time to the focal year as possible)
6	The count from a complete survey conducted in a year outwith the survey block (as close in time to the focal year as possible)

Table 2. Regional counts of grey seals conducted during the August aerial surveys, and the corresponding population estimates. The scalar used to convert counts to population estimates was the proportion of the population hauled out during the survey window estimated using telemetry data. The variance of around the scalar (and consequently the population estimate) results from a non-parametric bootstrap of day in August, nested within tagged individual. The total UK population is estimated by multiplying the count of the surveyed area by 1.04.

Region	Count		Population estimate (and 95% CIs)	
	2007-2009	2013-2015	2008	2014
Western Isles	3,808	4,065	15,956 (13,311– 19,839)	17,033 (14,209 - 21,178)
West Scotland	2,773	5,438	11,619 (9,693– 14,447)	22,786 (19,008 - 28,331)
North Coast, Orkney & Shetland	10,061	9,664	42,157 (35,168– 52,416)	40,494 (33,780 - 50,348)
North Sea	7,509	15,650	31,464 (26,248– 39,121)	65,576 (54,704 - 81,534)
Surveyed regions	24,151	34,817	101,197 (84,420–125,823)	145,889 (121,703 - 181,391)
UK total			105,245 (87,797 – 130,856)	151,725 (126,571– 188,647)

The status of UK harbour seal populations in 2015, including summer counts of grey seals

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Abstract

In August 2015, during the harbour seal moult, the Sea Mammal Research Unit (SMRU) thermal image surveys covered the north-east coast of Northumberland and the south-east coast of Scotland, the west and south-west coast from the Firth of Lorn to the Solway Firth, and Shetland. The Firth of Tay and Eden Estuary and the inner part of the Moray Firth were also surveyed. The SMRU 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, 2015). 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 2015, the minimum number of harbour seals counted in Scotland was **25,399** and in England & Wales **4,869** making a total count for Great Britain of **30,268** (Table 1). Including **948** harbour seals counted in Northern Ireland in 2011, the UK harbour seal total count for this period was **31,216**.

From August surveys carried out between 2011 and 2015, the minimum number of grey seals counted in Scotland was **23,353** and in England & Wales **13,880** making a total count for Great Britain of **37,233** (Table 2). Including **468** grey seals counted in Northern Ireland in 2011, the UK grey seal total count for this period was **37,701**.

In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn), the moult count was the second lowest ever recorded for this area. The severe decline in the Firth of Tay & Eden Estuary harbour seal SAC continued, with the 2015 moult count (60) being twice the number counted in 2014 (29). The 2015 count suggests that only 6% of the average population counted between 1990 and 2002 currently remain within this harbour seal SAC. No additional declines have been identified in other parts of the UK, for which new data are available (i.e. east coast of England, West Scotland), where populations seem to be stable or possibly even increasing.

A new round-Scotland survey was started in August 2016.

Introduction

Most surveys of harbour seals are carried out in August, during their annual moult. At this time of 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. A new round-Scotland survey started in 2011 and was completed in 2015. A complete survey of Northern Ireland and the Republic of Ireland was carried out in 2011 and 2012.

In England, the Lincolnshire and Norfolk coast holds approximately 90% of the English harbour seal population and is usually surveyed twice annually during the August moult. Since 2004, additional breeding season surveys (in early July) of harbour seals in 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 2015 by the Thames Harbour Seal Conservation Project, run by the Zoological Society of London.

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. The thermal imager can detect groups of seals at distances of over 3km. This technique enables rapid, thorough and synoptic surveying of complex coastlines. In addition, 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 group composition. The grey seal counts from these images have previously been used to inform the models used to estimate the total grey seal population size (Lonergan *et al*. 2011, SCOS BP 10/4).

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 16th and 19th August 2015 (Barker & Obregon, 2015).

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 2015 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 2015) for UK seal management units (SMUs) 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 2015, is **25,399** (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) while counts in the West Scotland Seal Management Area appear to have increased.

The most recent minimum estimate for England & Wales, obtained from surveys carried out mainly in 2015, is **4,869** (Table 1). This is 21% higher than the 2007-2009 count (4,032) and 48% 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 in 2002 (1,267).

The sum of all the most recent counts carried out between 2007 and 2014 gives a UK total count of **31,216** 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 2014 is shown in Figure 2. 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 2015 is **23,353** (Table 2). This is 23% higher than the total Scotland count of 18,968 from August surveys between 2007 and 2009.

There were **13,880** grey seals counted in eastern England in 2008 to 2015 and, combined with an estimate of 1,302 in West England & Wales and the 2011 count of **468** in Northern Ireland (Table 2) gives a most recent UK total count of grey seals in August of **37,701**.

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

The parts of Scotland surveyed in August 2015 comprised the south-east, west and south-west coast of Scotland (from the Firth of Lorn to the Solway Firth) and Shetland. Details of the survey can be found in the Scottish Natural Heritage (SNH) Commissioned Report No. 929 (Duck & Morris, 2016).

Figure 3 shows when each part of the Scottish coast was last surveyed between 2008 and 2015. Areas surveyed in 2015 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 2015, 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 2015 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 2015, 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 East Scotland, south - harbour seals

The southern part of East Scotland, from the Border to Aberlady Bay was surveyed on 3 August 2015. No harbour seals were seen on this section of coast. From surveys carried out in 2013 and 2015, there were **224** harbour seals in East Scotland compared with 283 counted between 2007 and 2009 and 764 counted in 1997 (Table 1). The East Scotland harbour seal count declined by 21% between 2007/9 and 2013/15, equivalent to an annual average decline of 3.8%.

2.1.1 East Scotland, south - grey seals

In August 2015, 26 grey seals were counted between the Border and Aberlady Bay, giving a total count for East Scotland of **2,296** (Table 2).

2.2 West Scotland

2.2.1 West Scotland - harbour seals

The current count of harbour seals in the large West Scotland Management Area is **15,184** from surveys carried out in 2013, 2014 and 2015 compared with 10,626 from the previous survey carried out between 2007 and 2009 and 8,811 from surveys in 1996 and 1997 (Table 1). The West Scotland harbour seal count increased by 43% between 2009 and 2015, equivalent to an average annual increase of 5.3%.

2.2.2 West Scotland - grey seals

The current grey seal count for the West Scotland Seal Management Area is **5,064** from surveys carried out in 2013, 2014 and 2015 compared with 2,515 from surveys carried out between 2007 and 2009 and 3,435 from surveys carried out in 1996 and 1997 (Table 2).

2.2.3 West Scotland – North - harbour seals

Most of West Scotland - North was surveyed in August 2013 (Duck & Morris, 2014). The remaining small section, from the head of Loch Broom to Rubha Reidh, was surveyed in 2014. A total of **1,115** harbour seals were counted in 2013 and 2014 compared with 692 in 2008 (Table 1). This represents an overall increase of 61% or an average annual increase of 8.3% and is in marked contrast to the declines in harbour seals numbers observed in Orkney and the North Coast, in Shetland and on the East Coast.

2.2.4 West Scotland – North - grey seals

In West Scotland - North, **390** grey seals were counted in 2013 and 2014 compared with 177 counted in 2008 and 379 counted in 1996 (Table 2).

2.2.5 West Scotland – Central - harbour seals

All of West Scotland - Central was surveyed in August 2014. A total of **6,424** harbour seals were counted compared with 4,004 counted in 2007 and 2008 (Table 1). This represents an overall increase of 60% or an average annual increase of 8.2%, very similar to that observed in West Scotland - North. The highest count of harbour seals was recorded in 13 of the 16 subregions that comprise West Scotland - Central.

2.2.6 West Scotland – Central - grey seals

In West Scotland - Central, **1,056** grey seals were counted in August 2014 compared with 561 in 2007 and 2008 and 931 in 1996 and 1997 (Table 2).

2.2.7 West Scotland – South - *harbour seals*

In West Scotland – South, a total of **7,645** harbour seals were counted in 2014 and 2015 compared with 5,930 in 2007 and 2009 (Table 1). This represents an overall increase of 29% over seven years or an average annual increase of 3.7%.

2.2.8 West Scotland – South - *grey seals*

In West Scotland – South, a total of **3,618** grey seals were counted in 2014 and 2015 compared with 1,777 counted in 2007 and 2009 and 2,125 counted in 1996.

2.3 Southwest Scotland

2.3.1 Southwest Scotland - harbour seals

All of Southwest Scotland, from the southern tip of the Mull of Kintyre to the Solway Firth, was surveyed in August 2015. A total of **1,200** harbour seals were counted compared with 923 counted in 2007 and 2009 (Table 1). This was the highest count of harbour seals for the Southwest Scotland Seal Management Area. Most seals were in the Firth of Clyde (97%) with the remainder in Dumfries and Galloway.

2.3.2 Southwest Scotland - grey seals

In 2015, **374** grey seals were counted in Southwest Scotland compared with 233 counted in 2007 and 2009 and 75 counted in 1996 (Table 2). Of these, 81% were counted in the Firth of Clyde (Table 6).

2.4 Shetland

Shetland, including Foula but excluding Fair Isle, was surveyed between 10 and 12 August 2015.

2.4.1 Shetland - harbour seals

A total of **3,369** harbour seals were counted in 2015 (Table 1) compared with 3,039 in 2009 (Duck & Morris 2016) and 5,994 in 1997 (Table 1). 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 is of particular interest as it shows the first increase since 1993 (Figure 5), following a period of decline (Lonergan et al., 2007).

2.4.1 Shetland - grey seals

In Shetland in 2015, **1,558** grey seals were counted compared with 1,536 in 2009 (Duck & Morris 2016) and 1,724 in 1997 (Table 2).

2.5 Moray Firth

Detailed breeding and moulting season ground-counts of harbour seals in inner subarea of the Moray Firth (from Loch Fleet to Ardersier) were collected annually by Aberdeen University's Lighthouse Field Station between 1988 and 2005. These ground-based counts are shown in Figure 8 (moulting season counts) and Figure 9 (breeding season counts, excluding pups). SMRU's aerial survey counts for the same areas are included, together with counts from adjacent haul-out sites which lie to the north-east of Loch Fleet and to the east of Ardersier (harbour seals in Table 3 and Figure 7; grey seals in Table 4). A detailed view of the part of the Moray Firth surveyed annually by SMRU, between Helmsdale and Findhorn, together with the August counts of harbour and grey seals in 2015, is shown in Figure 10.

2.5.1 Moray Firth - harbour seal moult season counts (August)

SMRU's August aerial surveys of harbour seals in the Moray Firth started in August 1992 and the counts, together with ground counts by the University of Aberdeen, are shown in Table 3 with the trends in two different parts of the Moray Firth in Figure 8. SMRU counts represent a combination of both thermal imaging and fixed-wing surveys of the area. Between the early/mid-1990s and 2005/6, counts indicated a decline in the Moray Firth harbour seal population. This may, at least in part, have been due to a bounty system for seals which operated in the area at the time (Thompson *et al*., 2007; Matthiopoulos *et al*., 2014). There is considerable variability in the August total counts for the entire Moray Firth although there seems to have been a steady decline in counts between Loch Fleet and Ardersier in recent years which is less obvious in the larger area, between Helmsdale and Findhorn.

In the Moray Firth SMA, **745** harbour seals were counted in 2013 and 2015. The count for the coast between Loch Fleet and Ardersier (354) was the lowest recorded by SMRU (Table 3), including the lowest count for the Cromarty Firth. In contrast, the highest count of harbour seals at Culbin and Findhorn was recorded (Table 3).

Numbers between Helmsdale and Brora and at Ardersier have been very low in the past two years while numbers in Loch Fleet have increased since approx. 2009. Numbers in the Dornoch Firth have declined, numbers in the Cromarty Firth have been more variable since 2010 than previously, numbers in the Beauly Firth have declined dramatically, numbers at Culbin have increased dramatically, new haul-out sites have established at Milton and in Munlochy Bay. The causes for these changes have not been identified, but some are likely to be simple redistribution.

2.5.2 Moray Firth - grey seal counts (August)

SMRU counted **1,917** grey seals in the Moray Firth SMA in August (Table 4). This was the highest grey seal count recorded by SMRU for the Moray Firth and included 743 grey seals at Culbin and Findhorn.

2.5.3 Moray Firth - harbour seal breeding season counts (June & July)

During the 2015 breeding season, SMRU completed only two aerial surveys of harbour seals in the Moray Firth on the 17th and 30th June. Adverse weather conditions and limited pilot availability prevented additional surveys from taking place. The mean number of adults counted during these surveys, with standard errors, is shown in Figure 10. Following a long period of decline in breeding season haul-out group size from 1993 to 2007 and an increase in 2009 and 2010, numbers have declined in recent years, especially at haul-out sites between Loch Fleet and Arderseir. As during the moult, this is partly due to a significant reduction in seals using the Beauly Firth which used to be the main pupping site in the Moray Firth. Whereas the maximum pup count for the Beauly Firth in 2010 was 172, it has never been higher than 10 since 2013. The mean adult count for the 2015 Moray Firth breeding season surveys, between Helmsdale and Findhorn, was **601**, 7.0% lower than the 2014 count of 646 (7% lower). The 2015 mean adult count, between Loch Fleet and Ardersier, was 355 compared with 422 in 2014 (16% lower).

2.6 Firth of Tay & Eden Estuary Special Area of Conservation (SAC)

The Firth of Tay and Eden Estuary SAC is shown in Figure 12 with the distribution and numbers of harbour seals counted during the August 2015 survey.

The 2015 harbour seal moult count for the SAC (60) was 52% higher than the 2014 count of 29 (Figure 14; Table 5). The 2015 count represents only 9% of the mean of counts between 1990 and 2002 (641). Counts since 2010 were all below 100. 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 numbers of grey seals counted in the Firth of Tay & Eden Estuary SAC during harbour seal moult surveys are in Table 6.

3. Harbour seal surveys in England & Wales

3.1. England & 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 2015 count for Northeast England was 100, a combined count from 2008 (Holy Island) and 2015 (Tees Estuary). 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, with the August 2015 mean count of 91 being the highest since recording began in 1988 (Bond, 2015).

Two aerial surveys of harbour seals were carried out by SMRU in Lincolnshire and Norfolk during August 2015 (Table 7). The 2015 count for the coast between Donna Nook and Scroby Sands (4,289) was slightly higher than the 2014 count (4,192). The Zoological Society of London surveyed the wider Thames Estuary between Hamford Water (in Essex) and Goodwin Sands (off the Kent coast) and counted 451 harbour seals (Barker & Obregon, 2015), slightly fewer than in 2014 (489).

The combined counts for the Southeast England Management Unit (Flamborough Head to Newhaven) in 2015 (4,740) was very similar to the 2014 count (4,685; 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 last 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, 26,576 in 2014; Galatius *et al*., 2014; 2015).

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 various different sources listed in the Table.

3.2. England & Wales – harbour seal breeding season counts (June & July)

The only regular harbour seal breeding season surveys in England & Wales are the annual SMRU aerial surveys around The Wash. Five surveys were carried out between 16 June and 17 July 2015. The peak count of older seals (1+ age classes) was 4,539 on 3 July with 1,242 pups while the peak pup count was 1,351 on 27 June with 4,238 older seals. For comparison, peak counts from recent previous surveys were: 4,020 older seals and 1,802 pups on 30 June 2014, 1,308 pups and 3,345 older seals in 2013 and 1,496 pups with 3,551 older seals in 2012.

Estimated peak pup counts have increased at an average rate of 8% p.a. since 2003 although there is considerable variation about the fitted exponential (R^2=0.87).

4. UK harbour seal surveys in 2016

4.1 Harbour seal surveys in 2016 – breeding season

Only one of four breeding season fixed-wing surveys planned for the Moray Firth in June and July 2016 was completed due to adverse weather conditions. The results will be presented to SCOS in 2017.

Five breeding season fixed-wing surveys were carried out around The Wash in June and July 2016. The results will be presented to SCOS in 2017.

4.2 Harbour seal surveys in 2016 – moult season

A new round-Scotland survey started in 2016. Orkney and the north coast were surveyed but weather conditions prevented the Western Isles from being surveyed. Most of the Moray Firth and the east coast of Scotland were surveyed instead.

In Southeast England SMRU intends to carry out two August surveys of the coast between Donna Nook and Scroby Sands.

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

Seal Management Unit / Country		Harbour seal counts 2011-2015		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)
3 Western Isles		2,739	(2008; 2011)	1,804	(2008)		2,820	(1996)
4 North Coast & Orkney		1,938	(2013)	2,979	(2008-2009)		8,787	(1997)
5 Shetland		3,369	(2015)	3,039	(2009)		5,994	(1997)
6 Moray Firth		745	(2008; 2011; 2013; 2015)	776	(2007-2009)		1,409	(1997)
7 East Scotland		224	(2013; 2015)	283	(2007; 2010)		764	(1997)
SCOTLAND TOTAL		**25,399**	(2011; 2013-2015)	**20,430**	(2007-2009)		**29,514**	(1996-1997)
8 Northeast England	b	91	(2008; 2015)	58	(2008-2009)	*	54	(1997)
9 Southeast England	c	4,740	(2015)	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		**4,869**	(2008; 2015)	**4,032**	(2008-2009)		**3,289**	(1995; 1997)
BRITAIN TOTAL		**30,268**	(2008; 2011; 2013-2015)	**24,462**	(2007-2009)		**32,803**	(1995-1997)
NORTHERN IRELAND TOTAL	e	**948**	(2011)	**1,101**	(2002; 2008)			
UK TOTAL		**31,216**	(2008; 2011; 2013-2015)	**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, 2015). 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 2015 collected and provided by the Zoological Society London (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 Ireland by Seal Management Unit compared with two previous periods. Grey seal summer counts are known to be more variable than harbour seal summer counts. Caution is therefore advised when interpreting these numbers.

Seal Management Unit / Country		Grey seal counts 2011-2015		2007-2009		1996-1997	
1 Southwest Scotland		374	(2015)	233	(2007; 2009)	75	(1996)
2 West Scotland	a	5,064	(2013-2015)	2,515	(2007-2009)	3,435	(1996-1997)
3 Western Isles	*	4,038	(2008; 2011)	3,808	(2008)	4,062	(1996)
4 North Coast & Orkney		8,106	(2013)	8,525	(2008-2009)	9,427	(1997)
5 Shetland		1,558	(2015)	1,536	(2009)	1,724	(1997)
6 Moray Firth		1,917	(2008; 2011; 2013; 2015)	1,113	(2007-2009)	551	(1997)
7 East Scotland		2,296	(2013; 2015)	1,238	(2007; 2010)	2,328	(1997)
SCOTLAND TOTAL		**23,353**	(2011; 2013-2015)	**18,968**	(2007-2009)	**21,602**	(1996-1997)
8 Northeast England	b	6,942	(2008; 2015)	2,350	(2008-2009)		
9 Southeast England	c	5,637	(2015)	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		**13,880**	(2008; 2015)	**5,289**	(2008-2009)		
BRITAIN TOTAL		**37,233**	(2008; 2011; 2013-2015)	**24,257**	(2007-2009)		
NORTHERN IRELAND TOTAL	e	**468**	(2011)	**243**	(2002; 2008)		
UK TOTAL		**37,701**	(2008; 2011; 2013-2015)	**24,501**	(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, 2015). 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 2015 collected and provided by the Zoological Society London (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; Büche & 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 reporting.
- 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).

* 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, 1992-2015. Mean value if more than one count in any year; red = lowest count, green = highest count. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys incorporated hand-held oblique digital photography. See Figure 10 for a map showing the 2015 distribution of seals in the Moray Firth and Figure 7 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
	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
(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
	Loch Fleet		16		27	33	59	56	64	71	80	83	82	65	114	113	133	135	156	144
	Dornoch Firth (SAC)	662		542	593	405	220	290	231	191	257	144	145	166	219	208	157	143	111	120
	Cromarty Firth	41		95	95	38	42	113	88	106	106	102	90	90	140	101	144	63	100	22
	Beauly Firth (incl. Milton & Munlc	220		203	219	204	66	151	178	127	176	146	150	85	140	57	60	30	37	34
	Ardersier (incl. Eathie)			221	234	191	110	205	202	210	197	154	145	277	362	195	183	199	28	34
	Culbin & Findhorn			58	46	111	144	167	49	93	58	79	92	73	123	163	254	218	260	330
	Burghead to Fraserburgh			0	1					3		0				29		39		
	Dornoch Firth to Ardersier			1,061	1,141	838	438	759	699	634	736	546	530	618	861	561	544	435	276	210
TOTALS	Loch Fleet to Ardersier				1,168	871	497	815	763	705	816	629	612	683	975	674	677	570	432	354
	Loch Fleet to Findhorn				1,214	982	641	982	812	798	874	708	704	756	1,098	837	931	788	692	684
	Helmsdale to Findhorn				1,407		829			911	1,024	762	777	775	1,199	924	1,033	858	693	705
	Moray Firth SMA *				1,409		831			915	1,028	763	778	776	1,200	954	1,063	898	733	745

* 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, 1992-2015. Mean value if more than one count in any year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys were by hand-held oblique digital photography. See Figure 10 for a map showing the 2015 distribution of seals in the Moray Firth.

	Area	1992	1993	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	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
(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
	Loch Fleet		0		0	0	0	0	0	0	1	3	1	0	7	7	20	18	7	10
	Dornoch Firth (SAC)	233		903	456	121	321	79	473	431	748	516	523	819	717	679	74	604	127	716
	Cromarty Firth	9		0	0	0	0	0	0	0	1	0	0	0	1	2	1	3	1	0
	Beauly Firth (incl. Milton & Munlc	8		2	3	8	0	0	0	0	3	4	0	0	2	3	1	5	2	0
	Ardersier (incl. Eathie)			36	24	85	0	3	44	55	142	74	142	94	297	74	24	109	2	14
	Culbin & Findhorn			0	0	0	0	10	0	11	11	28	75	58	58	179	121	218	93	743
	Burghead to Fraserburgh			30	65					205		61				18		258		
TOTALS	Dornoch Firth to Ardersier			941	483	214	321	82	517	486	894	594	665	913	1,017	758	100	721	132	730
	Loch Fleet to Ardersier				483	214	321	82	517	486	895	597	666	913	1,024	765	120	739	139	740
	Loch Fleet to Findhorn				483	214	321	92	517	497	906	625	741	971	1,082	944	241	957	232	1,483
	Helmsdale to Findhorn				486		327			608	1,008	677	1,190	1,043	1,717	1,100	557	1,038	259	1,644
	Moray Firth SMA †				551		392			872	1,272	797	1,260	1,113	1,787	1,133	590	1,311	532	1,917

* 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.

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

Table 5. August counts of harbour seals in the Firth of Tay & Eden Estuary harbour seal SAC, 1990-2015. Mean value if more than one count in any year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys were by hand-held oblique digital photography. See Figure 11 for a map showing the 2014 distribution of harbour seals in the SAC and Figure 12 for a histogram of these data.

Area	1990	1991	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Survey method	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	1fw	2fw ,1ti	1fw	1fw ,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw
(MEAN) COUNTS																				
Upper Tay	27	73	148	89	113	115	51	83	134	91	91	63	49	45	41	16	40	36	21	51
Broughty Ferry	77	83	97	64	35	52	0	90	55	51	31	27	13	28	15	18	16	3	0	2
Buddon Ness	13	86	72	53	0	113	109	142	66	25	96	64	27	8	23	11	8	10	1	3
Abertay & Tentsmuir	319	428	456	289	262	153	167	53	126	63	34	31	50	8	9	0	5	0	0	0
Eden Estuary	31	0	0	80	223	267	341	93	78	105	90	90	83	22	36	32	19	1	7	4
SAC total	467	670	773	575	633	700	668	461	459	335	342	275	222	111	124	77	88	50	29	60

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 & Eden Estuary harbour seal SAC, 1990-2015. Mean value if more than one count in any year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys were by hand-held oblique digital photography. See Figure 11 for a map showing the 2014 distribution of seals in the SAC and Figure 13 for a histogram of these data.

Area	1990	1991	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Survey method	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	1fw	2fw ,1ti	1fw	1fw ,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw
(MEAN) COUNTS																				
Upper Tay	0	0	18	20	61	64	78	50		42	22	27	26	55	98	16	39	127	62	115
Broughty Ferry	0	3	0	9	0	0	0	16		0	8	1	8	0	0	2	3	0	2	0
Buddon Ness	0	0	1	104	0	101	0	33		11	25	85	7	0	12	22	13	18	0	2
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
Eden Estuary	0	0	16	0	10	0	25	4		27	57	31	33	0	39	17	36	14	39	32
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

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, 1988-2015. In years where more than one survey was carried out, values are means with number of surveys in parentheses. Blank grey cells mean '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		91 (31)	228 (2)	3,336 (2)	455	270 (2)	451

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. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2015). Single SMRU fixed-wing count in 1994.
Southeast England - All SMRU aerial surveys, except for Essex & Kent 2013-2015: data from surveys (aerial/by boat/from carried out by the Zoological Society of London (Barker & Obregon, 2015). 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, 1995-2015. In years where more than one survey was carried out, values are means with number of surveys in parentheses. Blank grey cells mean '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	6,926	16 (31)	3,766 (2)	369 (2)	528	520 (2)	454

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. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2015). 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 2013-2015: data from surveys (aerial/by boat/from carried out by the Zoological Society of London (Barker & Obregon, 2015).

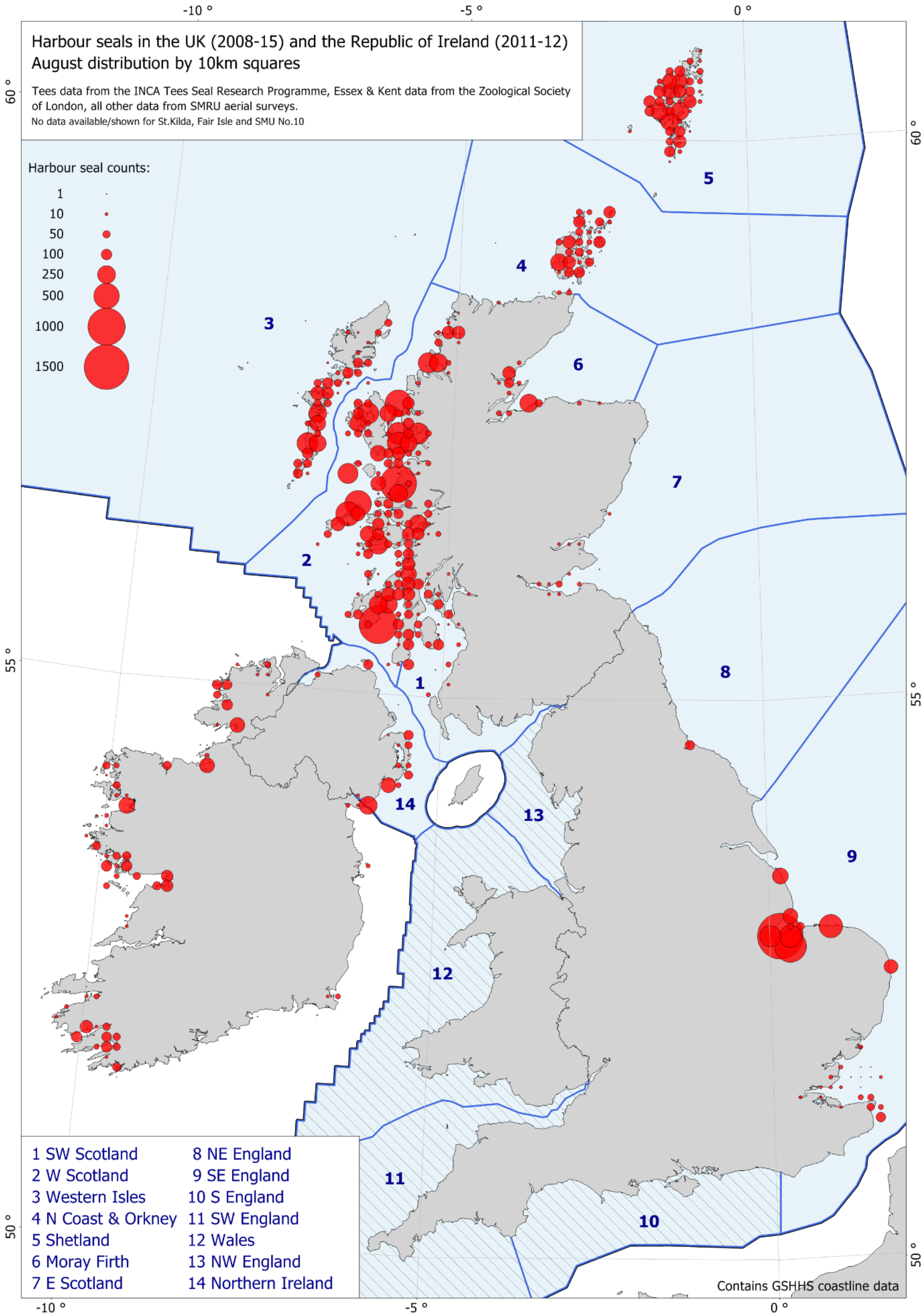

Figure 1. August distribution of harbour seals around the British Isles. Very small numbers of harbour seals (<50) are anecdotally but increasingly reported for the Management Units 10-13, but are not included on this map.

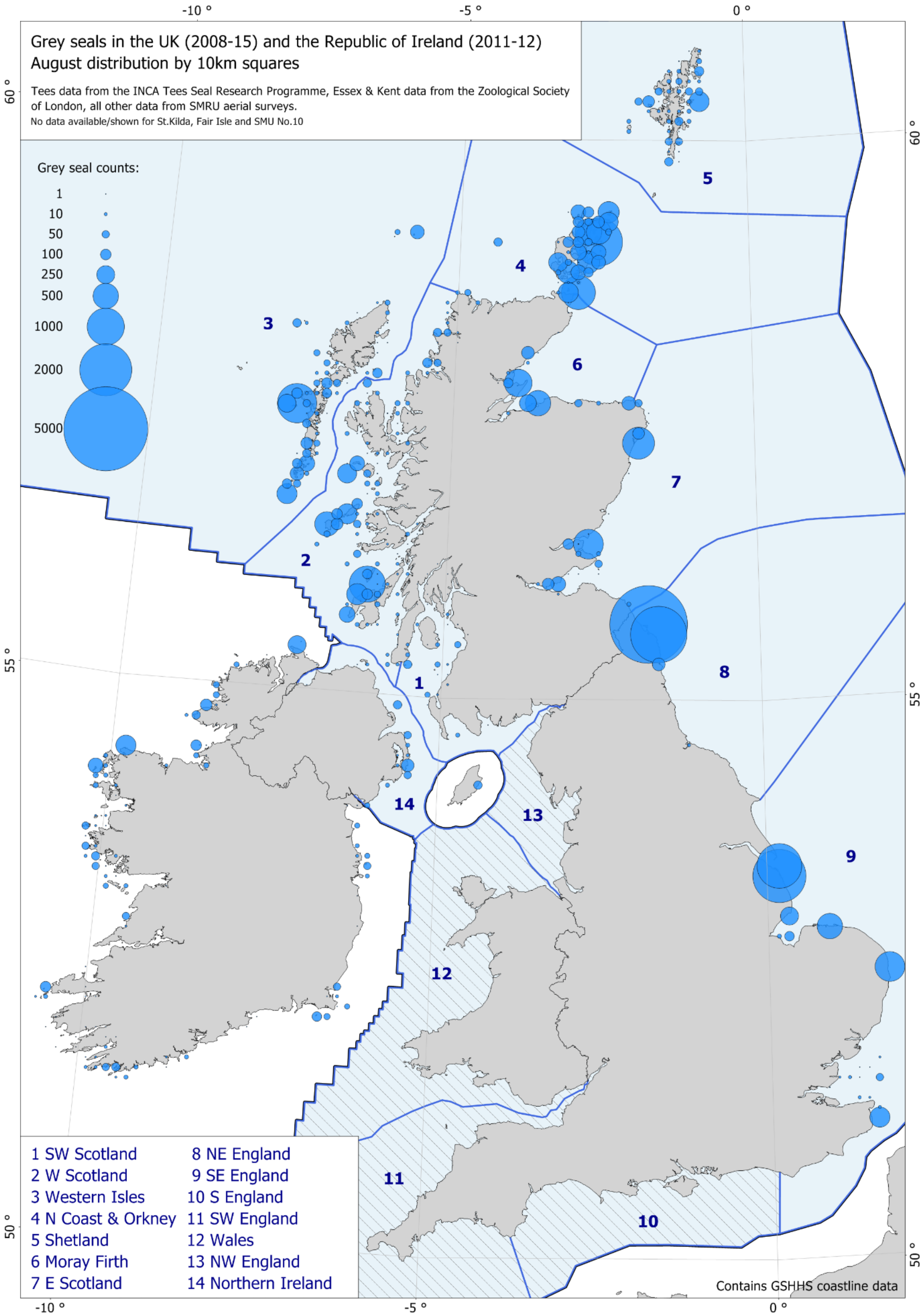

Figure 2. August distribution of grey seals around the British Isles. Only few August counts are available for grey seals in the Management Units 10-13. Current estimates would add approximately 1,300 animals for this Unit, but these are not included on this map.

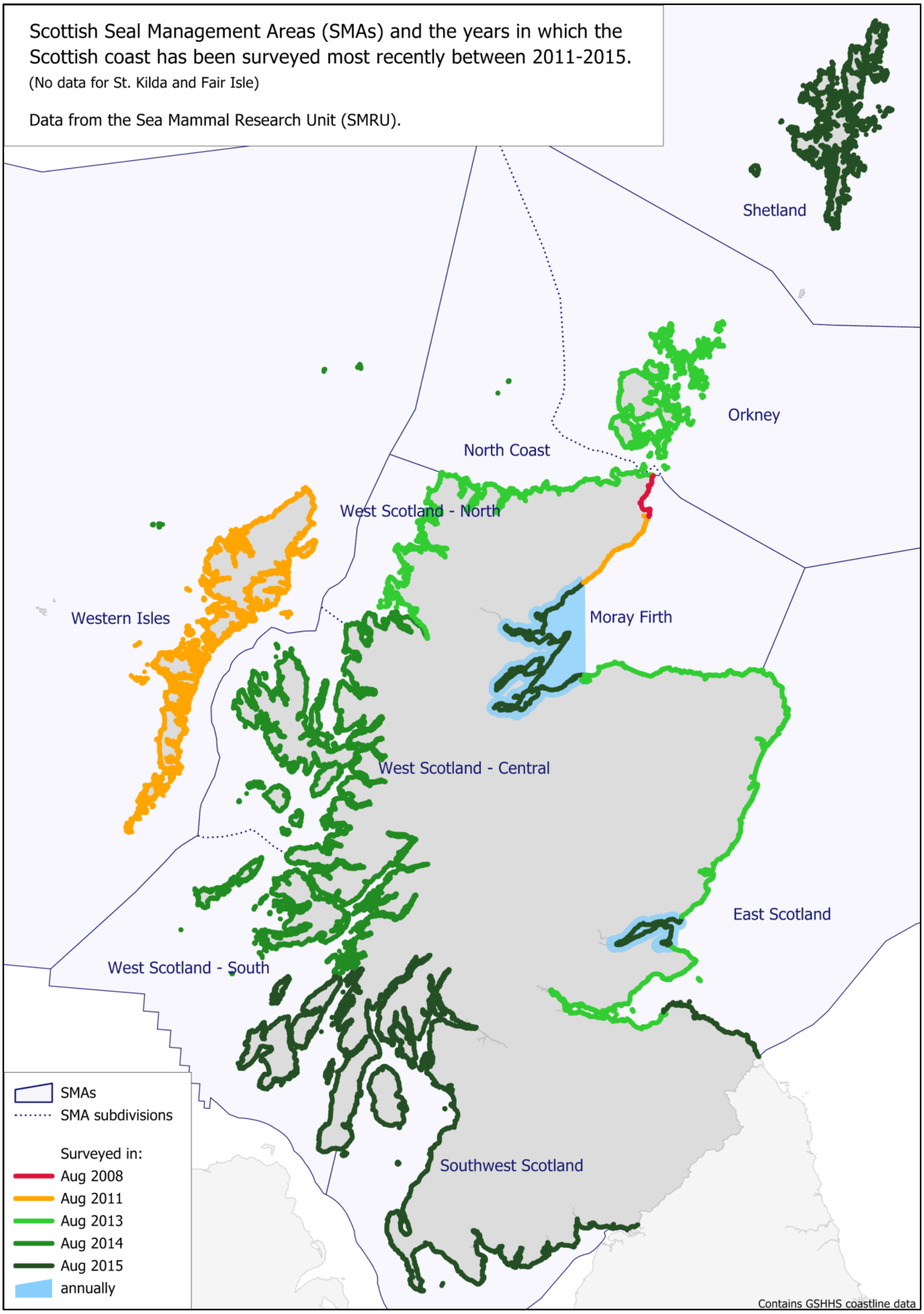

Figure 3. Years in which different parts of Scotland were surveyed most recently by helicopter using a thermal imaging camera. Most areas were surveyed between 2011 and 2015. The enclosed areas of the Firth of Tay and the Moray Firth (between Findhorn and Helmsdale) are surveyed every year, usually by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

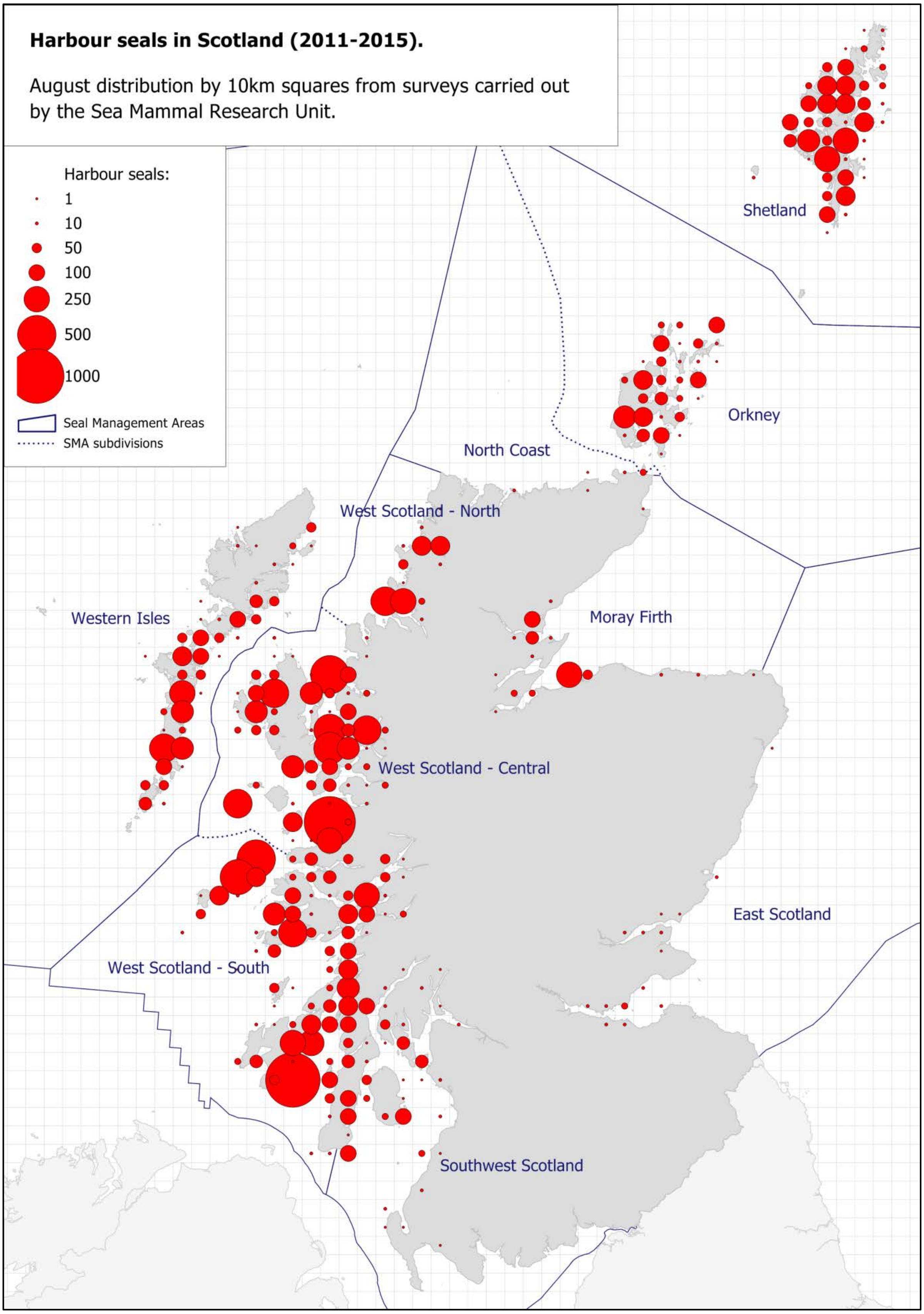

Figure 4. August distribution of harbour seals in Scotland. All areas were surveyed by helicopter using a thermal imaging camera, except for the Moray Firth area between Helmsdale and Findhorn, which was surveyed by fixed-wing aircraft without a thermal imager.

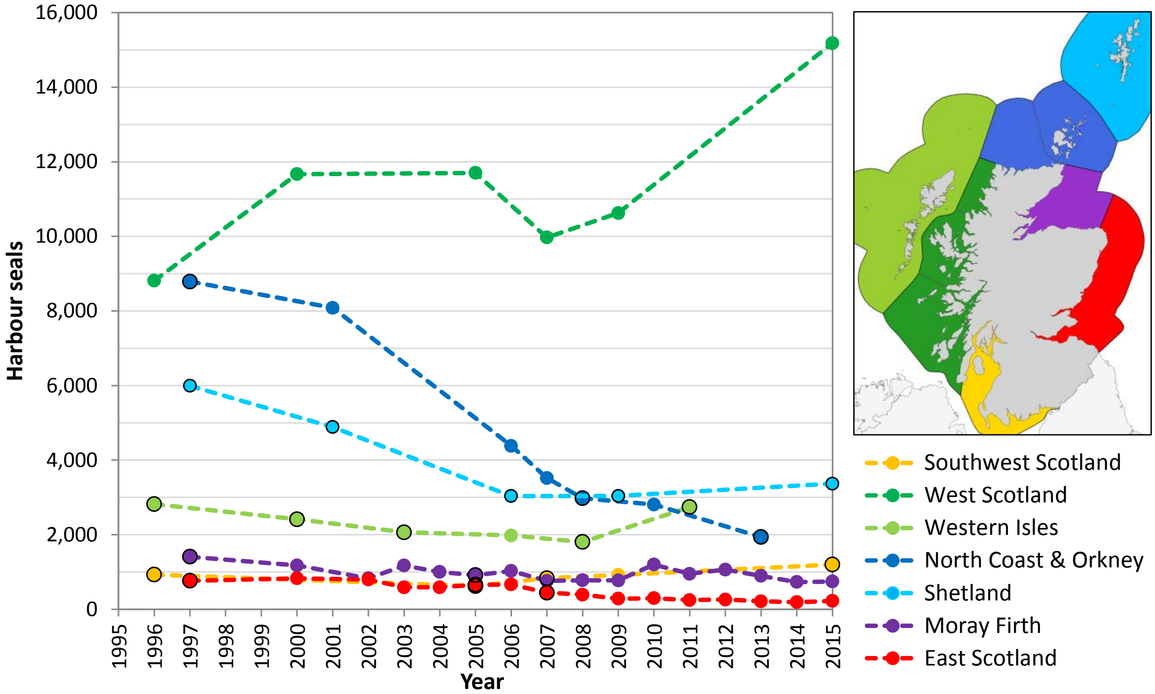

Figure 5. August counts of harbour seals in Scottish Seal Management Areas, 1996-2015. Data from the Sea Mammal Research Unit. Note that because these data points represent counts of harbour seals distributed over large areas, individual data points may not be from surveys from only one year. Points 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.

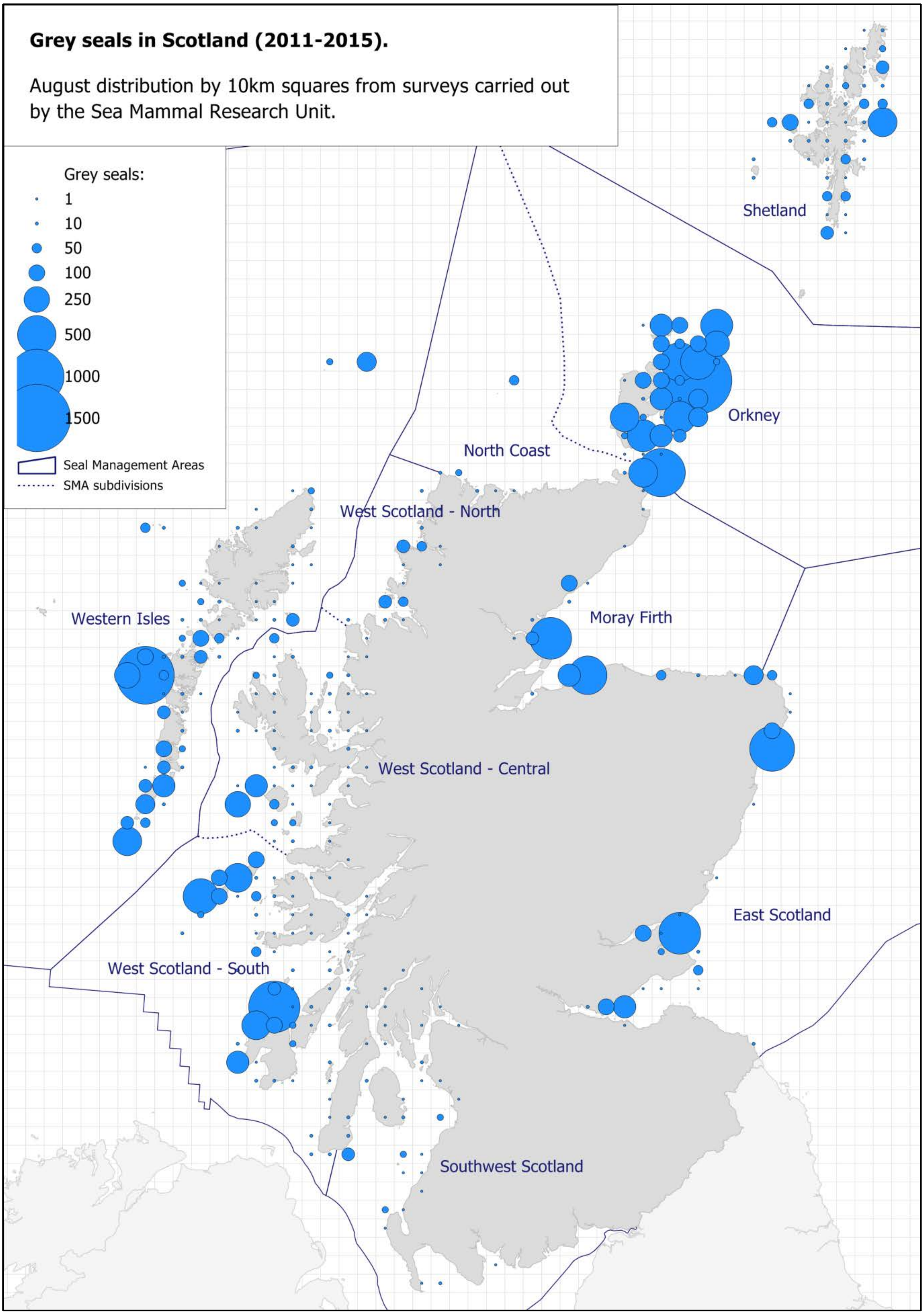

Figure 6. August distribution of harbour seals in Scotland. All areas were surveyed by helicopter using a thermal imaging camera, except for the Moray Firth area between Helmsdale and Findhorn, which was surveyed by fixed-wing aircraft without a thermal imager.

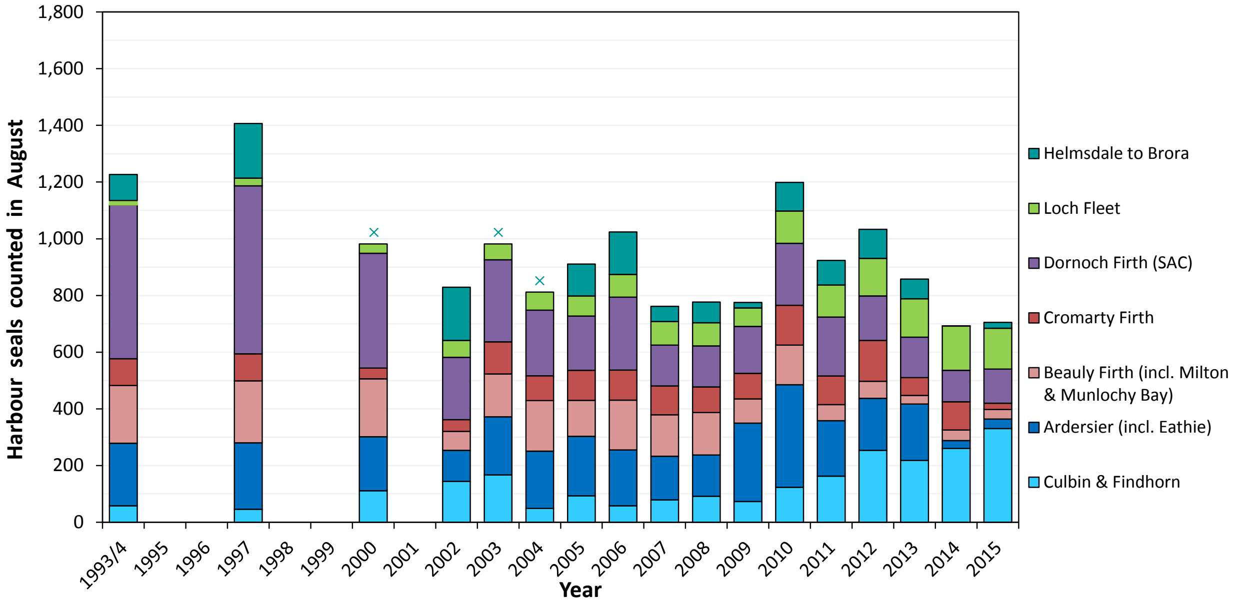

Figure 7. August counts of harbour seals in different areas of the Moray Firth, 1994-2015. Data are from the Sea Mammal Research Unit. x: Helmsdale to Brora not surveyed in 2000, 2003 or 2004.

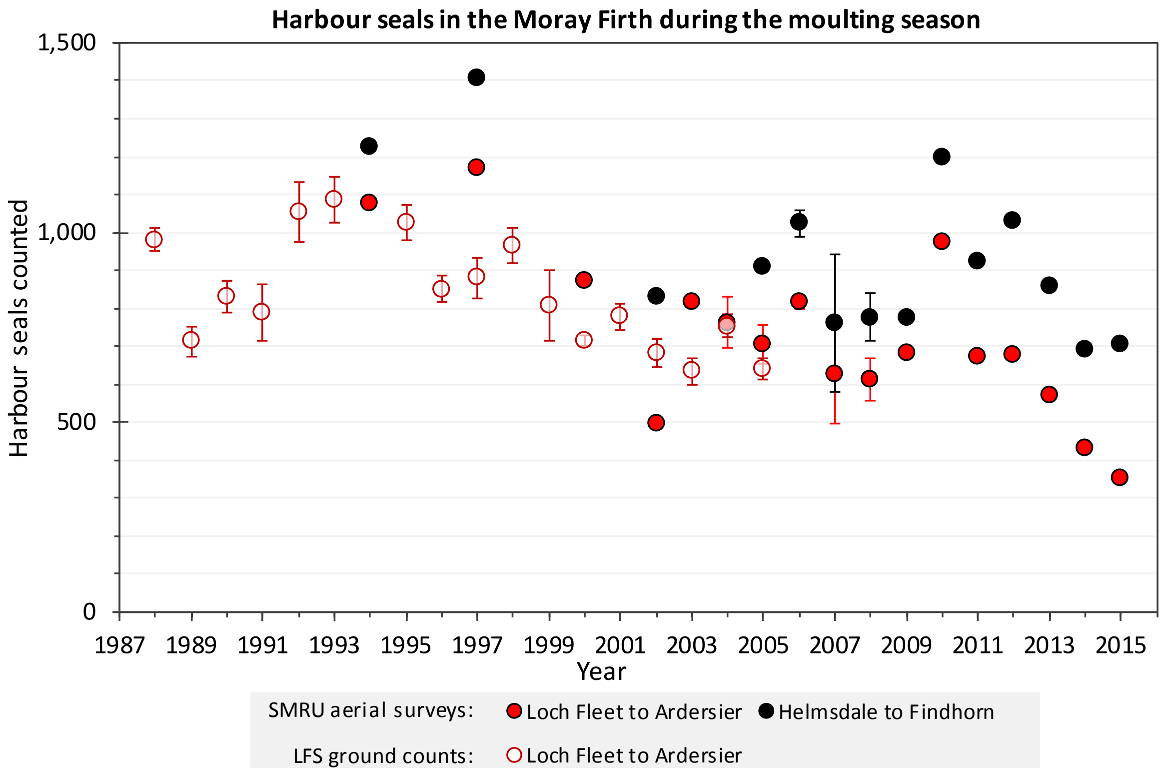

Figure 8. Counts of harbour seals in the Moray Firth during the moult season (August), 1988-2015. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

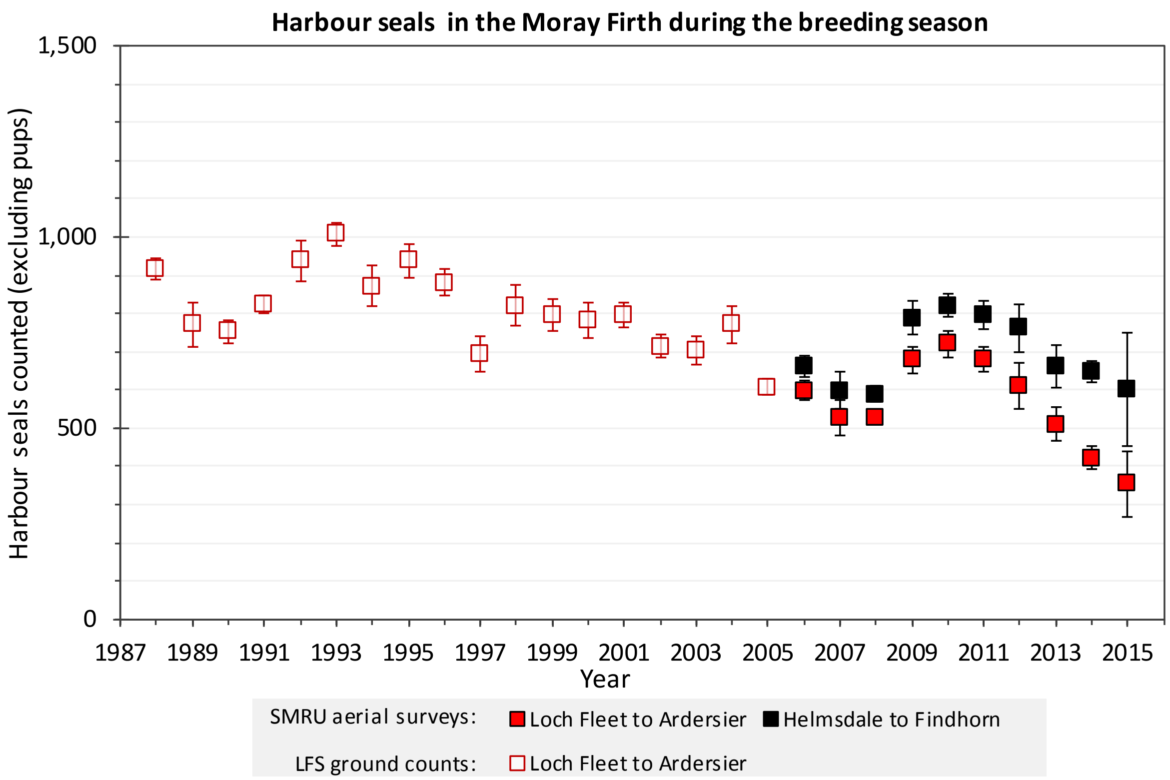

Figure 9. Counts of harbour seals in the Moray Firth during the breeding season (June & July), 1988-2015. Plotted values are means ±SE. LFS = Lighthouse Field Station (University of Aberdeen).

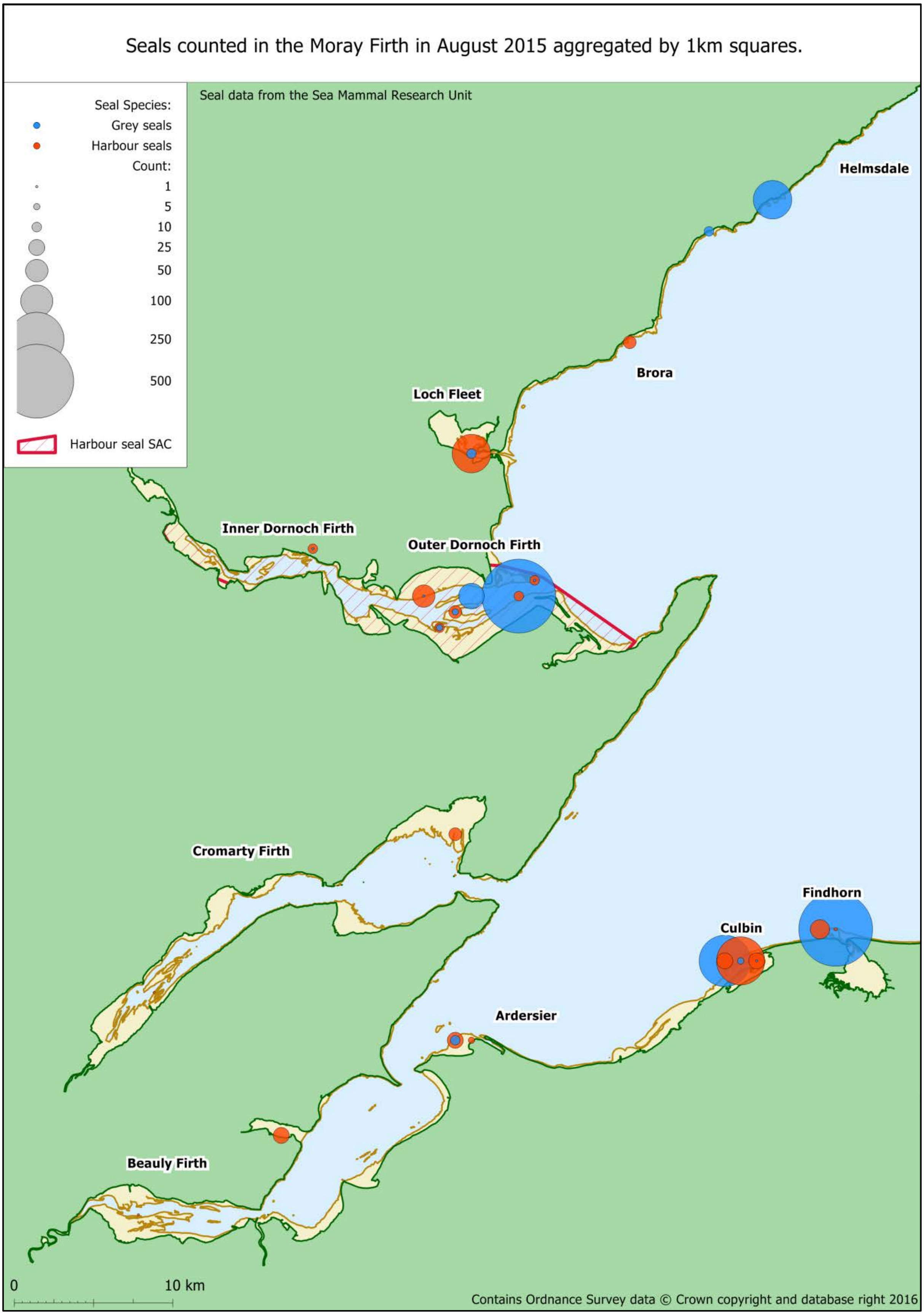

Figure 10. Distribution of harbour and grey seals in the annually surveyed part of the Moray Firth, between Findhorn and Helmsdale, from an aerial survey carried out on 20th August 2015.

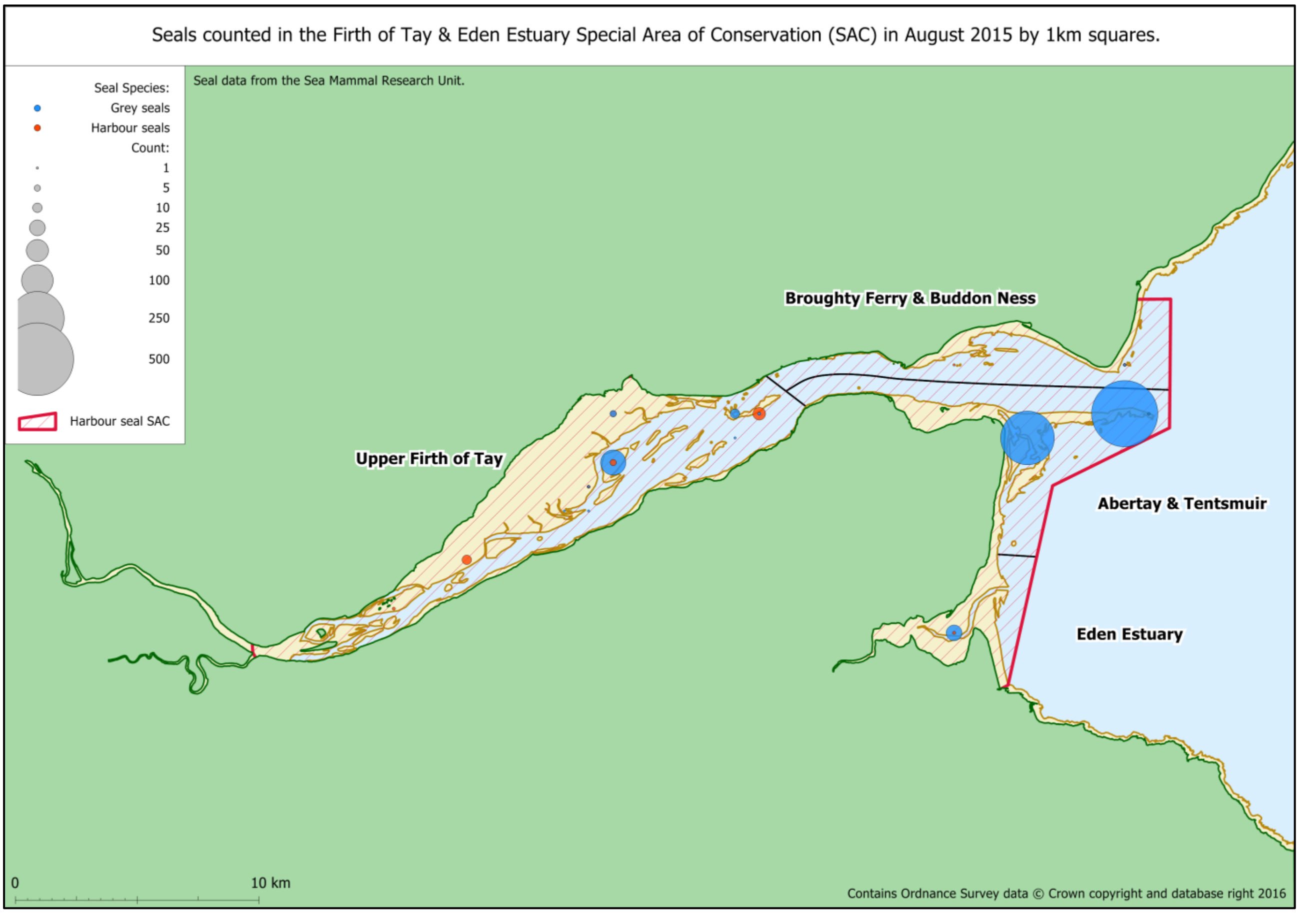

Figure 11. Distribution of harbour seals in the Firth of Tay & Eden Estuary SAC on 19th August 2015.

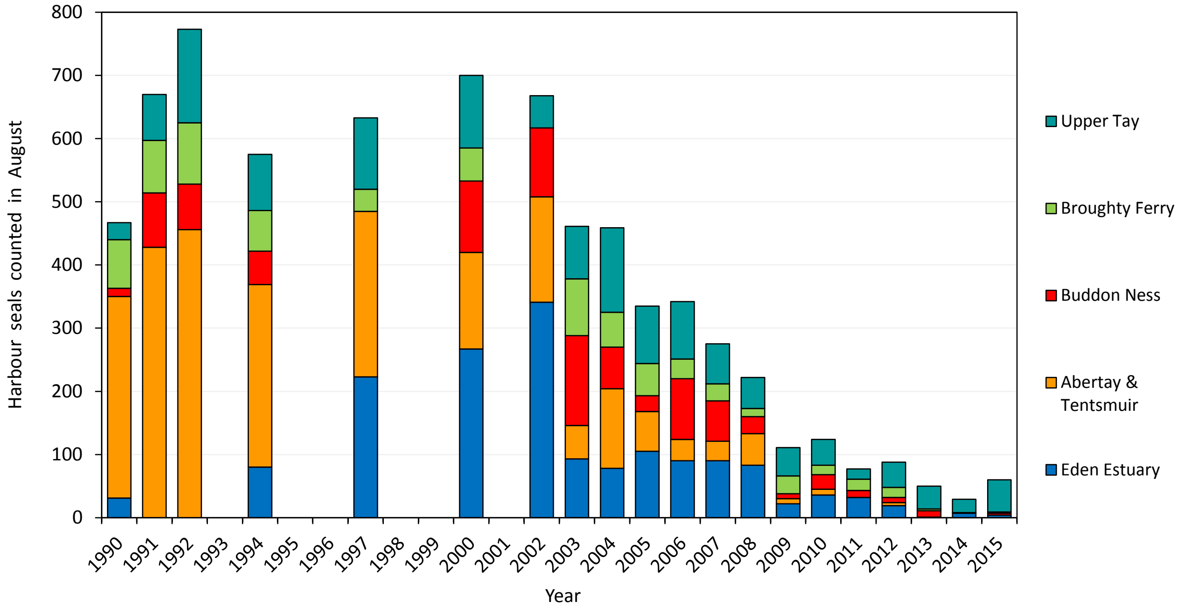

Figure 12. August counts of harbour seals in different areas of the Firth of Tay & Eden Estuary SAC, 1990-2015. Data are from the Sea Mammal Research Unit.

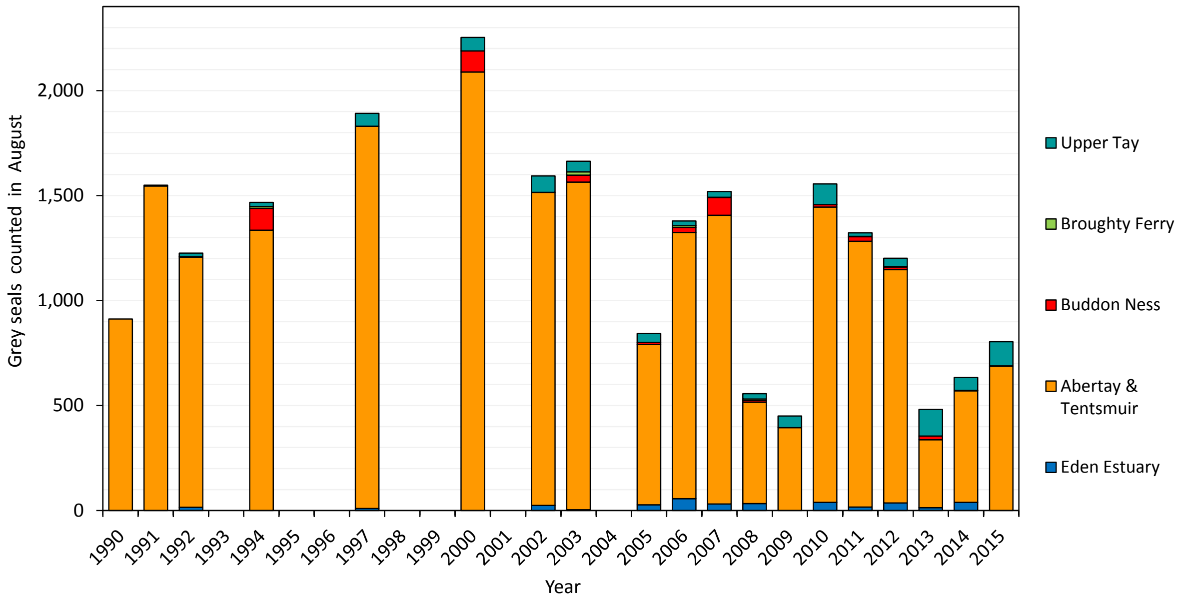

Figure 13. August counts of grey seals in different areas of the Firth of Tay & Eden Estuary SAC, 1990-2015. Data are from the Sea Mammal Research Unit.

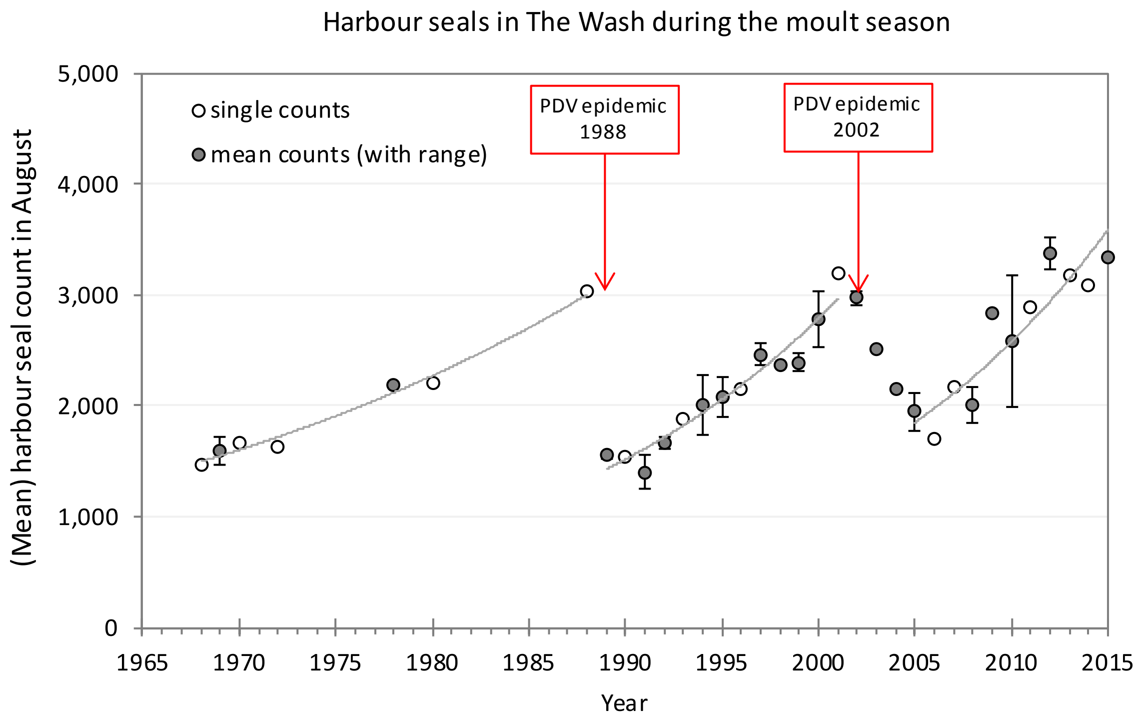

Figure 14. Counts of harbour seals during the August moult season in The Wash, 1967-2015. Vertical bars indicate the range of the counts used to calculate the mean (where more than one survey was carried out).

Distribution and abundance of harbour seals (*Phoca vitulina*) during the 2015 breeding season in The Wash

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Abstract

This report presents the results of a series of aerial surveys of the harbour seal population along the English east coast between Donna Nook in Lincolnshire and Scroby Sands off the Suffolk coast during the breeding season from 16th June to 17th July 2015.

The report presents the results of the single survey carried out for Natural England around the time of the peak numbers of pups ashore, in this case on the 27th June. In addition it presents the results of four additional breeding season surveys carried out on behalf of Dudgeon Offshore Wind Limited (DOWL) as part of their monitoring requirements under Marine Licence L/2012/00218/5. A separate report has been provided to DOWL by SMRU Consulting.

Results suggest that:

- Five surveys were completed on the 16th, 21st, 27th June and 3rd, 17th July 2015.
- As usual, flights were restricted to weekends because of RAF range activity. Poor weather c conditions on the weekend of 10th July prevented flying and delayed the final flight to the 17th July. This had no negative effects on the results.
- The highest count obtained in 2015 was 1351 on the 27th June. Examination of the series of counts suggests that this is close to the actual maximum number of pups for the season.
- This count is approximately 18% lower than the 2014 pup count of 1802 which was the highest ever recorded.
- Despite apparently wide inter-annual variation, the pup production has increased at around 8.2% p.a. since surveys began in 2001.
- The ratio of pups to total population remained high in 2015 maintaining the previously noted increase. The ratio was 3.4 times higher in 2015 than in 2001 suggesting a large increase in apparent fecundity over that period but no change over the past 5 years.

Introduction

Until recently, harbour seal monitoring programmes have been designed to track and detect medium to long-term changes in population size. Historically it was difficult to estimate absolute abundance because an unknown proportion of the population was likely to be at sea and uncountable on any survey. The monitoring programme for the Wash and East Anglia were therefore designed to obtain consistent indices of population size to track the status of the population.

The population monitoring counts are usually carried out during the annual moult, in early August, when the highest and most stable numbers of seals are present on haulout sites (Thompson et al. 2005) (Figure 1). Unfortunately, such counts provide a rather damped index of population size that does not provide information on productivity or the current status of the population. The numbers of pups produced each year provides a direct measure of the productivity which is a better indicator of the current population status. Conversely, pup production alone is not a reliable index of total population size as it is sensitive to short term fluctuations in fecundity. Reliably estimating total population size from pup production requires accurate estimates of fecundity. At present there are no independent estimates of fecundity for the English harbour seal population. Estimates have been obtained for a small portion of the Moray Firth population, but these cannot be applied to the Wash because fecundity is likely to vary between years and between sites within years. A comprehensive assessment of both short term status and long term population trends therefore requires both types of census data.

The breeding season is also the time when disturbance of seal haulout groups is likely to have direct effects. E.g. disturbance of mother/pup pairs will lead to temporary separation which may have direct effects on pup survival, especially if the disturbance is repeated. Series of surveys during the breeding season should provide early indications of such problems if they arise. Recent high resolution tracking data from telemetry tagged harbour seals during piling operations close to the Wash indicates avoidance behaviour at substantial ranges and suggests that there is the potential for hearing damage despite this avoidance (Hastie *et al*. 2015; Russell *et al*. (in press)).

The potential implications of disturbance to harbour seal could include reductions in fecundity (birth rate) and disruption/disturbance of breeding. These potential population scale impacts cannot be detected by observing the behaviour of tagged seals at sea during pile driving activities. Pup production estimates, in conjunction with the annual moult survey estimates provide an index of population productivity that should be a more responsive indicator of population status.

On the English east coast harbour seals breed on open sand banks where pups are relatively easy to observe and count. Since 2001 the Sea Mammal Research Unit have carried out pup counts of the entire breeding population in the Wash. Since 2004 Natural England have commissioned single annual breeding season surveys to develop a time series of pup counts as an adjunct to the annual moult surveys, to obtain a more sensitive index of current status and to monitor the distribution of breeding seals. These counts are conducted at the end of June or beginning of July when the peak counts are expected. Periodically an additional series of surveys are needed within a breeding season to re-estimate the date of the peak number of pups ashore. In addition, the repeat surveys provide information on the ratio between peak pup counts and pup production and can provide information on the likely error on estimates of pup production. Sequences of five surveys spread across the breeding season were carried out in 2008 and 2010. Here we report the preliminary results of a series of five counts carried out throughout the breeding season in 2015.

Historical data

One or two complete surveys of the Wash were carried out during the moult, in the first half of August in each year from 1988 to present. The results, combined with counts at the same time of year from the period 1968-1982 are shown in Figure. 1. The counts increased between the late 1960s and 1988, at an average of 3.4% p.a. (R^2=0.62, p<<0.0001). The 1988 count was obtained approximately one week before the first reports of sick and dead seals being washed up on the UK coast. The number hauling out fell by approximately 50% between 1988 and 1989, coincident with the PDV epidemic. After 1989 the number increased again, at an average of 5.9% pa (R^2=0.77, p<<0.0001). The post epidemic rate of increase was significantly higher than the pre epidemic rate (t=2.87, df=20, p<0.01).

Post epidemic counts were also obtained at the other major east coast haulouts outside the Wash, at Blakeney (45km east) and Donna Nook (40km north). At both sites the counts fell after 1988, reaching a minimum in 1990 (Figure 2). Between 1990 and 2001 Blakeney counts increased by an average of 14.4% pa. (R^2=0.47, p<0.01), and Donna Nook counts by 18% pa (R^2=0.35, p<0.03). The total for all three east coast sites increased at an average rate of 7.2% pa. (R^2=0.87, p<<0.0001) (Figure 2).

In 2002 there was another outbreak of PDV. The timing of the epidemic and the population size were similar to 1988. The population in the Wash declined by an estimated 22% based on results of surveys in 2003 and on a fitted population growth model (Thompson, Duck & Lonergan, 2005). There appears to have been a continued decline or at least a failure to recover in the moult counts for the English east coast population in the three or four years following the 2002 epidemic. Overall, the combined count during the moult for the English East coast population in 2006 was 12% lower than the mean count in 2005. Since 2006 the counts have increased such that by 2010 and 2011 the counts were similar to the pre epidemic counts. This apparent lack of recovery or continued decline immediately after the epidemic contrasts with the rapid recovery of the Wadden Sea population that has been increasing at around 12% p.a. since 2002. The initial failure to recover from the 2002 epidemic is unexplained but is similar to the apparent lack of recovery in the years immediately following the 1988 PDV epidemic.

Previous breeding season surveys 2004 to 2014

Based on pup surveys during the hunting in the 1960s and early 1970s and anecdotal observations in recent years suggesting similar birth patterns, we estimated that the peak number of pups would be encountered at the end of June or beginning of July. Intense military aircraft activity precludes surveys between sunrise on Monday and midday on Friday so survey flights are restricted to the weekends. We have surveyed the breeding population between 27th June and 4th July in each year from 2004 to 2014. In addition in both 2008 and 2010 we carried out four additional surveys between 12th June and 13th July to establish the form of the pups ashore curve. Surveys were carried out over the period 1.5 hours before to 2 hours after low water. All tidal sand banks and all creeks accessible to seals were examined visually. Small groups were counted by eye and all groups of more than 5 animals were photographed using either colour reversal film in a vertically mounted 5X4" format, image motion compensated camera in 2001, 2004 & 2005 or with a hand held digital SLR camera since. The equipment and techniques are described in detail by Hiby, Thompson & Ward (1986) and Thompson et al. (2005). Photographs were processed and all seals were identified to species. Harbour seals were then classified as either pups or 1+ age class. No attempt was made to further differentiate the 1+ age class.

Methods

2015 surveys

Five aerial surveys were conducted between 16th June and 17th July 2015 along the Lincolnshire and Norfolk coast. Surveys were planned on a weekly basis to estimate usage of the area by breeding harbour seals and provide an estimate of pup production over the peak of the pupping season. Adverse weather prevented us from flying the final survey on the planned date. The delayed flight resulted in a 2 week interval between surveys 4 and 5. This is not expected to have any adverse effects on the production estimate. As in previous years, surveys were carried out at weekends as a large portion of the planned flight route is in military controlled air space which is closed to low flying aircraft during working hours.

In addition to the harbour seal surveys which focussed on The Wash, surveys covered the mixed harbour and grey seal (*Halichoerus grypus*) haulout sites at Donna Nook, Blakeney and Scroby Sands

In four of the five flights, surveying began at Donna Nook in Lincolnshire and continued south, tracking the coastline around The Wash and continued east along the Norfolk coast to Blakeney and then travelled over-land to complete the survey at Scroby Sands (Figures 3, 4 and 5). Time constraints due to tides precluded survey at Donna Nook on 21st June so surveying began at the north-western edge of The Wash. The low numbers of pups recorded at Donna Nook means that this will have little or no effect on the production estimate. Example flight-tracks are provided below.

All photography was conducted obliquely using a Digital SLR cameras with 18 to 270mm zoom lens. All surveys followed standard SMRU survey methods and routes and were flown in a twin engine Piper PA-23, Aztec. The entire coast is searched from a variable height of 180 to 400m. When groups of seals are sighted the aircraft either flies parallel with the shore for groups of seals spread along open stretches of beach, or performs one or more tight turns to circle smaller or more evenly dispersed groups. Groups hauled out along creeks or dispersed in the salt marsh areas were first identified during intensive visual searches by the 3 man crew and then photographed.

GPS tracks were recorded from all flights, sampling at 3 second intervals, synched with the time on the camera. Discrete haul-outs can therefore be associated with precise locations. Both the cameraman and the observer/tracker recorded the locations and frame numbers directly onto maps and note pads.

The number of discrete groups of harbour seals ranged from 44-60 and few were observed at sites other than those previously recorded in the survey area, during the pupping surveys. Additional, solitary animals were counted but not photographed.

Results and Discussion

Counts for The Wash were obtained for the five surveys. Counts for each haulout site are presented in Table 1. The maximum pup count was 1351 pups on 27th June together with 3907 older seals (1+ age classes). The highest count of 1+ age classes was 4539 on 3rd July. Only seven pups were counted on the 27th June at Donna Nook and four at Blakeney point.

The maximum pup count was 25% lower than the previous highest peak count of 1802 pups and 4020 older seals (1+ age classes) during the 2014 breeding season survey. The 2014 survey produced the highest pup count ever in the Wash. This was 22% greater than the previous highest count in 2012. Figure 8 indicates that there are large inter-annual fluctuations in pup counts but despite the large variations, the trend in the counts can be approximated by an exponential increase at an annual rate of increase of 8.2% p.a. since 2001.

The pups in the Wash were distributed over approximately 50 separate haulout groups, although the number of sites is to some extent a function of the arbitrary division or pooling of groups. Figure 6 shows the distribution of haulout sites in the Wash. Figure 7 shows the counts of pups at each site obtained during the 3/7/2015 breeding season survey.

The maximum pup count from the 2015 breeding season surveys was 25% lower than the previous year, but has little impact on the fitted trend since 2001 (Table 2). The fitted trend suggests a continual upward trend in pup production of the Wash harbour seal population (Figure 8). At present we do not have a direct conversion from peak count to pup production, but there is no reason to suspect a systematic change in that ratio. Therefore the observed 8.2% p.a. increase in pup count should be a reliable indication of the rate of increase of pup production.

The ratio of peak pup count to total moult population count remained high in 2015, at 0.40 pups per moulting seal (Figure 9). Although much lower than the value of 0.58 in 2014 the ratio remains high compared to historical levels, maintaining the previously noted increase. The ratio was 3.4 times higher in 2015 than in 2001 suggesting a large increase in apparent fecundity over that period but little change over the past 5 years. Interestingly an apparent increase in this fecundity index has also been noted in the Wadden Sea population over the past decade. The apparent increase in the Wadden Sea precludes the simplest explanation for the change being the result of movement of females from the Wadden Sea into the Wash to pup and out of the Wash to moult elsewhere.

The data produced by the 2015 surveys will be incorporated into the wider monitoring programme for the SAC population in The Wash. Results will be presented to the UK's Statutory Nature conservation Agencies through the NERC Special Committee on Seals.

The breeding season surveys have been repeated in 2016. The 2015 and 2016 time series of pup counts will be used in combination with similar time series of pup counts from 2008 and 2010 and a time series of pup counts from the Moray Firth population to develop a robust pup production estimation model. This analysis will be presented to SCOS 2017. In addition to the pup production estimates the survey programmes will allow a comparison of the fine scale distribution of pupping in the Wash and adjacent sites in years with and without piling activity and will facilitate a small spatial scale analysis of any displacement response to changes in patterns of presence of grey seals.

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Table 1. Counts of harbour seal pups and 1+ ages at haulout sites in the Wash, 2015.

	Degrees decimal	Degrees decimal	16/06/2015		21/06/2015		27/06/2015		03/07/2015		17/07/2015	
Site name	Lat	Lon	1+ages	pups	1+ages	pups	1+ages	pups	1+ages	pups	1+ages	pups
Inner & Outer Knock	53.082	0.364	146	11	97	15	193	22	163	36	166	36
Inner Dogs Head	53.036	0.376	44	1	52	3	37	2	73	24	60	29
Friskney	53.034	0.309	48	3	56	11	81	18	53	17	44	15
Friskney Middle	52.997	0.225	27	12	33	18	79	26	32	14	9	6
Friskney South	52.953	0.119			27	12	23	8	42	8	36	7
Long Sand N/E End	53.019	0.334										
Long Sand Middle	53.005	0.297	173	6	92	16	84	15	124	27	78	18
Ants	52.978	0.264	9	1	24	8			26	3	4	2
Rodger	52.963	0.217					4	1	9	3		
NW total			447	34	381	83	501	92	522	132	397	113
Black Buoy	52.924	0.117	212	19	167	73	51	8	28	5	109	4
Boston Channel	52.900	0.029	173	46	233	102	319	65	162	37	135	40
Herring Shoal	52.904	0.064	310	97	12	5	100	14	80	8	41	12
Toft East	52.932	0.153	34	3	69	15	32	2	49	5	41	3
Toft West	52.920	0.133			3	0	3	0	43	19	10	3
Mare Tail	52.917	0.152			161	72	5	4	37	15	5	4
Main End	52.907	0.193			42	21	70	22	34	5		
Gat End	52.912	0.203			22	10						
Gat Sand	52.935	0.198	59	6	35	27	40	7	80	16	50	12
SW total			788	171	744	325	620	122	513	110	391	78
Puff	52.899	0.121	79	28	83	15	50	22	15	6	8	8
Kenzies Creek	52.900	0.106	101	22	43	13	185	97	190	53	193	30
Fleet Haven Marsh	52.877	0.152										
Fleet Haven Middle	52.884	0.157	192	62	128	70	396	139	296	95	284	91
Fleet Haven Lower	52.909	0.157										
Fleet Haven Mouth	52.922	0.158										
Evans Creek	52.878	0.169					104	58	126	34	127	13
Dawesmere Creek	52.859	0.191	100	40	111	41	162	46	300	36	114	27

Creeks total			472	152	365	139	897	362	927	224	726	169
OWMK 1	52.875	0.233	37	16	5	6					6	9
OWMK 2	52.867	0.250										
Nene Channel 1(or pooled)	52.875	0.220	75	14	163	41	169	20	146	23	15	22
Nene Channel 2	52.867	0.216			16	10	65	24	17	2	37	11
Nene Channel 3 Barge	52.860	0.214	142	27	63	33	28	8	99	52	51	14
Nene Channel 4	52.845	0.206			7	6	2	1	21	3	54	17
Nene Channel 5	52.827	0.219					127	26			14	11
IWMK	52.852	0.235	54	15			135	56	123	36	9	10
Salman's Sled	52.857	0.258	128	61	214	105			132	75	87	79
Breast Sand	52.828	0.275	218	87	112	56	174	98	209	58		
Thief West	52.878	0.273	49	10	35	5	23	2	58	6	32	1
Thief East	52.878	0.273			4	0	3	2	6	1		
Seal Sand (West)/Black Shore	52.875	0.312							12	3	24	10
Seal sand (East)	52.881	0.352	214	40	140	34	178	56	180	36	164	18
Seal Sand/Daseleys	52.882	0.351			24	14			14	3		
Hull Sand	52.840	0.307	401	112			558	198	647	196	338	76
Bull Dog Sand	52.866	0.378	42	6	17	8	133	73	148	64	199	34
Pandora	52.862	0.355	287	43	227	45	17	0	371	95	220	54
Black Guard	52.883	0.372							3	3	24	11
Old Bell	52.900	0.372										
Styleman's Middle	52.887	0.380	6	2	37	25			12	3	9	2
Pie Corner	52.834	0.327					78	47	170	62		
Lynn Channel	52.810	0.367	94	25	394	202	521	164	171	55	191	19
Sunk Sand	52.975	0.493	20	0	34	2	9	0	38	0	83	2
East total			1767	458	1945	750	2220	775	2577	776	1557	400
Wash Total			3474	815	3435	1297	4238	1351	4539	1242	3071	760

Table 2. Counts of harbour seal pups and 1+ age classes in the Wash from 2001 to 2015.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351
1+ ages	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	3907

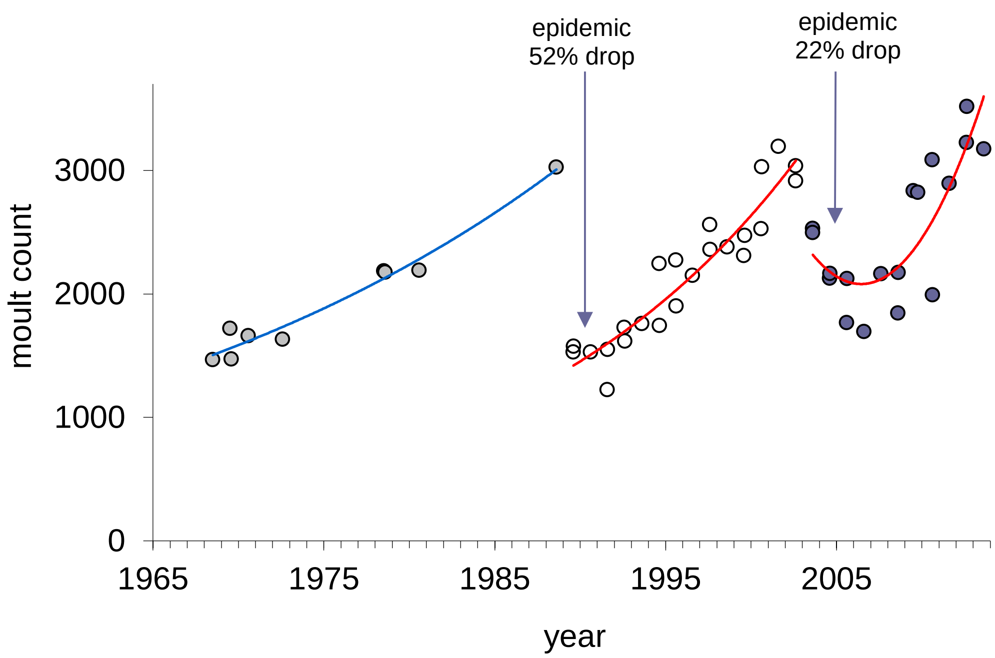

Figure 1. Aerial survey counts of harbour seals in the Wash during the annual moult in August for the period 1968 to 2014. Dramatic declines in 1988 and 2002 were the result of epidemics of phocine distemper virus. Fitted lines from 1965 to 1988 and 1989 to 2002 are exponential growth curves (growth rates given in text). A 2nd order polynomial has been fitted to the post-2002 counts for illustration.

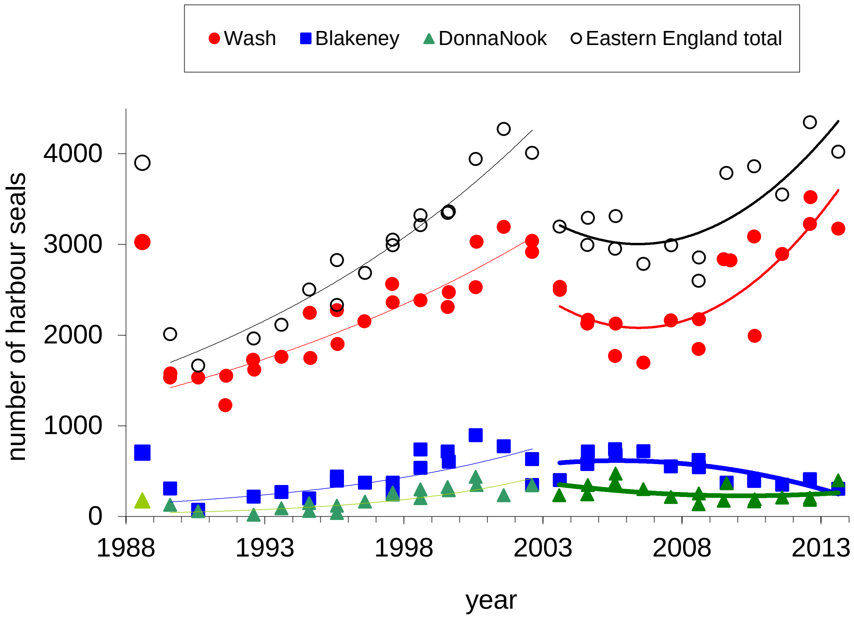

Figure 2. Aerial survey counts of harbour seals at major sites in East Anglia during recovery from the 1988 and 2002 PDV epidemics. There were no significant changes between 2003 and 2013, the fitted polynomial is included simply for illustration.

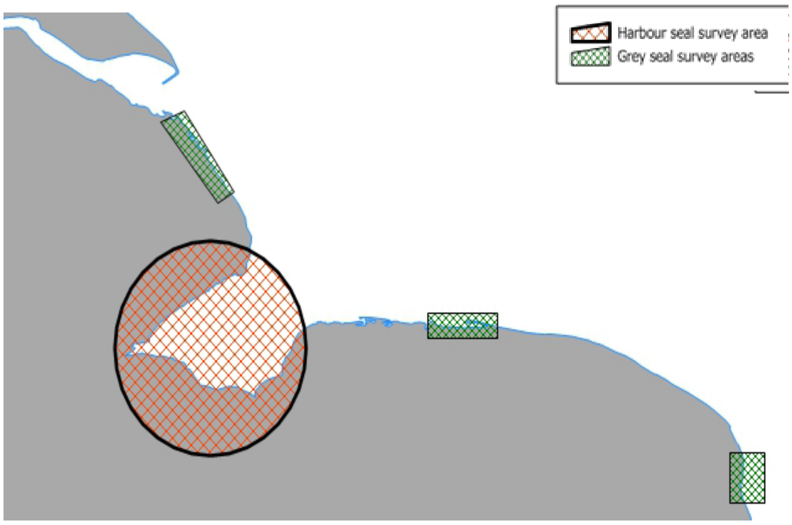

Figure 3. Survey areas of the Lincolnshire and Norfolk coast. Grey seal survey areas from north to south: Donna Nook; Blakeney; Scroby Sands. Harbour seal survey area: The Wash.

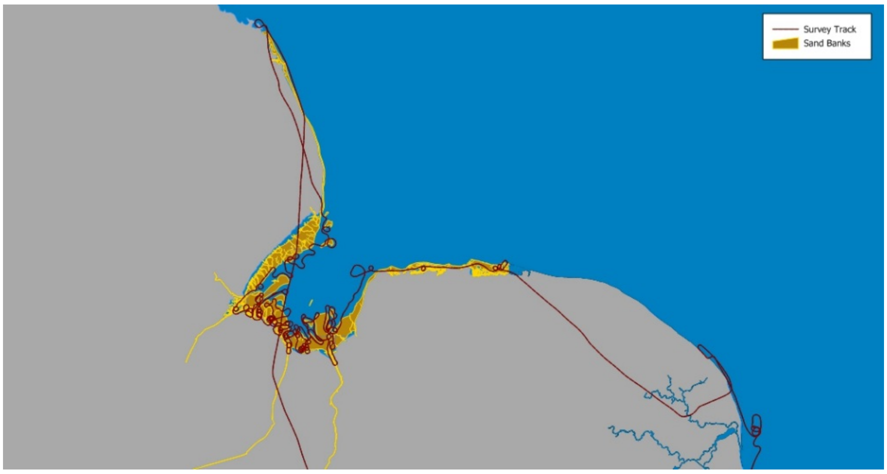

Figure 4. Flight track from 16/06/2015. Total flight time was 5 hours 24 minutes (11:01 – 16:25).

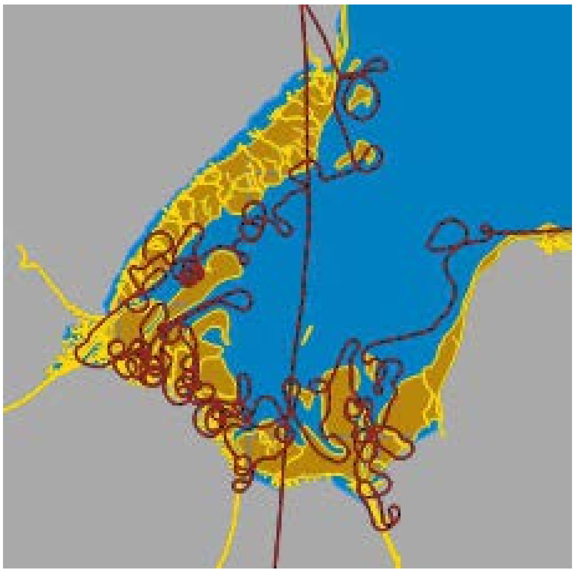

Figure 5. Survey route over the haulout sites in The Wash, 17/07/2015. Total flight time was 4 hours 43 minutes (12:54 – 17:37).

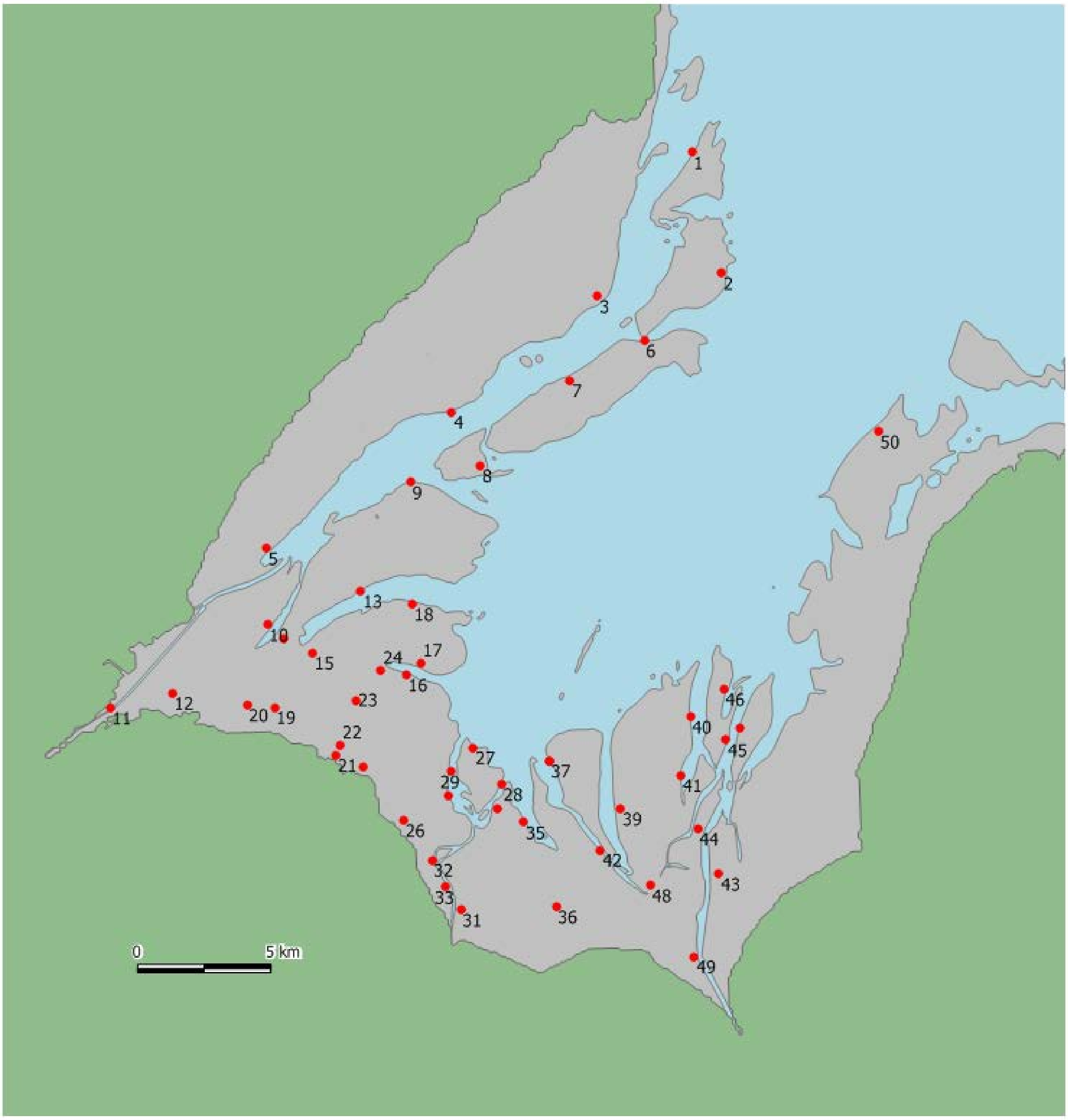

Figure 6. Locations of seal haulout sites during the pupping season in the Wash. Numbers correspond to counts in Table 1.

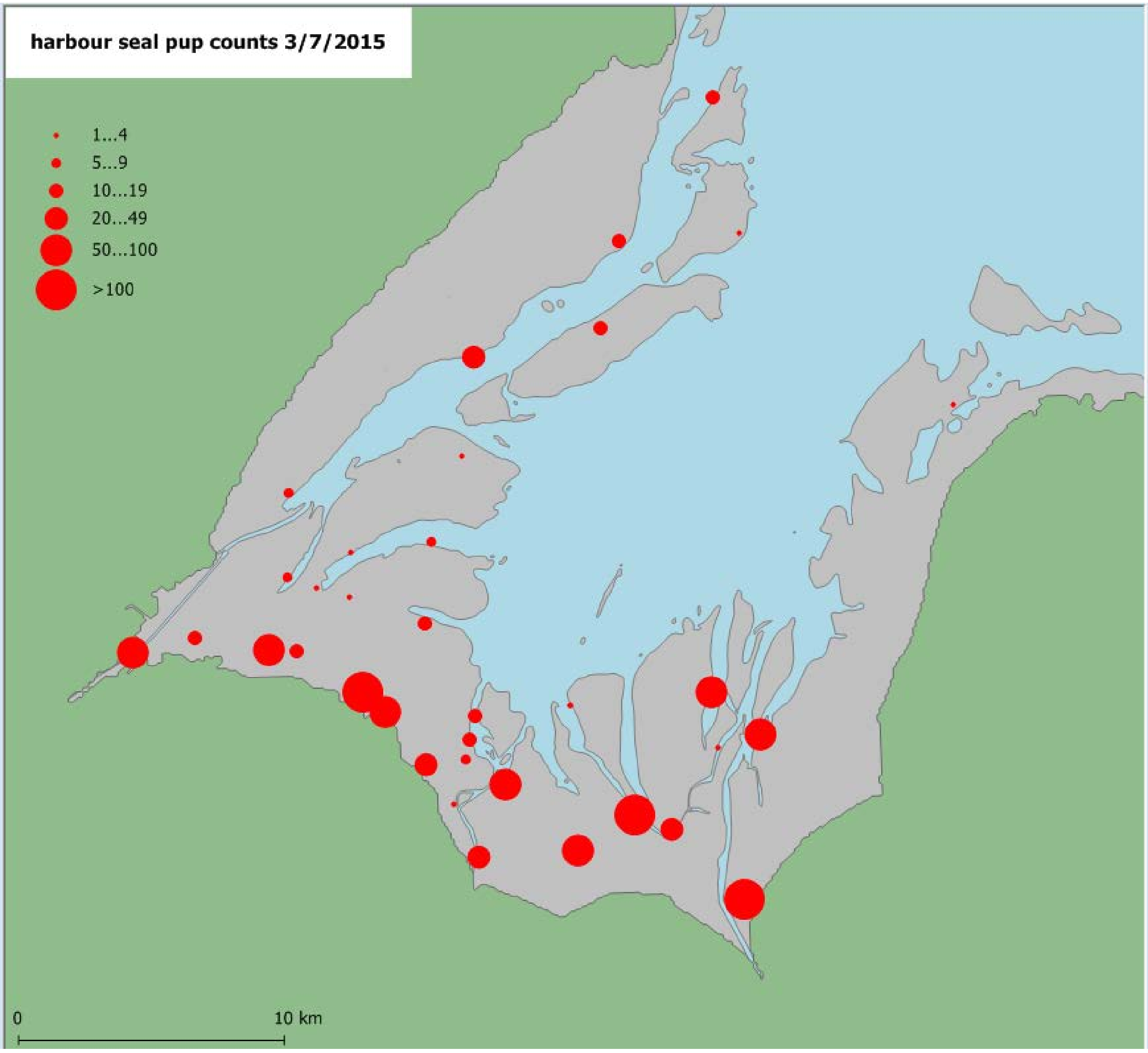

Figure 7. Numbers of pups counted at each site during the peak count survey.

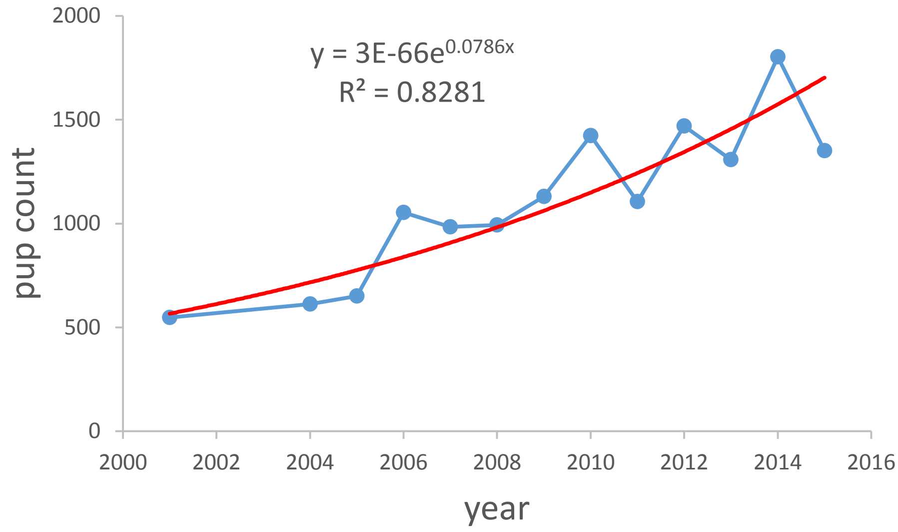

Figure 8. Maximum pup counts for The Wash population between 2001 and 2015. Fitted line is a simple exponential. The average growth rate over the 15 years was 8.2% p.a.

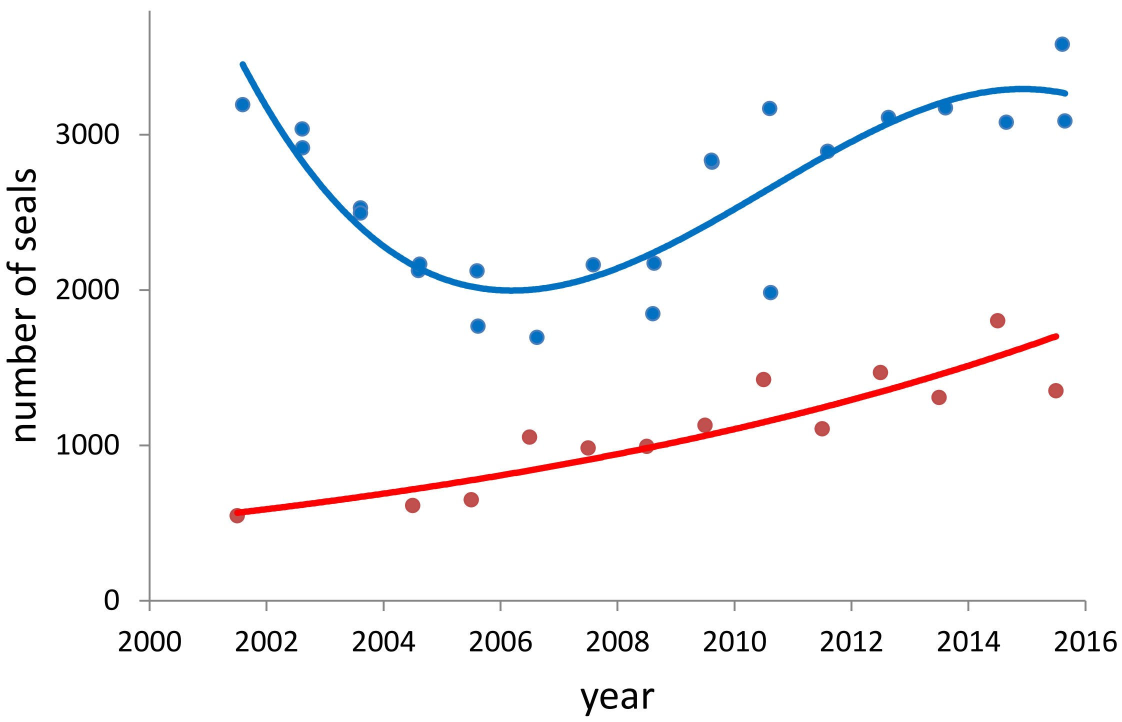

Figure 9. Maximum counts of pups in The Wash between 2001 and 2014 alongside the annual moult count over the same period. , An index of fecundity, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size).has increased over the period of surveys. The fitted line is a simple exponential through the pup counts and a cubic polynomial through the moult counts for illustration only.

Additional research requirements to improve knowledge and understanding of seal ecology in Scotland

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Summary

Scottish Government have asked what additional research is considered most necessary by the Committee to improve our knowledge and understanding of seal ecology in Scotland to help inform management and thus sustainable harbour seal populations for the future?

The wording of the question suggests that the main concern is the decline in some components of the Scottish harbour seal population and that it is recognised that the ecological interactions of both UK seal species may need to be considered in order to identify the main causes of the observed population changes.

Introduction

It is a relatively simple task to identify a list of natural and anthropogenic factors that could possibly have influenced the dynamics of seal populations and even to identify factors that could come into play in the future. It is a much more difficult task to quantify their likely contribution as drivers of the observed population dynamics. A study to fully understand all of the potential drivers of population dynamics in large predators, interacting with multiple components of a large and complex ecosystem would be a major undertaking and a long term commitment. There is therefore a clear requirement to prioritise those factors most likely to be acting as significant drivers.

Even with such a list of prioritised factors it is highly unlikely that resources will be available to investigate a large proportion of them. Funding priorities will likely be driven to a large extent by current and identifiable future policy requirements. Funding will necessarily be directed towards those topics deemed most likely to provide direct policy support. To be useful, the criteria for prioritising research into seal ecology and population dynamics/processes should take into account these non-science pressures.

The SCOS meeting provides a unique opportunity for a group of selected experts with a wide ranging and in-depth knowledge of seal research to debate these topics with those members of the SNCBs responsible for providing advice on managing seal populations and representatives of Government Departments responsible for managing them. These government representatives have in-depth knowledge of the requirements for managing the anthropogenic activities affected by or possibly responsible for changes in seal populations.

The SCOS meeting is however, very short and has a full programme. It is not expected that SCOS will produce a prioritised list within the meeting. However a section of the Science day and part of the Committee discussion session will be given over to this question and it is expected that SCOS will continue to work on this issue after the meeting.

This document is intended to be a stimulus for the discussion at the SCOS meeting. It is not meant to provide a prioritised list of research topics; that will hopefully come as a result of the discussions and further work.

Background

The population trajectories of both grey and harbour seals vary regionally. Information on the trends in both species, by region, have been reported annually in the SCOS Advice documents.

Until 2000 the primary interest, and the main driver of research priorities for UK seals, was the long-term and continuing increase in grey seal populations around Scotland and in the North Sea. Interactions between grey seals with their prey base was a major driver of research priorities because of the perceived competition between grey seals and various fisheries. Interest in harbour seal populations had been generally seen as of broader relevance, with population monitoring effort directed at a level to satisfy statutory requirements, such as the Habitats Directive. Interest in harbour seal population dynamics increased as a consequence of the loss of around 50% of one of the UK's largest populations in East Anglia, during the 1988 phocine distemper virus outbreak.

Attention on harbour seal populations increased when it became obvious that the large populations in Orkney and Shetland and populations in SACs in the Moray Firth and Tay were declining rapidly. In Orkney and the Tay these declines have continued.

At around the same time there were changes in grey seal population trajectories, with growth rates in populations in the Western Isles and more latterly in Orkney slowing or stopping. Conversely populations in the North Sea and particularly at new mainland sites have continued to grow rapidly. These changes altered the relationships between pup counts and total population estimates in such a way that estimating true population size became problematical.

Over the past 15 years the main research programmes at SMRU and the University of Aberdeen have been focussed on addressing various aspects of these issues.

The emergence of marine renewable energy industries over a similar time period has increased the regulatory requirements for knowledge about seal populations, drivers of population dynamics and behaviour relative to the developments. The geographical overlap between many of the potential development sites and the declining harbour seal populations meant that, in Scotland at least, the primary interest in seals switched to identifying reasons for regional harbour seal declines.

Harbour seal decline workshop

As a direct response to this Marine Scotland commissioned a workshop on the decline in the abundance of harbour seals around the coast of Scotland and discussion of mitigation and management measures, held in St Andrews in November 2012. (The workshop report can be downloaded from http://www.smru.st-and.ac.uk/pageset.aspx?psr=152).

The workshop participants were firstly asked to consider six aspects relating to the causes of the observed decline in the abundance of harbour seals around Scotland over the previous decade.

The major causes currently under consideration included:

- Nutritional stress – as a result of decreased quality or quantity of prey
- Increased competition with grey seals – although the nature of the competition still to be determined
- Increased competition with other marine animals – as above
- Disease
    - Infectious (i.e. viral, bacterial, fungal, parasitic, protozoal)
    - Non-infectious (e.g. persistent organic pollutants)
    - Toxins (biotoxins from harmful algae, e.g. domoic acid, saxitoxin, okadaic acid, yessotoxins)
- Deliberate killing – shooting is known to have been an issue in the Moray Firth
- Trauma (accidental killing) – increased traumatic interactions with vessels have been demonstrated in certain regions but the true extent of this impact is not known. *(It should be noted that this topic has been superceded by the recognition that such mortality is due to predation by grey seals)*.
- Bycatch – in fisheries
- Pollution – this related back to non-infectious diseases as a potential causal factor
- Predation – certainly an increase in killer whale sightings in Shetland and Orkney especially over the last few years has raised this as a potential problem for harbour seal

population abundance, particularly in the summer. *(Again it should be noted that at the time of the workshop predation by grey seals was not considered a major factor).*

Additional causes that were recognised by the workshop break-out groups were:

- Loss of habitat – either foraging, moulting or breeding
- Anthropogenic disturbance – including increased ocean noise, boat traffic, disturbance from haulout sites
- Direct competition with fisheries – also depleting the prey base
- Dispersal and emigration– the permanent movement of animals into other, European populations or perhaps into the stable populations on the west coast
- Climate change
- Natural variation – unidentified reductions in survival and fecundity
- Entanglement in marine debris

This list is fairly comprehensive, but no realistic attempt was made to prioritise the likelihood of each topic being a major driver of the observed declines.

Research into several of these topics has been carried out and is ongoing. A list of topics that have been effectively ruled out is provided in the main Advice document from SCOS 2015.

List of possible research questions

An alternative/complimentary way of listing research topics is to identify a list of individual research questions that address a single aspect of the biology/ecological interactions of seals. This is perhaps more likely to produce tractable questions that can be addressed by individual research projects, but is even more difficult to prioritise.

Here we present one example of such a list covering both grey and harbour seal research requirements. It represents a straw poll within SMRU and is therefore unlikely to be comprehensive. It is presented here mainly as an aid to the discussions:

1) How many grey & harbour seals are there regionally & nationally? What precision of estimates is required? Information for Wales & SW England is sparse

Reasons: Habitats Directive & MFSD reporting; as a baseline for judging potential changes/risks

2) How many can we expect to have under plausible conditions? What range of conditions? When?

Reason: For planning of developments & regulation

3) What is driving the apparent density dependent control of grey seal populations?

Reason: current best guess seems very low

4) What is the sex ratio in both grey and harbour seals?

Reason: For harbour seal- abundance estimates; for grey seals - to reconcile independent estimate and pup production

5) What are the extinction risks for populations in individual seal management regions, including what abundance would be safe?

Reason: Conservation requirements

6) How many did there use to be?

Reason: As background information for considering changes/threats

7) What is controlling numbers?
    i. What kills them naturally?
    ii. How many get bycaught?

iii. How many are killed deliberately?

Reason: To identify causes and possible mitigation and to understand the potential for intervention

8) Is there evidence of competition between grey seal and harbour seal?
   i. Do they compete for resources?
   ii. Do grey seal exclude harbour seal from haulout or foraging locations?
   iii. Is grey seal predation a major issue?

Reason: The most likely natural factor, to understand potential for intervention

9) Where do they go?

Reason: to know where human activities may affect them & where to look if problems occur

10) How does distribution change through the year
    i. Is there a net movement of grey seal into the North Sea in summer?
    ii. Is there movement of grey seal down the west coast in summer?
    iii. How do moulting & breeding locations relate?

Reason: To know where human activities may affect them & where to look if problems occur

11) What connections are there with populations in other countries

Reason: To know where human activities may affect them & where to look if problems occur

12) What, where when and how, much do they eat?
    i. What sort of places do they both require and prefer in terms of spatial distribution and environmental characteristics?
    ii. How important is the proximity of haulout sites?
    iii. How do seals search for and locate foraging sites. What is the role of intrinsic and extrinsic information in the process of establishing foraging patterns?
    iv. How successful are they in terms of acquisition of necessary resources in relation to these environmental conditions?
    v. How flexible are their prey choices?

Reason: to understand effects on fishing and effects of fishing on them

13) What factors affect productivity in both species?
    i. How does the size and condition of pups influence their chances of survival?
    ii. What is the “cost” of breeding to the mother?
    iii. What is the relationship of maternal expenditure to pup survival?

14) What likely threats are there? Including for example:
    i. Effects of climate change
    ii. Disease e.g. PDV
    iii. Novel pollutants
    iv. Biotoxins
    v. Marine industrial developments

Reason: Preparedness

Seal Impact Assessment Methods Workshop

Kate Brookes

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Background

This workshop was held following a recommendation from the 2015 NERC Special Committee on Seals (SCOS). SCOS had been asked a question by Scottish Government, on whether PBR was the most suitable means of carrying out assessments of the impact of marine renewable developments on seals. Scottish Government's current policy is to use PBR, which is considered to work well for seal licensing applications, but does not assess across the lifetime of a renewables development, among other concerns (see SCOS 2015 for more detail). SCOS's advice was that a workshop which addressed the issue more fully would be a suitable route forward.

Attendance

Chair: Kate Brookes (MSS)

In Person Attendees: John Baxter (SNH), Finlay Bennet (MSS), Ewan Edwards (MSS), Bob Furness (Macarthur Green), Kate Grellier (Natural Power), Phil Hammond (SMRU), John Harwood (SMRU Consulting), Gordon Hastie (SMRU), Erica Knott (SNH), Nancy McLean (Natural Power), Eunice Pinn (JNCC), Oana Racu (MSP&P), Debbie Russell (SMRU), Carol Sparling (SMRU Consulting), Elaine Tait (MSP&P), Dave Thompson (SMRU), Ian Walker (MSP&P).

Teleconference Attendees: David Bova (MSLOT), Gayle Holland (MSLOT), Roger May (MSLOT), Jared Wilson (MSS)

Agenda

Morning

Presentations (20 minutes each)

- Dave Thompson and Debbie Russell – Potential Biological Removal (PBR)
- John Harwood – Interim Population Consequences of Disturbance (iPCoD)
- Bob Furness – Seabird assessments: The merits and use of PBR in seabird assessments and the merits and limitations of PVA
- Finlay Bennet – Using PVA outputs to inform decision making on tolerance thresholds of change in assessments
- Phil Hammond - IWC Revised Management Procedure and the practicalities of how it is implemented
- Nancy McLean and Kate Grellier – Assessment framework used for harbour seals and bottlenose dolphins in Moray Firth and Forth and Tay wind farm EIAs

Afternoon

Discussions regarding information presented in the morning session.

Summary of discussions

Introduction

Proposed marine renewable developments in Scottish waters represent a potential risk to marine mammal populations. Of particular concern are harbour seals, populations of which have shown rapid declines in some management areas, such as East Scotland, and Orkney and the North Coast. Scottish Government's policy has been to use the Potential Biological Removal (PBR) method to assess whether the estimated potential mortality of seals due to a development is within acceptable limits and will allow the population to tend towards a predetermined target level; maximum net productivity level (MNPL). This was driven by the requirement to determine appropriate numbers of seals that could be shot under licence, to reduce interactions with aquaculture and fishing interests. The policy was adopted on the basis of advice from SCOS in 2008/2009 and at the time was considered to be the current 'best available method' for managing impacts on seal populations, until a more sensitive and/or robust method could be developed. It is based on a simple population model and was developed for use under the US Marine Mammal Protection Act. It is simple to compute, is not dependent upon detailed understanding of population dynamics and can operate with only the current population estimate. Since PBR requires that all anthropogenic mortality is accounted for in the take, potential mortality as a result of interaction with marine renewable developments has also been assessed against these thresholds to date.

PBR has been a useful framework for assessing applications related to seal licensing, since the number of licences granted can be re-evaluated annually to ensure that the take is within acceptable limits. However, the PBR estimation process is not designed to forecast population trajectories. In its question to SCOS regarding whether the use of PBR in marine renewable impact assessments was appropriate, the Scottish Government raised issues around the use of an annually calculated metric such as PBR for use in assessments that should cover the lifetime of a renewables project (often in the region of 25 years), during which time, the PBR threshold may have changed.

There is a specific issue in the Orkney and North Coast management area, where there are plans for commercial scale tidal stream renewable developments. The harbour seal population in this area has declined by 76% since 2001 (9% per annum). Currently, the Scottish Government does not issue licences to shoot seals in this area because of the extent of the decline and because its cause is not known, despite research into the issue (e.g. Hall et al., 2015). Since tidal stream renewables are still in their infancy, the extent to which they may impact upon harbour seal populations is currently unknown. Precautionary assumptions are made regarding this, and these are likely to overestimate the true effects. Putting any such effects (whether they are overestimated or not) into a population context is difficult, and any increase in mortality rate has the potential to increase the rate of decline of the harbour seal population in this management unit.

The workshop on 3rd February 2016 brought together attendees from MS, MSS, JNCC, SNH, SMRU and environmental consultancies to discuss a way forward in the approach that is used to estimate the impacts of future developments on seal populations. The questions posed at the beginning of the workshop were:

- Is PBR the most suitable approach for managing seal impacts across the lifespan of a 25 year marine renewable energy development?
- Could an alternative framework provide a more suitable evidence base?
- How feasible would it be to implement a novel framework?

Discussions

The discussions held were wide ranging and we have not attempted to record them verbatim. Below is a summary of the points that were made.

1. **Discussion around management objectives**
   - It was recognised that we require a clear description of the management objectives for seal populations.
   - What level of impact from marine renewables is acceptable and how do we assess that? This should be undertaken with reference to management objectives, including site based conservation objectives for statutory protected areas whose populations may forage within or transit across areas proposed for development.
   - We need a better understanding of the causes of declines in already-declining populations – e.g. are these human induced or “natural”?
   - There was discussion around the relevance of considering potential anthropogenic drivers that are unlikely to be responsible for declines. There was recognition of the value of identifying and excluding those potential anthropogenic drivers that can be assessed as unlikely to contribute to population declines.
   - There was discussion about which sources of mortality could or should be included in any future analysis.

2. **Discussion of assessment options**
   - One option discussed was to understand and accept the limitations of PBR, but to continue using it for all purposes, in the absence of a suitable alternative.
   - To complement this, there was discussion around some additional adjustments and checks to give more confidence that the outputs from PBR are reasonable (further details below).
   - It was suggested that PBR could be retained for the purposes of seal licensing; but to use different method for renewables developments.
   - However, the preferred option would be to develop a ‘new’ method suitable for ‘long term’ licensing requirements.
   - There was broad agreement that a population consequences assessment that estimated effects and their cumulative impact upon the populations of interest using PVA (population viability analysis) would be the most appropriate assessment tool. This is because PVAs provide a framework that uses assumed or estimated demographic rates (principally survival and productivity) in a mathematical model to forecast future population levels of a wild animal population, either under currently prevailing circumstances or as a consequence of some perturbation to the system.
   - A standard PVA using a Leslie matrix (e.g. Vortex) was suggested as being a potentially useful model to start from, due to its relative ease to use.
   - Discussion touched on what is being done in the current marine licensing context i.e. exploratory use of iPCoD (interim population consequences of disturbance). Although iPCOD is designed to consider the effects of disturbance to populations through the use of dose response functions (currently generated through expert elicitation, but with the potential to be based on observations), in this context, where only mortality is being assessed, iPCoD operates as a standard PVA.
   - Running simulations many times (thousands) allows for estimates of the likely range of population consequences, as well as an estimate of the uncertainty around these. The output would be a statistical distribution of predicted decline.
   - There was discussion about what metrics would most usefully describe the assessed population changes and inform decision making, taking account of the potential for

metrics to be sensitive to error, and the extent to which this should be a consideration in their use for decision making. There are two main categories of metric: probabilistic approaches and ratio approaches (also known as counterfactuals) and examples of both were identified. Counterfactuals broadly describe the difference between population outcomes with and without the effects under examination. They can be presented for many different aspects of populations (e.g. population size, probability of extinction), but what metric should be used was not discussed during the workshop.

- Actual variation of numbers of seals shot and estimates of number of seals by-caught every year could be included in a population consequences assessment..
- To address uncertainties around the numbers of harbour seals likely to collide and be killed by tidal turbines, a "survey, deploy & monitor" approach should be employed. The longer term goals of this should be to improve knowledge of effects, with a view to managing the risk to seals.
- One suggestion was to use a combination of different methods and assess the end result to achieve a consensus of opinion.
- Predictive population models should be as sophisticated as the data that are available will allow, but can start with simple PVA models built, for example, on the parameters available in Harwood & King (2014). Improving understand of population dynamics and demographic parameters will allow development of more sophisticated models. Inclusion of environmental covariates may also improve the functioning of these models, e.g. Caillat & Smout (2015).

3. The way forward

Moving to a population consequences assessment

There was some consensus around the idea that ratio based metrics are informative metrics for decision making purposes in the context of assessments of marine renewable developments.

Metrics for assessments of the impacts of marine renewables to seabird populations, have been and continue to be developed (e.g. Cook & Robinson, 2016 and on-going work at CEH), and there should be coordination between progress made on frameworks between the two species groups. Awareness of the criticisms of Green et al. (2016) regarding the use of PBR and a range of metrics associated with PVA in the context of assessing impacts to seabirds is likely to be a consideration for those undertaking assessments of marine mammals.

If very few data are available, a simple PVA can be run, but where a more sophisticated model is available, this should be used in preference. Examples for the Orkney and North Coast seal management area would be the extremes of using the iPCOD framework, which is available now, and using the Bayesian state space model that is currently under development at SMRU (Caillat & Smout, 2015). The extent to which more sophisticated modelling approaches may support the adoption of different metrics was not discussed in any detail. Methods such as the framework used by the IWC for its Catch Limit Algorithm are able to be flexible to the availability of data. In situations where there are fewer data, or greater uncertainty, the number of animals that can be removed is reduced. As more data become available and/or the uncertainty decreases, the allowable removal can increase. This is seen as an advantage especially if there is a desire to set reduced limits if there is greater estimation error of the magnitude of effects or population sizes, and associated vital rates.

Part of the process of developing a PVA is to determine the most appropriate values to use for the necessary demographic parameters. While this can often be difficult with different species groups, for marine mammals, much of the work has already been carried out and is available in Harwood &

King (2014). PVA models usually assume no density dependence, which in the context of these assessments can make interpretation difficult. Population models that include density dependence are less likely to show linear declines, rather, they are likely to be parameterised such that a reduction in the number of individuals leads to an increase in the survival or fecundity rates for the remaining individuals, which can slow the rate of decline, or in stable populations lead to the population returning to its pre-impacted size. However, very few data are available to parameterise models with density dependence, and in some impact assessments, decisions have been made to assume that it does not occur. This is largely considered to increase the precaution in assessments since it does not allow for recovery of a population (examples such as the increase in the harbour seal population off eastern England following the PDV (phocine distemper virus) demonstrate that populations are capable of recovery).

In assessments undertaken on depleted populations, irrespective of the metric used to describe changes to the population, making the assumption of no density dependence along with the assumption of a closed population represents a precautionary approach. This means that the numbers of animals “lost” from the modelled population, or the predictions about the probability of a decline are likely to be over estimates. Regulators and their advisors who use these results should be mindful of this and caution is urged against the over-interpretation of the outputs.

Tests and improvements to PBR

While PBR is still in place as a tool for advising management of the effect of removals from a seal population, there is a need for a robustness analysis of its performance. An analysis should be undertaken using a PVA (or more sophisticated population model if it is available) and should compare forecast population trajectories without any removals with forecast trajectories if removals are permitted with an upper annual limit set using a PBR calculation. The analysis should contrast the potential effects in a number of scenarios where the uncertainty around the numbers of seals likely to be killed varies.

These would include:

situations in which death is almost certain but the total number of seals shot is likely to vary from year to year, e.g. shooting of seals around salmon farms,

situations where there is great uncertainty about the number of seals that may die each year, e.g. collisions with tidal turbines, and situations where death is almost certain and variation among years is limited, e.g. by-catch.

PVA simulations should be run for seal management areas that are increasing, approximately stable, and decreasing. The most informative output metric is likely to be the statistical distribution of the rate of decline in population size that is attributable to the removals over 12, 24 or 36 year periods (to be determined on the basis of reporting cycles required under legislation).

Any software that has been developed for performing PVA would be suitable for this purpose, although there are some advantages to using the iPCoD code, which is available on the Marine Scotland website[44]. Harwood & King (2014), provides instructions for developing population models of most of the Scottish harbour seal management areas, with some updates to take account of counts conducted since 2013.

These models could also be used to generate simulated time series of data that could be used in combination with the statistical estimation models to determine whether the forecast changes in abundance could be detected by different monitoring programmes.

[44] http://www.gov.scot/Topics/marine/science/MSInteractive/Themes/pcod

Conclusion

The workshop attendees clearly felt that there was a need to improve or move on from using PBR for all of Scottish Government's licensing requirements. Several options were discussed, including tests to demonstrate the effectiveness of PBR, as well as methods by which assessments may be undertaken in the future. This is an area for development, and questions remain, but is it now clear that for renewable energy assessments, where consenting would cover many years, that an alternative to PBR is required.

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Glossary

EIA	Environmental Impact Assessment
iPCOD	Interim Population Consequences of Disturbance
IWC	International Whaling Commission
JNCC	Joint Nature Conservancy Council
MSLOT	Marine Scotland Licensing Operations Team
MSP&P	Marine Scotland Policy and Planning
MSS	Marine Scotland Science
NERC	Natural Environment Research Council
PBR	Potential Biological Removal
PDV	Phocine Distemper Virus
PVA	Population Viability Analysis
SCOS	Special Committee on Seals
SMRU	Sea Mammal Research Unit
SNH	Scottish Natural Heritage

Provisional Regional PBR values for Scottish seals in 2017

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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 2015 survey counted 43% more seals in Southwest Scotland and increased the Western Scotland estimate by approximately 10% . These translate into increased PBRs for those regions. The 2015 counts for Shetland, the Moray Firth and Eastern Scotland were similar to previous counts. Grey seal numbers in the Moray Firth increase by a factor of three leading to a large increase in PBR. Other grey seal counts in 2015 were similar to previous surveys.

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 2007 shows that around 31% were hauled out during the survey windows (Lonergan et al., 2011a). The 20th centile of the distribution of multipliers from counts to abundances implied by that data is 2.56. (N.B. The multiplier for converting grey seal counts to N_{min} has been revised in light of new information on haulout behaviour. This result will be presented to SCOS 2016 and, if accepted, will be used to revise these figures. The new multiplier will increase the mean population estimate by approximately 30%, and the tighter confidence intervals will pull the lower 20th percentile up towards that mean estimate. Overall this may increase the value of N_{min} by around 45 to 50%. The PBR will therefore increase by approximately 45 to 50%).

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).

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.

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

Seal Management Area		Area covered
1	South-West Scotland	English border to Mull of Kintyre
2	West Scotland	Mull of Kintyre to Cape Wrath
3	Western Isles	Western Isles incl. St Kilda, 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 Coast	Fraserburgh to English border

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 haulouts; environmental conditions; the spatial structure of existing data; practical constraints on future data collection; and management requirements.

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 2016

Seal Management Area	2011-2015 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
2a West Scotland - South	7,645	(2014-2015)	7,645												321
2b West Scotland - Centra	6,424	(2014)	6,424												270
2c West Scotland - North	1,115	(2013; 2014)	1,115												47
3 Western Isles	2,739	(2008; 2011)	2,739	16	32	49	65	82	98	115	131	147	164	0.5	82
4 North Coast & Orkney	1,938	(2013)	1,938	11	23	34	46	58	69	81	93	104	116	0.1	11
4a North Coast	73	(2013)	73												0
4b Orkney	1,865	(2013)	1,865												11
5 Shetland	3,369	(2015)	3,369	20	40	60	80	101	121	141	161	181	202	0.1	20
6 Moray Firth	745	(2008; 2011; 2013; 2015)	745	4	8	13	17	22	26	31	35	40	44	0.1	4
7 East Scotland	224	(2013; 2015)	224	1	2	4	5	6	8	9	10	12	13	0.1	1
SCOTLAND TOTAL	**25,399**	(2011; 2013-2015)	**25,399**	**150**	**301**	**454**	**605**	**760**	**911**	**1,064**	**1,215**	**1,367**	**1,522**		**805**

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 2016

	2011-2015			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)	957	5	11	17	22	28	34	40	45	51	57	1.0	57
2 West Scotland	5,064	(2013-2015)	12,964	77	155	233	311	388	466	544	622	700	777	1.0	777
2a West Scotland - South	3,618	(2014-2015)	9,262												555
2b West Scotland - Centra	1,056	(2014)	2,703												162
2c West Scotland - North	390	(2013; 2014)	998												60
3 Western Isles	4,038	(2008; 2011)	10,337	62	124	186	248	310	372	434	496	558	620	1.0	620
4 North Coast & Orkney	8,106	(2013)	20,751	124	249	373	498	622	747	871	996	1,120	1,245	1.0	1,245
4a North Coast	266	(2013)	681												41
4b Orkney	7,840	(2013)	20,070												1,204
5 Shetland	1,558	(2015)	3,988	23	47	71	95	119	143	167	191	215	239	1.0	239
6 Moray Firth	1,917	(2008; 2011; 2013; 2015)	4,908	29	58	88	117	147	176	206	235	265	294	1.0	294
7 East Scotland	2,296	(2013; 2015)	5,878	35	70	105	141	176	211	246	282	317	352	1.0	352
SCOTLAND TOTAL	**23,353**	(2011; 2013-2015)	**59,784**	**355**	**714**	**1,073**	**1,432**	**1,790**	**2,149**	**2,508**	**2,867**	**3,226**	**3,584**		**3,584**

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

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 31% of grey seals were hauled out during the survey windows (Lonergan *et al*., 2011a). The 20th centile of the distribution of multipliers from counts to abundances implied by that data is 2.56.

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.

4) Western Scotland (F_R = 0.7)

The population is largely closed, likely to have limited interchange with much smaller adjacent populations. The population has apparently increased substantially in the last 5 years. 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 much larger adjacent population to the north is apparently increasing. The intrinsic population growth rate is taken from other similar populations.

5) Moray Firth (F_R= 0.1)

Counts for the Moray Firth showed large inter annual fluctuations after a period of gradual decline from 2000. The counts in 2014 and 2015 are the two lowest moult counts since recent surveys began in the 1980s. 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. We suggest that based on the low count and the absence of any apparent recovery, the F_R should again be set to a 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 haulout counts (Lonergan *et al*. 2011a) also suggest substantial long-distance movements of individuals.

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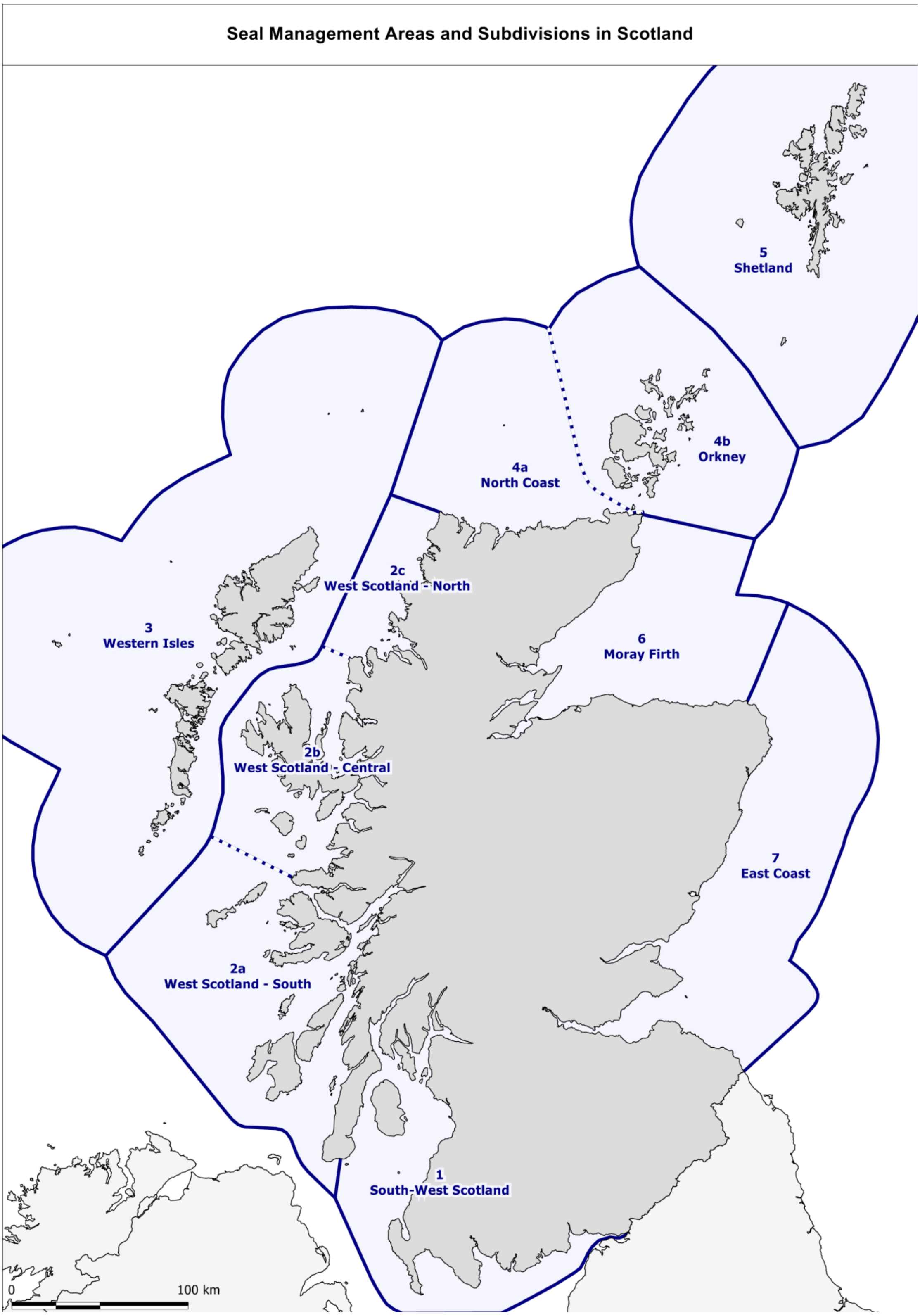
Figure 1. Seal management areas in Scotland.



Marine Strategy Framework Directive

Estimating the European Grey Seal population

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Abstract

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

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

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

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

Introduction

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

For the North-east Atlantic, progress towards defining and achieving GES for these indicators is coordinated by the Commission for the Protection of the Marine Environment of the North-east Atlantic (OSPAR) across Contracting Parties (CPs), with technical advice from the International Council for the Exploration of the Sea (ICES). The UK acts as lead developer for the seal indicators and the Joint Nature Conservation Committee (JNCC) coordinates this work.

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

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

- M-3: Abundance and distribution each of harbour and grey seals (1.1 Species distribution, 1.1.2 Distributional pattern within range; 1.2 Population size, 1.2.1 Population abundance).
- M-5: Grey seal pup production (1.3 Population condition, 1.3.1 Population demographic characteristics).

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

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

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

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

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

Materials and Methods

<u>Pup production data</u>

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

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

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

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

Independent counts

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

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

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

Priors and Movement Model

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

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

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

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

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

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

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

Fitting Procedure

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

Results and Discussion

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

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

Further work

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

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

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

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

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Table 1. Prior and posterior parameter distributions.

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

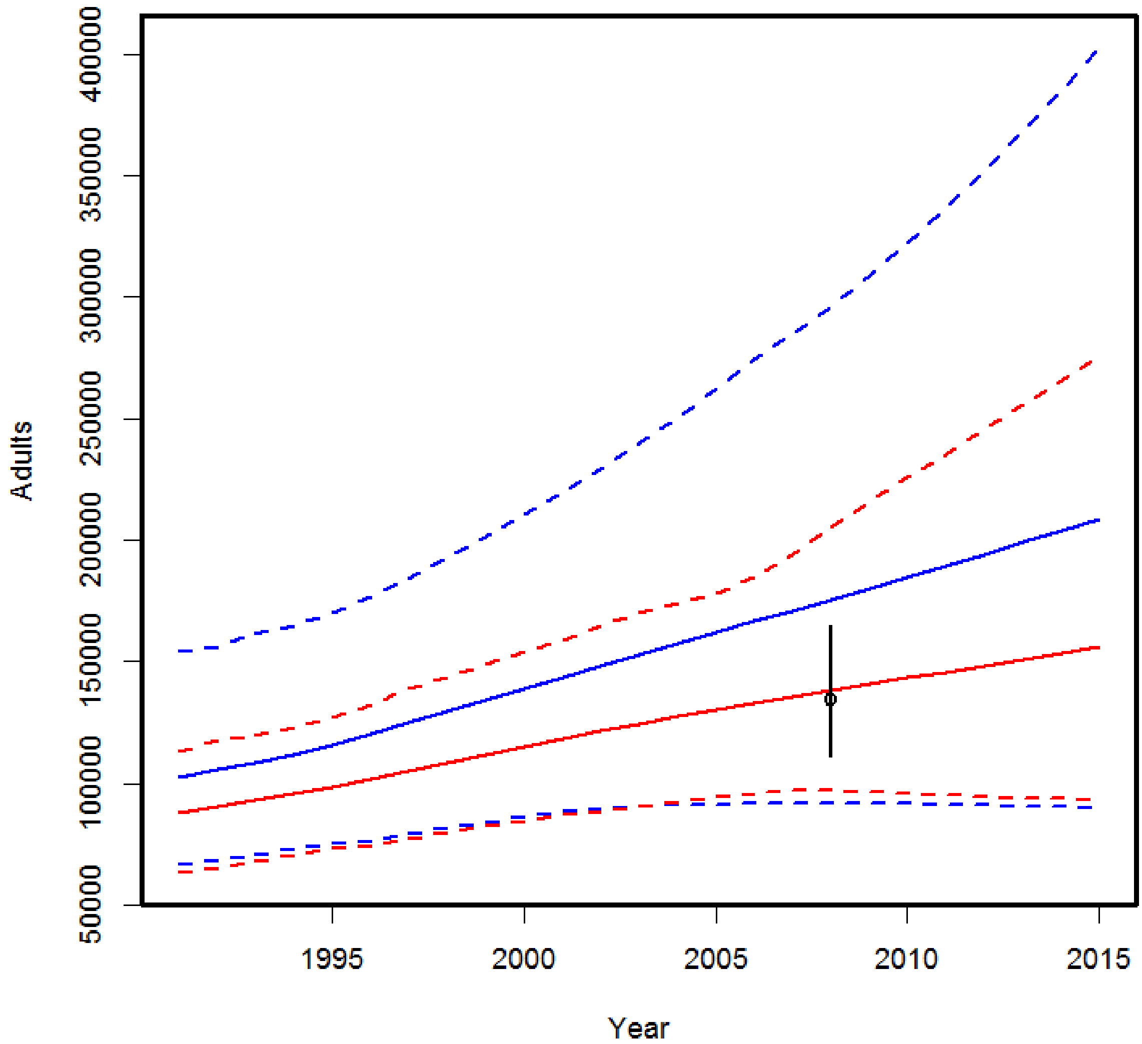
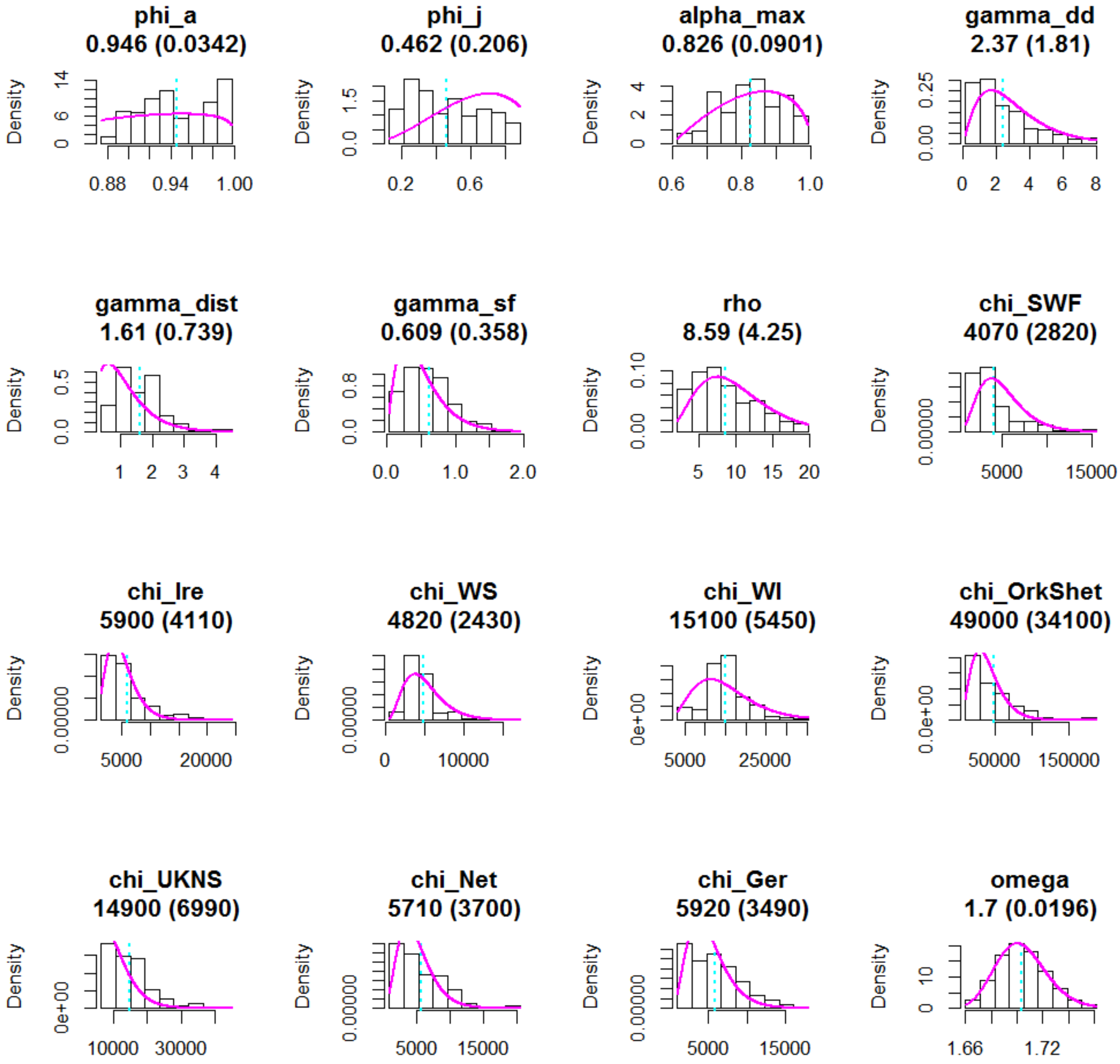


Figure 1. Posterior mean estimates of total population size from two models of grey seal population dynamics, fit to pup production estimates from 1991-2013 and a total population estimate from 2008 (circle, with horizontal lines indicating 95% confidence interval on the estimate). Lines show the posterior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

(a)


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

(b)

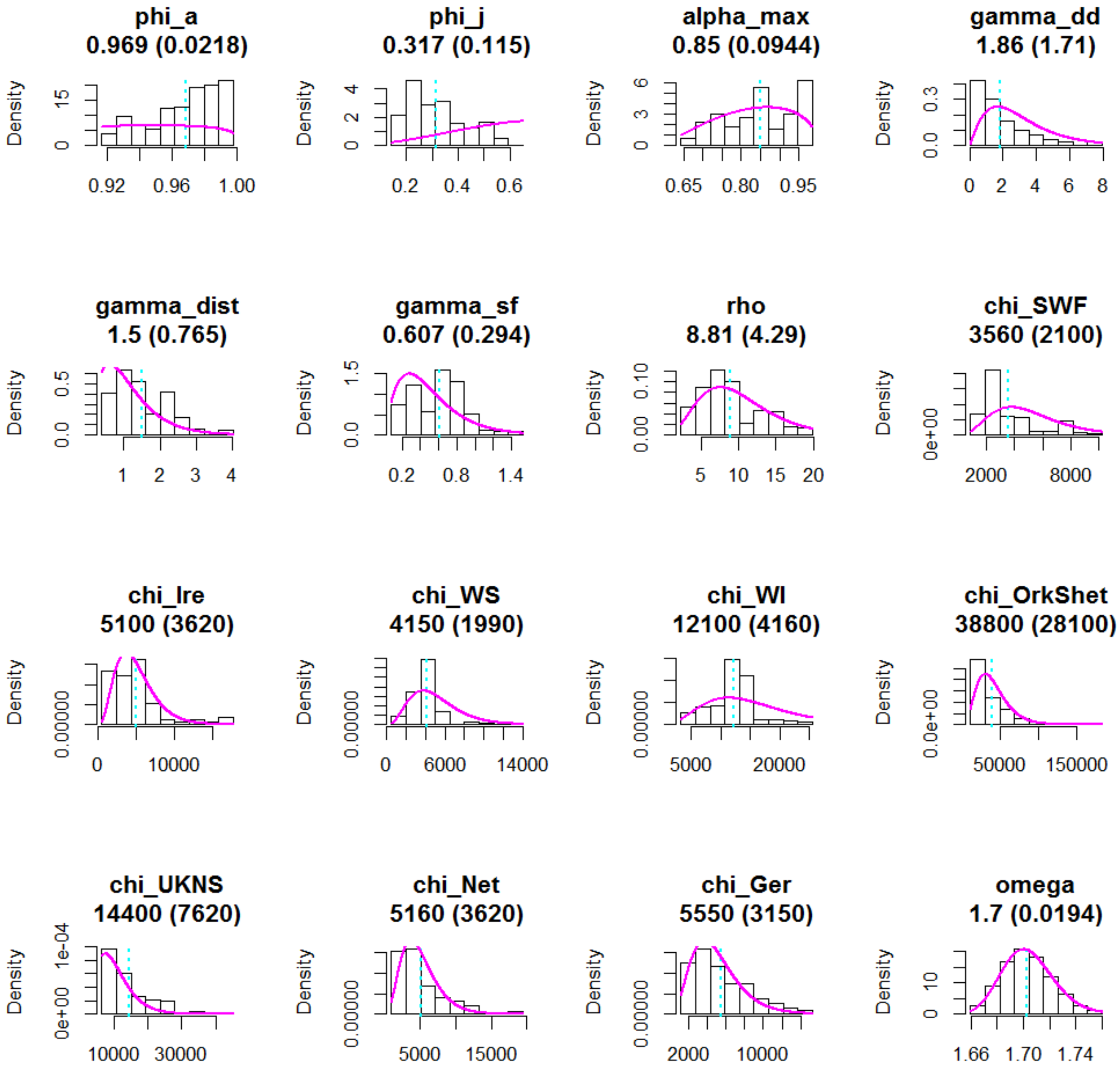


Figure 2. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1991-2013 and total populations estimate from 2008. The vertical line shows the posterior mean; its value is given in the title of each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

2016 Annual review of priors for grey seal population model

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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 A1).

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 study in Canada based on re-sightings of branded pups, 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). 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).

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 fecundity 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. unpublished). Smout, King & Pomeroy (2010; SCOS-BP 15/06) estimated apparent fecundity rates of 0.77 (95% CI: 0.75 - 0.79) and 0.86 (95% CI: 0.84 - 0.88) for North Rona and the Isle of May, respectively, indicating there may be substantial between colony variation in fecundity rates. Similarly to Bowen *et al.* (2006), this observational study indicated lower fecundity rates than the pregnancy rates estimates in other studies. The estimates from Smout, King & Pomeroy 2010 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 A2). 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.

Sable Island grey seal branding study

After the 2016 SCOS meeting the results of additional analyses of the long-term brand sighting study of grey seals at Sable Island, Nova Scotia, were presented to the Canadian National Marine Mammal Peer Review Committee (den Heyer & Bowen; 2016). The results are relevant to the priors discussion above and are briefly described below.

As in Scotland, the Sable Island pup production 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.

A Cormack-Jolly-Seber model was used to estimate age- and sex-specific adult survival. 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. 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.

As in UK studies only female grey seals with pups are regularly sighted on the breeding colony, thus, those females that skip breeding are unobservable (temporary emigration). A multi-state open robust design model was used to estimate the transition probabilities between breeding (observable) and non-breeding (unobservable) states for individually marked females. Females that gave birth had on average an 85% chance of pupping in the following year. However, females that did not give birth had a 56% chance of giving birth in the following year, suggesting that female quality plays a role in breeding probability.

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.

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Appendix – Priors for grey seal population model

Table A1. 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 ϕ_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 ϕ_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. ρ	Ga(4,2.5)	10 (5)	as SCOS 2015 main analysis		as SCOS 2015 main analysis		as SCOS 2015 main analysis	
NS carrying cap. χ_1	Ga(4,2500)	10000 (5000)	as SCOS 2015 main analysis		as SCOS 2015 main analysis		as SCOS 2015 main analysis	
IH carrying cap. χ_2	Ga(4,1250)	5000 (2500)	as SCOS 2015 main analysis		as SCOS 2015 main analysis		as SCOS 2015 main analysis	
OH carrying cap. χ_3	Ga(4,3750)	15000 (7500)	as SCOS 2015 main analysis		as SCOS 2015 main analysis		as SCOS 2015 main analysis	
Ork carrying cap. χ_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 ω	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 A2. 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