Scientific Advice on Matters Related to the Management of Seal Populations: 2018

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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 2018, 35 questions were received from Marine Scotland, Defra and Natural Resources Wales. SCOS's answers to these questions are provided in detail in the main Advice below and summarised here.

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

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

The most recent surveys of the principal Scottish grey seal breeding sites were flown in 2016. The results from the 2016 surveys together with the 2016 estimates from the annually ground counted sites in eastern England, produced a pup production estimate of 58,700. Adding in an additional 6,300 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 65,000 (95% CI 57,800-71,800) pups (Table s1).

The pup production estimates are converted to estimates of total population size (1+ aged population) using a mathematical model and projected forward to 2018. The pup production model is currently under review and being updated.
The population model provided an estimate of 150,000 (approximate 95% CI 131,000-171,600) UK grey seals (1+ aged population) in 2017.

Summary *Table s1.* ***Grey seal pup production estimates in 2016***.

Location	Pup production in 2016
England	**8,500**
Wales	**1,650**
Scotland	**54,750**
Northern Ireland	**100**
Total UK	**65,000**

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

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

Harbour seals are counted while they are on land during their August moult, giving a minimum estimate of population size. Not all areas are counted every year, but the aim is to cover the UK coast at least once every 5 years. Combining the most recent counts (2014-2016) gives a total of 32,600 counted in the UK (Table s2). Scaling this by the estimated proportion hauled out (0.72 (95% CI: 0.54-0.88)) produced an estimated total population for the UK in 2017 of 45,100 (approximate 95% CI: 37,000-60,400).

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 with general declines in counts of harbour seals in several regions around Scotland. However, the declines are not universal with some populations either stable or increasing.

Populations along the English East coast, from Kent to the Scottish border have generally increased year on year, with those increases punctuated by major declines associated with two major PDV epidemics in 1988 and 2002. Recent trends, i.e. those that incorporate the last 10 years (2006 to 2016) show significant growth in both English seal management units (SMU).
Populations along the East coast of Scotland and in the Northern Isles have generally declined. The recorded declines have differed in intensity but in all areas the current population size is at least 40 % below the pre-2002 level. Populations in North Coast & Orkney and East Scotland SMUs are continuing to decline. Although continued declines are not evident in Shetland or the Moray Firth, there is no indication of recovery.

Populations in western Scotland and Northern Ireland are either stable or increasing. Counts in the central section of the large West Scotland management region have been increasing since the 1990s and in all other areas they have remained stable, except for Northern Ireland which appears to have declined slowly throughout.

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

Location	Most recent count (2015-2017)
England	**5,100**
Wales	**<50**
Scotland	**26,600**
Northern Ireland	**950**
Total UK	**32,600**

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 the moulting surveys. Information on vital rates would improve our ability to provide advice on population status. At present vital rate estimates for UK harbour seals are only available from a long-term study of the Loch Fleet population in the Moray Firth. However, studies are underway to obtain similar data from new sites in Orkney and western Scotland.

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

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

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

Potential biological Removals (PBR).

The Potential Biological Removals (PBR) is a relatively simple metric developed to provide advice on the levels of removals from a marine mammal population that would still allow the population to approach a defined target. Provisional regional values for PBR for Scottish seals for 2019 were calculated and presented. The latest harbour seal survey count for the Western Isles SMU was approximately 25% higher than the previous estimate, resulting in a 25% higher PBR for harbour seals in that management region. Part of West Scotland SMU was resurveyed, this resulted in a 4% higher PBR. The grey seal count for the Western Isles was approximately 40% higher than the previous estimate, resulting in a 40% higher PBR for grey seals in that management region.
SCOS recommended that recovery factors used in the PBR calculations should be left unchanged at present.

Interactions with Marine Renewable Energy developments

SCOS discussed potential interactions between seals and marine renewable developments, both offshore wind and tidal energy generation and discussed the use of Acoustic Deterrent Devices as mitigation measures. A summary of the most recent information on these topics is presented.

Interactions with Fisheries

SCOS discussed the current state of knowledge on interactions between seals and salmon fisheries. Work is continuing in Scotland focused mainly on the use of acoustic deterrent devices and capture and removal of problem seals. Modifications to coastal (stake) salmon nets and the use of acoustic deterrent devices have been shown to be effective in limiting if not eliminating depredation.
The issue of seal bycatch in commercial fisheries was discussed. The most recent estimate of seal bycatch in UK fisheries is 572 animals (95% CI 429-1077). However, this is based on assumptions about observed bycatch rates from sampling that is predominantly in the Western Channel and Celtic Sea, where most gillnet effort is located. Sampling effort is too low in other areas to provide reliable area-specific estimates.

Although slightly lower than the 2016 estimate, the estimated bycatch levels in the Celtic Sea exceed a PBR for the combined grey seal population of SW England, Wales and Ireland. An additional but un-recorded number of seals are bycaught by Irish and French boats operating in the Celtic Sea. Despite the bycatch, grey seal populations in Wales and Ireland are increasing, suggesting that some of the bycaught seals are immigrants from Scottish populations.

Competition between grey and harbour seals

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

Scientific Advice

Background

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

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

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

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

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

General information on British seals

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

Grey seals

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

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

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

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

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

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

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

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

Harbour seals

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

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

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

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

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

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

Major declines have now been documented in several harbour seal populations around Scotland, with declines since 2001 of 76% in Orkney, 30% in Shetland between 2000 and 2009, and 92% between 2002 and 2013 in the Firth of Tay. However the pattern of declines is not universal. The Moray Firth count apparently declined by 50% before 2005, remained reasonably stable for 4 years, then increased by 40% in 2010 and has fluctuated since, showing no significant trend since 2000. The

Outer Hebrides apparently declined by 35% between 1996 and 2008 but the 2011 count was >50% higher than the 2008 count. The recorded declines are not thought to have been linked to the 2002 PDV epidemic that seems to have had little effect on harbour seals in Scotland.

Historical status

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

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

Legislation protecting seals

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

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

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

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

Both grey and harbour seals are listed in Annex II of the EU Habitats Directive, requiring specific areas to be designated for their protection. To date, 16 Special Areas of Conservation (SACs) have been designated specifically for seals. Seals are features of qualifying interest in seven additional SACs. The six-yearly SAC reporting cycle requires formal status assessments for these sites. These were last completed in 2013 and are due for renewal in 2019.

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

Questions for SCOS 2018 were received from the three mainland administrations (Marine Scotland, MS; Department for Environment, Food and Rural Affairs, Defra; Natural Resources Wales, NRW) and are listed in Annex II. Some of these questions were essentially the same, requiring regionally specific responses in addition to a UK wide perspective. These very similar questions were therefore amalgamated, with the relevant regional differences in response being given in the tables and text. The question numbers by administration are shown in the boxes for cross reference. The remaining questions were regionally unique, requiring responses that focussed on the issue for a given area. The questions are grouped under topic headings, in the order and as they were given from the administrations.

1. What are the latest estimates of the number of seals in UK waters?	MS Q1; Defra Q1; NRW Q5

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. Outside of the breeding season animals may re-distribute themselves, thus, regional differences in population estimates do not necessarily reflect the abundance of animals in each region at other times of the year.

The most recent surveys of the principal Scottish grey seal breeding sites were flown in 2016. Results from the 2016 surveys together with the 2016 estimates from the annually ground counted sites in eastern England, produced a pup production estimate of 58,700. Adding in an additional 6,300 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 65,000 (approximate 95% CI 57,800-71,800, rounded to the nearest 100) pups (Table 1).

The pup production estimates are converted to estimates of total population size (1+ aged population) using a mathematical model and projected forward to 2018. The stages in the process (pup production → mathematical model → total population size) and the trends observed at each stage are briefly described below and presented in detail in SCOS-BPs 18/01, 18/02, 18/03, Russell et al. (2019)[1] and Thomas et al. (2019)[2]. The pup production model is described in detail in Russell et al. (2019)[2] and is currently under review and being updated.

Based on the standard model and the 2016 pup production estimates, the adult population size associated with the regularly monitored colonies in 2017 was 135,700 (95% CI 118,500-155,200). When combined with pup production at less frequently monitored sites this gives an estimated 2017 UK grey seal population of 150,000 (approximate 95% CI 131,000-171,600). Details in SCOS-BP 18/03 and below.

[1] Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D. and Hiby, A.R.(2019) Monitoring long-term changes in UK grey seal *Halichoerus grypus* pup production. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3100
[2] Thomas, L., Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D. (2019). Modelling the population size and dynamics of the British grey seal. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3134

Table 1 ***Grey seal pup production estimates in 2016.***

Location	Pup production in 2016
England	8,500
Wales	1,650*
Scotland	54,750
Northern Ireland	100*
Total UK	65,000

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

Pup Production

Major colonies in Scotland are now surveyed biennially (see SCOS-BP 14/01). Aerial surveys to estimate grey seal pup production were carried out in Scotland in 2016, using a digital camera system for the third time. Counts of seal pups on these surveys were used to estimate pup production on the biannually monitored colonies around Scotland. Pup productions at the major colonies on the East coast of England are estimated annually from ground counts. These data, combined with estimates from less frequently monitored colonies, indicate that the total number of pups born in 2016 at all UK colonies was approximately 65,000 (approximate 95% CI 57,800-71,800).

Regional estimates at biennially surveyed colonies were 4,500 (approximate[3] 95% CI 3,900-5200) in the Inner Hebrides, 15,700 (95% CI 13,700-18,200) in the Outer Hebrides, 23,800 (95% CI 20,700-27,550) in Orkney and 14,600 (95% CI 12,700-16,900) at the North Sea colonies (including Isle of May, Fast Castle, Farne Islands, Donna Nook, Blakeney Point and Horsey/Winterton). An additional 6,300 pups were estimated to have been born in Wales and at less frequently surveyed colonies in Shetland as well as other scattered locations throughout Scotland, Northern Ireland and South-west England, producing a total UK pup production of 65,000.

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 18/01 & Russell et al. (2019)[1] for details). In both the Inner and Outer Hebrides, the estimated pup production increased between 2014 and 2016 at 6% p.a. and 5% p.a. respectively. However, this should be treated with caution as the survey methodology changed after 2010. Improved camera technology and reduced survey height may have changed both the efficiency of counting and the stage classification of pup images. Technical problems, aircraft availability and loss of film processing capability precluded direct cross calibration of the old and new methods. Investigation of the potential effects of these methodological changes is ongoing. A detailed description of the trends in pup production up to 2010, at regional and colony levels is presented in Russell et al. (2019)[1]. Between 2000 and 2010, i.e. prior to the change in technique, the pup production estimates had remained stationary in the Inner Hebrides and declined at an average of 1% p.a. in the Outer Hebrides. In Orkney, the estimated 2016 pup production was the same as the 2014 estimate and again similar to the 2012 estimate. Pup production in Orkney increased by <1% p.a. between 2012 and 2016. As in the Hebrides, the rate of increase in Orkney has been low since 2000, with pup production increasing at around 1.4% p.a. between 2000 and 2010.

[3] Approximate CVs based on the overall CV of the total pup production estimated by the population dynamics model: see SCOS-BP 18/03. This will likely overestimate the CV for individual regions

In all three regions where the pup production is estimated entirely from aerial survey counts there was an apparent step change coincident with the transition to a new digital camera system. For logistical and technical reasons it has not been possible to directly cross calibrate the two methods. However, as the new time series extends it becomes easier to estimate the magnitude and nature of these changes. A preliminary analysis of the effects suggests that the effect will be colony and substrate specific and has implications for the selected values of some of the parameters in the pup production model. The current pup production model is fully described in Russell et al. (2019)[1]. A series of sensitivity analyses are under way and will be reported to SCOS in 2019.

Pup production at colonies in the North Sea continued to increase rapidly up to 2016 (Table 2). These show an annual increase of 8% p.a. between 2014 and 2016, slightly less than the 10.8% p.a. between 2012 and 2014, and the 12% p.a. rate of increase between 2010 and 2012. The majority of the increase in the North Sea has been due to the continued rapid expansion of newer colonies on the mainland coasts in Berwickshire, Lincolnshire, Norfolk and Suffolk. Interestingly, these colonies are all at easily accessible sites on the mainland, where grey seals have probably not bred in significant numbers since the last ice age. The estimated pup production at the Farne Islands increased dramatically, by >18% p.a. between 2014 and 2016, the more southerly mainland colonies increased by an average of 8.5% p.a. which is substantially lower than the average 22% p.a. increase between 2010 and 2014. Estimates are available for the ground counted colonies on the English east coast (Farne Islands, Donna Nook, Blakeney and Horsey) in 2015 and 2016. The 2015 counts suggest a much lower annual increase for the English mainland colonies, with the largest colony at Blakeney showing a slight decrease after 12 years of extremely rapid (>30% p.a.) growth. The same slowdown in the rate of increase has been observed at both Donna Nook and Horsey. At the Farne islands the pup production estimate increased by 28% between 2014 and 2016, after a period of little change since 2000.

The most recent data for pup production from the major breeding sites in Wales are estimates from 2016. Counts in 2017 were disrupted by a severe storm that reportedly killed 75% of the pups present at around the peak of the pupping season. The 2016 estimates from Ramsey and Skomer have therefore been combined with earlier estimates for North Wales to derive an estimate for the Welsh pup production compatible with the 2016 Scotland wide air-survey results. The 2016 estimates were of 96 pups in North Wales[4]; 465 pups in North Pembrokeshire in 2016[5,6] and 345 pups born on Skomer and adjacent mainland sites in 2016.[7] The relative size of pup production at the different breeding colonies by region is shown in Figure 2.

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[4]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.
[5]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.
[6] Lock, K., Newman, P., Burton, M. & Jones, J. (2017). Skomer MCZ Grey Seal Survey, Marloes Pe ninsula 1992 – 2016. NRW Evidence Report 195
[7]https://www.welshwildlife.org/wp-content/uploads/2014/07/Seal-Report-2014-final-.pdf

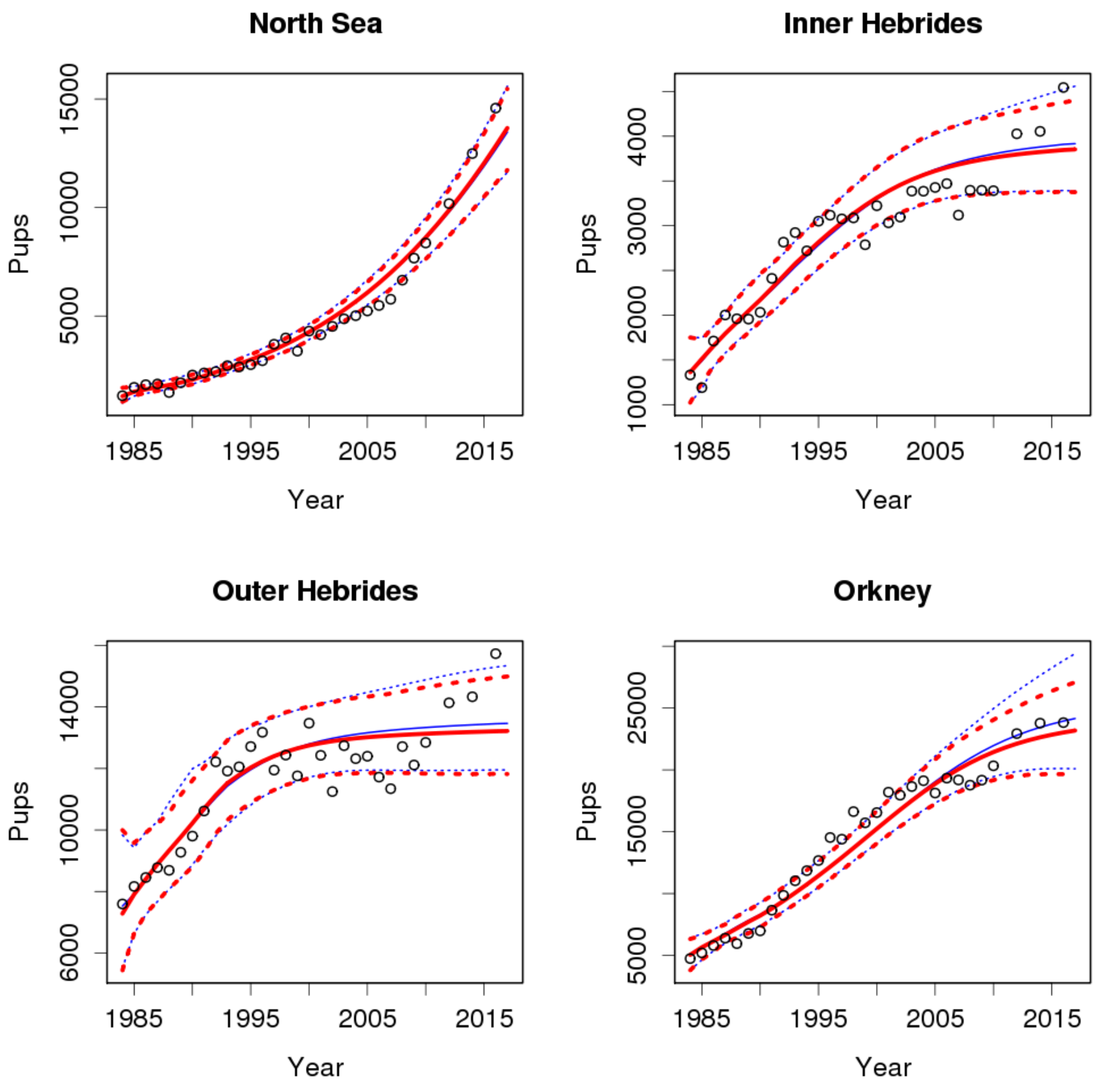

Figure 1. *Mean estimates of pup production (solid lines) and 95% Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates from 1984-2014 (circles) and two independent total population estimates from 2008 and 2014.* Thinner blue lines (partly obscured) show the fit to pup production estimates alone; thicker 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 2016 compared with production estimates from 2014*** *(see SCOS-BP 18/01 for details).*

Location	Pup production in **2016**		Pup production in 2014		Average annual change 2014 to 2016
Inner Hebrides	4,541		4,054		+5.8%
Outer Hebrides	15,732		14,316		+4.8%
Orkney	23,849		23,758		+0.2%
Firth of Forth	6,426		5,860		+4.7%
Main annually monitored Scottish island groups	**50,548**		**47,988**		**+2.6%**
Other Scottish colonies [1] (incl. Shetland & mainland)	4,193	[1]	3,875	[1]	+4.0%
Total Scotland	**54,741**		**51,863**		**+2.7%**
Donna Nook +East Anglia	5,919		5,027		+8.5%
Farne Islands	2,238		1,600		+18.3%
Annually monitored colonies in England	**8,157**		**6,627**		**+10.9%**
SW England (last surveyed 2016)	350		250	[3]	
Wales	1,650	[2]	1,650	[3]	
Total England & Wales	**10,157**		**8,527**		**+9.1%**
Northern Ireland	100	[3]	100	[3]	
Total UK	**64,998**		**60,490**		**+3.7%**

1 Estimates derived from data collected in different years

2 combination of survey counts of most colonies in 2017 and an estimate for other colonies based on a multiplier derived from 2004 survey results. These numbers may be revised once all new survey data is included.

3 includes estimated production for colonies that are rarely monitored

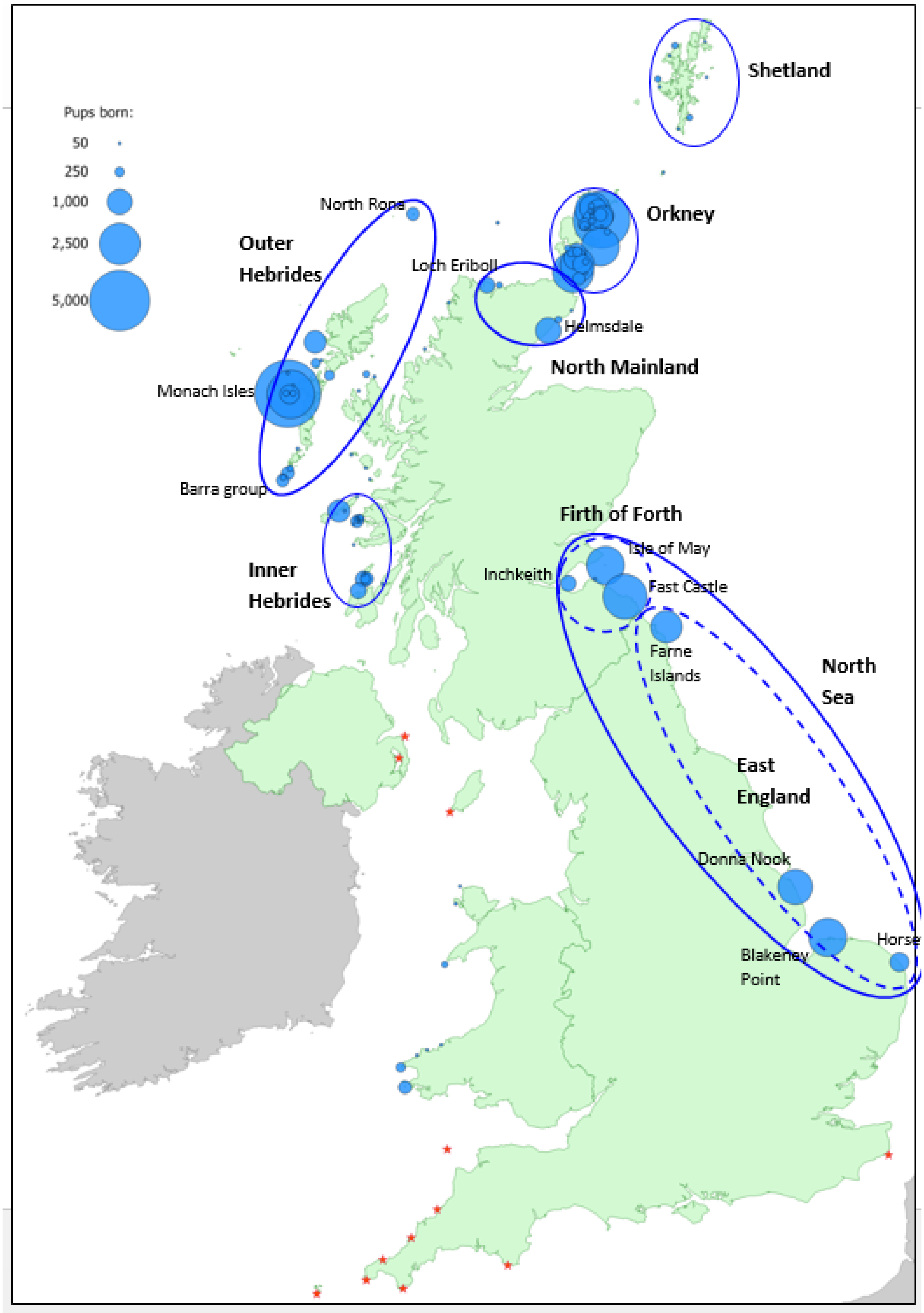

Figure 2. *Distribution and size of the main grey seal breeding colonies. Blue ovals indicate groups of colonies within each region. Red stars represent less frequently surveyed colonies in England, Northern Ireland and the Isle of Man which will be revised in 2019 report.*

Population size

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

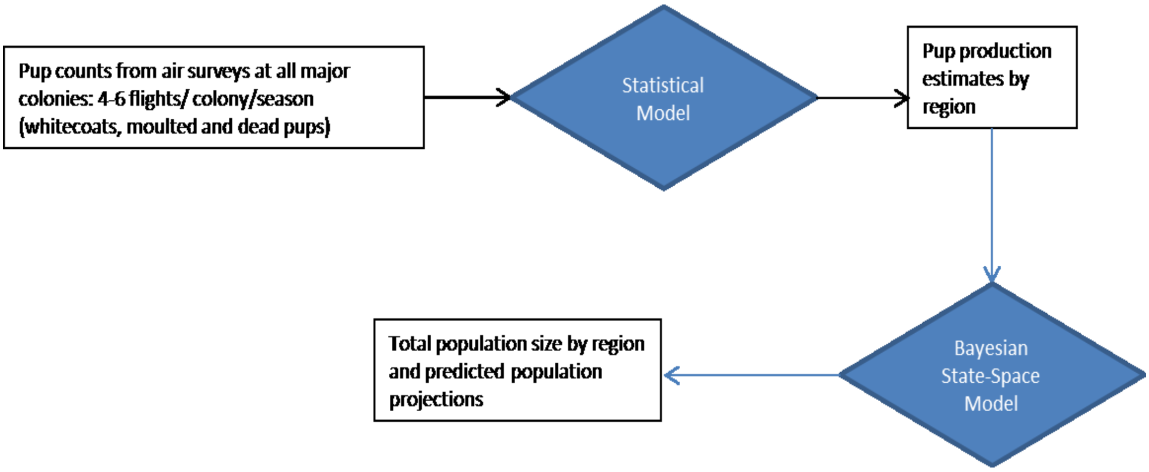

Figure 3. *Schematic diagram of steps involved in estimating total population size from pup counts (see also SCOS BP-09/02, SCOS BP-10/02).*

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

Data from surveys with consistent methodology indicate that from at least 1984 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 quantify the relative contributions of these factors (SCOS-BPs 06/07, 09/02). In 2010 and 2011, we incorporated additional information in the form of an independent estimate of population size based on counts of the numbers of grey seals hauled out during the summer and information on their haulout behaviour (SCOS-BP 10/04 and 11/06). Between 2007 and 2009, 26,699 grey seals were counted during harbour seal moult surveys across the UK (excluding southwest UK). Using telemetry data, it was estimated that 31% (95% CIs: 15 - 50%) of the population was hauled out during the survey window and thus available to count[8]. 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).

[8]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.

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

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

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

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

In 2012, SCOS discussed the priors on the model input parameters in some detail, following re-examination of the data being used and the differences made to the population estimates by changing a number of them to less informative priors (SCOS-BP 12/01 and SCOS-BP 12/02). In 2014 SCOS decided to use the results from a model run using these revised priors (SCOS-BP 12/02) and incorporating a prior based on a distribution for the ratio of males to females in the population (see SCOS-BP 14/02 for details) and the independent estimate of total population size from the summer surveys. Work on updating these priors is continuing. A re-analysis of all the combined data available from pup tagging studies (hat tags, phone tags and GPS/GSM tags) suggested that there was no significant sex-specific differences in first year pup survival. SCOS-BP 18/02 presents details of prior distributions used in the model and the justification for the selected values.

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 what was considered to be a more reasonable range of 0.8 to 0.97. Posterior mean adult survival with this revised prior was 0.95 (SD 0.03).

This year, an identical model was fitted with three different inputs. For the main analysis, these were pup production estimates from 1984-2016, as given in briefing paper SCOS-BP 18/01, and independent estimates of population size from 2008 and 2014. In additional analysis 1, the same data were used, but only for the period 1984-2010 to include only data prior to the change in survey methods between 2010 and 2012. In additional analysis 2, data for the period 1984-2010 was also used, but with pup production data derived using a slightly different assumption (PCORRECTMOULT parameter, the estimated misclassification of moulted pups as white coated pups, set to 0.5 for all years).

The model allowed for density dependence in pup survival, using a flexible form for the density dependence function, and assumed no movement of recruiting females between regions. The same model and prior distributions for demographic rates were used, including a prior on sex ratio and a constraint on adult survival to the range 0.80-0.97. The only change to priors was an increase in the prior on North Sea carrying capacity from 10,000 to 20,000 as the continued rapid exponential increase indicated that it was not close to its carrying capacity.

Grey seal population estimate

From the standard model run the estimated adult population size in the regularly monitored colonies in 2017 was **135,700 (95% CI 118,500-155,200)** for the model incorporating density dependent pup survival, using the revised priors and including the independent estimates for 2008 and 2015 (details of this analysis and posterior estimates of the demographic parameters are given in SCOS-BP 18/02 and SCOS-BP 18/03). A comprehensive survey of data available from the less frequently monitored colonies was presented in SCOS-BP 11/01 and updated in 2016 (SCOS-BP 18/01). Total pup production at these sites was estimated to be approximately 6,300. The total population associated with these sites was then estimated using the average ratio of 2016 pup production to 2017 population size estimate for all annually monitored sites. Confidence intervals were estimated by assuming that they were proportionally similar to the population dynamics model confidence intervals for the standard model run. This produced a population estimate for these sites of **14,300 (approximate 95% CI 12,500 to 16,400)**. Combining this with the annually monitored sites gives an estimated 2017 UK grey seal population of **150,000 (approximate 95% CI 131,000-171,600)**.

Potential problems associated with transition to the new digital methods have also highlighted potential sensitivity of the pup production estimates to some of the parameter estimates used. These aspects of the pup production model are being investigated. A detailed description of the model and the pup production trajectories is presented in Russell et al. (2019) [1]. A detailed analysis of the effects of changing parameters is underway as part of a process to develop a new Bayesian pup production model. As a preliminary to that development, two additional runs of the population dynamics model were carried out with different versions of one of these parameters, the estimated misclassification of moulted pups as white coated pups (PCORRECTMOULT) and the effect of including the recent digital pup count data.

The estimated pup production trajectories are significantly lower given 1984-2010 data than with the 1984-2016 data used in the main analysis. Pup production is estimated to have peaked in Outer Hebrides in the late 1990s, in Inner Hebrides in the early 2000s and be levelling off in Orkney in 2010 (when the time series stops). The North Sea pup production is estimated to still be increasing at a near-exponential rate, but with a somewhat lower trajectory than when the 2012-16 data are included. These differences were due to changes in the pup production estimates before and after the transition to digital. The estimated population size in 2010, based on the truncated time series was 107,100 (95% CI 93,700-127,400), approximately 10% lower than the estimate from 2010 obtained when the full 1984-2016 data are used.

When the same model was run with the truncated 1984-2010 pup production calculated with a fixed value of PCORRECTMOULT set to 0.5, the estimated pup projection trajectories are slightly lower than for additional analysis 1, further reducing the estimated total population size in 2010 to 104,000 (95% CI 88,100-124,100), approximately 3% lower than for additional analysis 1 and 13% lower than the main analysis. These preliminary analyses clearly show the importance of further investigation of the methods used to derive pup production.

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 posterior distribution on adult survival from the population dynamics model has a mode close to the upper bound 0.97 of the prior. In addition, mark-recpature-based estimates of adult female survival at Sable Island in Canada[17] were higher than this upper bound (0.976, SE 0.001). Hence, consideration should be given to raising the upper bound on the prior for this parameter.

Thomas et al. (2019)[2] discusses how sensitive the estimate of total population size may be to the parameter priors, and concludes that fecundity and adult male:female ratio are two parameters that strongly affect total population size but for which the prior specification is particularly influential. Hence a renewed focus on priors for these parameters may be appropriate.

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. These developments are ongoing. One factor that will require consideration is how to incorporate uncertainty in the ground counts made at some North Sea colonies. A revised pup production model will therefore be developed to estimate pup production with the counts from the most recent set of surveys carried out over the 2016 breeding season.

Population trends
Model selection criteria suggest that density dependence is acting mainly on pup survival (see SCOS-BP 09/02). The independent population estimate from 2008 was consistent with this conclusion. Although the 2015 independent estimate and revised 2008 estimate have allowed the model to fit a higher trajectory, they are still consistent with the density dependent pup survival model. This also implies that the overall population should closely track the pup production estimates when experiencing density dependent control, as well as during exponential growth. The model run with the full data set and variable PCORRECTMOULT estimated that total population sizes for the biennially monitored colonies have increased by approximately 1.8% p.a. (SCOS-BP 18/03) between 2012 and 2017. All of this is due to a continuing 5.9% p.a. increase in the North Sea population; the Hebridean populations are effectively stationary, increasing at <0.1% p.a. since 2012 and Orkney is growing very slowly at 0.7% p.a.

Even within the North Sea the pattern of increase is not evenly spread and contains some apparently wide fluctuations. The colonies on offshore islands in the central North Sea had been relatively stable but apparently increased rapidly between 2014 and 2016. Colonies on the mainland coast and especially in the southern North Sea, have increased rapidly since 2000, but the rate of increase has been lower in the past 3 years, perhaps an early indication it is approaching a carrying capacity.

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

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

Region	Pup Production	Year	Possible population trend
UK	**65,000**	2016	Increasing
Ireland	2,100	2012[1]	Increasing
Wadden Sea	1,400	2017[2]	Increasing
France	50	2016	increasing
Norway	650	2017[3]	Possible decline
Russia	800	1994	Unknown
Iceland	1,000	2012[8]	Declining
Baltic	6,400	2013[4,5]	Increasing
Europe excluding UK	**12,400**		unknown
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	**179,700**		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_2018.pdf.
[3]Nilssen, K.T. and Bjørge, A. 2017a. Havert og steinkobbe [Grey and harbour seals]. Pages 68–69 in I.E. Bakketeig, M. Hauge & C. Kvamme (eds). Havforskningsrapporten 2017. Fisken og havet, særnr, 1-2017. 98 pp.
[3]Nilssen, K.T. and Bjørge, A. 2017b. Status for kystsel. Anbefaling av jaktkvoter for 2018 [Status for coastal seals. Recommendation for harvest quotas for 2018]. Document to the Norwegian Marine Mammal Scientific Advisory Board, October 2017. 9 pp. [4]Data summarised in*: Grey seals of the North Atlantic and the Baltic*. 2007. Eds: T. Haug, M. Hammill & D. Olafsdottir. NAMMCO Scientific Publications, Vol. 6.
[5]Baltic pup production estimate based on mark recapture estimate of total population size and an assumed multiplier of 4.7 HELCOM fact sheets (www.HELCOM.fi) & http://www.rktl.fi/english/news/baltic_grey_seal.html
[6] M.O. Hammill, den Heyer, C.E., Bowen, W.D., and Lang, S.L.C. 2017. Grey Seal Population Trends in Canadian Waters, 1960-2016 and harvest advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2017.
[7]NOAA (2009) http://www.nefsc.noaa.gov/publications/tm/tm238/247_f2015_grayseal.pdf
[8]Erlingur Hauksson pers. com https://www.hafogvatn.is/static/research/files/skra_0069286pdf.

Current status of British harbour seals

Harbour seals are counted while they are on land during their August moult, giving a minimum estimate of population size. Not all areas are counted every year but the aim is to cover the UK coast every 5 years. Combining the most recent counts (2008-2017) gives a total of 32,600 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 2017 of 45,100 (approximate 95% CI: 37,000-60,400). 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 2017, 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.

Populations along the English East coast, from Kent to the Scottish border have generally increased year on year, with those increases punctuated by major declines associated with two

major PDV epidemics in 1988 and 2002. Recent trends, i.e. those that incorporate the last 10 years (2006 to 2016) show significant growth in both SMUs on the east coast of England.

Populations along the East coast of Scotland and in the Northern Isles have generally declined. The recorded declines have differed in intensity but in all areas the current population size is at least 40 % below the pre-2002 level. Populations in Orkney & North Coast and East Scotland SMUs are continuing to decline. Although continued declines are not evident in Shetland or the Moray Firth, there is no indication of recovery.

Populations in western Scotland and Northern Ireland are either stable or increasing. Counts in the central section of the large West Scotland management region have been increasing since the 1990s and in all other areas they have remained stable, except for Northern Ireland which appears to have declined slowly throughout.

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 18/04. 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 in the Moray Firth and the Tay and Eden estuaries SAC are surveyed annually. Seals spend a higher proportion of their time on land during the moult than at other times and counts during the moult are thought to represent the highest proportion of the population with the lowest variance. Initial monitoring of the population in East Anglia in the 1960s used these maximum counts as minimum population estimates. In order to maintain the consistency of the long term monitoring of the UK harbour seal population, the same time constraints are applied throughout and surveys are timed to provide counts during the moult. Most regions are surveyed using thermographic aerial imagery to identify seals along the coastline. However, conventional photography is used to survey populations in the estuaries of the English and Scottish east coasts.

Table 4 ***UK harbour seal minimum population estimates based on counts during the moult; rounded to the nearest 100.***

Location	Most recent count (2008-2016)
England	**5,100**
Wales	**<10[1]**
Scotland	**26,600[2]**
Northern Ireland	**950**
Total UK	**32,600[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

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[9]. A conversion factor of 0.72 (95% CI: 0.54-0.88) to scale moult counts to total population was derived from haulout patterns of harbour seals fitted with flipper mounted ARGOS tags (n=22) in Scotland[10].

The most recent counts of harbour seals by region are given in Table 5 and Figure 4, 5 & 6. These are minimum estimates of the British harbour seal population. Results of surveys conducted in 2017 are described in more detail in SCOS-BP 18/06a. It has not been possible to conduct a synoptic survey of the entire UK coast in any one year. Data from different years are grouped into recent, previous and earlier counts to illustrate, and allow comparison of, the general trends across regions.
Combining the most recent counts (2014-2017) at all sites, approximately 32,600 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 ~36,000 harbour seals for the British Isles (i.e. the UK and Ireland).

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

Breeding season aerial surveys of the harbour seal population along the east Anglian coast are flown annually, in addition to the large range wide surveys flown during the moult in August. In 2015 and 2016 the east Anglian coast was surveyed five times during the breeding season in June and July[11]. These flights confirmed that the peak number of pups ashore occurred around the beginning of July. In 2017 a survey was carried out on 4th July. The 2017 count was 19% lower than the 2016 peak and 4% lower than the 2015 peak count. This continues the pattern of high inter annual variability (SCOS-BP 18/05). These wide fluctuations are not unusual in the long term time series and despite the apparently wide inter-annual variation, the pup production has increased at around 6.5% p.a. since surveys began in 2001.

The ratio of pups to the moult counts remained high in 2017, more than double the same ratio in 2001 and higher than the same metric in the larger Wadden Sea population. This ratio can be seen as an index of the productivity of the population. Interestingly, an increase in this apparent fecundity index has recently been noted in the Wadden Sea population as the moult counts have not increased there for the last four years while the pup production has continued to increase.

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[9] The diurnal timing restriction is occasionally relaxed for sites in military live firing ranges where access is only at weekends.

[10] 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.

[11] Thompson, D., Onoufriou, J. and Patterson, W. 2016. Report on the distribution and abundance of harbour seals (*Phoca vitulina*) during the 2015 and 2016 breeding seasons in the Wash. *Report number SMRUC-DOW-2016-06*, December 2016. http://www.smru.st-andrews.ac.uk/reports/

Table 5 ***The most recent August counts of harbour seals at haulout sites in Britain and Ireland by seal management unit compared with three previous periods: 1996-1997, 2000-2006 & 2007-2009.*** *Details of sources and dates of surveys used in each compiled regional total are given in SCOS-BP 18/04.*

Seal Management Unit / Country		Harbour seal counts			
		2015-2017	2007-2009	2000-2006	1996-1997
1	Southwest Scotland	1,200	923	623	929
2	West Scotland	15,889	10,626	11,702	8,811
3	Western Isles	3,533	1,804	1,981	2,820
4	North Coast & Orkney	1,349	2,979	4,384	8,787
5	Shetland	3,369	3,039	3,038	5,994
6	Moray Firth	879	776	1,028	1,409
7	East Scotland	346	283	667	764
SCOTLAND TOTAL		**26,565**	**20,430**	**23,423**	**29,514**
8	Northeast England	87	58	62	54
9	Southeast England	4,965	3,952	2,964	3,222
10	South England	23	15	13	5
11	Southwest England	0	0	0	0
12	Wales	5	5	4	2
13	Northwest England	10	5	5	2
ENGLAND & WALES TOTAL		**5,092**	**4,035**	**3,048**	**3,280**
BRITAIN TOTAL		**31,657**	**24,465**	**26,471**	**32,794**
NORTHERN IRELAND TOTAL		**948**	**1,101**	**1,176**	
UK TOTAL		**32,605**	**25,566**	**27,648**	
REPUBLIC OF IRELAND TOTAL		**3,489**	**2,955**	**2,955**	
BRITAIN & IRELAND TOTAL		**36,094**	**28,521**	**30,603**	

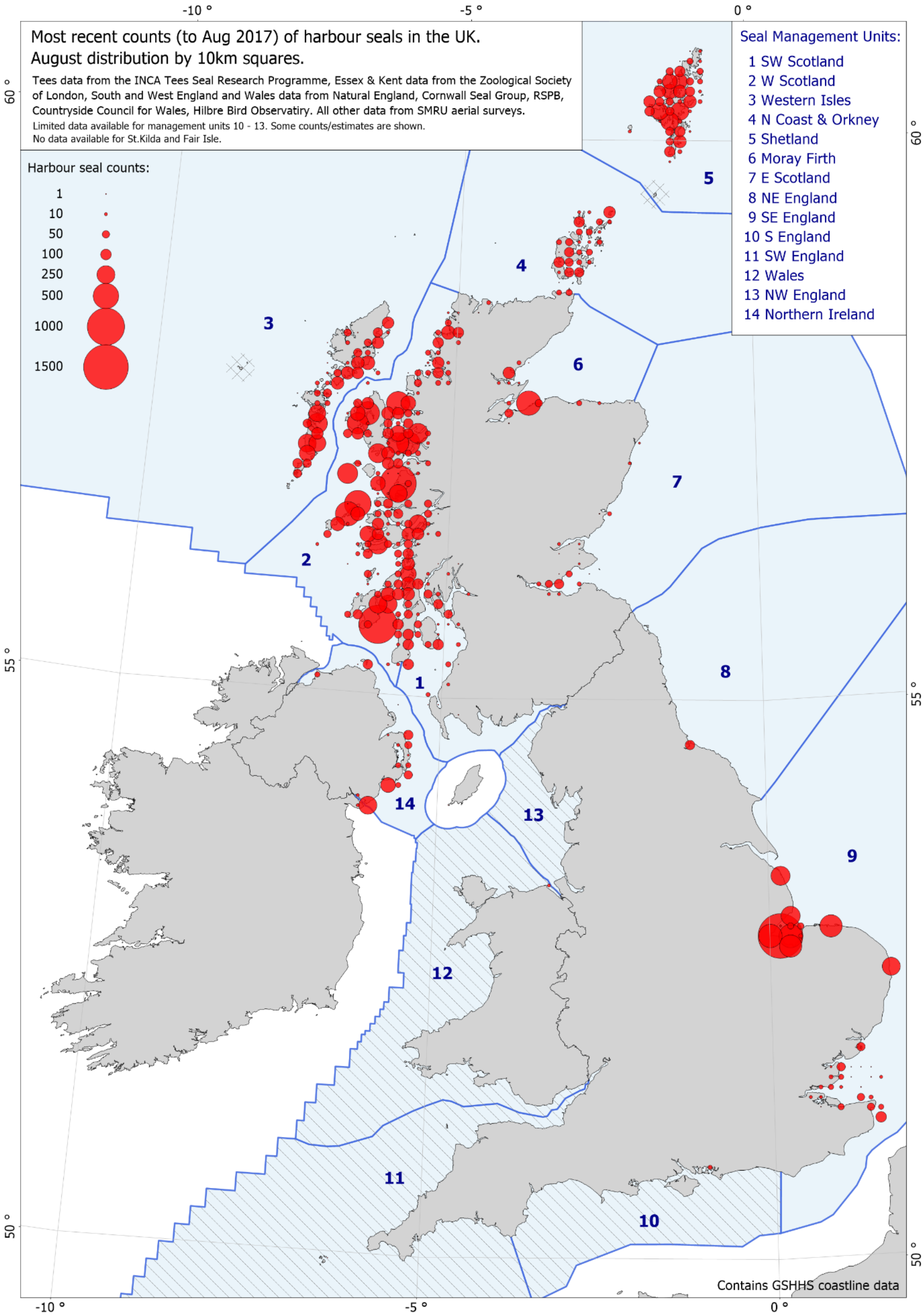

Figure 4. *August distribution of harbour seals around the British Isles. Small numbers of harbour seals (<20) are anecdotally reported for the West England & Wales SMUs, but are not included on this map. Estimates are composites of the most recent survey counts in each region between 2015 and 2017.*

Population trends
Overall, the UK harbour seal population has increased from 25,600 (rounded to the nearest 100) in the 2007-09 period to 32,600 animals during the 2015-2017 period. As no count was available in Northern Ireland in the 1990s, a UK wide comparison is not possible, but the 2015-2017 count for the Great Britain (i.e. UK minus Northern Ireland) harbour seal population (31,700) was effectively the same as the 1996-97 level of 32,800 (Table 5). However, as reported in SCOS 2008 to 2017, patterns of changes in abundance have not been universal; although declines have been observed in several regions around Scotland some populations appear to be either stable or increasing (Figure 5). Details of regional and local trend analyses and model selection for each are given in Thompson et al. (2019) [12] and briefly described here.

***Trends by Seal Management Unit* (SMU).**
Western Isles: A complete survey of the Western Isles SMU carried out in 2017 produced a count of **3,533** (Table 5). This was the highest recorded count for the Western Isles and was 29.0% higher than the previous (2011) count of 2,739. The overall trend in the Western Isles is unclear: since 1996 three counts in succession showed a decline (2000, 2003, and 2008) but the most recent count is approximately 40% higher than the average between 1993 and 2017 and was almost as high as the count in 1996. A simple intercept only GLM model was the best fit to the Western Isles counts between 1993 and 2017, suggesting no significant trend over the survey period.

West Scotland: Parts of the West Scotland Management Unit- North and part of Centre were surveyed in 2017. The harbour seal count for West Scotland - North was **1,084** and the count for part of West Scotland - Centre was **5,166**. Combined with previous counts for the remainder of West Scotland, the total for West Scotland Centre was **7,160** and the overall total for the West Scotland SMU was **15,889** (Table 5).

The 2015 West Scotland harbour seal count was 43% higher than the 2009 count, equivalent to an average annual increase of 5.3%. However, as in the Western Isles, the data were best fitted by a simple intercept only GLM implying no change between the 1990s and 2015[12].

Although the West Scotland region is defined as a single management unit, it is very large geographically in terms of total coastline and contains a large proportion of the UK harbour seal population; 49% of the most recent UK total count. The trajectories of counts within north, central and south sub-divisions of this large region differ[12]:

- In the north of the region (Cape Wrath to Loch Ewe) (Figure 4), the selected model for data up to 2017 indicates that counts have increased since the early 1990s, by 4.86% p.a. (95% CI: 4.02, 5.70).

- In the central sub-region (Loch Ewe to Ardnamurchan) (Figure 4) the selected model for data up to 2014 indicates that counts have increased since the early 1990s, by 4.0% p.a. (95% CIs: 3.1, 5.0). However, the selected model for the Ascrib, Isay and Dunvegan SAC counts, which extend to 2017, was an intercept only GLM implying no detectable trend since the early 1990s.

- In the south sub-region (Ardnamurchan to Scarba) (Figure 4) there was no detectable trend in the overall population since the early 1990s. Counts for both the Southeast Islay Skerries SAC and the Lismore SAC have also remained stable over the same period.

[12] Thompson, D., Duck, C.D., Morris, C.D. and Russell, D.J.F. (2019). The status of harbour seals (*Phoca vitulina*) in the United Kingdom. Aquatic Conservation: Marine and Freshwater Ecosystems. Doi: 10.1002/aqc.3110

Southwest Scotland: 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, approximately three times higher than the 1990's count. Despite this apparent increase, the trend analysis selected a simple intercept only GLM suggesting that there was no detectable trend in the data.

North Coast and Orkney: The North coast Orkney and the SMU was surveyed in 2016. 1,349 harbour seals were counted compared with 1,938 in 2013. This count is >30% lower than the 2013 count, equivalent to an average annual decrease of 10%. The latest survey results therefore confirm that the rapid decline in the Orkney harbour seal population since 1997 continues. Trend analysis indicates that counts were stable until 2001, that the next count in 2006 showed a decline of 46% and that from 2006 onwards, there was a continued decline of 10.4% p.a. (95% CIs: 9.3, 11.5). Overall, the composite counts for the North Coast & Orkney SMU have declined from approximately 8800 in the mid-1990s to 1350 by 2016 (Table 1) representing an 85% decrease in what was the largest single SMU population in the UK. The counts for the Sanday SAC show a similar trend, with a step change between 2001 and 2006 and a continuing declining at 17.8% p.a. (95% CIs: 13.3, 22.0) since 2006.

A complete survey of Shetland was carried out in 2015. 3,369 harbour seals were counted compared with 3,039 in 2009. The count was 12% higher than the 2009 count, but was 44% lower than the 1997 count of c.6,000. The selected model for counts for the whole of Shetland incorporated a step change involving a drop of approximately 40% occurring between 2001 and 2005. Counts either side of the step change (1991-2001 and 2006-2015) do not show any obvious trend, though in both cases the sample size was limited (n=4 and 3, respectively).

Counts at the two Shetland SACs show different trajectories. The Mousa SAC counts show a monotonic exponential decline at an average rate of 11.1% p.a. (95% CIs: 8.7, 13.5) between 1991 and 2015 (Table 2). In contrast, an intercept only model was selected to fit the counts (1991-2015) of the Yell Sound SAC. However, including only counts between 1995 and 2015 (i.e. excluding 1991 and 1993), the selected model showed a decline of 5.3% p.a. (95% CIs: 2.6, 7.9).

In the Moray Firth, the count in the regularly surveyed region was **831** in 2017, and when combined with counts from previous years, the total harbour seal count for the Moray Firth SMU was **879**. This was 6.5% lower than the 2016 count of 940. The majority of these harbour seals (59.8%) were observed between Culbin and Findhorn, confirming the dramatic redistribution within the inner estuaries.

The majority of the counts in the Moray Firth are from haul outs between Loch Fleet and Findhorn an area that held approximately 90% of the SMU total in 2016. The selected model for this area shows that counts were decreasing at a rate of 5.6% p.a. (95% CIs: 2.5, 8.5) between 1994 and 2000, followed by a step change with a drop of c.28% occurring between 2000 and 2003 and no significant trend in counts thereafter. Counts of harbour seals within the Dornoch Firth and Morrich More SAC site have shown a monotonic decline of c. 8.0% p.a. (95% CIs: 6.3, 9.7) from the first surveys in 1992 to 2017.

The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2017 was 29, equalling the lowest count (in 2014) for this SAC. This count represents a 95% 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.

In the East Scotland SMU (Figure 4) the population is mainly concentrated in the Firth of Tay and Eden Estuary SAC and in the Firth of Forth. Small groups are also present in the Montrose Basin and at coastal sites in Aberdeenshire. Counts in the Firth of Forth have been sporadic and therefore trends were only fitted to counts within the SAC.

The selected model indicates that counts in the SAC remained stable between 1990 and 2002, at which time they represented approximately 85% of the total management region count. From 2002 to 2017 the counts in the SAC declined rapidly and monotonically at approximately 18.6% p.a. (95% CIs: 17.1, 20.0) (Figure 6a, Table 2); over the 15 year period counts fell from approximately 680 to less than 40, representing a 95% decline. By 2016 the SAC counts represented only approximately 15% of the SMU total.

The combined counts for the Southeast England SMU (Figure 4) in 2017 (**4,864**) was 3.9% lower than the 2016 count and similar to counts for 2014 and 2015. This may be an early indication that the population in SE England SMU is approaching its carrying capacity.

The combined counts for The Wash, Donna Nook and Blakeney Point, assumed here to represent the Southeast England SMU, are available from 1988 to 2017. The 1989 count was approximately 50% lower than the pre-epidemic count in 1988. The selected model for the combined counts incorporated two periods of exponential increase; 6.6% p.a. (95% CIs: 5.3, 7.9) between 1989 and 2002 and 2.8% p.a. (95% CIs: 1.3, 4.3) between 2003 and 2017. These periods of exponential increase were separated by a step change decrease of approximately 30% between 2002 and 2003 coincident with the second PDV epidemic. Although an exponential increase from 2003 to 2017 was marginally preferred by model selection there was an indication of a non-linear trend with a constant abundance followed by an increase and finally a levelling off in recent years.
The longer time series of counts for The Wash was best described by three distinct trajectories (Figure 6). From 1968 until 1988, the moult counts increased exponentially at 3.5% p.a. (95% CIs: 2.3, 4.76) reaching an estimated maximum count of c.3000 (95% CIs: 2500, 3500) in 1988. The counts then fell by approximately 50% between 1988 and 1989 as a result of a PDV epidemic. This collapse was followed by a second period of exponential increase, but at a higher rate of 6.0% p.a. (95% CIs: 4.2, 7.8), with counts reaching c.3100 (95% CIs: 2800, 3350) by 2002 before a recurrence of the PDV epidemic caused another decrease. The counts from 2003 to 2017 are best described by a GAM that initially estimates a decreasing trend until around 2006, increases rapidly until around 2010 and then levels off, suggesting that the population is approaching an asymptote. The recent counts for The Wash are similar to the levels in 1988 and 2002 immediately before the two PDV epidemics.

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 Wadden Sea counts from 2014 to 2017 indicate that the rapid 12% p.a. growth since the 2002 PDV epidemic has slowed or even stopped. This may be related to the 2014 influenza-A epidemic that killed at least 1600 seals in the Wadden Sea, but may also indicate that the Wadden sea population is reaching its carrying capacity. The coincidence of the timing of the slowdown in the Wadden Sea and SE England is notable.

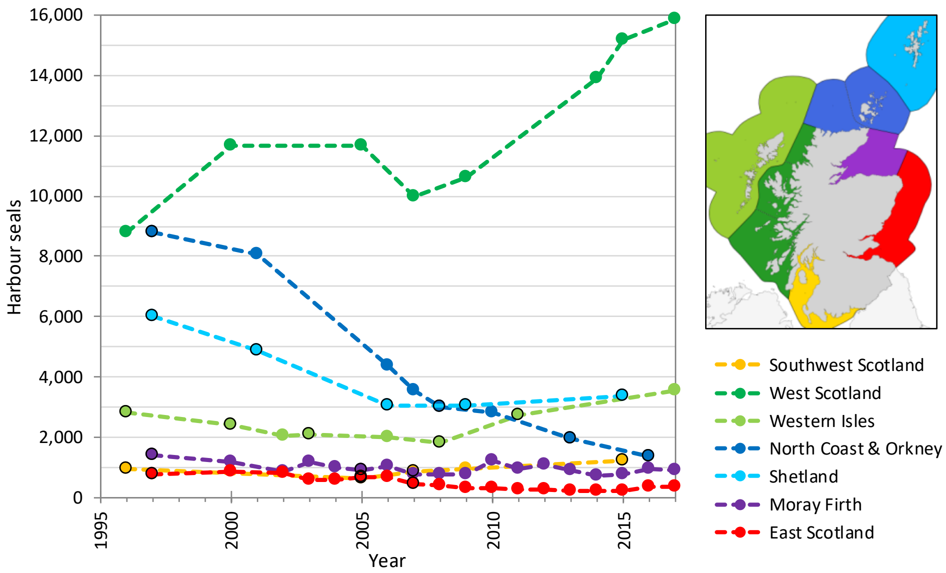

Figure 5. *Harbour seal counts in Seal Management Units around Scotland, 1996-2017 (black circled points indicate a single count in that year, plain points represent means of multiple counts).*

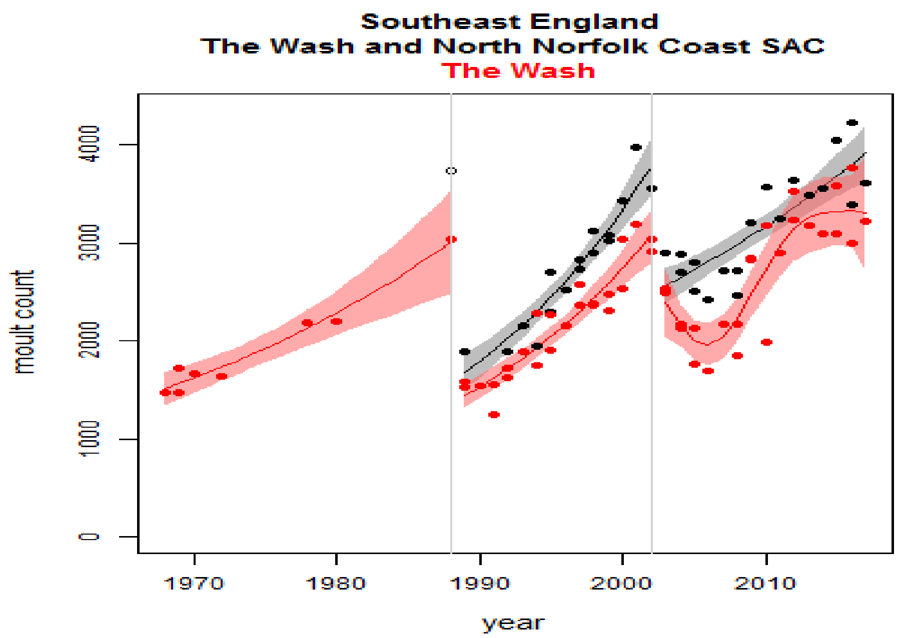

Figure 6*. Trends in harbour seals counts in The Wash (red) and the combined Wash and North Norfolk SAC,* between *1967 and 2017 (shaded areas indicate the 95% confidence intervals for the fitted curves). For further explanation see text and SCOS-BP 18/04).*

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	**26,600**	2011-2016
England	**5,100**	2016
Northern Ireland	**900**	2011
UK	**32,600**	
Ireland	3,500	2011-12
France	1,100	2017
Wadden Sea-Germany	16,100	2017
Wadden Sea-NL	6,800	2017[2]
Wadden Sea-Delta	700	2016
Wadden Sea-Denmark	3,000	2017
Limfjorden	1,100	2016
Kattegat	10,500	2016
Skagerrak	6,600	2016
Baltic (Kalmarsund)	1,100	2016
Baltic Southwestern	1,000	2017
Norway	6,600	2016
Iceland	7,700	2016
Barents Sea	1,900	2010
Europe excluding UK	**67,100**	
Total	**99,700**	

[1]Counts rounded to the nearest 100. They are minimum estimates of population size as they do not account for proportion at sea and in many cases are amalgamations of several surveys.

[2]A partial count of the Netherlands' Wadden Sea was obtained out in 2017 due to military restriction, count corrected by adding 900 for area missed.

Data sources

ICES. 2018. Report of the Working Group on Marine Mammal Ecology (WGMME) , 19– 22 February 2018, La Rochelle, France. ICES CM 2018/ACOM:28. 120 pp; Desportes,G., Bjorge,A., Aqqalu, R-A and Waring,G.T. (2010) Harbour seals in the North Atlantic and the Baltic. NAMMCO Scientific publications Volume 8; Nilssen K, 2011. Seals – Grey and harbour seals. In: Agnalt A-L, Fossum P, Hauge M, Mangor-Jensen A, Ottersen G, Røttingen I,Sundet JH, and Sunnset BH. (eds). Havforskningsrapporten 2011. Fisken og havet, 2011(1).; Härkönen,H. and Isakson,E. 2010. Status of the harbour seal (*Phoca vitulina*) in the Baltic Proper. NAMMCO Sci Pub 8:71-76.; Olsen MT, Andersen SM, Teilmann J, Dietz R, Edren SMC, Linnet A, and Härkönen T. 2010. Status of the harbour seal (*Phoca vitulina*) in Southern Scandinavia. NAMMCO Sci Publ 8: 77-94.; Galatius A, Brasseur, S, Czeck R et al, 2016, Aerial surveys of harbour seals in the Wadden Sea in 2016, http://www.waddensea-secretariat.org; Härkönen T, Galatius A, Bräeger S, et al HELCOM Core indicator of biodiversity Population growth rate, abundance and distribution of marine mammals, HELCOM 2013, www.helcom.fi; http://www.fisheries.is/main-species/marine-mammals/stock-status/; http://www.nefsc.noaa.gov/publications/tm/tm213/pdfs/F2009HASE.pdf; https://www.hafogvatn.is/en/research/harbour-seal/harbour-seal-census.
http://www.nammco.no/webcronize/images/Nammco/976.pdf,
Nilssen K and Bjørge A 2017. 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. How can we estimate the seal population in the SW of England?	Defra Q1

Potential survey methods in Southwest England Management Unit.

At present there are no reliable data on grey seal pup production in the Southwest England SMU. As a large, but unknown, proportion of seals breed in caves or small cliff beaches the standard aerial survey and walk through ground counting methods used in Scotland and eastern England will not be applicable. A similar problem exists in Wales. Although the great majority of Welsh grey seals pup on open beaches a proportion breed on inaccessible sites similar to those in Devon and Cornwall. Counting pups in caves can only be achieved by entering the caves, usually by boat, kayak or swimming. This is clearly a time consuming, expensive and potentially extremely dangerous procedure.

In an attempt to overcome these issues, a team from the Countryside Council for Wales (now NRW) conducted a comparative study of a comprehensive ground-based pup production census with a reduced effort plot-sampling survey to estimate pup production, derive a total population size and assess cost effectiveness[4]. Pup production in North Wales was estimated at 91 (95% confidence interval: 70–112) by the plot-sampling design and was a good approximation of the 'true' value of 96 derived from the census. The plot-sampling design reduced survey effort by 46% and saved 30% on logistical costs compared to the full census. The authors suggest that their approach will minimise effort and therefore cost and risk and should be applicable to other sites/areas.

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

Grey seals

There is evidence for regional differences in grey seal demographics but detailed information on vital rates are lacking. Regional information on fecundity and survival rates would improve our ability to provide advice on population status. New resources should be identified to address questions around fecundity and juvenile survival.

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

Age and sex structure

While the population was growing at a constant (i.e. exponential) rate, it was assumed that 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 (SCOS BP 18/03). As currently structured the model fits single global estimates for fecundity, maximum pup survival (i.e. at low population size), and adult female survival, and fits individual carrying capacity estimates separately for each region to account for differing dynamics through density dependent pup survival.

Survival and fecundity rates

The only contemporary data that we have on fecundity and adult survival in UK grey seals has been estimated from long term studies of marked or identifiable adult females at two breeding colonies, North Rona and the Isle of May. Results of these studies together with branding studies in Canadian grey seal populations and historical shot samples from the UK and Baltic have been used to define priors for a range of demographic parameters (SCOS-BP 18/02).

Adult female survival: Estimates of annual adult survival in the UK, obtained by aging teeth from shot animals were between 0.93 and 0.96 [13,14,15]. Capture-mark-recapture (CMR) of adult females on breeding colonies[16] has been used to estimate female survival on North Rona and the Isle of May of 0.87 and 0.95 (SCOS-BP18/02 - Table 2). Models fitted using this prior distribution have universally fitted high posterior mean estimates close to the upper limit of the prior (SCOS-BP 18/03). Interestingly, recent estimates from Sable Island suggest adult female survival during the main reproductive age classes (4 to 24 years old) may be above this upper bound. A Cormack-Jolly-Seber model was used to estimate age- and sex-specific adult survival from a long-term brand re-sighting programme on Sable Island[17]. Average adult female survival was estimated to be 0.976 (SE 0.001), averaged over all animals, but was higher for younger adults (0.989 with SE 0.001 for age classes 4-24) than older adults (0.904 SE 0.004 for age 25+).
In the current population estimation model density dependence acts through pup survival only, so adult survival does not vary with time or between regions. The fitted posterior value for adult survival was a constant rate of 0.96 (SE 0.01)

Fecundity: For the purposes of the population estimation model, fecundity is taken to be the proportion of breeding-age females (aged 6 and over) that give birth to a pup in a year (natality or birth rate). Pregnancy rates estimated from samples of seals shot in the UK [18,14] and Canada [19] were similar, 0.83 to 0.94 and 0.88 to 1 respectively. However, these are pregnancy rates and may overestimate natality if there are significant numbers of abortions.

Natality rates estimated from direct observation of marked animals produce lower estimates, which may be due to abortions, but may also be due to unobserved pupping events (due to mark misidentification, tag loss, or breeding elsewhere) and may therefore under-estimate fecundity. Such studies, from Sable Island estimate fecundity to be between 0.57 and 0.83[17,20]. UK estimates of

[13] Harwood, J., & Prime, J. H. (1978). Some factors affecting size of British grey seal populations. *Journal of Applied Ecology*, *15*(2), 401–411. http://doi.org/10.2307/2402600

[14] Hewer, H. (1964). The determination of age, in the grey seal (Halichoerus grypus) sexual maturity, longevity and a life-table. *Proceedings of The Zoological Society of London*, *142*(4), 593–623

[15] Lonergan, M. (2012). *Priors for grey seal population model*. SCOS Briefing paper 12/02,

[16] Smout, S., King, R., & Pomeroy, P. (Submitted). Environment-sensitive mass changes influence breeding in a marine top predator. *Journal of Animal Ecology*.

[17] den Heyer, C. E., & Bowen, W. D. (2017). Estimating changes in vital rates of Sable Island grey seals using mark-recapture analysis. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/054., 27.

[18] Boyd, I. (1985). Pregnancy and ovulation rates in grey seals (Halichoerus-grypus) on the British coast. *Journal of Zoology*, *205*, 265–272.

[19] Hammill, M. O., & Gosselin, J. (1995). Grey seal (Halichoerus grypus) from the Northwest Atlantic: Female reproductive rates, age at first birth, and age of maturity in males. *Canadian Journal of Fisheries and Aquatic Sciences*, *52*(12), 2757–2761.

[20] Bowen, W. D., Iverson, S. J., McMillan, J. I., & Boness, D. J. (2006). Reproductive performance in grey seals: age-related improvement and senescence in a capital breeder. *Journal of Animal Ecology*, *75*(6), 1340–1351. http://doi.org/10.1111/j.1365-2656.2006.01157.x

fecundity rates adjusted for estimates of unobserved pupping events were higher; 0.790 (95% CI 0.766-0.812) and 0.816 (95% CI 0.787-0.841) for a declining (North Rona) and increasing (Isle of May) population respectively[16].

In the current population estimation model, density dependence acts through pup survival only, so fecundity does not vary with time or between regions. The fitted posterior value for fecundity was 0.92 (SE 0.48) (SCOS-BP 18/03).

Pup survival: In the context of the population estimation model, pup survival is used to describe the probability that a female pup, born alive will still be alive at the start of the following breeding season. At present density dependent effects in the UK grey seal population are thought to operate primarily through changes in pup survival. The currently used density-dependent pup-survival population model therefore requires a prior distribution for the maximum pup survival, i.e. pup survival in the absence of any density dependent effects. The model then produces a single global posterior estimate of that parameter and region specific estimates of the current pup survival under the effects of density dependence.

Estimates of maximum pup survival, from populations experiencing exponential growth and therefore presumed not to be subject to strong density dependent effects are given in Russell et al. (2019)[1] (Table 2). Mean estimates of pup surival were between 0.54 – 0.76. Note that Pomeroy et al. (2010)[21] found high inter-annual variation in pup survival, which is not currently incorporated in the model.

The resulting posterior fitted value for maximum unconstrained pup survival was 0.45 (SE 0.07) (SCOS-BP18/03) from the standard model run on the 1984-2016 dataset. Values were slightly higher for other data inputs (0.46 and 0.48). The fitted values for unconstrained pup survival from the population dynamics models are lower than estimates based on mark resights. The reasons for this difference are unknown and should be investigated further.

It is also possible to derive current pup survival estimates from the model. The posterior estimates of pup survival at current population sizes differ between regions. In the North Sea where density dependence is having little effect, the current pup survival estimate is 0.45, close to the maximum, unconstrained rate. In the other three regions where population growth has slowed or stopped the current estimate is much lower, being 0.11 in the Inner and Outer Hebrides and Orkney.

Sex Ratio: The sex ratio effectively scales up the female population estimate derived from the model fit to the pup production trajectories. With the inclusion of two independent estimates of total grey seal population size, the fitted values of the demographic parameters and the overall population size estimates are sensitive to the population sex ratio for which we do not have good information. The reported values are produced by a model run with a prior on the sex ratio multiplier of 1.7 (SE 0.02), i.e. seven males to every ten females.

Den Heyer and Bowen[16] estimated survival rates of male and female branded seals at Sable Island. The differential survival of males and females would produce an effective sex ratio of 1:0.7 if maximum age is set to 40, reducing to 1:0.69 if maximum age is set to 45. This estimate is remarkably similar to the prior used in the 2016 model runs.

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[21] Pomeroy, P. P., Smout, S., Moss, S., Twiss, S. D., & King, R. (2010). Low and Delayed Recruitment at Two Grey Seal Breeding Colonies in the UK. *Journal of Northwest Atlantic Fishery Science*, *42*, 125–133. http://doi.org/10.2960/J.42.m651

Regional differences in grey seal demographics and genetics

The difference in population trends between regions for UK grey seals suggests underlying regional differences in the current values of demographic parameters. 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[22] and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona[23]. There is therefore some indication of sub-structure within the UK grey seal population, but it is not strong.

Recent genetics data from the Baltic grey seals[24] suggest that a combination of previous management practices and local climate change effects may be moving the boundaries between the North Sea and Baltic subspecies of grey seal.

The very rapid increases in pup production at colonies in the Southern North Sea in England, the Netherlands and Germany all point to large scale recruitment to those colonies from colonies in the Northern North Sea[25].

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.

Recent genetics studies show that harbour seals in southeast England, north and east Scotland, and northwest Scotland form three distinct genetic clusters and population trend analyses suggest that these three groups show different population trends.

Genetics

Genetic data from a study directed toward resolving patterns of population structure of harbour seals from around the UK and adjacent European sites[26] has recently been added to (with funding from Scottish Natural Heritage) and combined with the population trend and telemetry data to investigate source-sink dynamics of harbour seal populations.
DNA samples from approximately 300 harbour seals from sites throughout the UK and the Wadden Sea[26]. Results suggested two distinct groups, one in northern UK and the other in southern UK & mainland Europe. The northern cluster was further divided into: a north-western cluster equivalent to the West Scotland, Southwest Scotland and Western Isles SMUs; a north-eastern cluster

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[22]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.

[23]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.

[24] Fietz, K, Galatius, A, Teilmann, J, Dietz, R, Frie, AK, Klimova, A, Palsbøll, PJ, Jensen, LF, Graves, JA, Hoffman, JI & Olsen, MT 2016, 'Shift of grey seal subspecies boundaries in response to climate, culling and conservation' Molecular Ecology, vol. 25, no. 17, pp. 4097-4112. https://doi.org/10.1111/mec.13748

[25]Brasseur, S. M. J. M., van Polanen Petel, T. D., Gerrodette, T., Meesters, E. H.W.G., Reijnders, P. J. H. and Aarts, G. 2015. Rapid recovery of Dutch gray seal colonies fueled by immigration. *Marine Mammal Science*, 31: 405–426. doi:10.1111/mms.12160

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

equivalent to Shetland, Orkney, Moray Firth and the East Scotland SMUs; and a south-eastern cluster equivalent to the Southeast England SMU and the Wadden Sea.
Population trend data show similar regional sub-divisions to those seen in the genetics data with the southern UK population equivalent to the English east coast showing continual rapid increase punctuated by major declines associated with PDV epidemics in 1988 and 2002[12]. Populations along the East coast of Scotland and in the Northern Isles have generally declined while populations in western Scotland are either stable or increasing. 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[27,28]. 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 study investigating survival in first year harbour seal pups using telemetry tags was carried out in Orkney and on Lismore in 2007. Expand to say from birth to 200 days. Survival was not significantly different between the two regions and expected survival to 200 days was 0.3[29].

The apparent fecundity of the large harbour seal population in The Wash has shown extremely wide changes since the early 2000s. The rate has been approximately double that of earlier estimates and until recently was much higher than in the larger population in the Wadden Sea (SCOS-BP 18/05).

Decadal differences in body composition in grey seals was recently investigated at two grey seal breeding colonies (North Rona and the Isle of May) with contrasting demographic characteristics[30]. Factors influencing individual variation in lipid to protein mass ratio of breeding females was examined. Variation in postpartum maternal body composition was considerable and mothers with high lipid to protein mass ratio expended a higher proportion of lipid resource while conserving protein and weaned heavier pups. Average composition was similar between the colonies but increased at the Isle of May where pup production increased and declined at North Rona where pup production has decreased.

Somatic growth.

If harbour seal dynamics are the consequence of resource limits, either because of reduced prey density or increased competition with grey seals, it is likely that the growth rates of individual would carry some signal of those effects. Resource limitations are likely to result in slower growth and later age at sexual maturity, whereas causes of acute mortality could have the opposite effect.

A comprehensive length-at-age dataset for UK harbour seals was investigated but showed no evidence for major differences, or changes over time, in asymptotic length or growth parameters

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[27]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.
[28]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
[29]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.
[30] Hanson, N., Smout, S., Moss, S. and Pomeroy,P. (2019). Colony-specific differences in decadal longitudinal body composition of a capital-breeding marine top predator. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3093

from fitted von-Bertalanffy growth curves, across all regions[31], with the exception of one pairwise comparison; males from East Scotland were significantly shorter than those from the Moray Firth or West Scotland. However, the power to detect small changes was limited by measurement uncertainty and differences in spatial and temporal sampling effort. Asymptotic lengths at maturity were slightly lower than published lengths for harbour seal populations in Europe, the Arctic and Canada, with females being on average 140.5cm (95% CI, 139.4, 141.6) and males 149.4cm (147.8, 151.1) at adulthood.

This lack of signal is in contrast to data from Danish and Swedish harbour seal populations. Comparison of somatic growth curves of 2,041 specimens with known age, length and population size at birth showed that while all populations were similar in 1988, by 2002 there were clear differences between populations[32]. While seals in the Kattegat showed similar asymptotic lengths as in 1988, seals in the Skagerrak were significantly shorter. Asymptotic lengths of both male and female harbour seals declined by 7 cm. The restricted growth may have been related to relative foraging densities which were three times greater in the Skagerrak compared to the Kattegat. The authors suggest that reduced growth in the Skagerrak may be an early signal of density dependence.

Harbour Seal Populations

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 Q3

Overall the harbour population in the UK is increasing slowly, but the status of the local sub-populations varies around the UK. The most recent composite count for Scotland for 2015 to 2017 is 30% higher than the equivalent estimate for 2007-2009 and 10% lower than the 1996-97 count. Counts for the East coast of England also appear stable after a long period of increase since the 2002 PDV epidemic.

Declines are continuing in Orkney and along the East coast of Scotland. Counts in the Moray Firth and Shetland are variable, but have apparently remained stable after experiencing large reductions around 2002 of approximately 30% and 40% respectively. Counts also appear stable in the Western Isles, West and Southwest Scotland management areas. Some areas within the large West Scotland region appear to be increasing.

Results indicate that the current UK harbour seal population is at a similar size to the estimates from the late 1990s, but that there have been significant population declines in some regions and similar increases in others.

As reported in SCOS 2008 to 2017, 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 18/04 and Thompson et al. (2019)[12].

[31] Hall, A.J., Mackey, B., Kershaw, J. and Thompson, P. (2019). Age-length relationships in UK harbour seals during a period of decline in abundance. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3104
[32] Harding K C., Salmon M, Teilmann J, Dietz R & Harkonen T. (2018) Population Wide Decline in Somatic Growth in Harbor Seals—Early Signs of Density Dependence. Frontiers in Ecology and Evolution. 6:59. DOI=10.3389/fevo.2018.00059

The composite count for all of Scotland, based on recent (2015-2017) surveys in all areas, is approximately 30% higher than the previous composite count based on 2007-2009 surveys, representing a 3.3% p.a. increase (Figure 5; Table 5). The current estimate is about 15% lower than the equivalent for surveys in 1997-1998.

In Shetland the 2015 count was 12% higher than the previous count in 2009, but the fitted trend indicates that counts have remained stable after a 40% decrease around 2002.

There have been continuing declines in the Firth of Tay and Eden Estuary SAC, where the 2017 count of 29 represents a 95% decrease from the mean counts before 2002, and in Orkney where the 2016 count of 1,349 represents a 78% decrease since 1997. In the Moray Firth there is considerable variability in the August total counts for the entire region. The 2014 and 2015 surveys produced the lowest counts in the time series but the 2016 count was 25% higher. Overall there has been no significant trend in the counts of the Moray Firth since 2000.

The 2017 count of 15,900 in the large West Scotland Management Area was 50% higher than the 2009 count. Overall the fitted models for the west coast suggested no trend since the 1990s. However, the north and central parts of the region showed significant increases from the early 1990s to 2017. Again, the 2015 count in the Southwest Scotland SMU was 23% higher than the 2009 count, but the fitted trend suggests no change between the 1990s and 2015.

The combined count for the Southeast England SMU in 2017 (4,864) was slightly lower than in 2016, it was similar to the 2014 and 2015 counts. The Southeast England population has returned to its pre-2002 epidemic levels (Figure 5) but the last three counts suggest it may be at or near its carrying capacity. Pup production in the Wash continues to increase at around 7.5% p.a[33].

Fitted trends suggest that the UK harbour seal population can be divided into three geographically coherent groups[12]: Southeast (Southeast & Northeast England SMUs), where populations have shown continuous increases punctuated by two Phocine Distemper Virus (PDV) epidemics in 1988 and 2002; Northeast (East Scotland, Moray Firth, North Coast & Orkney and Shetland SMUs) where populations have declined since the late 1990s; Northwest (West Scotland, Western Isles, Southwest Scotland SMUs) where populations have remained stable or increased. These three regional groups of SMUs correspond to genetically distinct harbour seal regions (see answer to Q3 above).

Large changes in relative density have resulted from differences in regional population trends. E.g. in 1996-1997 the West Scotland SMU and Orkney & North Coast SMU each held 27% of the UK population but now hold 50% and 4% respectively; The southeast England SMU population was approximately half that of the Wadden Sea in 1980 but by 2016 the Wadden Sea count was approximately eight times larger.

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

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

A wide range of potential causes of the decline in Scottish harbour seals in some regions has been discussed at previous SCOS meetings. 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 four potential mechanisms namely: competition with grey seals for prey resources, predation by grey seals and/or killer whales, reduction in prey availability and exposure to toxins from harmful algae. Other factors including bycatch, pollution, loss of habitat, emigration, entanglement in marine debris, legal control and infectious diseases are now considered unlikely to be major factors in the regional declines.

The Sea Mammal Research Unit has been funded by Scottish Government to investigate the causes of the declines. A list of potential factors involved and the current assessment of their likely importance is given in Table 7. Studies are continuing to investigate the remaining potential causal factors, focusing on competition with grey seals, predation by grey seals and killer whales, harmful algal toxins, changes in prey availability and increased juvenile dispersal.
A study evaluating the harbour seal population source-sink dynamics using genetic and telemetry data is also in progress, in order to assist in understanding where management efforts should be directed. This work will be presented at SCOS 2019.
The focus of the Scottish Government funded project remains investigating the survival and fecundity rates in areas with contrasting population trajectories in order to determine which vital rates are being impacted and to assist in narrowing down the potential drivers. The results from these targeted studies will be compared to results from similar studies of other marine predator populations.

Table 7. ***The current view of the major potential drivers of the declines in harbour seals in some areas and their status***

	Factor	Status	Evidence
1.	Fisheries bycatch	unlikely	Data from bycatch observer programmes and absence of major gillnet fisheries in regions of decline suggest that bycatch is unlikely to be a significant factor in the declines.
2.	Pollution	unlikely	Levels of persistent organic pollutants are low in the areas of decline and highest in regions where populations are increasing[34].
3.	Loss of habitat	unlikely	Data from aerial surveys and telemetry studies show no evidence that foraging, moulting or breeding sites have been lost.
4.	Juvenile dispersal	possible	Genetic studies do not indicate large scale dispersal but may have little power to detect recent changes in recruitment patterns.
5.	Emigration	unlikely	Telemetry data do not indicate large scale, permanent emigration of seals from areas of decline[35], although temporary relocation between regions may be frequent.

[34]Hall, A.J. & Thomas, G.O. 2007. Polychlorinated biphenyls, DDT, polybrominated diphenyl ethers and organic pesticides in United Kingdom harbor seals - mixed exposures and thyroid homeostasis. *Environmental Toxicology Chemistry*, 26, 851-861.
[35]Sharples, R.J., Moss, S.E., Patterson, T.A. & Hammond, P.S. 2012. Spatial Variation in Foraging Behaviour of a Marine Top Predator (*Phoca vitulina*) Determined by a Large-Scale Satellite Tagging Program. *PLoS ONE*, 7.

6.	Entanglement in marine debris	unlikely	Data from stranded seals and from faecal samples from haulout sites indicate that entanglement in marine debris or ingestion of plastics are not major issues for UK seals.
7.	Legal control	unlikely	Introduction of the Marine (Scotland) Act 2010 and the licensing system is ensuring the declining populations are protected from directed takes.
8.	Infectious disease	unlikely	No evidence of an unusual mortality from strandings or seals taken into rehabilitation. Live capture-release studies show no evidence of disease in areas of decline. No evidence that Brucella infection is responsible[36]. However, other esoteric or secondary disease agents may still be a factor.
9.	Prey quality and availability	possible	It is not possible to rule out changes in the prey quantity or quality as factors involved in the decline of harbour seals, although recent analysis of body condition and nutritional health in live captured animals shows no evidence.
10.	Competition with other marine predators	possible	Competition for prey with the increasing grey seal population and/or other marine predators cannot be ruled out.
11.	Predation	possible	Predation by grey seals[37] and killer whales is still being reported at several locations.
12.	Toxins from harmful algae	possible	Domoic acid and saxitoxin continue to be detected in seals[38] and their prey.
13.	Climate change : direct effects	unlikely	Observed and potential changes in physical environment in UK waters are unlikely to exceed harbour seals' adaptive capabilities.
14.	Climate change : indirect effects	possible	Changes in prey distribution and/or availability or increases in harmful algal blooms or increased disease prevalence as a consequence of climate change are likely to impact harbour seal populations in future.

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? It would be particularly useful to have views on the utility of the current	MS Q5

[36] Kershaw, J.L., Stubberfield, E.J., Foster, G., Brownlow, A., Hall, A.J., Perrett, L.L. 2017. Exposure of harbour seals *Phoca vitulina* to Brucella in declining populations across Scotland. *Diseases of Aquatic Organisms*, 126,13-23

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

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

Western Isles Conservation Area.	

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

Until up-to-date, scientifically informed criteria are defined for establishing or revoking conservation measures SCOS cannot advise on the need for introducing any additional conservation areas. Conservation areas are currently designated for the Western Isles, Northern Isles and down the east coast as far as the border. The declines in Orkney and the East Scotland Seal Management Units are continuing and there is no sign of recovery in Shetland or the Moray Firth. Details of trend analyses are presented briefly in answer to Q1 and 2 above and in detail in Thompson et al. (2019)[12].

The 2011 survey in the Western Isles indicated that the population had increased since the 2007-09 surveys and was close to the 1996-97 levels. The population was apparently undergoing a protracted but gradual decline during the 2000s, but the 2011 count was close to the pre-decline numbers and a trend analysis suggested no significant change between 1992 and 2011. The most recent count for the Western Isles was 25% higher than the previous count, but inclusion of this new result does not change the overall trajectory, which still indicates a lack of any trend since 1992. The recent count may indicate that a recovery is underway but is not sufficient in itself to confirm this. SCOS therefore recommend that current conservation measures should be maintained. The adjacent and much larger West Scotland population is at an all-time high since surveys began. Trend analysis[12] suggests a stable overall population, but within this large region, the central section which holds the majority of the seals is showing a consistent and continuing increase. Trend analysis for the Southwest Scotland management area indicates no trend since 1989. SCOS advises that there is no apparent requirement to extend the conservation orders to the West and Southwest management areas.

In addition to the specific conservation orders, the potential biological removal (PBR) is calculated for each region for each year (SCOS-BP 18/06) and region specific recovery factors are assigned each year on the basis of current/recent population status. These are discussed in answer 7 below.

Seal Legislation

7. Does the Committee consider that there is a significant scientific requirement or advantage to updating the Conservation of Seals Act 1970, for example, definitions and applications of closed seasons, the netsmen's defence and the potential for the introduction of mandatory recording and/or licencing of shooting?	Defra Q12

SCOS recommend that there should be a requirement for mandatory reporting of seals killed. From both scientific and management perspectives the absence of any requirement to record and report on numbers of seals killed in England and Wales is a major omission that prevents any assessment of the effects of seal shooting. It is therefore not possible to provide advice on the effectiveness or value of shooting seals under the netsman's defence exemption in the Conservation of Seals Act.

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

Seal Licensing and PBRs

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

Provisional regional PBR values for Scottish seals for 2019 are given in SCOS-BP 18/06. The latest harbour seal survey counts for the Western Isles SMU was approximately 25% higher than the previous estimate, resulting in a 25% higher PBR for harbour seals in that management region. Part of West Scotland SMU was resurveyed, this resulted in a 4% higher PBR. The grey seal count for the Western Isles was approximately 40% higher than the previous estimate, resulting in a 40% higher PBR for grey seals in that management region.

SCOS recommend that recovery factors used in the PBR calculations should be left unchanged at present.

PBR values for the grey and harbour seal "populations" that haul out in each of the seven Seal Management Units in Scotland are presented in SCOS-BP 18/06. Sets of possible values are tabulated for each area with different values of recovery factor. The recovery factor (R_F) is a simple scaling factor between 0.1 and 1 that allows managers a degree of flexibility to account for different characteristics of the population. 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.

R_F has been held constant in all management regions. SCOS recommended that the Western Isles management area PBR be re-examined in light of the results of a new (2017) survey. The Western Isles population was apparently undergoing a protracted but gradual decline during the 2000s, but the 2011 count was close to the pre-decline numbers and the 2017 count was higher. A trend analysis[12] suggested no significant change between the early 1990s and 2017. The most recent count for the Western Isles was 25% higher than the previous count. On that basis there may be an argument for increasing the recovery factor to bring it in line with the other western Scottish management areas, currently set at 0.7.

In practical terms, the 2019 PBR for the Western Isles SMU is 105 and only one harbour seal has been reportedly shot each year for the past four years, approximately 3% of the number permitted under licence over the same period. As there is a conservation order in place for the SMU and no clear management requirement to increase the PBR, SCOS recommends that the recovery factor be left at 0.5 and reviewed again when a new count is available for the larger, adjacent West Scotland SMU.

For reasons of consistency, SCOS also recommend that the R_F applied to the West Scotland SMU should be reviewed when the results of the 2018 surveys are available, providing a revised count for the entire West Scotland SMU.

Seals and Marine Renewables

9. What is the latest understanding of the potential interactions between seals and offshore wind farms? In particular it would be useful to get an understanding of the behaviour of seals in relation to pile driving, including how quickly they return to baseline following any acoustic disturbance.	MS Q 12

Results of tracking studies showed clear evidence of avoidance by harbour seals during pile driving, at ranges up to 25km from piling sites, but also showed that avoidance behaviour was temporary and restricted to periods of active pile driving. Similar studies have shown changes in dive behaviour and possible avoidance behaviour by grey seals exposed to pile driving noise off the coast of the Netherlands. Again, seals returned to the same locations on later trips suggesting a short term response to pile driving activities.

Harbour seals have been tracked swimming within and in some cases clearly using operational wind farms as foraging sites. Grey seals have also been tracked swimming through operational wind farms with no indication of overt avoidance off both the UK and Danish coasts.

Results of a behavioural study during the construction of a wind farm using data from GPS/GSM tags on 24 harbour seals in the Wash were reported previously to SCOS. In summary, results showed that seals were not excluded from the vicinity of the windfarm during the overall construction phase but that there was clear evidence of avoidance during pile driving, with significantly reduced levels of seal activity at ranges up to 25km from piling sites. However, within 2hr of the cessation of pile driving, seal distribution returned to pre-piling levels[39] suggesting that avoidance behaviour does not continue beyond this time.

Recently, additional tag deployments on harbour seals which coincide with piling activity at wind farm developments have been carried out in East Anglia and the Moray Firth. A total of 20 seals in the Wash were tagged with GPS/GSM tags in October 2016 and early results suggest that all seals were exposed to pile driving noise during their at-sea trips. Between February and March 2017, immediately prior to the start of pile driving for an offshore wind farm, 31 harbour seals were tagged with GPS/GSM tags in the Moray Firth in collaboration with Aberdeen University. The majority of these seals were individuals for which historical behavioural and reproductive histories are known (from long term Photo ID studies); this potentially provides the opportunity to link behavioural responses to pile driving with life history data and measure the effects of pile driving to survival and fecundity.

In a similar study in Netherlands waters[40], grey seals were tracked during the construction of two windfarms in 2014 and 2015. Grey seals showed a wide range of responses to pile driving including: no change in behaviour, altered surfacing and diving behaviour, changes in swim direction away from the source, heading inshore, swimming perpendicular to the incoming sound, or stopping. Dive behaviour often changed, with reduced descent speed, suggesting a transition from foraging (diving straight down to the bottom), to more horizontal movement. The observed changes in behaviour were on average larger and occurred more frequently at smaller distances (<30km) from the pile

[39] Russell, D. J. F., G. D. Hastie, D. Thompson, et al. (2016) Avoidance of wind farms by harbour seals is limited to pile driving activities. Journal of Applied Ecology. 53(6):1642-1652

[40] Geert Aarts et al. 2018 Uncontrolled sound exposure experiments: behavioural reactions of wild grey seals to pile-driving. – Wageningen Marine Research, Wageningen University & Research. Abstract , INPAS symposium, Amsterdam , June 2018. Available at: http://www.smruconsulting.com/inpas-abstracts-announced/

driving events. Seals exposed to pile-driving, even at close distances of <20km, returned to the same area on subsequent trips[41] .

Post construction, harbour seals have been shown to move within operational windfarms. Off the Netherlands, four of 96 individuals tagged in 2010 and 2011 (tag duration: 25-161 days) entered the Alpha Ventus wind farm. Two of these four showed striking grid-like patterns of movements as they concentrated their activity at individual turbines. In 2012, while some turbines were operational, seven of 22 individuals tagged in south-east England entered the Sheringham Shoal wind farm; one on each of its 13 trips and showed similar grid-like movement patterns. The movement and dive data strongly suggest that these structures were used for foraging and the directed movements show that animals could effectively navigate to and between structures.

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 a total of 21 GPS tags on grey seals in the southern North Sea. There was extensive overlap between grey seal movements and wind farms; 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[39]. Similarly, grey seals tracked in the vicinity of operational windfarms in Denmark made frequent transits through the wind farms and did not apparently react to the presence of wind turbines.

10. Could the Committee provide a summary of the results/findings on the work currently underway to look at seal behaviour around tidal turbine devices in Scotland?	Defra Q11
Has there been any progress on improving our understanding of how seals behave around tidal energy devices?	NRW Q2
Has there been any progress on the trials to assess the physical damage that may be inflicted on seals through collision with tidal energy devices?	NRW Q3

Results of harbour seal tracking studies in Strangford Loch showed that seals avoided the operating tidal turbine but continued to transit through the channel passing the turbine. Transit rates were reduced during turbine operations.

Wild, free-ranging harbour seals also showed avoidance responses to playbacks of tidal turbine noise. Activity was reduced at ranges up to 500m during signal playback compared to silent control periods.

Physical effects of turbine blade impacts have been tested during controlled collisions between a simulated turbine blade and seal carcasses. Post-trial x-rays, CT scans and post mortem examination showed that slow speed collisions did not cause skeletal trauma, but collisions over 5.5 m.s^{-1} caused fractures and severe internal organ damage.

Since reporting in 2016, analysis of the behaviour of harbour seals and an operating tidal turbine (SeaGen in Strangford Narrows, Northern Ireland) has been completed. This analysed data from 32 harbour seals tagged with GPS/GSM tags; results showed that the turbine did not prevent transit of the animals through the channel and therefore did not result in a ‘barrier’ effect. However, the frequency of transits past the turbine by tagged seals declined by 20% (95% CI: 10–50%) when the

[41] Kirkwood, R., G. Aarts, and S. Brasseur. 2014. Seal monitoring and evaluation for the Luchterduinen offshore wind farm construction - 2014 report. IMARES report report number C152/14.

turbine was on, relative to when it was off. This effect was stronger when considering daylight hours only with a reduction of transit rate of 57% (95% CI: 25–64%). Seals tagged during the operational period transited approximately 250 m either side of the turbine suggesting some degree of local avoidance compared with the pre-installation results[42].

More recent analyses of these Strangford data have been carried out with the aim of estimating empirical avoidance rates of seals to the turbine. The authors[43] analysed the GPS/GSM location data with a Brownian Bridge movement model to develop a fine scale probability density surfaces for seal density in the 3x3 km^2 region centred at the SeaGen tidal turbine before deployment and after operation of the turbine. Results suggested a spatial avoidance of 68% (95% C.I., 37%, 83%) by seals within 200 meters of the turbine, i.e. seals were 68% less likely to occupy habitat within 200m of the turbine, resulting in a 90% reduction in collision risk compared with a risk estimate based on an assumption of no avoidance.

As part of the NERC/Defra funded RESPONSE project, a series of acoustic playbacks of tidal turbine sounds were carried out in a narrow, tidally energetic channel on the west coast of Scotland[44]. Concurrent land based visual observations were made of harbour seal activity during signal playbacks (simulated turbine signal based on SeaGen with an estimated source level of 175 dB re 1µPa-m(RMS)) as well as with equivalent control signals. Further, the behaviour of ten harbour seals was measured through swimming tracks of high resolution UHF/GPS telemetry tagged seals collected in conjunction with the playback trials[44]. Results of this study showed that there was no significant difference in the total numbers of seals sighted within the channel between playback and silent control periods. However, there was a localised impact of the turbine signal; tagged harbour seals exhibited significant spatial avoidance of the sound which resulted in a reduction in the usage by seals of between 11 and 41% at the playback location. The significant decline in usage extended to 500 m from the playback location at which usage decreased by between 1 and 9% during playback[44]. In practice, these empirical changes in usage could be used directly as avoidance rates when using collision risk models to predict the effects of tidal turbines on seals, although the observed responses were to a single point source and additional work will be needed to determine the effects of multiple sources equivalent to operational tidal arrays.

More recently, a study was carried out using a similar playback approach to harbour seals in Washington State, USA[45]. As above, a programme of land based visual observations of harbour seal activity during signal playbacks plus equivalent control signals was made. The signal had an estimated source level of 158 dB re 1µPa-m(RMS) and was a recording of the Ocean Renewable Power RivGen river current turbine. When seals were sighted, photographs were taken and were later analysed to estimate the location of each seal relative to the playback speaker using photogrammetric techniques. Results showed that seals did not exhibit a significant spatial avoidance response to the simulated turbine signal. Although this appears to contrast with the findings of the previous study[44], due to markedly lower source level used in this study[45], direct comparisons are difficult.

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[42] Sparling, C. E., M. Lonergan, and B. J. McConnell. In press. Harbour seals (Phoca vitulina) around an operational tidal turbine in Strangford Narrows: No barrier effect but small changes in transit behaviour. Aquatic Conservation of Marine Freshwater Ecosystems.

[43] Joy, R., J. D. Wood, C. E. Sparling, D. J. Tollit, A. E. Copping, and B. McConnell. In press. Empirical measures of harbor seal behavior and avoidance of an operational tidal turbine. Marine Pollution Bulletin.

[44] Hastie, GD, Russell, DJF, Lepper, P, Elliott, J, Wilson, B, Benjamins, S & Thompson, D 2018, 'Harbour seals avoid tidal turbine noise: implications for collision risk' Journal of Applied Ecology, vol 55, no. 2, pp. 684-693. DOI: 10.1111/1365-2664.12981

[45] Robertson, F., J. D. Wood, J. Joslin, R. Joy, and B. Polagye. 2018. Marine mammal behavioral response to tidal turbine sound. Final technical report for DE-EE0006385.

Analyses of land based observer data at the European Marine Energy Centre Fall of Warness tidal energy test site has also been published recently[46]. Observations of marine mammals were made from a cliff top (50m high) overlooking the Fall of Warness site between 2005 and 2015. The survey area when viewed from the clifftop, was subdivided into a grid system for recording purposes and the number of seals in each grid cell was recorded during regular scans of the test site; a total of 9,511 sightings of seals (not identified to species level) were made during the observations[46]. Results of spatially explicit analyses suggest that there may be a decrease in density immediately adjacent to the potential impact location (single test berth); however, beyond 1km there is no apparent effect[46]. Results also suggest that grid cells where test berths are located show small but statistically significant reductions in density with the installation of infrastructure, but no clear relationship between operational status and changes in seal density. Plots of density change with distance from test berth indicate very little variation with distance away from the test berth location, suggesting that harbour seal abundance may not be influenced by the location of a test berth[46] .

Scottish Government funded work is currently being carried out to assess the physical damage inflicted upon a seal when struck by a turbine blade in a series of collision impact tests; this was carried out on seal carcasses using a simulated turbine blade attached to the keel of a jet drive boat, driven over the carcasses at known speeds (a total of 28 collisions between 2.1 to 10.3 ms^{-1})[47]. Post-trial radiographs or CT scans of each seal showed no discernible evidence of skeletal damage as a result of collisions at the lower speeds (<5.5 $m.s^{-1}$); 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 lower speeds are unlikely to produce serious or fatal injuries in grey seals. However, at higher speeds (between 5.5 and 10.3 $m.s^{-1}$) collisions resulted in varying degrees of spinal fracture and three out of five seals showed signs of damage to the rib-cage. Massive diaphragmatic rupture was also found in all cases. Results of a GLM describing the effect of turbine blade speed on the probability of inducing severe trauma in seals suggests that the mean probability of severe, fatal injury exceeds 0.5 at 5.65 $m.s^{-1}$ (95% CIs: lower =4.4 $m.s^{-1}$, upper=7.2 $m.s^{-1}$).

Scottish Government is also currently funding research into the behaviour of harbour seals and other marine mammals in the vicinity of an operational tidal turbine. This utilises a combination of Active Acoustic Monitoring (AAM) and Passive Acoustic Monitoring (PAM) techniques for deployment on the turbine and on a seabed mounted platform to detect and track marine mammals at a high resolution (at a scale of metres). This aims to provide data on the movements of seals around an operating turbine that will form the basis of an analysis of close range encounter rates and behavioural responses by seals to the turbine. This is being carried out at the MeyGen Inner Sound development in the Pentland Firth, which is an array of four tidal turbines (three Andritz Hydro Hammerfest HS1000 turbines and one Atlantis Resources Ltd AR1500 turbine). The environmental monitoring system was successfully installed on the turbine support structure on 24 October 2016. However, following the installation of the Atlantis Turbine in February 2017, initial commissioning of the monitoring system revealed a technical failure with the seal tracking systems (AAM).

To examine fine scale movements of seals relative to the tidal turbines in a wider spatial context, 24 harbour seals were caught and tagged in the Inner Sound during October 2016 and April 2017. These data aim to provide real time locations of seals to base stations on shore each time a seal

[46] Long, C. 2017. Analysis of the possible displacement of bird and marine mammal species related to the installation and operation of marine energy conversion systems. Scottish Natural Heritage Commissioned Report No. 947.

[47] Onoufriou, J., A. Brownlow, S. Moss, G. D. Hastie, and D. Thompson. In review. Empirical determination of severe trauma in seals from collisions with tidal turbines. Journal of Applied Ecology.

surfaces, providing supporting evidence to determine if a collision occurs between a seal and a turbine. In total 115,100 locations were recorded from the tagged seals during the two tagging deployments. Seals spent a total of 16% of their time in the Inner Sound, with a relatively low number of locations (195) recorded within the MeyGen lease area. Only three seals were recorded at the surface within 100 m of any of the turbines; the closest surface location to any of the turbines was 35m, but locations underwater are unknown. A detailed analysis of these data and their implications will be provided as a briefing paper for the 2019 SCOS meeting.

11. Based on current work in Scotland to investigate interactions between seals and operational tidal devices, what are the questions that remain to be addressed? What research gaps still exist?	MS Q11

Good progress has been made in quantifying the behaviour of seals in tidal environments, their responses to the sounds of tidal turbines, and their broad scale movements (from tagging) in relation to turbines (at a scale of 10's to 100's of metres). However, information on the fine scale underwater movements (at a scale of metres) of individual seals around operating turbines, and the subsequent determination of empirical collision/avoidance rates with operating turbines remains the critical research gap with respect to understanding the potential impacts of tidal devices. Other data gaps relevant to the impacts of tidal devices on seals include accurate information on the demographic consequences of collision and disturbance, and the effects of arrays of tidal devices on foraging behaviour, changes to prey distribution and collision risk.

12. What is the latest research on the potential fitness and energetic consequences to seals as a result of disturbance caused by impulsive noise (e.g. pile driving)?	MS Q13

SCOS is not aware of any published research providing direct estimates of changes in demographic parameters as a result of disturbance due to impulsive noise nor any direct quantitative evidence of the fitness and energetic consequences of disturbance due to impulsive noise.

There is evidence for short term behavioural responses to pile driving noise, however, SCOS are not aware of any published information on longer-term fitness and energetic consequences. A workshop on the effects of impulsive noise on marine mammals was held in June 2018 (INPAS symposium, Amsterdam).

The paucity of information on the transfer functions (i.e. the relationships between metrics of disturbance and quantitative changes in important behavioural/physiological processes and/or demographic parameters) between disturbance and energetics and eventually fitness was recognised. An expert elicitation process similar to that for PTS (see below) was conducted after the INPAS workshop. The results of this EE have not yet been published but will be circulated to SCOS when the report becomes available.

13. What are the current developments with respect to improving and developing modelling frameworks that address population consequence of disturbance (e.g. DEPONS for harbour seals; iPCoD updates)?	MS Q14

DEPONS and iPCoD are two modelling approaches that aim to describe the population consequences of disturbance. Both are still under development, but iPCoD is at a more advanced stage and currently being used by developers and regulators. DEPONS is a model developed for harbour porpoises, a similar approach for harbour seals is at an early stage of development.

iPCoD updates: The Interim Population Consequences of Disturbance (iPCoD) framework was developed in 2013 to forecast the potential effects on marine mammal populations in UK waters of disturbance and/or permanent threshold shifts (PTS). The iPCoD facilitates decision making where there is limited knowledge about the potential effects on marine mammals. In the absence of data on specific interactions and their effects, a process of expert elicitation was carried out in 2013 to provide a consensus view on the form of transfer functions and the values of their intrinsic parameters. These would then be used to predict the effects of PTS on the survival and fecundity of harbour porpoise, bottlenose dolphins, harbour seals and grey seals.

In 2018 another elicitation round was carried out to update the transfer functions; specifically, to update transfer functions for the effect of a specified level of PTS on the survival of dependents (calves/pups), juveniles, mature females and on the probability of giving birth to viable offspring for the four species.

The elicitation exercise produced significantly different values for transfer function parameters. Overall, experts indicated that a 6 dB PTS in the 2-10 kHz band was unlikely to have a large effect on survival or fertility of the species of interest, but was likely to have a slightly larger effect on pups and juveniles than on mature females. The new transfer functions suggest a much smaller 'effect size' than in the earlier expert elicitation and this may alter the population trajectories predicted by iPCoD in some situations. The expert group recommend that research effort is directed to address the specific knowledge gaps currently requiring the use of expert elicitation, i.e. the link functions between both vital rates and either PTS or disturbance.

DEPONS (Disturbance Effects of noise on the harbour Porpoise population Of the North Sea) has been developed to describe the effects of disturbance on individual harbour porpoises and combine them with individual based movement models to estimate population level effects. This is at an advanced stage for porpoises but at present there is no equivalent of DEPONS for harbour seals. Such a research program, based on the results of the extensive telemetry and annual population monitoring datasets, is in the early stages in both the Netherlands and UK and the two projects are collaborating. Central to this effort is the development of an individual based movement model to identify which variables affect long and short-term movement and foraging performance of harbour seals in the UK waters. This will be followed by a series of simulations to predict and validate the effect of multiple stressors on movement and performance of harbour seals.

The first phase, i.e. building a spatially-explicit, physiology based short-term individual-based movement model for adult seals outside breeding and moulting season using Tay Bay and Firth of Forth as pilot study area, is progressing. Model procedures have already been implemented and are currently being parameterised; movement of modelled seals is based on seals' decision in relation to their body condition, distance to haul-out sites, resource distribution and seals' ability to memorise visited places. First results of stage I model simulations are expected by the end of 2018 and will be presented to SCOS 2019.

A more direct observational approach to the same questions is being taken in a joint project involving Aberdeen University and SMRU. In a study based on the Loch Fleet long term study animals they are combining detailed at sea behaviour data from seals with known reproductive histories to assess the direct effects of pile driving activities on demographic parameters.

14. What is our current understanding of TTS and PTS in seals? For example, at what frequencies do TTS and PTS occur and how long may TTS last?	MS Q15

Seals exposed to intense sounds may suffer hearing loss in the form of either temporary hearing threshold shift (TTS) or permanent threshold shifts (PTS). PTS threshold has not been measured in marine mammals and is inferred from TTS thresholds. New guidance on Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing published by NOAA give generic phocid seal recommended cumulative sound exposure thresholds for onset of PTS of 201 dB re 1µPa^{2}s for non-impulsive sounds and 185 dB re 1µPa^{2}s for impulsive sounds. This impulsive noise threshold recommendation is lower than cumulative sound exposure levels from pile driving noise that have been shown to produce TTS in harbour seals. Available information on experimental studies of TTS onset in harbour seals is summarised below.

Seals exposed to intense sounds may suffer hearing loss in the form of either temporary hearing threshold shift (TTS) or permanent threshold shifts (PTS). Both TTS and PTS can occur at any frequency. For obvious animal welfare reasons studies have concentrated on TTS onset, in the knowledge that continuous exposure to sounds that elicit TTS are likely to lead to PTS. In 2018 NOAA published new guidance on assessing the effects of anthropogenic sound on marine mammal hearing[48]. Specifically, it identifies the received levels, or thresholds, at which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for acute, incidental exposure to underwater anthropogenic sound sources. The NOAA advice provides conservative sound exposure levels against which operators can determine whether and how their activities can be expected to result in potential impacts to marine mammal hearing via acoustic exposure. The generic phocid seal recommended cumulative sound exposure thresholds for onset of PTS of 201 dB re 1µPa2s for non-impulsive sounds and 185 dB re 1µPa2s for impulsive sounds, weighted by a generic Phocid Weighting and with a 24hr accumulation period.

Studies on the effects of sound on the auditory system of harbour seals have been carried out with captive animals. Harbour seals exposed to 20 min of continuous octave-band white noise (OBN) with centre frequencies of 100, 500, 750 and 1000 Hz, at source levels 60 dB above hearing threshold suffered 4 - 8 dB TTS[49]. Harbour seals exposed to OBN centred at 4 kHz suffered TTS after 60 min at 136 dB re 1 µPa or after 15 min at 148 dB re 1 µPa[50].

[48] National Marine Fisheries Service. 2018. 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

[49] Kastak, D., Schusterman, R.J., Southall, B.L. & Reichmuth, C.J. (1999) Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. Journal of the Acoustical Society of America, 106, 1142-1148

[50] Kastelein, R.A., Gransier, R. & Hoek, L. (2013) Comparative temporary threshold shifts in a harbor porpoise and harbor seal, and severe shift in a seal (L). Journal of the Acoustical Society of America, 134.

Response to impulsive sound is likely to differ. Among the loudest anthropogenic impulsive noises experienced by seals in UK waters will be those produced during pile driving. Kastelein et al (2018)[51] exposed two captive harbour seals to 3 and 6 hours of playbacks of broadband pile-driving sounds at 1.3 s inter-pulse intervals with a relatively low received single-strike unweighted sound exposure level of 151dB re 1 $\mu Pa^2 s$ producing a cumulative sound exposure level (SEL_{cum}) of 190 to 193 dB re 1 μPa^2 s. Minor TTS occurred after 6hr exposures and was most pronounced at 4 kHz and 8 kHz (mean TTS in the two seals: 3.9 dB and 2.8 dB at 4 kHz and 2.4 dB and 2.8 dB at 8 kHz). Hearing recovered within 60 min post-exposure. TTS onset SEL_{cum} for those pile-driving sounds was estimated to be approximately192 dB re 1 $\mu Pa^2 s$.

After a TTS, the time to recovery depends on the level of shift incurred; in general, the greater the shift, the longer the recovery period[52,53]. For example, the auditory sensitivity of a harbour seal with mean TTSs of 2–12 dB as a result of OBN exposure at 2.5 kHz for 22 min at 137 dB re 1 µPa @1 m (~ 80 dB above hearing threshold) and durations of 25 and 50 min at 152 dB re 1 µPa @1 m (~ 95 dB above hearing threshold) recovered fully within 24h[54].

One harbour seal inadvertently exposed for 60 min to 4 kHz OBN at 163 dB re 1 µPa (~ 22–30 dB above TTS level) suffered a 44 dB TTS. This seal did eventually recover but after 4 days[50] The severe TTS in the seal suggests that the critical level (above which TTS increases rapidly with increasing SPL) is between 150 and 160 dB re 1 µPa for a 60 min exposure to OBN centred at 4 kHz. This should be regarded as the likely PTS onset level. However, the authors suggest that their result contradicts the equal energy hypothesis, so should be treated with caution when assessing effects of impulsive sounds.

Seals and Fisheries

15. We have seen increasing complaints from the fishing industry in certain areas where reports of depredation of large percentages of catch are reported. There is concern around interactions between fishers and seals and the use of lethal means of control. Can the Committee provide an update on what the extent of the issue is in specific problem areas? Could SCOS recommend a systematic reporting template or framework to record seal/fisher interactions?	Defra Q6

SCOS is not aware of any new information on the extent of the issue in England and Wales. There is a perceived problem and suggestions that it is getting worse. Increasing seal populations in central and southern North Sea are likely to increase levels of interactions between seals and fisheries in the region.

There are anecdotal accounts that seals cause considerable damage to catches at various locations on the English coast. The rapid and continuing increase in grey seal populations in the central and southern North Sea means that the existing problems are likely to will get worse. SCOS is not aware of any new information on the extent or scale of the problem or any quantitative information on the

[51] Kastelein, R., Helder-Hoek, L., Kommeren , A., Covi, J. & Gransier, R (2018) Effect of pile-driving sounds on harbor seal (Phoca vitulina) hearing: The Journal of the Acoustical Society of America 143 , 3583; doi: 10.1121/1.504049
[52] Carder, H.M. & Miller, J.D. (1972) Temporary threshold shifts from prolonged exposure to noise. Journal of Speech and Hearing Research, 15, 603-623
[53] Mills, J.H., Gilbert, R.M. & Adkins, W.Y. (1979) Temporary threshold shifts in humans exposed to octave bands of noise for 16 to 24 hours. Journal of the Acoustical Society of America, 74, 1185-1189.
[54] Kastak, D., Southall, B.L., Schusterman , R.J. & Reichmuth, C.J. (2005) Underwater temporary threshold shift in pinnipeds: Effects of noise level and duration. Journal of the Acoustical Soceity of America, 118, 3154-3163.

levels of damage. The MMO and Defra have an ongoing project to assess the scale of the problems for small boats on the English coast, but no results are available yet. Results from this work will inform future reporting of seal/fisher interactions.

The UK Protected Species Bycatch Monitoring Scheme has collected data for 20 years on the bycatch of marine mammals through on board observations, some of which is associated with depredation. It has also collected information on seal-damaged fish recovered from nets. As yet SMRU have not been able to conduct a quantitative assessment of these data, but are actively pursuing funds to do so at present.

Work has been carried out on seal fisheries interactions in Scotland in relation to salmon fisheries (wild capture fisheries and angling)[55]. Depredation of salmon by seals from coastal static net fisheries represented a significant economic loss to the fisheries concerned and an additional source of mortality for salmonids, a source of mortality that is probably largely dependent upon the presence of the net fishery. Modifications to coastal (stake) salmon nets and the use of acoustic deterrent devices have been shown to be effective in limiting if not eliminating such depredation. At present coastal static net fisheries are not operating in Scotland. Work with river boards has focused on the use of acoustic deterrent devices to limit access by seals to particular salmon rivers, and identifying individual problematic seals for tagging or removal.
There is no requirement to record any lethal measures being pursued in English or Welsh waters. Salmon River Boards have been issued with licences to shoot problematic seals as a last resort if non-lethal measures fail, under the Marine (Scotland) Act, and returns are published on Marine Scotland's website quarterly.

Seals and River Fisheries

16. What is the latest understanding of potential non-lethal options for deterring seals from entering and/or transiting up river systems or, if necessary, relocating them from there? It would be useful to have a short summary of the latest position on the effectiveness of recent work on relocation and ADD deployment in this role. It would also be interesting to have views on the applicability of alternative non-lethal options such as electric barriers.	MS Q10
Following your 2017 advice regarding non-lethal mitigation measures to minimise seal interactions with salmon netting stations, river fisheries, fish farms and marine renewable devices, and deterring seals from entering and/or transiting up river systems, do you have any additional information to further facilitate the development of non-lethal conflict resolution advice?	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 but is untested. For additional information on the use of ADDs around Marine Renewable Energy installations see Q18 below.

[55] (http://www.smru.st-andrews.ac.uk/research-policy/)

Marine Scotland commissioned a review of the options for limiting seal access to salmon rivers and on alternate lethal and non-lethal measures to limit depredation[56]. Several broad approaches are explored. While Acoustic Deterrent Devices (ADDs) have been shown to be effective in some situations, they are far from a complete solution, with additional mitigating solutions required for seals motivated to pass such acoustic barriers. The review considered some of the alternative approaches (e.g., physical exclusion techniques, relocation of animals, electric fields) that have attempted to exclude seals from rivers, but such examples are few and so far have shown that the methods tried were generally impractical, often resulting in undesired or counterproductive effects on salmonids. (see Q17 below for discussion of seal relocation). If the removal or exclusion of a specific seal is not possible, a change in the behaviour of problem individuals is required. A structured research programme is required to investigate these issues.

The adopted mitigation strategy for each river is likely to differ depending on the characteristics of the river and the local seal population, and may require more than one approach. Methods employed to reduce the turnover of individual problem seals (i.e. reducing the rate new individuals learn to exploit the resource), may be different from those needed to deal with seals that already specialise on salmon in rivers.

SCOS is not aware of any data on the effectiveness of relocation of grey or harbour seals in the UK. There is anecdotal information on a translocation of one harbour seal in the early 1980s from a site 50km up the River Ouse to The Wash. The seal returned to the river site within a week (M. Fedak (SMRU) pers com). Attempts to relocate harbour seals feeding on salmonids at Ballard Locks in Seattle to Hood Canal (>50km) were abandoned because seals returned to the capture site57 and harbour seals have been recorded returning to capture sites from release sites between 21 and 421km distant on the west coast of North America 58.

In light of the failure of previous relocation attempts and the difficulties of seal capture in rivers, SCOS does not consider that relocation is likely to be an effective method of removing problem seals from rivers. The committee acknowledges that there is no clear solution but that ADDs appear to have the potential to provide a workable solution. Understanding the factors driving the large degree of variability in the effectiveness of ADDs, in order to identify reasons for failures is a research priority. Innovative deterrents should be investigated and where appropriate should be tested under field conditions.

Seals and Fish Farms

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

[56] Coram, A.J., Harris, R.N. and Northridge, S.P. 2017. Briefing paper on options to limit seal access to salmon rivers and on any alternate non-lethal measures to limit depredation. Interim report to Scottish Government – SSI.

[57] NOAA-NWFSC Tech Memo-28: Impact of sea lions and seals on Pacific Coast salmonids. http://www.newportbeachca.gov/home/showdocument?id=1590

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

A review of SMRUs activities in this area was presented at SCOS 2016, and a more detailed literature review was commissioned by Marine Scotland in 2014[59]. A brief update is presented below.

A review currently underway for Marine Scotland has highlighted a lack of directed research into novel deterrent options, although the focus of this work was on seals in rivers. Research is warranted into several areas including new netting materials, translocation of problem individuals, implementation of electric gradient deterrents and conditioned taste aversion. At present, very limited trials of high-density polyethylene (HDPE) netting are being undertaken by commercial operators. Without scientific oversight the results of such trials may remain equivocal and might not enter the public domain. ADDs have been shown to be effective in certain circumstances[60] (see also answer to Q18) but additional work is required to assess reasons for the variability in effectiveness. JNCC have published a reference guide to acoustic deterrent devices for statutory nature conservation body (SNCB) advisors and practitioners considering their use to deter marine mammals from areas where there is a risk of injury.[61]

A novel ADD system based on a startle response, was tested at a marine salmon farm over a 19 month period[62]**.** Predation was monitored at the ADD protected site with and without signal and at two control sites. Results indicate a 91% reduction in lost fish when comparing predation levels with and without the signal at the test site and 97% when comparing the test site against control sites. Harbour porpoise and otter distribution around the farm were not affected by sound exposure.

A seal specific signal for a generic marine wildlife acoustic deterrence system (FaunaGuard, SEAMARCO, Harderwijk, Netherlands) has been tested on harbour seals in a large pool captive setting[63]. Seals responded by reducing time submerged and/or increased haulout time. An estimated effect threshold suggests that this system would effectively deter harbour seals out to ranges of 200-500m.

A new low-frequency acoustic deterrent is being tested on a salmon farm in Orkney with the aim of eliminating the disturbance of cetaceans while deterring seals. No results are available, work is ongoing and SCOS will be updated in 2019.
Capture and relocation of problem seals is currently under investigation but is not likely to be a reliable solution to problems of seal predation at fish farms (see answer to Q16 above).
Low voltage, pulsed electric fields have been tested in experimental situations with captive seals, but no effective field deployable systems have yet been developed. Alternative methods such as taste aversion have not been tested rigorously in either captive or field tests with grey or harbour seals. Further research into these alternative methods is required.

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

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

[61] McGarry, T., de Silva, R., Canning, S., Mendes, S., Prior, A., Stephenson, S. & Wilson, J., (2018), Guide for the Selection and Deployment of Acoustic Deterrent Devices, JNCC Report 615, ISSN 0963-8091

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

[63] Kastelein, R., Horvers, M., Helder-Hoek, L…. van der Meij, H. (2017). Behavioral Responses of Harbor Seals (Phoca vitulina) to FaunaGuard Seal Module Sounds at Two Background Noise Levels. Aquatic Mammals 2017, 43(4), 347-363.

Use of Acoustic Deterrents

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

SCOS is not aware of any new information and a comprehensive answer to this question was provided in (SCOS Advice, 2016, Q 16).

Three low-frequency 'porpoise friendly' devices are in development, the 'Genuswave'[64] and the FaunaGuard seal module (*SEAMARCO, Harderwijk, The Netherlands)* and a novel low frequency device are undergoing initial field trials (see Q15 and Q16 above).

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

During a series of open water behavioural response trials using the same Lofitech device harbour seals showed avoidance behaviour at ranges of up to 1km from the source[65]. These apparently contradictory results suggest that context is important in determining the reactions of seals to ADD signals.

A study of the effects of both low and high frequency ADD type signals on harbour porpoises[66] showed a significant reduction in porpoise acoustic activity during transmission of both signal types, but did not detect any effect on seal activity.

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	Defra Q3

[64]Note: The University of St Andrews has a commercial interest in this device.
[65] http://www.smru.st-andrews.ac.uk/files/2015/10/MR8-1_ADD_mitigation_VF2.pdf
[66] Benjamins, S., Risch, D., Lepper, P., Wilson, B. 2018. SARF112 – Influences of lower-frequency Acoustic Deterrent Devices (ADDs) on cetaceans in Scottish coastal waters. A study commissioned by the Scottish Aquaculture Research Forum (SARF). http://www.sarf.org.uk/

development of non-lethal conflict resolution advice?	

See answers to Questions 16, 17 and 18 above.

Seal Bycatch

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

The estimated bycatch of seals in UK fisheries in 2017 was 572 animals (95% CI 429-1077)[67]. This was lower than in 2016 because of a reduction in fishing effort between 2016 and 2017. Approximately 85% of the bycatch estimate occurs in the south-west, in ICES area VII. The remainder occurs in area IV which covers the North Sea and waters around Shetland and Orkney with less than 1% occurring in area VI around the Hebrides and Northwest Scotland.

Estimated bycatch levels in the Western Channel and Celtic Sea exceed the PBR for the combined grey seal populations of SW England, Wales and Ireland. An additional but unknown number of seals are bycaught by non-UK registered boats operating in the Celtic Sea. Despite the bycatch, grey seal populations in Wales and Ireland are increasing, suggesting that bycaught seals include animals that may have originated from Scottish breeding populations.

Table 8 below shows the estimates by ICES Division and general area. All three seals caught by boats with observers in 2017 were identified as grey seals. As previously, the by catch estimates for grey and harbour seals are pooled and based on the time series of observed bycatch over the recent past. It is assumed that the bycatch will be almost exclusively grey seals, especially in the south west. Approximately 85% of the bycatch (484 seals) was estimated to have occurred in ICES area VII, around the south and south-west of the UK and Ireland. The majority of this occurred in the Western Channel and Celtic Sea, (360 seals per year), largely due to the overlap of high levels of fishing effort and relatively high seal densities. Bycatch rates in the Eastern Channel are estimated at around 114 seals per year.

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

[67] Northridge, S. P., Kingston, A. R. & Thomas, L. J. 2018. Annual report on the implementation of Council Regulation (EC) No 812/2004 during 2016, *Report to Defra*. 44 pp. Report available from Defra

Although the total bycatch estimate of 572 is not large compared to the entire UK grey seal population of over 140,000 animals, the local populations around the Celtic Sea, where most bycatch is known to occur are much lower. Total combined pup production in SW England, Wales and Ireland was approximately 4100 in 2016. With the same assumptions as used to derive a PBR for the Welsh grey seal population (N_{min} = 2.3*pup production; FR = 0.5 (SCOS 2016 answer to Q9)) this pup production produces a PBR of 283 grey seals. Using the less conservative recovery factor (FR = 1.0) applied to Scottish grey seal populations would increase this PBR to 566. The current estimated bycatch for UK registered vessels in ICES areas 7 a,e,f,g & j was 369 (Table 8), approximately 30% greater than the conservative PBR.

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

Table 8. ***Seal bycatch estimates by ICES Division 2017 (from Northridge et. al 2018 table A2.11[50])***

Region	ICES Division	Estimated total bycatch	Two-Sided 95% LCL	Two-Sided 95% UCL	One-sided 90% UCL
North Sea	4a	27	22	32	31
	4b	11	9	17	16
	4c	45	33	112	100
West Scotland offshore	6b	5	4	6	6
Irish Sea	7a	8	6	17	15
Eastern Channel	7d	114	70	303	269
Western Channel and Celtic Sea	7e	179	137	318	293
	7f	153	123	215	204
	7g	10	8	24	21
	7h	11	9	16	15
	7j	8	6	12	11
Biscay	8abcd	3	2	4	4

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

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

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

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

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

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

21. What is our understanding of disturbance issues (with respect to seals on haulout or breeding sites) around the UK? Should we be looking for a systematic reporting system/template or regulations?	Defra Q11

With respect to disturbance on haulout sites, as far as SCOS is aware, there is no formal or co-ordinated nationwide reporting system for recording disturbance events. Such a system could provide information to assess the effects of disturbance on local population dynamics or local haulout site use, but problems with degree of coverage would make it difficult to extrapolate from reports to wide area effects.

There is no formal, UK-wide reporting of disturbance events, although there are NGO led regional (e.g. Cornish Wildlife Trust's disturbance reporting scheme) and local (e.g. Ythan seal watch and Friends of Horsey Seals recording programmes) disturbance monitoring/reporting schemes.

It is an offence under the Marine (Scotland) Act to intentionally disturb seals at any haulout site designated by the Minister for protection. This includes all SAC's where seals are a primary feature and a selected list of sites chosen to include as large a proportion of the population as possible in the minimum number of sites. Such restrictions do not apply in the rest of the UK.

Disturbance at either haulout sites or breeding sites is more an animal welfare and a local population management issue. Disturbance at breeding sites can lead to abandonment of pups in both species. If this is permanent and occurs relatively early in the lactation period the pups will die of starvation. Such disturbance could constitute an offence under both UK and Scottish legislation. However, relatively short, sporadic disturbance of mother pup pairs may have little impact on pup survival as evidenced by the extensive research programs on grey seal breeding colonies in Europe and Canada and harbour seal pup tagging studies that have involved intensive disturbance at some early stage in lactation, but do not appear to have disrupted the mother pup bond.

At a local scale, repeated disturbance may lead to abandonment of specific haulout sites. Again, although there is anecdotal information there appear to have been no targeted studies of the effects of such disturbance on the subsequent haulout patterns and locations of the affected individuals. Studies of the effects of boat-based disturbance on harbour seals suggest that even repeated disturbance events, severe enough to cause seals to go into the water, did not increase the likelihood of individual seals moving to a different site and appeared to have little effect on their movements and foraging behaviour[68].

Anecdotal reports of severe disturbance at sites such as Horsey/Winterton are interesting in light of the extremely rapid and continuing increase in pup production at the site. The population is growing at more than the theoretical maximum for a grey seal population suggesting that pup survival must be high and that the site is attracting immigrants/new recruits from other sites. Despite the very close approaches by large numbers of people, the haulout site on the public beach at Horsey continues to be used throughout the summer holiday season. Use of haulout sites within military bombing ranges also indicates that both species are capable of habituating to severe sporadic disturbance.

In terms of the scientific aspects of seal monitoring and management, the current situation, i.e. no organised collection of disturbance reports, means that occasional, unreported disturbance events can disrupt or at least add additional uncertainty to the annual monitoring programs for both seal species. In the absence of an extensive network of reporters it is difficult to see how that uncertainty could be reduced. SCOS suggested that reporting of disturbance events could form the basis of a potential, coordinated, citizen science project.

22. What is the latest information on the potential for a PDV outbreak that might impact on seal populations?	MS Q16

The harbour seal population in Southeast England is now similar in size to the re-epidemic populations in both 2002 and 1988. It is estimated that <10% of the population has any immunity. It is therefore possible that a PDV epidemic could reoccur at any time and we could expect similar mortalities to those observed in either 1988 or 2002.

In 1988 and 2002, two phocine distemper virus (PDV) outbreaks occurred in harbour seals (Phoca vitulina) in Europe. Tens of thousands seals died, mainly in the southern North Sea. The 1988 epidemic halved the Southeast England population, but had relatively little effect in Scotland. The 2002 epidemic had very little effect in Scotland. In the Southeast England management area the initial drop was much less severe than in 1988. However, the population continued to decline for

[68] Paterson, W.D., Russell, D.J.F., Wu, Gi-Mick, McConnell, B.J., Currie, J., McCafferty, D. and Thompson, D. (2019). Post-disturbance haulout behaviour of harbour seals. Aquatic Conservation: Marine and Freshwater Ecosystems. Doi: 10.1002/aqc.3092

the following 4 years reaching a minimum in 2006 after which it recovered, reaching pre-epidemic levels by 2012.

Bodewes et al (2013)[69] investigated whether PDV was still circulating among seals in Dutch coastal waters. Based on blood samples collected between 2002 and 2012 they concluded that most seals in 2003 carried antibodies to the PDV and were therefore likely to be protected against the disease. However, after 2003 only adults and pups under two months old gave positive results. They concluded that these were adults that had survived the epidemic and their pups that received some degree of immunity from their mothers.

Using a simple population dynamics model they estimated that by 2013 only 11% of the Dutch seal population would have protective serum-antibodies against PDV and that a recurrence of the PDV epidemic would likely infect 80% of the population leading to >50% mortality. The Wadden Sea population has not increased since 2013 but it would be expected that the proportion immune would have continued to decline.

If the patterns of infection and mortality and subsequent population recovery had been the same in the Southeast English population we would expect the same patterns of immunity. However, in 2002 the apparent mortality was less than half that seen in the Wadden Sea, the population continued to decline for four years and this was unlikely to have been a direct consequence of PDV infection and the recovery was slower than in the Wadden Sea. However, irrespective of these difference it is certain that immunity has declined in the UK and a large majority of the population will be susceptible.

Lonergan et al. (2010)[70] used antibody levels in blood samples to show that 51 % (95 % CI: 41 - 61 %) of the harbour seals in the UK at the end of the 1988 epizootic had been exposed to the virus, and that the equivalent figure after the 2002 outbreak was 22 % (95 % CI: 16 to 30 %), consistent with the differing levels of initial population decrease. Interestingly, after both epidemics the antibody prevalence was similar in the Wash were mortality was high, to that in eastern & northern Scotland, were mortality was low or un-observed. This suggests that the level of mortality is not necessarily directly linked to the proportion of the population exposed but rather represent differences in case mortality.

Given the differences in mortality rates between the Wadden Sea and SE England in 2002 and between regions with similar post epidemic antibody levels it is difficult to accurately predict the likely effects of a re-occurrence of PDV, but mortality rates similar to those observed in 1988 and 2002 could be expected.

At present there is no co-ordinated UK wide plan for dealing with or recording the extent of any epidemic. A contingency plan is under development in Scotland. SCOS recommends that a co-ordinated response plan including case reporting, carcass collection and post mortem protocols and an emergency research plan should be developed for the UK and that it should be integrated with similar plans for the wider European harbour seal population.

23. The conclusions of the OSPAR seals abundance assessment	Defra Q13

[69] Bodewes,R., Morick,D.,van de Bildt, M. et al (2013) Prevalence of phocine distemper virus specific antibodies: bracing for the next seal epizootic in north-western Europe. Emerging Microbes & Infections. 2: e3 available @ www.nature.com/articles/emi20132

[70] Lonergan M, Hall A, Thompson H, Thompson PM, Pomeroy P, Harwood J (2010) Comparison of the 1988 and 2002 phocine distemper epizootics in British harbour seal *Phoca vitulina* populations. Dis Aquat Org 88:183-188. https://doi.org/10.3354/dao02153

identified a number of areas where the potential course in the decline in seal population remains unclear including: The historical and present dynamic between grey seals and harbour seals. As grey seal populations recover, harbour seals may face increased competitive pressure from grey seals that could have a detrimental effect on their abundance. The increase of additional human pressures such as pollution and underwater noise could influence future growth by determining the level of carrying capacity. Can the Committee provide a summary on the current knowledge on how the increase of grey seals could impact harbour seal populations? Can the Committee also suggest what monitoring requirements would help address the current knowledge gaps in the assessment?	

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

One putative explanation for the regional harbour seal population declines is competition with grey seals. There are significant overlaps in both diet [71] and at-sea distributions[72] so there is the potential for competition for prey resources to occur and grey seals are now known to be direct predators of harbour seals[73,74].

The observed trends in both harbour and grey seals around the UK indicate that there is no simple/clear link between the status of grey and harbour populations; Harbour seal populations are apparently stable or locally increasing in the west, where grey seals have been at their carrying capacity since harbour seal surveys began; Harbour seals are increasing in the southern North Sea where grey seal populations are growing at close to their theoretical maximum and they are suffering serious declines in the northern North Sea and Northern Isles over a period when grey seals have approached their carrying capacity.

However, the lack of a simple relationship does not necessarily rule out a competition effect. Density dependent effects would presumably be operating as the populations approach their carrying capacities. In the west of Scotland any such density dependence would have been fully operational before harbour seal surveys began and competition from grey seals would have been relatively constant throughout. The relatively stable harbour seal populations could represent the steady state populations under that level of competition. The rapid harbour seal declines in the northern North Sea and Northern Isles have occurred over a period during which the regional grey seal population has approached its carrying capacity, a period when density dependent effects could have led to increasing levels of interspecific competition. The

[71] Wilson, L. and Hammond, P.S. (2019). The diet of harbour and grey seals around Britain: seeking evidence for the "ghost of competition past". Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.XXXX

[72] Russell, D. J. F., Jones, E. L., & Morris, C. (2017). Updated Seal Usage Maps: The Estimated at-sea Distribution of Grey and Harbour Seals. (Scottish Marine and Freshwater Science; Vol. 8, No. 25). Scottish Government. https://doi.org/10.7489/2027-1

[73] Van Neer, A., Jensen, L. F. & Siebert, U. (2015) Grey seal (*Halichoerus grypus*) predation on harbour seals (*Phoca vitulina*) on the island of Helgoland, Germany. *Journal of Sea Research*. 97: 1–4. DOI:10.1016/j.seares.2014.11.006

[74] Brownlow, A., Onoufriou, J., Bishop, A., Davison, N., & Thompson, D. (2016). Corkscrew seals: grey seal (*Halichoerus grypus*) infanticide and cannibalism may indicate the cause of spiral lacerations in seals. *PLoS One*, 11(6): DOI: 10.1371/journal.pone.0156464

observed declines could therefore represent the effects of increasing levels of competition with grey seals. The increasing trends in both species in the central and southern North Sea could simply indicate that density dependent effects have not yet become evident. Recent reports from the Wadden Sea suggest that the moult counts of harbour seals have remained constant for the past four years, following a 15 year period of rapid increase. This may be an early indication that the rapidly increasing grey seal population in the southern North Sea is beginning to influence harbour seal populations.

Research into the diet of grey and harbour seals in 2011 and 2012[75,76] indicated that they feed on similar prey, at the same time of year and in the same regions. However, the fish size classes preferred by the different species varied. Investigating these aspects empirically and will require accurate assessment of prey availability, coordinated diet sampling and foraging behaviour studies and data on fish prey abundance at an appropriately fine scale.

Establishing the level of predation by grey seals on harbour seals and estimating the associated uncertainty for a given region will be difficult. Cases of grey seal predation on harbour seals are geographically widespread and can be identified post mortem. However, establishing the scale of the mortality based on the sporadic reports of such cases has not been possible.
However there is evidence that predation by grey seals may be a major contributory factor in local declines. Hanson et al. (2017)[77] pointed out that the observed levels of mortality due to grey seal predation in the Firth of Tay and Eden SAC was unsustainable and sufficient to account for the continuing decline there.
Studies to investigate the impact of both pollution (including emerging contaminants as well as the legacy pollutants) and underwater noise continue to be carried out. For example, recent results on the concentrations of organochlorine pollutants in grey seal pups from the Isle of May (SCOS-BP 17/06) suggest a modest but significant decrease in PCBs has occurred between 2002 and 2015, whereas DDT levels have increased over the same period. In both cases, the concentrations measured are below the limits that cause immediate negative health effects in seals. The consequences of the observed changes are unknown and investigation of the impact of PCBs, PBDEs and DDTs on measures of energy balance are continuing. Findings from these studies can be used in risk assessments to estimate their likely effect on populations.
SCOS identified the need for a research plan to directly investigate inter-species competition between grey and harbour seals and recommended that such a research programme should be coordinated with international research efforts. A research plan and background briefing paper will be presented to the 2019 SCOS meeting.

24. What is known about the possible impact of seaweed harvesting on seals?	MS Q 17

Seaweed harvesting has the potential to impact on seals in several ways. Current methods of hand collection and small scale industrial collection both onshore and in shallow/tidal waters have the potential to cause disturbance to seals at or around haulout sites. Potential large scale

[75]Wilson, L.J. and Hammond P.S, 2016. Harbour seal diet composition and diversity. Scottish Marine and Freshwater Science Report, 7:21, Marine Scotland Science.
[76]Hammond, P.S. and Wilson, L.J. 2016. Grey seal diet composition and prey consumption. Scottish Marine and Freshwater Science 7:20, Marine Scotland Science.
[77] Hanson N, Thompson D, Duck C, Baxter, J. & Lonergan, M. (2017) Harbour seal (Phoca vitulina) abundance within the Firth of Tay and Eden estuary, Scotland: recent trends and extrapolation to extinction. Aquatic Conservation: Marine and Freshwater Ecosystems. 27: 268-281. DOI: 10.1002/aqc.2609

industrial harvesting of offshore kelp could reduce the value of kelp forest as foraging habitat, both by excluding seals during harvesting and by medium term degradation of the habitat. At present there have been no direct assessments of the importance of kelp beds to seals.

Commercial harvesting of seaweed is currently a small scale industry, but has the potential to develop into a large scale industrial operation in inshore waters, particularly around the north and west coasts of Scotland. The likelihood that such activities will cause problems will depend on the exact locations involved.

It is unlikely that it would cause disturbance unless the activity was close to haulout sites. Currently kelp harvesting occurs in Orkney and the Hebrides and small scale green seaweed collection occurs in Fife. However the resource map covers all haulout sites and large areas of potentially important offshore foraging locations. Projected future harvesting areas cover a large number of sites in the southern Inner Hebrides. Although it has been shown that repeated short term boat based disturbances at haulout sites can be well tolerated by harbour seals (SCOS-BP 18/12), the protracted nature of harvesting activities may well cause significant changes in haulout behaviour patterns particularly during the breeding season.

Potential large scale industrial harvesting of offshore kelp could reduce the value of kelp forest as foraging habitat, both by excluding seals during harvesting and by medium term degradation of the habitat. There is also the potential to degrade the use of kelp forests as refuges from predators such as killer whales. To date there have been no targeted studies of the importance of kelp beds as either foraging or refuge habitats. Existing telemetry data should be used to assess the importance of kelp beds to seals.

If and when there is an expansion in the commercial harvesting of seaweed a targeted study should be established at the earliest opportunity to assess the level of disturbance and determine its effects on haulout site use.

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;
Professor A. Hall	Sea Mammal Research Unit, University of St Andrews;
Dr F. Daunt	Centre for Ecology and Hydrology, Edinburgh;
Dr J. Armstrong	Marine Scotland, Science, Aberdeen;
Dr J. Teilmann	Aarhus University, Denmark;
Dr G. Englehardt	Centre for Environment Fisheries and Aquaculture Science, Lowestoft;
Professor B. Wilson	Scottish Association for Marine Scoence, Dunstaffnage, Oban
Dr O. Ó Cadhla	National Parks and Wildlife Service, Ireland;
Dr B. Adams (Secretary)	Natural Environment Research Council, Swindon Office.

ANNEX II Questions to SCOS.

Questions from Marine Scotland
Organisation: *Scottish Government*
Date: 15/06/2018

Question No.	Question	Driver/rational behind question(1-2 sentences)
1	What are the latest estimates of the number of seals in Scottish waters?	General update on the estimated numbers of grey seals and harbour seals in Scottish waters.
2	What is the latest understanding 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?	Information about the structure or make up of these populations that might assist management measures.
3	Is the existing harbour seal decline recorded in several local areas around Scotland continuing or not and what is the position in other areas?	Information on the latest trends in local harbour seal populations around Scotland to inform management measures.
4	What is the latest understanding of the decline in harbour seals? In particular, what causal factors have so far been eliminated, those that remain contributory and those considered most likely to be significant and which should be or remain the main focus for further investigation?	To seek clarity on the potential drivers that can be eliminated and those that require further effort, in order to consider the need for any conservation and management measures.
5	In light of the latest information on harbour seal trends, should the Scottish Government consider introducing any additional seal conservation areas to protect vulnerable local populations or, alternatively, should it consider revoking any existing seal conservation areas?	Scientific advice to assist policy consideration of whether or not additional seal conservation areas might be necessary to protect harbour seals or whether or not any existing ones should be reviewed – specifically in the Western Isles.
6	What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system?	This seeks an update on the PBR figures to inform management under the seal licensing process.
7	What is the latest understanding of interactions between seals and fish farms and possible measures to mitigate any interactions? It would be particularly useful to have the Committee's view on currently available non-lethal options that could be applied in Scotland (as well as other countries) to seek to address these interactions. Furthermore, an	With the forthcoming implementation of US regulations, it is important to start to identify non-lethal options that we can advise industry to consider using for seal control. These can be used through partnership pilot projects.

	assessment of other options that prove promising but may require more detailed investigations would be extremely useful.	
8	Has there been any further research on understanding the effectiveness of existing ADDs for (a) preventing seal predation at fish farms and fisheries, and (2) as a tool to mitigate injury to seals as a result of underwater noise (e.g., pile driving and explosions)	To identify whether devices(s) are effective in deterring seals which can be used to advise industries. Furthermore, where there is a lack of data, what and how should information be gathered.
9	What advice can be provided on the use of ADDs (i.e. types, frequencies, trigger mechanisms and usage patterns) that might be most effective in deterring seals without disturbing cetaceans? It would be particularly helpful to consider these issues with respect to the use of ADDs at fish farms in the more restricted waters off the west coast of Scotland.	Scientific advice to inform consideration of policy guidance on ADD usage.
10	What is the latest understanding of potential non-lethal options for deterring seals from entering and/or transiting up river systems or, if necessary, relocating them from there? It would be useful to have a short summary of the latest position on the effectiveness of recent work on relocation and ADD deployment in this role. It would also be interesting to have views on the applicability of alternative non-lethal options such as electric barriers.	To identify non-lethal options that we can advise industry to consider using for seal control.
11	Based on current work in Scotland to investigate interactions between seals and operational tidal devices, what are the questions that remain to be addressed? What research gaps still exist?	Understanding the potential risks between seals and tidal turbines is vital in informing marine licensing decisions and meeting conservation objectives.
12	What is the latest understanding of the potential interactions between seals and offshore wind farms? In particular it would be useful to get an understanding of the behaviour of seals in relation to pile driving, including how quickly they return to baseline following any acoustic disturbance.	Understanding the potential risks between seals and wind farms is vital in informing marine licensing decisions and meeting conservation objectives. It will also better inform impact assessments
13	What is the latest research on the potential fitness and energetic consequences to seals as a result of disturbance caused by impulsive noise (e.g. pile driving)?	Understanding the potential risks between seals and wind farms is vital in informing marine licensing decisions and meeting conservation objectives
14	What are the current developments with respect to improving and developing modelling frameworks that address population consequence of disturbance (e.g. DEPONS for harbour seals; iPCoD updates)?	To better inform assessment of single and cumulative impact assessments.
15	What is our current understanding of TTS and PTS in seals? For example, at what frequencies do TTS and PTS occur and how long may	To better understand the consequences of disturbance.

	TTS last?	
16	What is the latest information on the potential for a PDV outbreak that might impact on seal populations?	The last outbreak of PDV occurred in 2002, what is the best estimate of when the next might occur?
17	What is known about the possible impact of seaweed harvesting on seals?	An update on the latest information about the current impact of any known seaweed harvesting on seals.

Questions from Defra

Organisation: *Defra*

Date: 01 /05 /2018

Question No.	Question	Driver/rational behind question(1-2 sentences)
1	What are the latest estimates of the number of seals in English water? How can we estimate the seal population in the SW of England?	General update on information regularly provided by the Committee in previous years but relating to seals in English waters.
2	What is the latest information about the population structure, including survival and age structure, of grey and common/harbour seals in English waters and is there any new evidence of populations or sub-populations specific to local areas?	General update on information regularly provided by the Committee in previous years but relating to seals in English waters.
3	Following your 2017 advice regarding non-lethal mitigation measures to minimise seal interactions with salmon netting stations, river fisheries, fish farms and marine renewable devices, and deterring seals from entering and/or transiting up river systems, do you have any additional information to further facilitate the development of non-lethal conflict resolution advice?	To identify device(s) and/or practises that we can advise industry to use for seal control, before considering shooting. The project 'Assessing options for non-lethal seal deterrents' is going ahead for England and feeding in to the project may be a means by which some of elements of questions may be delivered. Further where uncertainty remains high, this would provide further direction and/or refinement.
4	Following the 2017 summary, has there been any further work on understanding of the relative effectiveness of existing models of acoustic deterrents for preventing seal predation at fisheries or fish farms (including locations with or without a high level of cetacean presence)?	To identify device(s) and/or practises that we can advise industry to use for seal control, before considering shooting. The project 'Assessing options for non-lethal seal deterrents' is going ahead for England and feeding in to the project may be a means by which some of elements of questions may be delivered. Further where uncertainty remains high, this would provide further direction and/or refinement.
5	What is the latest information on the levels of bycatch in the South West? Are there any areas where it has not been possible to collect seal population/bycatch data and can the Committee provide advice on how to collect additional information?	Bycatch of seals is an important aspect of fisheries management. It is important that we understand the scale and distribution of the problem so we can look at appropriate mitigating measures, if needed.
6	We have seen increasing complaints from the fishing industry in certain areas where reports of depredation of large percentages of catch are reported. There is concern around interactions between fishers and seals and the use of lethal means of control. Can the Committee provide an update on what the extent of the issue is in specific problem areas? Could SCOS recommend a systematic reporting template or framework to record seal/fisher interactions?	We have had a number of reports from fishers regarding depredation of large percentages of their catch in both the Norfolk and Thames region. Fishers are claiming that up to 50% of their catch is being affected. We would like to better understand the extent of the problem in these specific areas.
7	What is our understanding of disturbance issues around the UK? Should we be looking for a systematic reporting system/template or regulations?	Cornwall Wildlife Trust have a hotline for reporting disturbance and a database of disturbance incidents involve seals being flushed into the water by a variety of

		recreational activities and occasional commercial wildlife watching vessel. Reports along the east coast (Horsey/Winterton) in local newspapers showing people getting incredibly close to grey seals during the moult (plus it also happens during the pupping season), plus anecdotal reports of attempts to put children on top of seals for pictures and a seal being punched by a member of the public?! Grey seals along the north Norfolk coast are not protected from disturbance
11	Could the Committee provide a summary of the results/findings on the work currently underway to look at seal behaviour around tidal turbine devices in Scotland?	Understanding the risks around the interactions between seals and marine energy generation devices is important when considering potential conservation measures.
12	Does the Committee consider that there is a significant scientific requirement or advantage to updating the Conservation of Seals Act 1970, For example, definitions and applications of closed seasons, the netsmen's defence and the potential for the introduction of mandatory recording and/or licencing of shooting?	It is important to retrospectively evaluate if legislation has done what was expected and if there have been any other effects as a result (both positive and negative).
13	The conclusions of the OSPAR seals abundance assessment identified a number of areas where the potential course in the decline in seal population remains unclear including: • The historical and present dynamic between grey seals and harbour seals. As grey seal populations recover, harbour seals may face increased competitive pressure from grey seals that could have a detrimental effect on their abundance. • The increase of additional human pressures such as pollution and underwater noise could influence future growth by determining the level of carrying capacity. Can the Committee provide a summary on the current knowledge on how the increase of grey seals could impact harbour seal populations? Can the Committee also suggest what monitoring requirements would help address the current knowledge gaps in the assessment?	The relationship between decline in seal populations and human activities is unclear. In those areas where marked and prolonged declines have been detected clarity on the potential divers will enable us to consider the most appropriate management and conservation measures.

NB: Feel free to add additional lines if required.

Questions from NRW

Organisation: *Natural Resources Wales*
Date: 19/ 6 /2018

Question No.	Question	Driver/rational behind question(1-2 sentences)
Example	*Can current knowledge on common seals and their behaviour around ADDs be effectively applied to grey seals knowing they have different behaviours?*	*Could ADDs be used as a mitigation technique to deter grey seals from marine renewable devices (tidal stream/tidal range structures). Could ADDs be used as the sole mitigation approach in such situations?*
1	Recent evidence from Wales has shown that pup production at several sites is increasing and the onset of the pupping season is getting earlier - is this pattern being seen in other parts of the UK and what is the committee's view on the cause of this change in phenology?	Recent evidence from Wales has shown that pup production at several sites is increasing, and the onset of the pupping season is getting earlier (Bull et al 2016, 2017; Strong et al in prep; Morgan et al 2018). Might the combination of increased pup production and earlier onset be a density dependent response?
2	Has there been any progress on improving our understanding of how seals behave around tidal energy devices?	The tidal energy industry is progressing in Wales, with multiple developments at various stages in the planning consent process. Understanding of the potential impact of these devices on seals is currently limited, and it is important that we are kept up to date on the latest developments to inform NRW's advice.
3	Has there been any progress on the trials to assess the physical damage that may be inflicted on seals through collision with tidal energy devices?	In Wales, several different tidal energy developments are proposed with varying rotation speed, size and shape of moving parts/devices. Could SCOS share information on any planned future trials to help us understand how these might inform Welsh developments?
4	Has there been any progress in describing the prevalence and spatio-temporal trends of grey seal predation on other seals and harbour porpoises?	There have been several cases of grey seal predation in Wales – both of other grey seals and of porpoises. It is important to be kept up to date on the latest understanding of this phenomenon.
5	What is the current status of grey and harbour seal populations in the UK?	Update on the UK seal monitoring and modelling outputs
6		

ANNEX III

Briefing Papers for SCOS

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

List of briefing papers

18/01 Grey seal pup production in Britain in 2016.
Duck, C. & Morris, C.D.

18/02 2018 Annual review of priors for grey seal population model.
Russell, D.J.F., Thompson, D. and Thomas, L.

18/03 Estimating the size of the UK grey seal population between 1984 and 2017.
Thomas, L.

18/04 The status of UK harbour seal populations in 2017 including summer counts of grey seals.
Duck, C., Morris, C.D. Lonergan, M., Empacher, F., Thompson, D. and Harwood, J.

18/05 Preliminary report on the distribution and abundance of harbour seals (*Phoca vitulina*) during the 2017 breeding season in The Wash. Thompson, D.

18/06 Provisional Regional PBR values for Scottish seals in 2019.
Thompson, D., Morris, C.D. and Duck, C.D.

Grey seal pup production in Britain in 2016

Callan D. Duck and Chris D. Morris
Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews KY16 8LB

Abstract

In the 2016 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 in the Inner Hebrides colonies was estimated to be **4,541.** Pup production at colonies in the Outer Hebrides was **15,732** (14,316 in 2014), in Orkney production was **23,849** (23,758 in 2014), in the Firth of Forth production was **6,426** (5,860 in 2014). Total pup production at the main biennially monitored colonies in Scotland was **50,548.**

At the four main English North Sea colonies, pup production in 2016 was **8,157** compared with 7,159 in 2015 and 6,627 in 2014. Following 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%), production in 2016 was estimated to be **2,404** which means it is still the biggest grey seal breeding colony in England. There was quite an increase in production at the Farne Islands in 2016 (jumping to 2,065 from 1,876 in 2015)

Combining with an estimated additional **4,193** pups born at other colonies in Scotland (including 2,665 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 **64,898**.

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 2016 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 (SCOS-BP 18/02).

SMRU successfully surveyed all the main grey seal breeding colonies between September and December 2016. 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 since 2012. 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 2016, pup production at the main biennially monitored breeding colonies in Scotland was estimated to be **50,548** compared with 47,988 in 2014, an average annual increase of 5.3% (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 2016, pup production at the annually monitored colonies in England was estimated to be **8,175** compared with 6,627 in 2014, 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 **4,193** 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 **64,898** (Table 1).

Pup production at colonies in the Inner Hebrides

In 2016, grey seal pup production at 13 colonies the Inner Hebrides was estimated to be **4,541** compared with 4,054 in 2014, an average annual increase of 12.0% (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 2016 was **15,732** compared with 14,316 in 2014, an average annual increase of 9.9% (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 increased.

Pup production at colonies in Orkney

At 28 colonies in Orkney, pup production was **23,849** in 2016 compared with 23,758 in 2014, an average annual increase of 0.4% (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 2016 was **6,426** compared with 5,860 in 2014, an average annual increase of 9.7% (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 2016 was **2,665**, compared with an estimated 2,348 born in 2014 (included in 4,193 for other colonies, above). 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, **8,157** pups were born at the annually monitored colonies on the east coast compared with 6,627 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). Blakeney Point remains the biggest colony in England, marginally ahead of the Farne Islands which saw a large increase in 2016 (Figure 10). Pup production continues to increase at colonies on the English east coast.

References

Pomeroy, P.P., Twiss, S.D. & Redman, P. 2001. Philopatry, site fidelity and local kin associations within grey seal breeding colonies. Ethology 10:899-919.

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.

Duck, C.D. and Morris, C.D. 2013. Grey seal pup production in Britain in 2012: First use of a digital system. SCOS Briefing Paper 13/01. pp 71-88 in: Scientific advice on matters related to the scientific management of seal populations: 2013. Unpublished Report to the Special Committee on Seals: 2013. Url: http://www.smru.st-and.ac.uk/documents/1803.pdf

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 2016 compared with production estimates from 2014.

Location	Pup production in **2016**	Pup production in 2014	Average annual change 2014 to 2016
Inner Hebrides	4,541	4,054	+5.8%
Outer Hebrides	15,732	14,316	+4.8%
Orkney	23,849	23,758	+0.2%
Firth of Forth	6,426	5,860	+4.7%
Main annually monitored Scottish island groups	**50,548**	**47,988**	**+2.6%**
Other Scottish colonies [1] (incl. Shetland & mainland)	4,193 [1]	3,875 [1]	+4.0%
Total Scotland	**54,741**	**51,863**	**+2.7%**
Donna Nook +East Anglia	5,919	5,027	+8.5%
Farne Islands	2,238	1,600	+18.3%
Annually monitored colonies in England	**8,157**	**6,627**	**+10.9%**
SW England (last surveyed 2016)	350	250 [3]	
Wales	1,650 [2]	1,650 [3]	
Total England & Wales	**10,157**	**8,527**	**+9.1%**
Northern Ireland	100 [3]	100 [3]	
Total UK	**64,998**	**60,490**	**+3.7%**

1 Estimates derived from data collected in different years

2 combination of survey counts of most colonies in 2017 and an estimate for other colonies based on a multiplier derived from 2004 survey results. These numbers may be revised once all new survey data is included.

3 includes 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 2016.

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	3,385	12,319	19,123	5,015	39,842
2005	3,425	12,397[6]	18,126[6]	5,232	39,182

YEAR	Inner Hebrides	Outer Hebrides	Orkney	North Sea	Total
2006	3,470	11,719	19,332	5,484	40,005
2007	3,118	11,342	19,184	5,771	39,415
2008	3,317	12,279	17,813[7]	6,501	39,910
2009	(3,317)[8]	11,887[8]	18,548	7,360[8]	41,112
2010	3,108	11,831	18,562	8,119	41,620
2011					n/a
2012	4,027[9]	14,134	22,920	10,180	51,261
2013					n/a
2014	4,054	14,331	23,776	12,487	54,648
2015					n/a
2016	4,541	15,732	23,849	14,583	58,705

[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)[2], **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	60
	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**	35
	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	**771**
	Mainland Scotland	SMRU annual	2016			**2,665**
	Shetland	SNH ground	2012			**761**
Total	**Other Scottish colonies**		**to 2014**			**4,197**

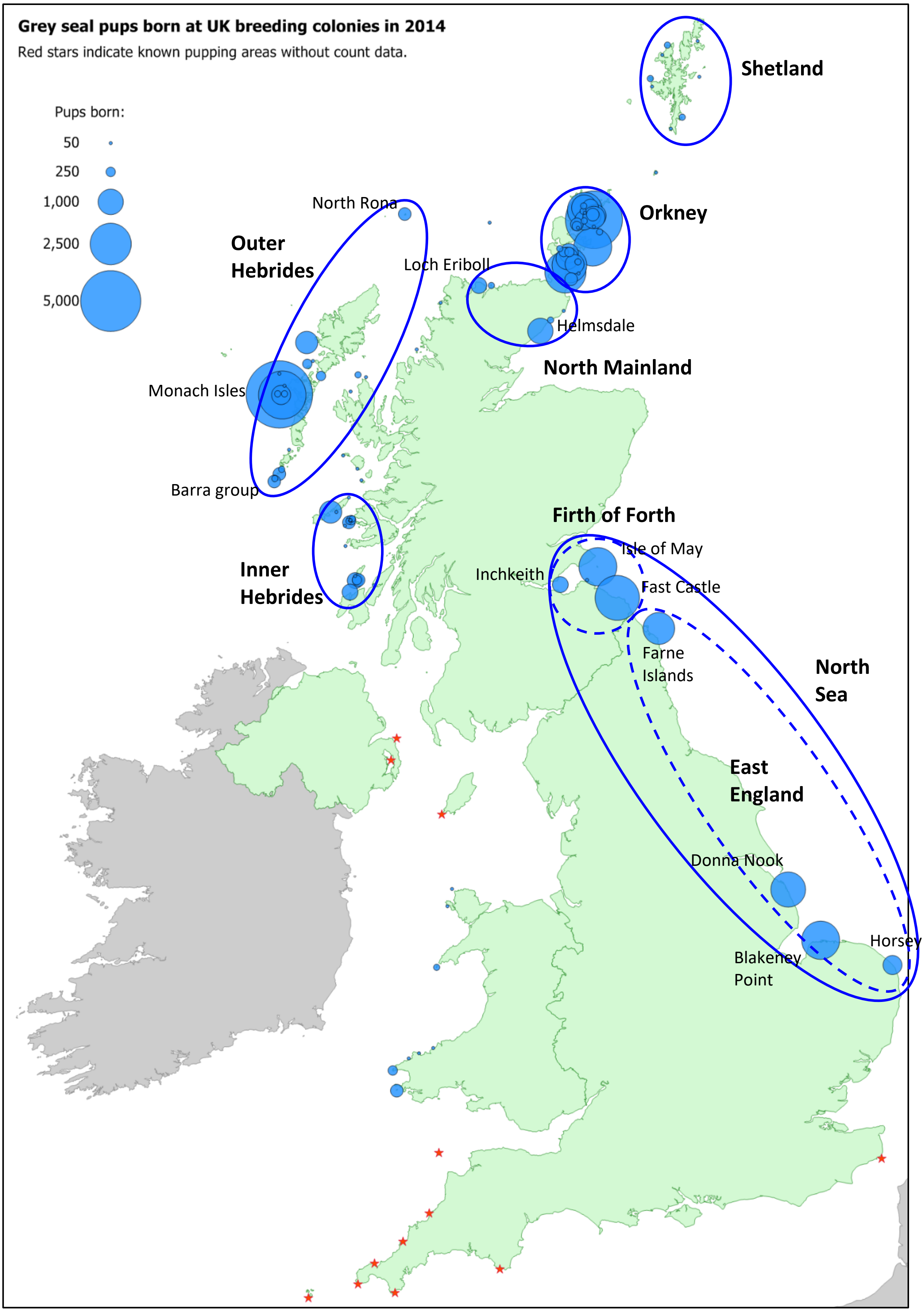

Figure 1. Pup production at the main grey seal breeding colonies in the UK in 2014. Smaller numbers of grey seals will breed at locations other than those indicated here, including in caves.

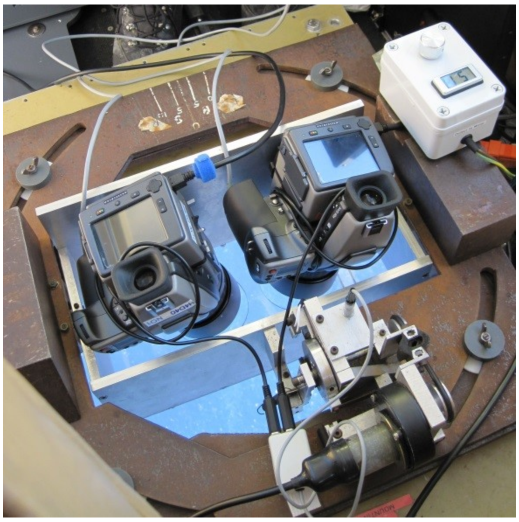

Figure 2. Two Hasselblad H4D-40 medium format cameras fitted in SMRU's Image Motion Compensation (IMC) mount. Each camera is set at an angle of 12 degrees to increase strip width. The cradle holding the cameras rocks backwards and forwards during photo runs. Rocking speed is set depending on the altitude 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.

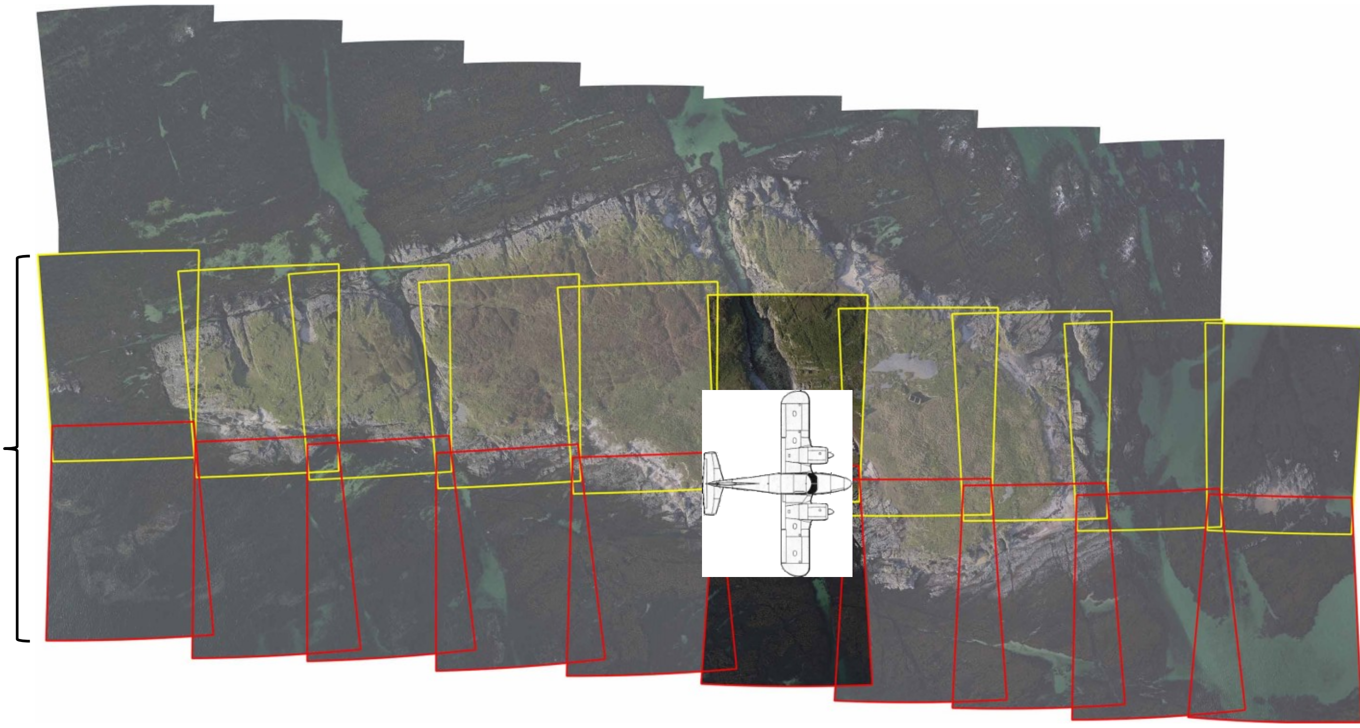

Figure 3. The individual footprints of each pair of photographs taken on a run over Eilean nan Ron, off Oronsay in the Inner Hebrides, flying at 1,100ft (red: left-hand camera; yellow: right-hand camera).

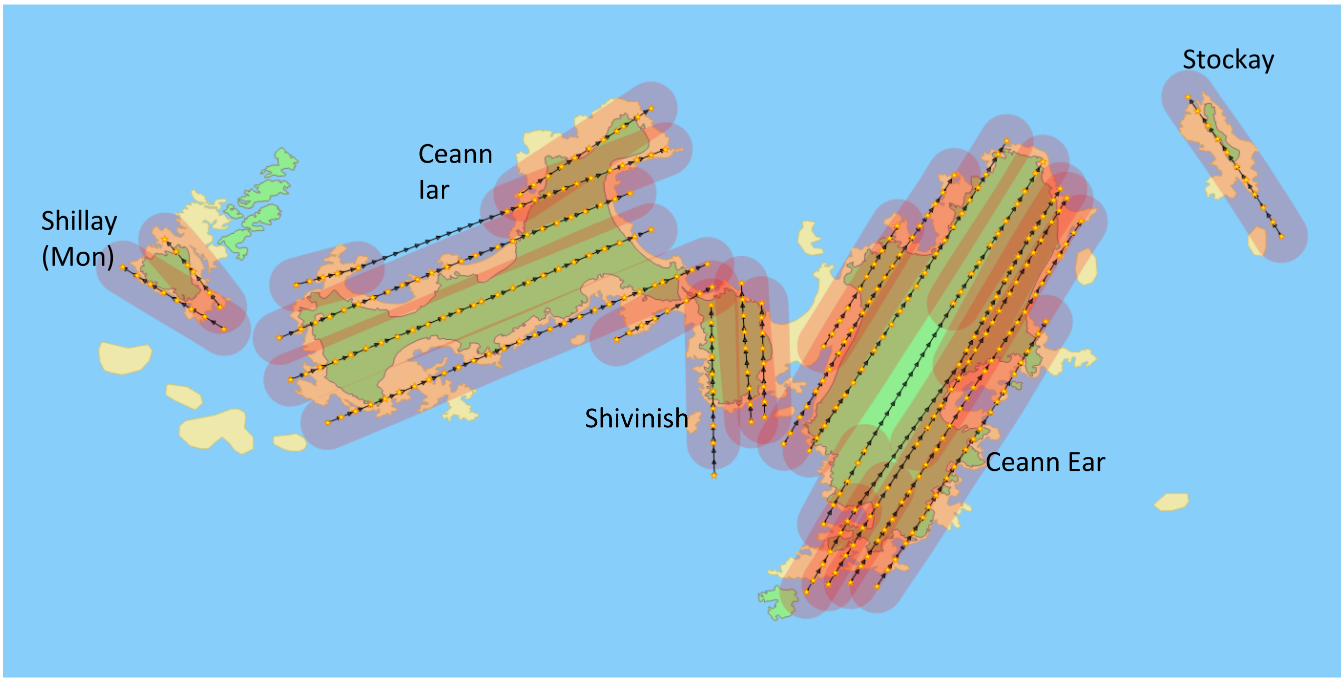

Figure 4. Survey runs and approximate camera trigger locations (yellow dots) for five colonies in the Monach Isles in the Outer Hebrides on 26 October 2012.

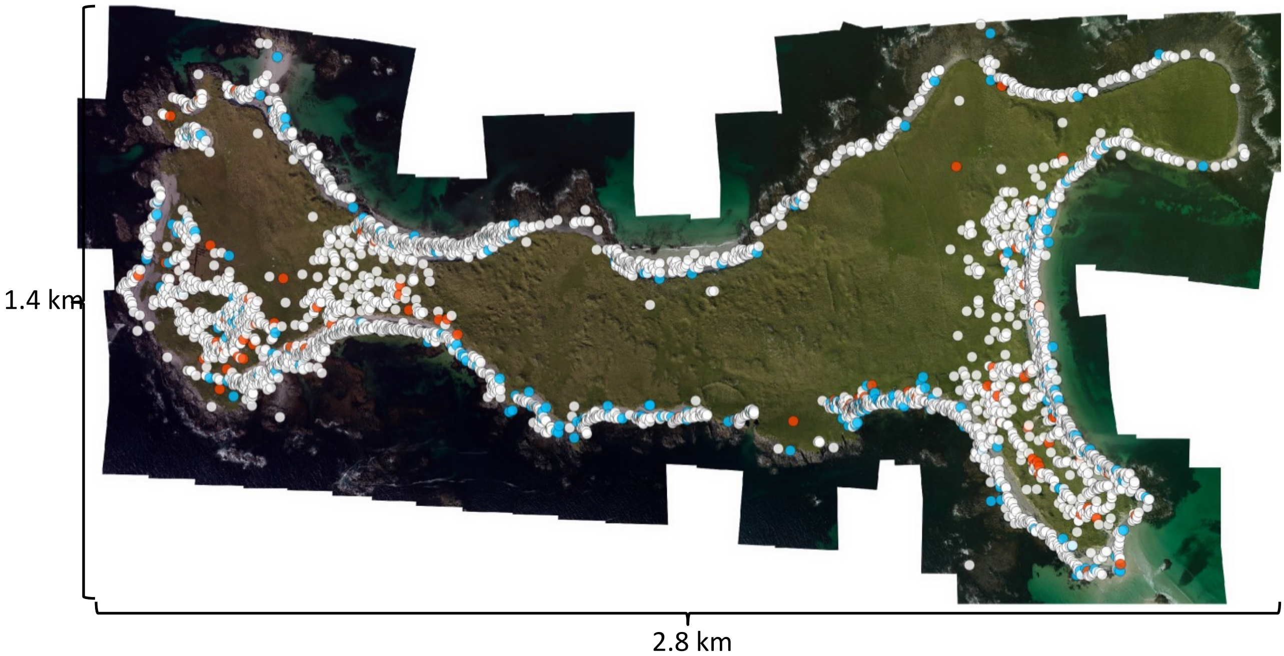

Figure 5. Ceann Iar, the second biggest of the Monach Isles in the Outer Hebrides, is the largest grey seal breeding colony in Europe (ca. 6,000 pups are born each year). This screenshot shows white-coated (white), moulted (blue) and dead pups (red) counted from approximately 200 stitched photographs 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.

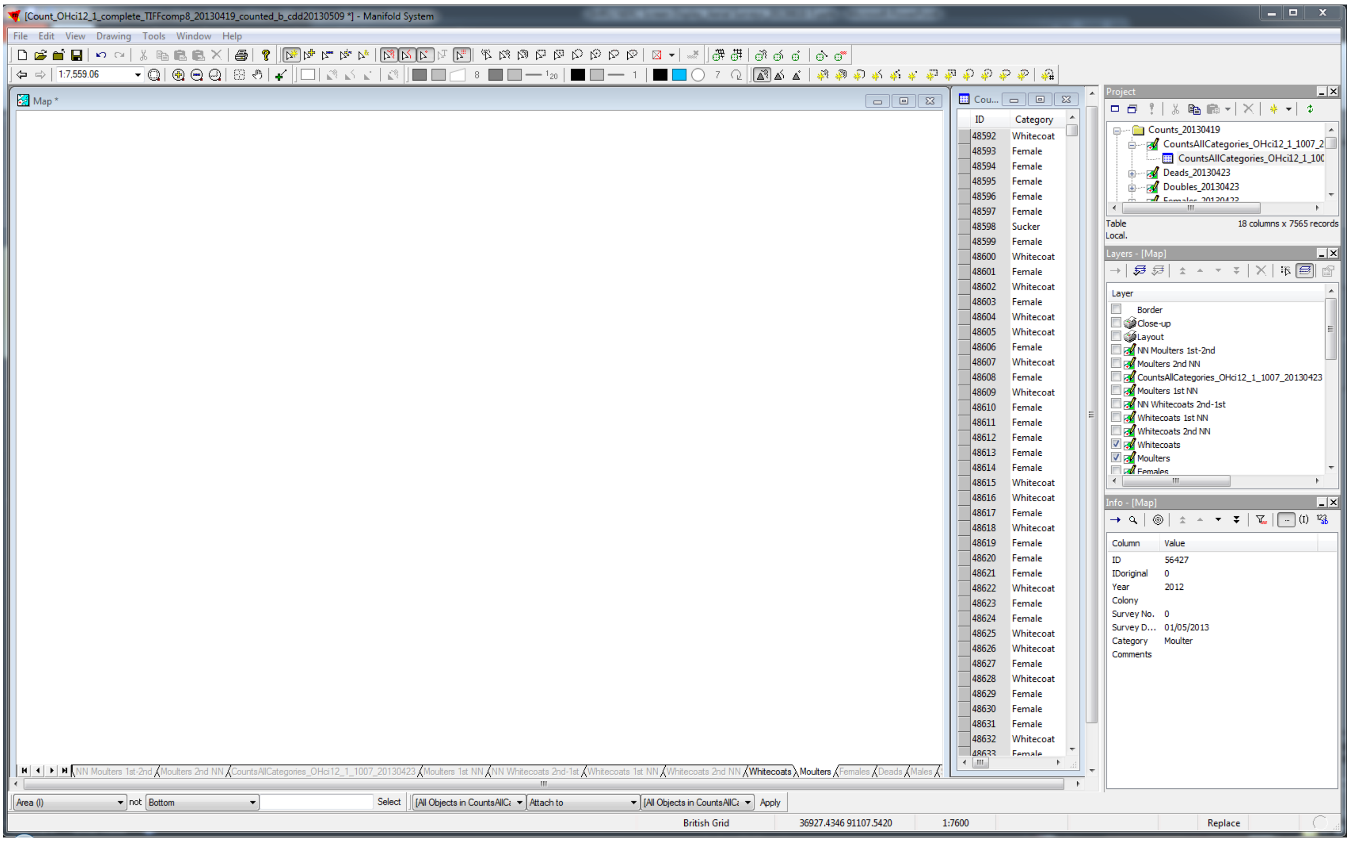

Figure 6. Manifold GIS 8.0® screenshot showing grey seal pups counted on Ceann Iar. Pups of each category (whitecoat, moulted, dead) are counted on a separate layer. The images are not currently geo-referenced but there is the potential for further processing, thus obtaining approximate coordinates for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

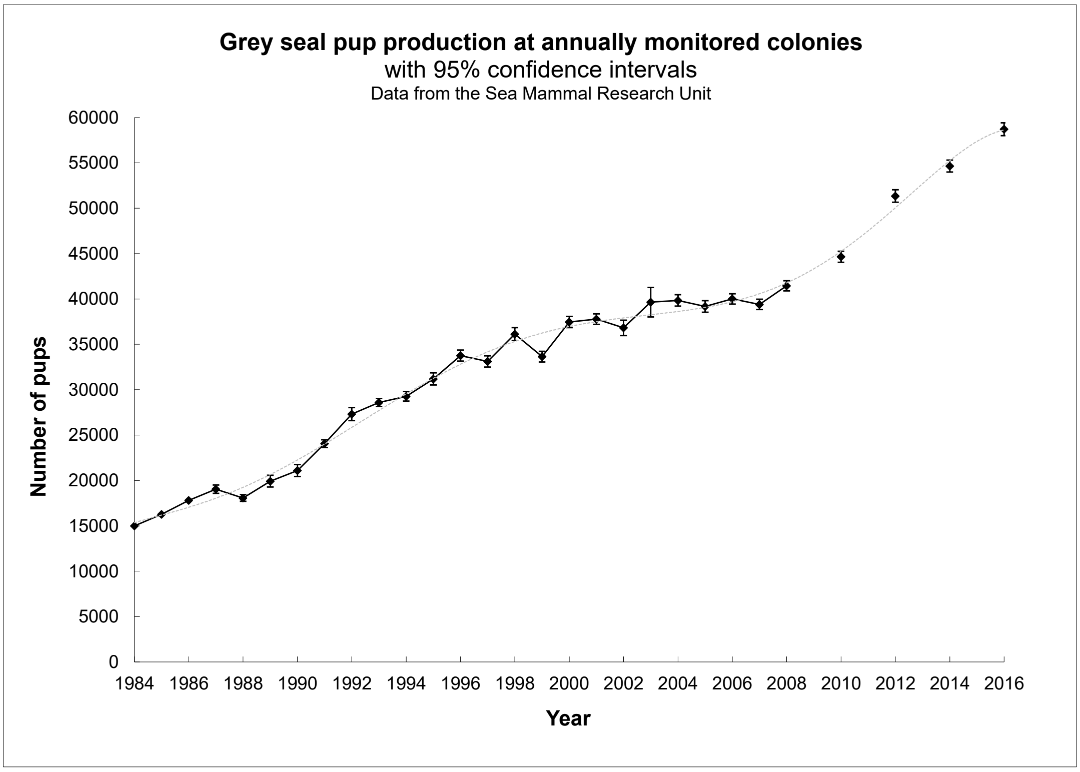

Figure 7. Grey seal pup production at all the major annually monitored colonies in Scotland and England, with 95% confidence intervals from 1984 to 2016.

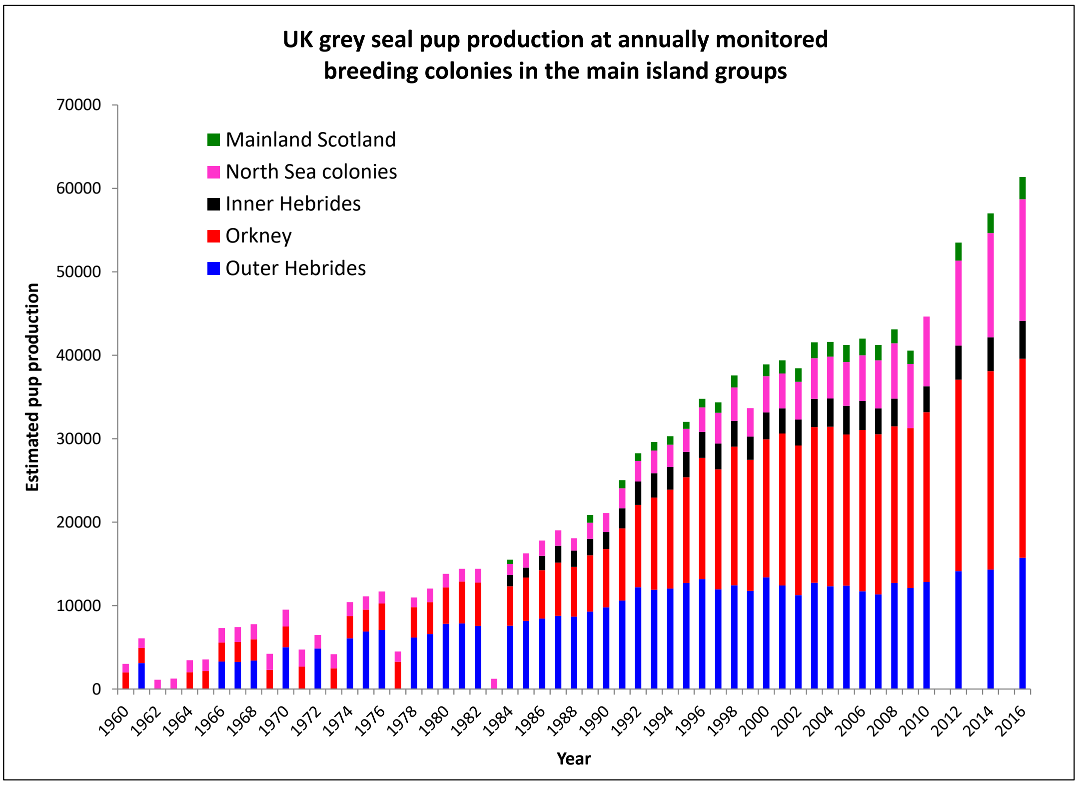

Figure 8. Grey seal pup production at the main 'island' groups between 1960 and 2016. No Inner Hebrides production in 2009.

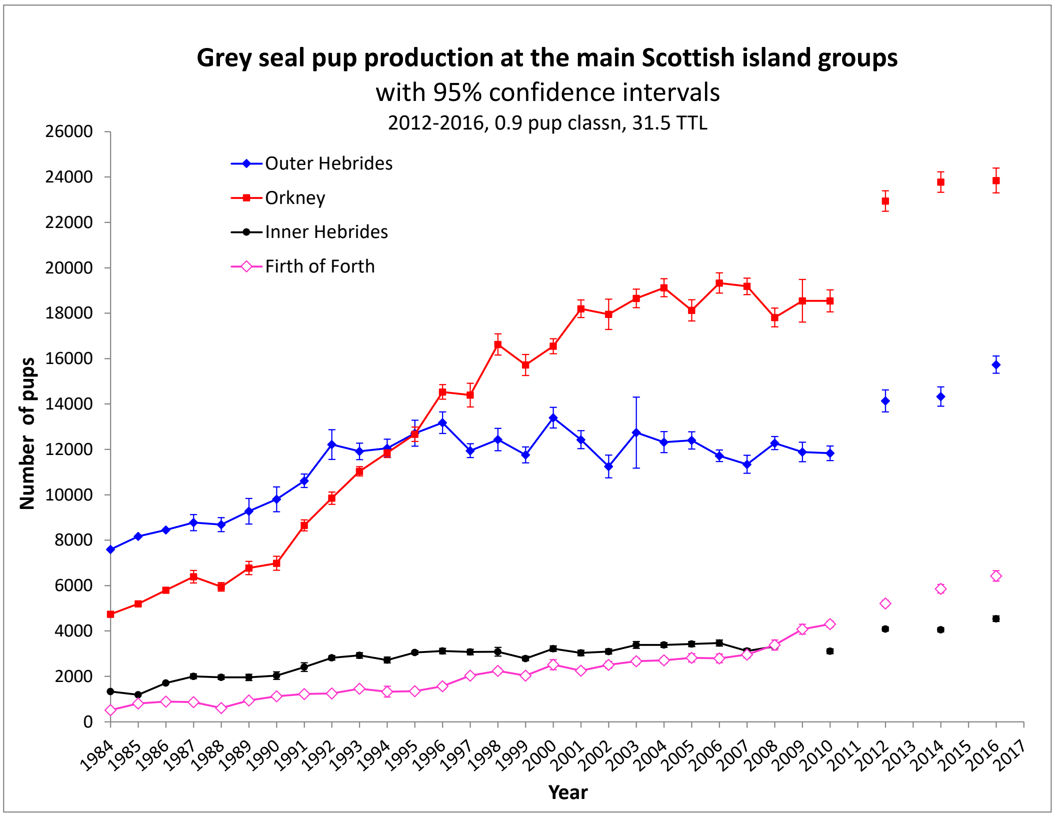

Figure 9. Grey seal pup production at the four main island groups in Scotland, with 95% confidence intervals, calculated using the standard Time to Leave of 31.5 days.

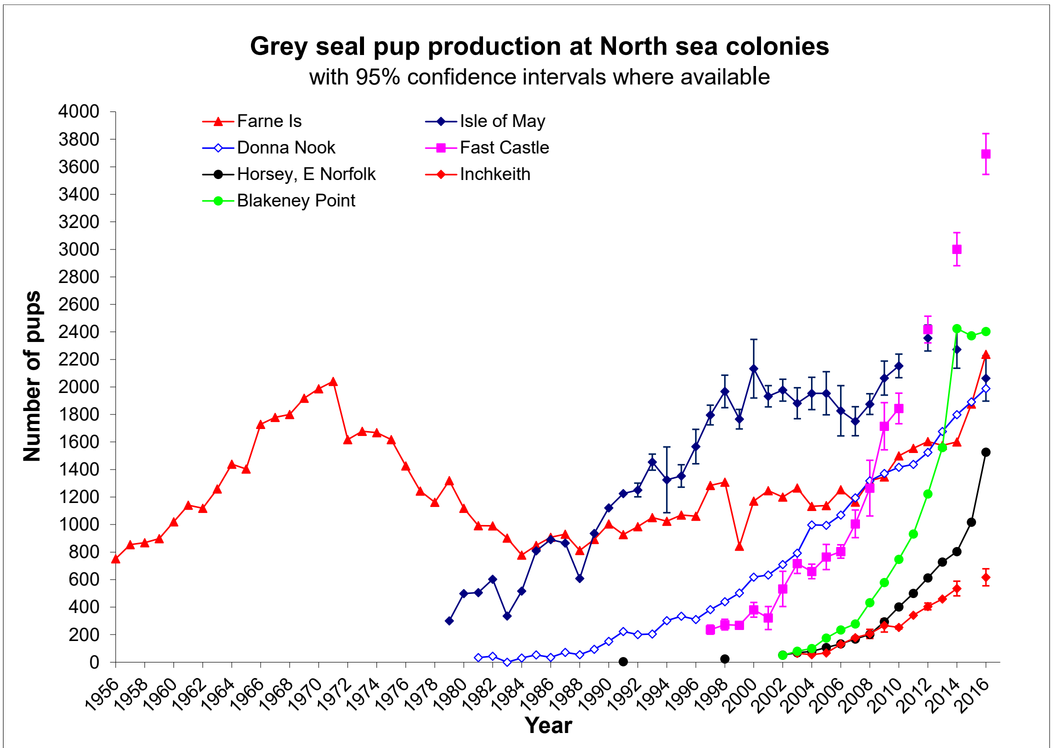

Figure 10. Grey seal pup production at the North Sea colonies. In 2014, Fast Castle became the biggest colony in the North Sea and Blakeney Point became the biggest grey seal breeding colony in England, overtaking the Farne Islands and Donna Nook.

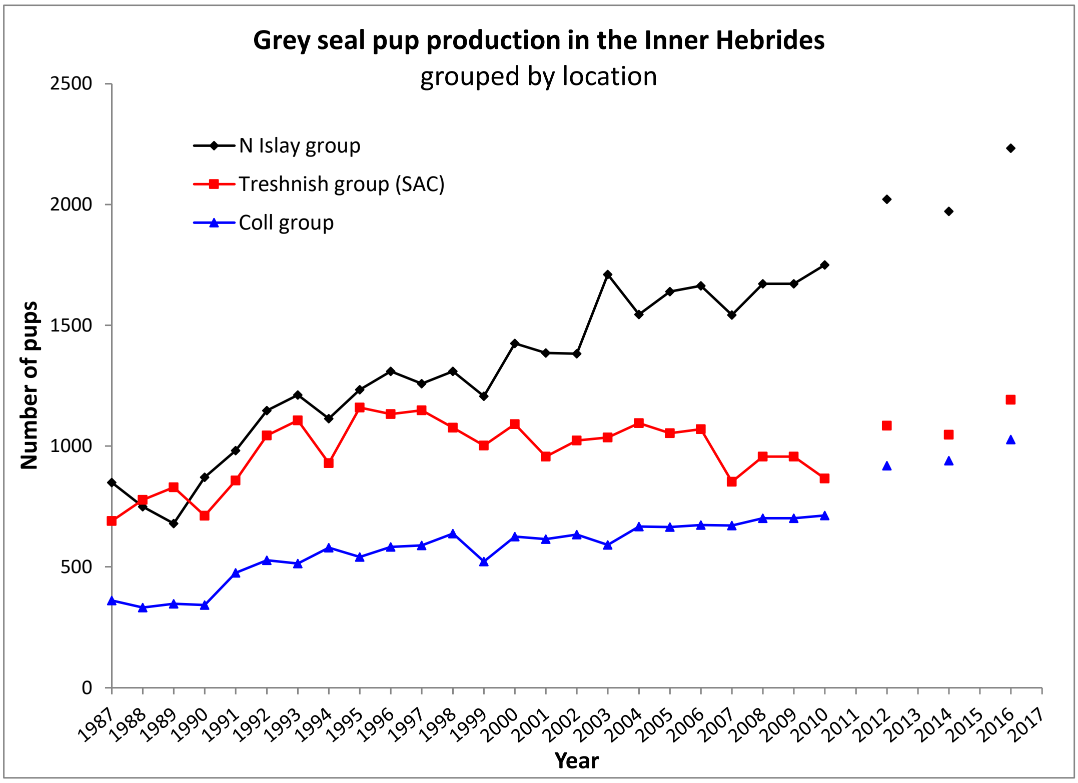

Figure 11. Grey seal pup production at colonies in the Inner Hebrides, grouped by location. Regular surveys of grey seals breeding in the Inner Hebrides only started in the 1980s.

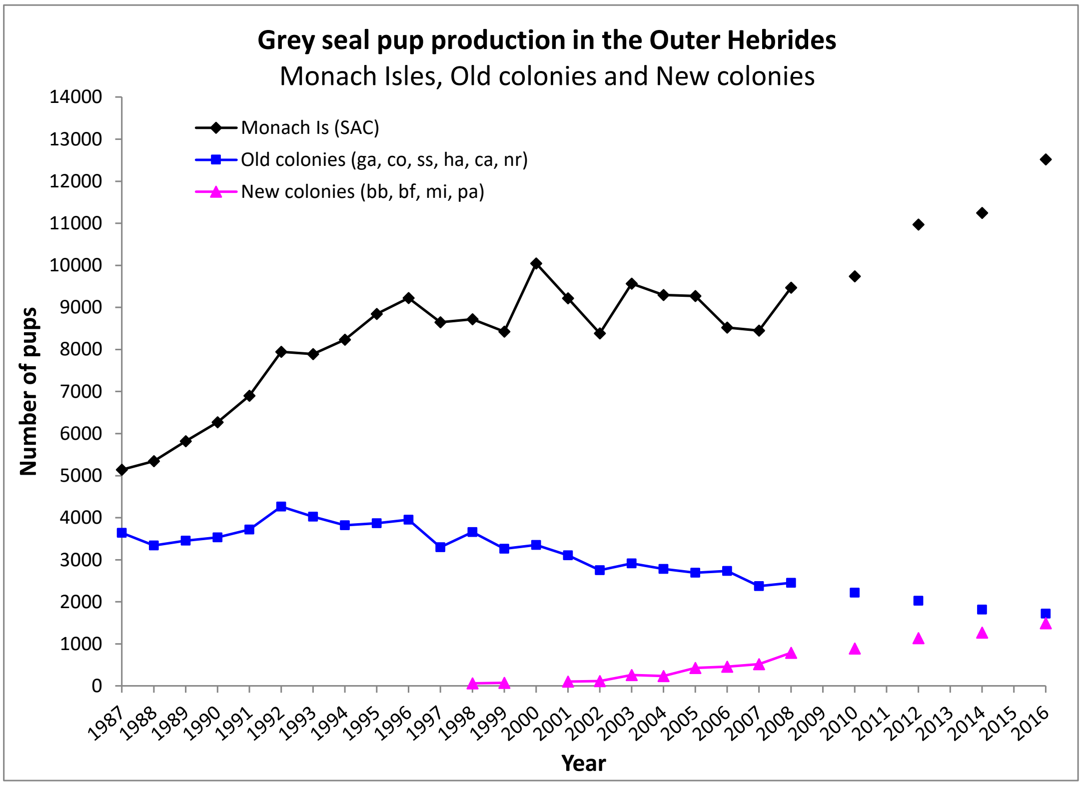

Figure 12. Grey seal pup production in the Outer Hebrides, comparing breeding colonies on the Monach Isles, long established (old) colonies and newly established colonies.

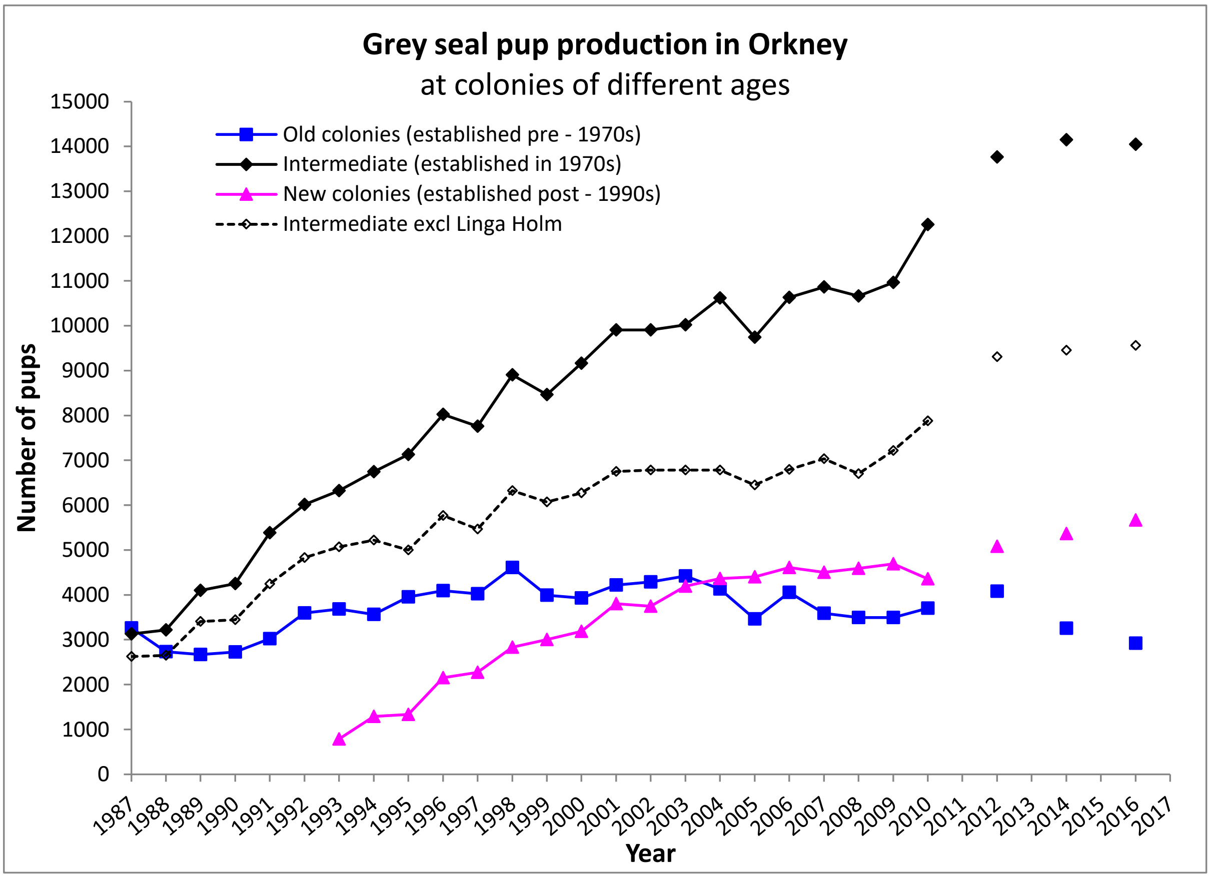

Figure 13. Grey seal pup production at colonies in Orkney, comparing colonies well established before the 1970s (Old), colonies established during the 1970s (Intermediate) and colonies established during or after the 1990s (New).

Annual review of priors for grey seal population model 2018

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Summary
Prior distributions (Table 1) for the grey seal population model (Thomas 2018) are required for the following model parameters: adult female survival ϕ_a, maximum pup survival $\phi_{p\max}$, fecundity α, shape of density dependence acting on pup survival ρ, region-specific carrying capacity (in terms of pup production) χ_{1-4}, number of adults per female ω, and precision of the pup production estimates ψ. The data used to inform these priors are presented below and in Tables 2 and 3. The resulting prior distributions, which have been used since 2016 (Thomas, 2016), are shown in Figure 1 and Table 1. Further discussion of previous and current prior selection is given in Lonergan (2012; 2014), and Russell (2017). Recent data, and any implications for the current priors, are highlighted. For study sites for which there are multiple estimates for a parameter, only the most comprehensive study is presented. This briefing paper is based on Supporting Information in Thomas et al. (Submitted).

Table 1. Prior parameter distributions input in Thomas (2018). Be and Ga denote beta and gamma distributions, respectively. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions.

Parameter	Prior distribution	Prior mean (SD)
adult survival $\boldsymbol{\phi_a}$	0.8+0.17*Be(1.6,1.2)	0.90 (0.04)
pup survival $\boldsymbol{\phi_{p\max}}$	Be(2.87,1.78)	0.62 (0.20)
fecundity $\boldsymbol{\alpha}$	0.6+0.4*Be(2,1.5)	0.83 (0.09)
dens. dep. shape $\boldsymbol{\rho}$	Ga(4,2.5)	10 (5)
carrying capacity $\boldsymbol{\chi_1}$	Ga(4,5000)	20000 (10000)
carrying capacity $\boldsymbol{\chi_2}$	Ga(4,1250)	5000 (2500)
carrying capacity $\boldsymbol{\chi_3}$	Ga(4,3750)	15000 (7500)
carrying capacity $\boldsymbol{\chi_4}$	Ga(4,10000)	40000 (20000)
observation precision $\boldsymbol{\psi}$	Ga(2.1,66.67)	140 (96.61)
sex ratio $\boldsymbol{\omega}$	1.6+Ga(28.08, 3.70E-3)	1.7 (0.02)

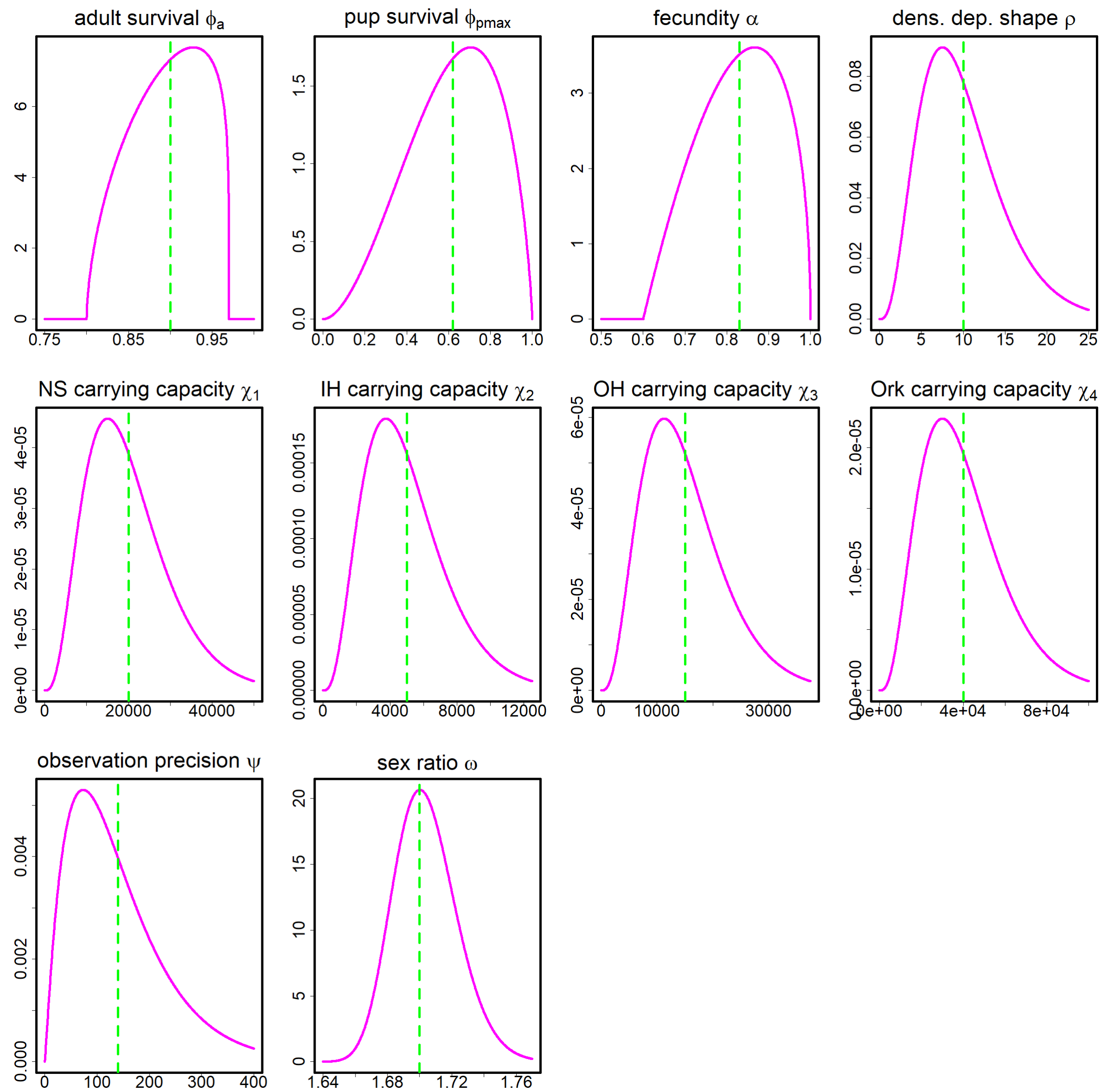

Figure 1. Prior probability density functions for each model parameter input in Thomas (2018), drawn from the distributions specified in Table 1. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions. Prior means are shown as green dashed vertical lines.

Parameters

Adult female survival ϕ_a

Relevant studies are summarized in Table 2. Estimates of annual adult survival in the UK, obtained by aging teeth from shot animals are between 0.935 and 0.96 (Harwood & Prime, 1978; Hewer, 1964; Lonergan, 2012). Capture-mark-recapture (CMR) of adult females on breeding colonies can be used to estimate female survival but may produce underestimates as they are dependent on the assumption that females not returning to the study colony have died. Using capture-mark-recapture (CMR), adult survival was estimated to be between 0.871 and 0.954 (Smout, King & Pomeroy, submitted; see Table 2 for more details). Based on the above data, and the fact that the lower limit on adult survival cannot be lower than 0.8 (Lonergan, 2012), the prior on adult female survival is specified as a beta distribution Be(1.6, 1.2) which is scaled (multiplied by 0.17 and added to 0.8) to allow non-zero probability density only between 0.8 and 0.97. The resulting distribution has mean

0.90 and SD 0.04. However, recent estimates from Sable Island suggest adult female survival may be above this upper bound. den Heyer & Bowen (2017) used a Cormack-Jolly-Seber model to estimate age- and sex-specific adult survival from a long-term brand re-sighting programme on Sable Island. Average female adult survival was estimated to be 0.976 (SE 0.001), averaged over all animals, but was higher for younger adults (0.989 with SE 0.001 for age classes 4-24) than older adults (0.904 SE 0.004 for age 25+).

Maximum pup survival $\boldsymbol{\phi}_{\boldsymbol{p}max}$

Relevant studies are summarized in Table 2. Data from populations that were growing rapidly and therefore apparently not constrained by density dependence acting on pup survival were required to inform this prior. There are various published estimates of first-year survival during periods of exponential growth (Table 2). Mean estimates of pup surival were between 0.54 – 0.76. On the basis of these estimates, the prior on maximum female pup survival is defined as a diffuse beta distribution Be(2.87, 1.78) which has mean of 0.62 (SD 0.20). Note that Pomeroy, Smout, Moss, Twiss, & King (2010) found high inter-annual variation in pup survival, which is not currently incorporated in the model.

Fecundity $\boldsymbol{\alpha}$

Relevant studies are summarized in Table 3. For the purposes of this model, fecundity refers to the proportion of breeding-age females (aged 6 and over) that give birth to a pup in a year (natality or birth rate). For the most part, studies have measured pregnancy rather than natality rates. The resulting estimates are thus maxima in terms of fecundity as abortions will cause pregnancy rates to exceed birth rates. Mean estimated adult female pregnancy rates from examination of shot animals were between 0.83 and 0.94 in the UK (Boyd, 1985; Hewer, 1964), and between 0.88 and 1 at Sable Island, Canada (Hammill & Gosselin, 1995). CMR studies report lower estimates, which may be a result of unobserved pupping events (due to mark misidentification, tag loss, or breeding elsewhere), but also because such estimates represent births rather than pregnancy. Such studies, from Sable Island estimate fecundity to be between 0.57 and 0.83 (Bowen, Iverson, McMillan, & Boness, 2006; den Heyer & Bowen, 2017). UK estimates of fecundity rates for populations of marked study animals, adjusted for estimates of unobserved pupping events were 0.790 (95% CI 0.766-0.812) and 0.816 (95% CI 0.787-0.841) for a declining (North Rona) and increasing (Isle of May) population, respectively (Smout et al., Submitted). Based on the available data, the prior on fecundity (α) is specified as a beta distribution Be(2, 1.5) which is scaled (multiplied by 0.4 and added to 0.6) to only allow probability density between 0.6 and 1. The resulting distribution has mean 0.83 and SD 0.09.

Shape of density dependence acting on pup survival $\boldsymbol{\rho}$

Pup survival at carrying capacity is not dependent on this parameter, and hence carrying capacity also does not depend on it. Instead, the parameter influences the shape of the population growth trajectory, by determining the shape of the relationship between pup survival and pup production. Fowler (1981) used both theory and empirical data to suggest that most density-dependent change in vital rates happens close to carrying capacity for species with life history strategy typical of large mammals (i.e., long lived and low reproductive rate). Empirical examples (their Figure 4) show relationships consistent with values of ρ in the range 5-10. To avoid being too prescriptive, a diffuse distribution was specified: a Gamma distribution Ga(4, 2.5), which has a mean of 10 and SD 5.

Region-specific carrying capacity $\boldsymbol{\chi_{1-4}}$

No independent information was available about carrying capacity, and so the priors were specified with a variance wide enough to make their influence on population size estimates negligible. Truly non-informative priors (e.g., improper priors with infinite variance) make the particle filtering algorithm extremely inefficient, since most simulated trajectories are infeasible given the data, hence a trade-off is required between a prior with a large enough variance to be non-informative, but not too large so as to make the algorithm prohibitively inefficient. Having the initial rejection control step in the algorithm helped to some extent in this regard. Gamma distributions with a SD:mean ratio of 1:2, with the mean set subjectively based on expert opinion (Table 1) were found to meet these criteria.

Number of adults per adult female $\boldsymbol{\omega}$

This parameter is also referred to as the sex ratio, although strictly the ratio of males:females is given by $\omega - 1$. Relevant studies (on sex-specific survival rates) are summarized in Table 2. A sex ratio of 0.73:1 was derived from shot samples (Harwood & Prime, 1978). This was based on the following assumptions: that the shot males were a representative sample of the breeding population (≥10 years old); that female survival was 0.935; and that survival was the same between the sexes up until age 10. Using telemetry tags and "hat tag" re-sighting data (taking into account detection probability inferred by telemetry data), sex-specific pup survival was estimated (Lonergan 2014; Table 2). Although there were no significant differences in survival between males and females, the mean male survival was lower than females. Combined with data from Hewer (1964), the resulting sex ratio would be between 0.66:1 and 0.68:1 (Lonergan, 2014). Also considered were pup survival estimates derived from shot samples from the Baltic (Kauhala, Ahola, & Kunnasranta, 2012). For Sable Island, the sex ratio is estimated to be 0.69:1 based on estimates of age and sex-specific survival, and assuming a stationary age distribution (Hammill, den Heyer, Bowen, & Lang, 2017). Based on these findings, the prior used was a highly informative scaled Gamma distribution Ga(4, 2.5) + 1.6. This results in a prior mean of 1.7 (SD 0.02); 90% of the prior probability density is between 1.68 and 1.73.

Precision of the pup production estimates $\boldsymbol{\psi}$

The pup production estimates at colony level from aerial survey data generally have a coefficient of variation of 10% or less. Uncertainty in the ground count estimates is not quantified. The resulting uncertainty in pup production at the region level is hard to predict – if the colony estimates were independent it would be smaller, but they are not independent since they share some parameters. Hence a moderately diffuse prior was specified on ψ (Ga(2.1,66.67), implying a prior on CV of pup production (which is $1/\psi$) of 10% with SD 5 (i.e., with 90% of the prior probability density between 5%

Table 2. Survival data used to inform the survival and sex ratio priors. CMR refers to Capture-Mark-Recapture studies and can be based on brands (permanent but can be misidentified), passive tagging (can be lost or misidentified), active tagging (can be lost), Photo-ID (can be misidentified). Except for active tagging, estimates of survival depend on the accuracy of re-sighting probabilities and, if appropriate, tag loss. If sex-specific sample sizes are not reported then total *n* is given.

Age class	females			males			Total n	Time period	Data	Location	Considerations	Source
	mean	uncertainty	n	mean	uncertainty	n						
Pup	0.66		1036	0.66		294		1972, 1975	Aged shot individuals	Farne Islands, UK	Accounted for effect of previous culls on sample structure. Based on life tables.	Harwood & Prime 1978
Pup	0.65	95% CIs: 0.39 - 0.85	180	0.50	95% CIs: 0.25 – 0.75	182		1997 - 1999	CMR (hat tag)	Isle of May and Farne Islands, UK	Tag loss accounted for. Telemetry data used to inform re-sighting probability	Reanalysis of data from Hall, McConnell & Barker 2001; Hall, McConnell & Barker 2002; grey pup seal telemetry data (Carter et al., 2017)
Pup	0.54	95% CIs: 0.18 - 0.86	27	0.43	95% CIs: 0.11 – 0.82	28		2002	CMR (telemetry data)	Isle of May, UK	Tag loss accounted for	Reanalysis of data from Hall, Thomas & McConnell 2009
Pup	0.76 0.55			0.38 0.53			1185 2295	2000 - 2004 2005 - 2009	Aged shot individuals	Baltic	Samples assumed representative. Based on life tables	Kauhala, Ahola & Kunnasranta 2012
≤ 4	0.735 0.331	SE = 0.016 SE = 0.024	1700 1182					1985 - 1989 1998 - 2002	CMR (brand)	Sable Island, Canada	Includes the data from Schwarz & Stobo (2000)	den Heyer, Bowen & Mcmillan 2014
Adult	0.95		239					1956 - 1966	Aged shot individuals	UK	Samples assumed representative. Based on life tables	Data from Hewer 1974, analysed by Lonergan 2012
≥ 10				0.80		294		1972, 1975	Aged shot individuals	Farne Islands, UK	Accounted for population trajectory. Assumed samples are representative within focal age class.	Harwood & Prime 1978
≥ 7	0.935 (0.90-0.96)		1036					1972, 1975	Aged shot individuals	Farne Islands, UK	As above	Harwood & Prime 1978 (reanalysed by Lonergan 2012)
Adult	0.941	95% CIs: 0.929 - 0.954	273					1987 - 2014	CMR (brand, flipper tag, photo ID)	Isle of May	Tag loss and differential sighting probability accounted for. Survival confounded with permanent emigration	Smout, King & Pomeroy, Submitted
Adult	0.886	95% CIs: 0.871 - 0.900	584					1993 - 2013	As above	North Rona, UK	As above	As above
≥4	0.976	SE = 0.001	3178			1727		1969 - 2002	CMR (brand)	Sable Island, Canada	Tagged as pups. Confounded with permanent emigration (rare)	den Heyer & Bowen 2017
4-24	0.989	SE = 0.001	As	0.970	SE = 0.002	As		As	As above	As above	As above	As above

			above			above	above				
≥25	0.904	SE = 0.004	As above	0.77	SE = 0.01	As above	As above	As above	As above	As above	As above
Adult	0.976	SE = 0.001	As above	0.943	SE = 0.003	As above	As above	As above)	As above	As above	As above

Table 3. Fecundity data used to inform the fecundity priors. CMR refers to Capture-Mark-Recapture studies and can be based on brands (permanent but can be misidentified), passive tagging (can be lost or misidentified), Photo-ID (can be misidentified). Estimates of fecundity depend on the accuracy of re-sighting probabilities and, if appropriate, tag loss.

Rate	**Mean**	**Uncertainty**	**n**	**Time period**	**Data**	**Location**	**Considerations**	**Source**
Pregnancy	0.93		79	1956 - 1963	Shot samples			Hewer 1964
Pregnancy	0.94	95% CIs: 0.89 - 0.97	140	1979 - 1981	Shot samples	Farne Islands, UK		Boyd 1985
Pregnancy	0.83	95% CIs: 0.74 - 0.89	88	1978	Shot samples	Outer Hebrides, UK		Boyd 1985
Pregnancy	0.88-1		526	1968 - 1992	Shot samples	Sable Island, Canada	Aged ≥ 6 years old	Hammill & Gosselin 1995
Birth	0.73	0.015	174	1983 - 2005	CMR (brand)	Sable Island, Canada	Aged 4-15 years. Unobserved pupping not considered (likely rare)	Bowen *et al.* 2006
Birth	0.83	0.034	32	1983 - 2005	As above	As above	Aged 16-25 year Unobserved pupping not considered (likely rare)	As above
Birth	0.57	0.03	39	1983 - 2005	As above	As above	Aged 26-35 years Unobserved pupping not considered (likely rare)	As above
Birth	0.790	95% CIs: 0.766 - 0.812	584	1993 - 2013	CMR (brand, flipper tag, photo ID)	North Rona, UK	Accounted for unobserved pupping	Smout *et al.* Submitted
Birth	0.816	95% CIs: 0.787 - 0.841	273	1987 - 2014	CMR (brand, flipper tag, photo ID)	Isle of May, UK	As above	As above
Birth	0.79		1727	1992 - 2002	CMR (brand)	Sable Island, Canada	Estimated transitions: unobserved to breeder = 0.41 - 0.64, breeder to breeder = 0.76 – 0.89	den Heyer & Bowen 2017

References

Bowen, W. D., Iverson, S. J., McMillan, J. I., & Boness, D. J. (2006). Reproductive performance in grey seals: age-related improvement and senescence in a capital breeder. *Journal of Animal Ecology*, *75*(6), 1340–1351. http://doi.org/10.1111/j.1365-2656.2006.01157.x

Boyd, I. (1985). Pregnancy and ovulation rates in grey seals (Halichoerus-grypus) on the British coast. *Journal of Zoology*, *205*, 265–272.

Carter, M. I. D., Russell, D. J. F., Embling, C. B., Blight, C. J., Thompson, D., Hosegood, P. J., & Bennett, K. A. (2017). Intrinsic and extrinsic factors drive ontogeny of early-life at-sea behaviour in a marine top predator. *Scientific Reports*, *7*(1), 1–14. doi: 10.1038/s41598-017-15859-8

den Heyer, C. E., & Bowen, W. D. (2017). Estimating changes in vital rates of Sable Island grey seals using mark-recapture analysis. *DFO Can. Sci. Advis. Sec. Res. Doc. 2017/054.*, 27.

den Heyer, C. E., Bowen, W. D., & Mcmillan, J. I. (2014). Long-term Changes in Grey Seal Vital Rates at Sable Island Estimated from POPAN Mark-resighting Analysis of Branded Seals. *DFO Can. Sci. Advis. Sec. Res. Doc. 2013/021*, (April), 26.

Fowler, C.W. 1981. Density dependence as related to life history strategy. *Ecology* 62: 602-610.

Hall, A. J., McConnell, B. J., & Barker, R. J. (2001). Factors affecting first-year survival in grey seals and their implications for life history strategy. *Journal of Animal Ecology*.

Hall, A. J., Thomas, G. O., & McConnell, B. J. (2009). Exposure to persistent organic pollutants and first-year survival probablility in gray seal pups. *Environmental Science & Technology*, *43*(16), 6365–6369.

Hall, A., McConnell, B., & Barker, R. (2002). The effect of total immunoglobulin levels , mass and of Grey Seal pups condition on the first-year survival, *16*(4), 462–474.

Hammill, M. O., den Heyer, C. E., Bowen, W. D., & Lang, S. L. C. (2017). Grey Seal Population Trends in Canadian Waters, 1960-2016 and harvest advice. *Research Document* , (October), 1–35.

Hammill, M. O., & Gosselin, J. (1995). Grey seal (Halichoerus grypus) from the Northwest Atlantic: Female reproductive rates, age at first birth, and age of maturity in males. *Canadian Journal of Fisheries and Aquatic Sciences*, *52*(12), 2757–2761.

Harwood, J., & Prime, J. H. (1978). Some factors affecting size of British grey seal populations. *Journal of Applied Ecology*, *15*(2), 401–411. http://doi.org/10.2307/2402600

Hewer, H. (1964). The determination of age, in the grey seal (Halichoerus grypus) sexual maturity, longevity and a life-table. *Proceedings of The Zoological Society of London*, *142*(4), 593–623.

Hewer, H. (1974). *British seals*. New York: Taplinger Publishing Co. Inc.

Kauhala, K., Ahola, M., & Kunnasranta, M. (2012). Demographic structure and mortality rate of a Baltic grey seal population at different stages of population change, judged on the basis of the hunting bag in Finland. *Annales Zoologici Fennici*, *49*, 287–305.

Lonergan, M. (2012). *Priors for grey seal population model*. SCOS Briefing paper 12/02, Sea Mammal Research Unit, University of St Andrews. http://www.smru.st-andrews.ac.uk/research-policy/scos/

Lonergan, M. (2014). *Addendum to: Lonergan, M. 2013. The case for moving away from 73 males per 100 female*. SCOS Briefing paper 14/04, Sea Mammal Research Unit, University of St Andrews. http://www.smru.st-andrews.ac.uk/research-policy/scos/

Pomeroy, P. P., Smout, S., Moss, S., Twiss, S. D., & King, R. (2010). Low and Delayed Recruitment at Two Grey Seal Breeding Colonies in the UK. *Journal of Northwest Atlantic Fishery Science*, *42*, 125–133. http://doi.org/10.2960/J.42.m651

Russell, D. 2017 Annual review of priors for grey seal population model. SCOS Briefing paper 17/01A, Sea Mammal Research Unit, University of St Andrews. http://www.smru.st-andrews.ac.uk/research-policy/scos/

Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D. and Hiby, A.R.(2019) Monitoring long-term changes in UK grey seal Halichoerus grypus pup production. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3100

Schwarz, C. J., & Stobo, W. T. (2000). Estimation of juvenile survival, adult survival, and age-specific pupping probabilities for the female grey seal (Halichoerus gryprus) on Sable Island from capture – recapture data, *253*(1994), 247–253.
Smout, S., King, R., & Pomeroy, P. (Submitted). Environment-sensitive mass changes influence breeding in a marine top predator. *Journal of Animal Ecology*.
Thomas, L. (2016) Estimating the size of the UK grey seal population between 1984 and 2015. SCOS Briefing Paper 16/02. Sea Mammal Research Unit, University of St Andrews.
Thomas, L. (2018) *Estimating the Size of the UK Grey Seal Population between 1984 and 2016.* SCOS Briefing Paper 18/02. Sea Mammal Research Unit, University of St Andrews.
Thomas, L., Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D. (2019). Modelling the population size and dynamics of the British grey seal. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3134

Estimating the size of the UK grey seal population between 1984 and 2017.

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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, and (2) independent estimates assumed to be of total population size just before the breeding season. 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 with the exception that one prior distribution (on carrying capacity in North Sea region) has been slightly altered.

The above model was fitted with three different inputs. For the main analysis, these were pup production estimates from 1984-2016, as given in briefing paper SCOS-BP 18/01, and independent estimates of population size from 2008 and 2014. In additional analysis 1, the same data were used, but only for the period 1984-2010. In additional analysis 2, data for the period 1984-2010 was also used, but with pup production data derived using a slightly different assumption (PMOULT parameter set to 0.5 for all years).

For the main analysis, estimated population size in regularly monitored colonies in 2017 was 135,700 (95% CI 118,500-155,200). The population overall is estimated to be increasing at a rate of 2% per year. For additional analysis 1, the estimated population size in 2010 was 10% lower than for the main analysis in the same year, and the estimated rate of population increase was closer to 1% per year. For additional analysis 2, estimated population size in 2010 was a further 3% lower.

We conclude that estimates of the current population size and trajectory are somewhat sensitive to the assumptions made when deriving pup production estimates, and on whether and how the post-2010 data are included.

Introduction

This paper presents estimates of British grey seal population size and related demographic parameters, obtained using a Bayesian state-space model of population dynamics fitted to pup production estimates (from aerial surveys of breeding colonies) and independent estimates of total population size (from haul-out counts). The model and fitting methods are the same as those employed in recent years (e.g., Thomas 2016) and are described in detail in Thomas et al. (2019).

The main analysis uses pup production estimates for 1984-2016 (SCOS-BP 18/01), plus independent estimates of total population size from 2008 and 2014 (Russell et al. 2016). The survey and analysis methods for deriving pup production estimates have changed somewhat over the years, and it was of interest to compare estimates of population size derived using different pup production inputs. To facilitate this, two additional analyses were undertaken: first, only data up to 2010 was used; second, data up to 2010 was used but with a pup production estimation parameter changed (probability of correctly classifying moulted pups as moulted, PMOULT, set to 0.5). This latter set of pup production estimates were derived by Russell et al. (2019), and the results using these data that are reported here are taken from Thomas et al. (2019).

For the main analysis, we present estimates of population size at the start of the 2017 breeding system (i.e., projected forward one year from the last data point). For the two additional analyses, we present estimates for 2010, the last year of data in those analyses.

Note that all estimates of population size relate to seals associated with the regularly-monitored colonies. A multiplier is required to account for the ~10% of seals that breed outside these colonies.

Methods

Full details of the population dynamics model, data and fitting methods are given in SCOS-BP 18/05. In summary, an age-structured population dynamics model is specified for each of four regions (North Sea, Inner Hebrides, Outer Hebrides and Orkney), with 7 ages included in the model: pups, age 1-5 females (assumed not to reproduce) and age 6+ females (which may breed). The model assumes constant adult (age 1+) survival (indexed by a parameter ϕ_a), constant fecundity (probability that an age 6+ female will birth a pup, α) and density-dependent pup survival with separate carrying capacity in each region (carrying capacity parameters $\chi_1 - \chi_4$ and common parameters for maximum pup survival $\phi_{p\max}$ and shape of the density dependence function ρ). The modelled pup production is linked to the data by assuming the data follow a normal distribution centred on true pup production and with precision parameter ψ. Adult males are not tracked explicitly in the population model, but instead, the total population size (of males and females) is derived by multiplying estimated adult females by a parameter ω that represents the ratio of total adults to adult females (sometimes called “sex ratio” as shorthand, although sex ratio is actually given by $\omega - 1$). The modelled total population size (age 1+ animals) is linked to the independent estimates using the empirically derived uncertainty on the independent estimates. Informative prior distributions are used on model parameters, as detailed in SCOS-BP 18/03 and Thomas et al. (2019). These prior distributions were largely identical to those used in 2016 and 2017, with one minor change: expected carrying capacity in North Sea was doubled from 10,000 to 20,000 (with a prior coefficient of variation as before of 50%).

Three runs are reported here, using different input data:

- Main analysis. Pup production data from 1984-2016 (SCOS-BP 18/01), plus independent estimates of population size from size from 2008 and 2014 (Russell et al. 2016).
- Additional analysis 1. Pup production data from 1984-2010, as reported by Duck and Morris (SCOS-BP 18/01), plus an independent estimate of population size from 2008 (Russell et al. 2016).
- Additional analysis 2. Pup production data from 1984-2010, as reported by Russell et al. (2019) i.e., with PMOULT set to 0.5, plus an independent estimates of population size from 2008 (Russell et al. 2016). (This is the dataset analyzed in Thomas et al. (2019))

The pup production estimates for these last two analyses differ only in the years 2008, 2009 and 2010, with the latter being on average 8% lower in those years. Also, the pup production estimate for Inner Hebrides for 2009 is marked as missing in the latter dataset, where the value from 2008 is copied over to 2009 in the former.

Model fitting, as in previous reports, used a stochastic simulation-based procedure called a particle filter (Thomas et al. 2019). Reliability of reported results depends on the number of simulations. For the main analysis, 2 billion simulations were used, which resulted in reported results accurate to 3 significant figures in most cases (2 for some parameters); for the additional analyses, 1 billion simulations were used for additional analysis 1, while 4 billion simulations were used for additional analysis 2. (The latter used a larger number of simulations for additional accuracy because it was used in a submitted paper.)

Results

Main analysis

Estimated pup productions from the model match the observed values reasonably well (Figure 1), although there is evidence for systematic lack of fit from the last three observations in each region (2012, 2014 and 2016), all of which are above the fitted trend. Pup production is estimated to be increasing strongly in North Sea, stable in Outer Hebrides, nearly so in Inner Hebrides and approaching stability in Orkney (Figure 1). Estimates of pup production based on just the pup production data are very similar to those based on pup production data and the independent estimates of population size (compare red and blue lines in Figure 1).

Total population size from the pup production data alone (blue line in Figure 2) is estimated to be higher than the independent estimates of population size. When the independent estimates are included in inference, the total population size estimate decreases to become larger than the independent estimate from 2008 and smaller than that from 2014 (red line in Figure 2). Posterior mean population size in regularly-monitored colonies in 2017 was 135,700 with 95% credible interval (CI) 118,500-155,200. Estimates by region are given in Table 2 and estimates for all years 1984-2017 are given in the Appendix.

Posterior parameter distributions are shown in Figure 3, with numerical summaries in Table 1. Adult survival is estimated to be rather higher than the prior distribution, with posterior mean 0.96 (SE 0.01) and most mass near the upper boundary of 0.97. Pup survival is estimated to be lower than the prior (mean 0.45 SE 0.07) and fecundity somewhat higher (mean 0.92 SE 0.48). Three regions (Inner Hebrides, Outer Hebrides and Orkney) are estimated to be close to or slightly over carrying capacity (i.e., posterior mean on carrying capacity parameter at or close to the pup production in 2016), while North Sea is at approximately half of carrying capacity (although that estimate is very imprecise with SE/mean=0.5 like the prior). Estimated sex ratio is unchanged from the prior.

Additional analysis 1: 1984-2010 data

The estimated pup production trajectories are significantly lower given 1984-2010 data (Figure 4, top 4 panels) than with the 1984-2016 data used in the main analysis (Figure 1). Pup production is estimated to have peaked in Outer Hebrides in the late 1990s, in Inner Hebrides in the early 2000s and be levelling off in Orkney in 2010 (when the time series stops). North Sea is estimated to still be increasing at a near-exponential rate, but with a somewhat lower trajectory than when the 2012-16 data are included. These differences are down to the pup production estimates and not the 2014 independent estimate of population size, because they are evident when just pup production data is used in the analysis (blue lines in both plots).

Posterior mean population size in 2010 is 107,100 (95% CI 93,700-127,400), approximately 10% lower than the estimate from 2010 obtained when 1984-2016 data are used (Table 3). The two population trajectories are compared in Figure 5.

Additional analysis 2: 1984-2010 data and PMOULT=05

Estimated pup projection trajectories are slightly lower than for additional analysis 1 (Figure 4, lower 4 panels). Posterior mean on total population size in 2010 is 104,000 (95% Ci 88.1-124.1), approximately 3% lower than for additional analysis 1 and 13% lower than the main analysis (see also Figure 5).

Discussion

Estimated population size from the main analysis is slightly higher than that reported in last year's briefing paper (Thomas 2017) for a comparable year – for example the estimate for this year for 2016 is 133,300 (95% CI 117,000-152,400), while that of Thomas (2017) was 128,200 (95% CI 106,200-154,400), a difference of 4%. The difference is due to the addition of the pup production estimate for 2016, which like that for 2012 and 2014 (since the advent of digital aerial photography for the surveys), is higher than expected based on previous counts. As additional analysis 1 has shown, together, the three most recent pup production estimates cause an increase of approximately 10% in the 2010 population estimate – this difference will be even more pronounced by the time of the 2017 population estimate because the estimated rate of growth in the population is rather less if only data up to 2010 are used (Figure 5). Additional analysis 2 has shown that a relatively small change in the pup production estimation procedure for the pre-digital surveys can produce a further change in estimated total population size, although only of a few percentage points. Overall, it seems clear that an investigation of the methods used to derive pup production is warranted.

Depending on the data used, it appears that pup production in Outer Hebrides, Inner Hebrides and Orkney has stabilized; there is even evidence that the trajectory first overshot carrying capacity before falling back. This pattern of damped oscillation can occur under delayed density dependence as here, where there is a 5-year lag between pup survival declining due to the onset of density dependent processes and the resulting cohort of pups recruiting into the breeding population. This (and other possible population dynamics models) is discussed in Thomas et al. (2019).

Given the very different trajectory of North Sea compared with the other regions, it is of interest to compare the estimated pup survival rates. The population dynamics model used has a parameter for maximum pup survival rate, $\phi_{p\max}$, which occurs when pup production is far from carrying capacity. In the main analysis, the posterior mean on this parameter is 0.45. Thomas et al. (2019) showed that at carrying capacity, pup survival is given by

$$\phi_{pcc} = \frac{1 - \phi_a}{0.5\alpha\phi_a^5}$$

(equation 4 in Thomas et al. (2019)); plugging in the posterior mean estimates for the main analysis (Figure 1), gives $\hat{\phi}_{pcc}$=0.11. Pup survival in the North Sea is estimated to be closer to 0.45, while that in the other regions is estimated to be close to or at 0.11. (Note that estimates of uncertainty on these quantities should be derived for proper interpretation.)

The posterior distribution on adult survival has a mode close to the upper bound 0.97. In addition, den Heyer & Bowen (2017) obtained mark-recpature-based estimates of adult female survival in Canada that was higher than this upper bound (0.976 SE 0.001). Hence, consideration should be given to raising the upper bound on the prior for this parameter.

Thomas et al. (submitted) discuss how sensitive the estimate of total population size may be to the parameter priors, and conclude that fecundity and adult:female ratio are two parameters that strongly affect total population size but for which the prior specification is particularly influential. Hence a renewed focus on priors for these parameters may be appropriate.

References

Duck, C.D. and C. Morris. 2018. Grey seal pup production in Britain in 2017. SCOS Briefing Paper 18/01.

Russell, D.J.F. 2018. 2018 Annual review of priors for grey seal population model. SCOS Briefing Paper 18/03.

Russell, D.J.F., C.D. Duck, C. Morris, C. and D. Thompson. 2016. Independent estimates of grey seal population size: 2008 and 2014. SCOS Briefing Paper 16/03.

Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D. and Hiby, A.R.(2019) Monitoring long-term changes in UK grey seal Halichoerus grypus pup production. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3100

Thomas, L., Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D. (2019). Modelling the population size and dynamics of the British grey seal. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.3134

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

Thomas, L. 2017. Estimating the size of the UK grey seal population between 1984 and 2016. SCOS Briefing Paper 17/02

Table 1. Prior parameter distributions and summary of posterior distributions. Be denotes beta distribution, Ga Gamma distribution (with parameters shape and scale, respectively). Main analysis uses both 1984-2016 pup production estimates, and the 2008 and 2014 total population estimates; additional analysis 1 uses 1984-2010 pup production estimates and the 2008 total population estimate; additional analysis 2 uses 1984-2010 pup production estimates derived with the PMOULT parameter set to 0.5 and the 2008 total population estimate.

Parameter	Prior distribution	Prior mean (SD)	Posterior mean (SD)		
			Main analysis: 1984-2016 data	Additional analysis 1: 1984-2010 data	Additional analysis 2: 1984-2010 data with PMOULT=0.5
adult survival ϕ_a	0.8+0.17*Be(1.6,1.2)	0.90 (0.04)	0.96 (0.01)	0.96 (0.01)	0.95 (0.01)
pup survival ϕ_{pmax}	Be(2.87,1.78)	0.62 (0.20)	0.45 (0.07)	0.46 (0.07)	0.48 (0.09)
Fecundity α	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.92 (0.05)	0.92 (0.06)	0.90 (0.06)
dens. dep. ρ	Ga(4,2.5)	10 (5)	3.02 (0.66)	4.81 (1.43)	5.95 (.173)
NS carrying cap. χ_1	Ga(4,5000)	20000 (10000)	34200 (12500)	22500 (13500	15500 (822)
IH carrying cap. χ_2	Ga(4,1250)	5000 (2500)	3930 (354)	3260 (215)	3110 (173)
OH carrying cap. χ_3	Ga(4,3750)	15000 (7500)	13300 (914)	12100 (609)	11700 (535)
Ork carrying cap. χ_4	Ga(4,10000)	40000 (20000)	24500 (3320)	19600 (2580)	17800 (1680)
observation CV ψ	Ga(2.1,66.67)	140 (96.6)	73 (16.3)	108 (30.7)	111 (34.5)
sex ratio ω	1.6+Ga(28.08, 3.70E-3)	1.7 (0.02)	1.7 (0.02)	1.7 (0.02)	1.7 (0.02)

Table 2. Estimated size, in thousands, of the British grey seal population at the start of the 2017 breeding season, derived from a model fit to pup production data from 1984-2016 and the additional total population estimates from 2008 and 2014. Numbers are posterior means with 95% credible intervals in brackets.

	Estimated population size in thousands (95% CI)
North Sea	41.8 (32.1 51.4)
Inner Hebrides	8.9 (7.4 10.9)
Outer Hebrides	30.5 (26.4 36.5)
Orkney	54.5 (45.1 67.4)
Total	135.7 (118.5 155.2)

Table 3. Estimated size, in thousands, of the British grey seal population at the start of the 2010 breeding season. Main analysis uses both 1984-2016 pup production estimates, and the 2008 and 2014 total population estimates; additional analysis 1 uses 1984-2010 pup production estimates and the 2008 total population estimate; additional analysis 2 uses 1984-2010 pup production estimates derived with the PMOULT parameter set to 0.5 and the 2008 total population estimate. Numbers are posterior means with 95% credible intervals in brackets.

	Estimated population size in thousands (95% CI)		
	Main analysis: 1984-2016 data	Additional analysis 1: 1984-2010 data	Additional analysis 2: 1984-2010 data with PMOULT=0.5
North Sea	27.7 (22.6 32.5)	25.5 (19 31.7)	24.8 (17.1 32.1)
Inner Hebrides	8.8 (7.4 10.7)	7.6 (6.4 9.3)	7.4 (6.2 9.1)
Outer Hebrides	30.3 (26.4 36.1)	28.1 (24.1 34.1)	28.5 (23.6 35.1)
Orkney	52.5 (44.8 62.1)	46 (37.3 58.3)	43.1 (34.6 54.4)
Total	119.2 (105.9 136.2)	107.1 (93.7 127.4)	104 (88.1 124.1)

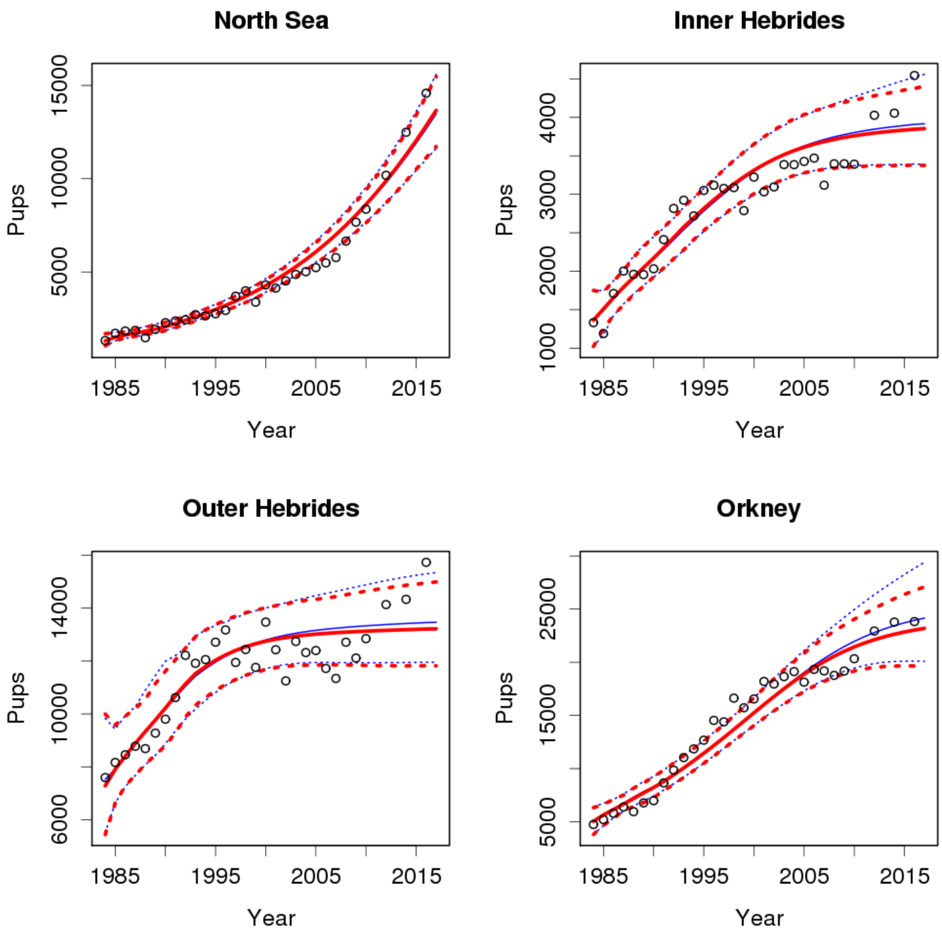

Figure 1. Posterior mean estimates of pup production (solid lines) and 95%CI (dashed lines) from the model of grey seal population dynamics, fitted to pup production estimates from 1984-2016 (circles) and the total population estimates from 2008 and 2014. Thinner blue lines (partly obscured) show the fit to pup production estimates alone; thicker red lines show the fit to pup production estimates plus the total population estimates.

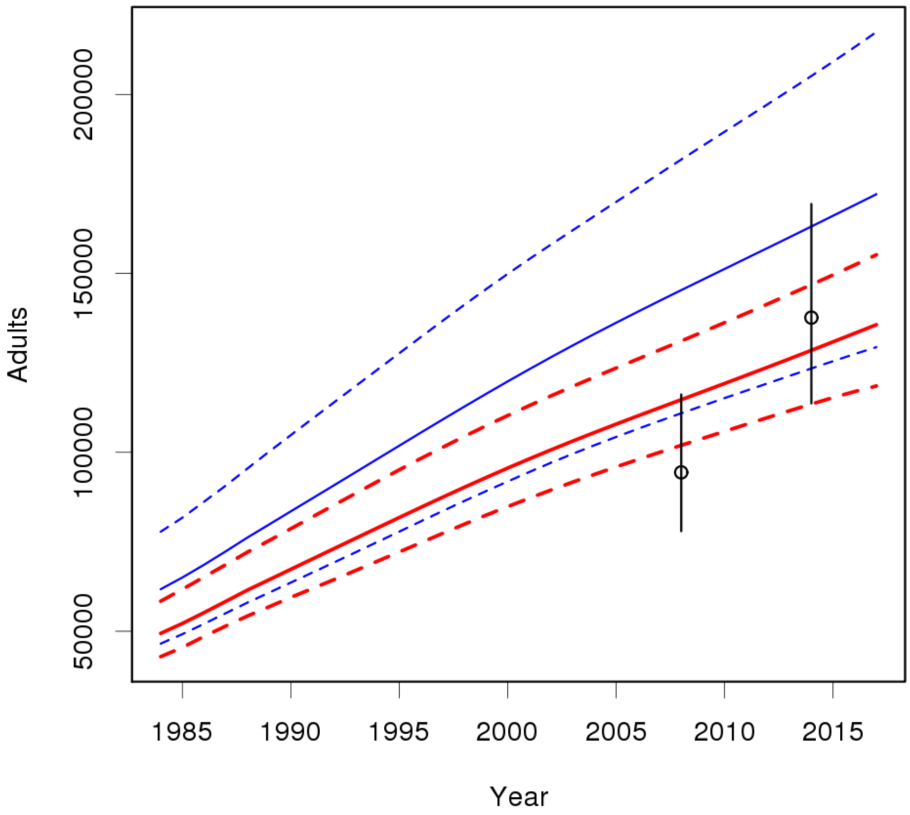

Figure 2. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2016 from the model of grey seal population dynamics, fit to pup production estimates from 1984-2016 and total population estimates from 2008 and 2014 (circles, with vertical lines indicating 95% 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.

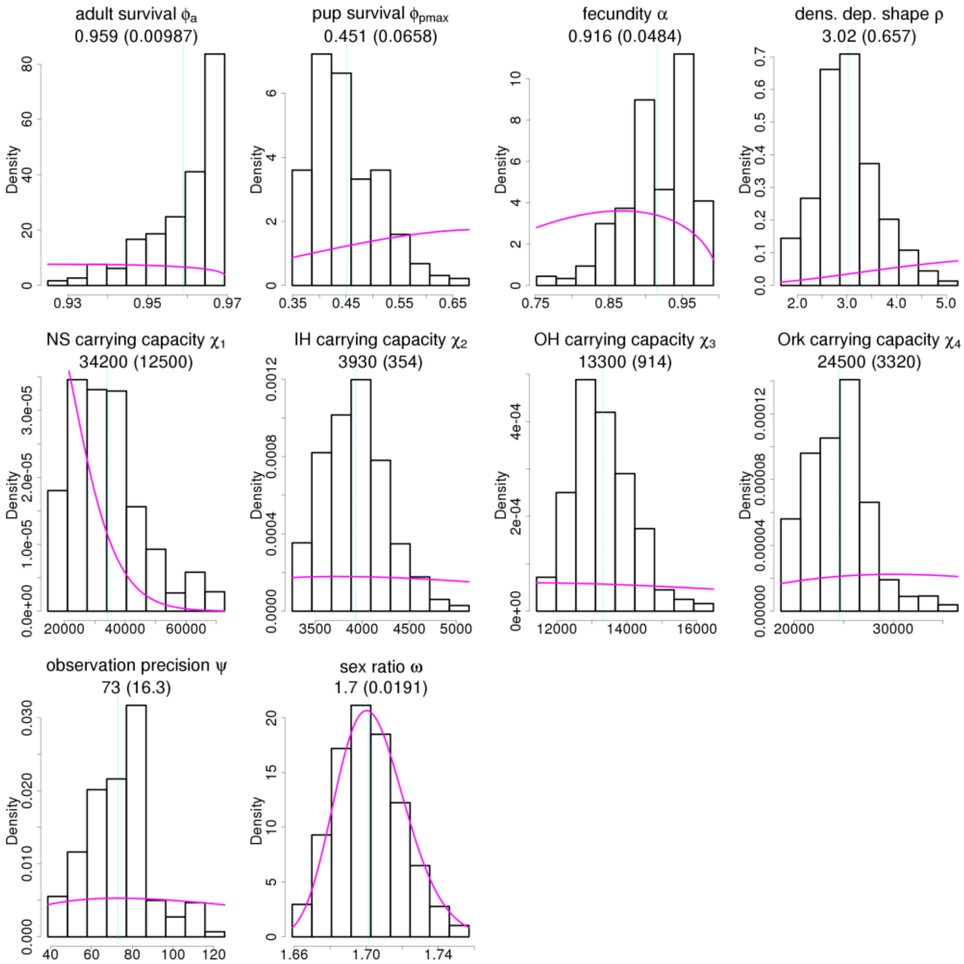

Figure 3. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1984-2016 and total populations estimate from 2008 and 2014. The vertical dashed line shows the posterior mean; its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses.

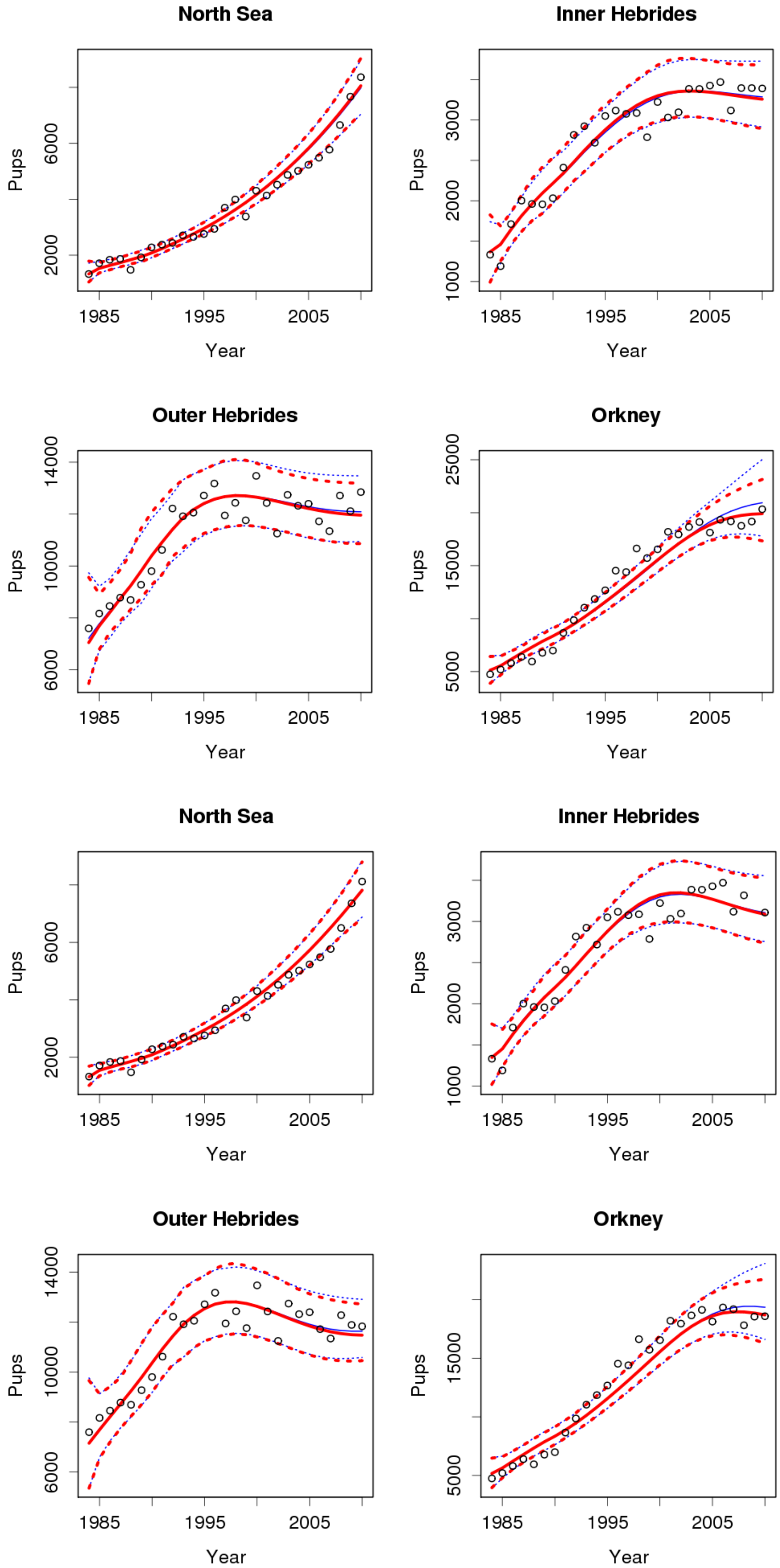

Figure 4. Posterior mean estimates of pup production for additional analysis 1 (top 4 plots) and 2 (bottom 4 plots). Note that the pup production data from 2008-2010 are different between the two analyses.

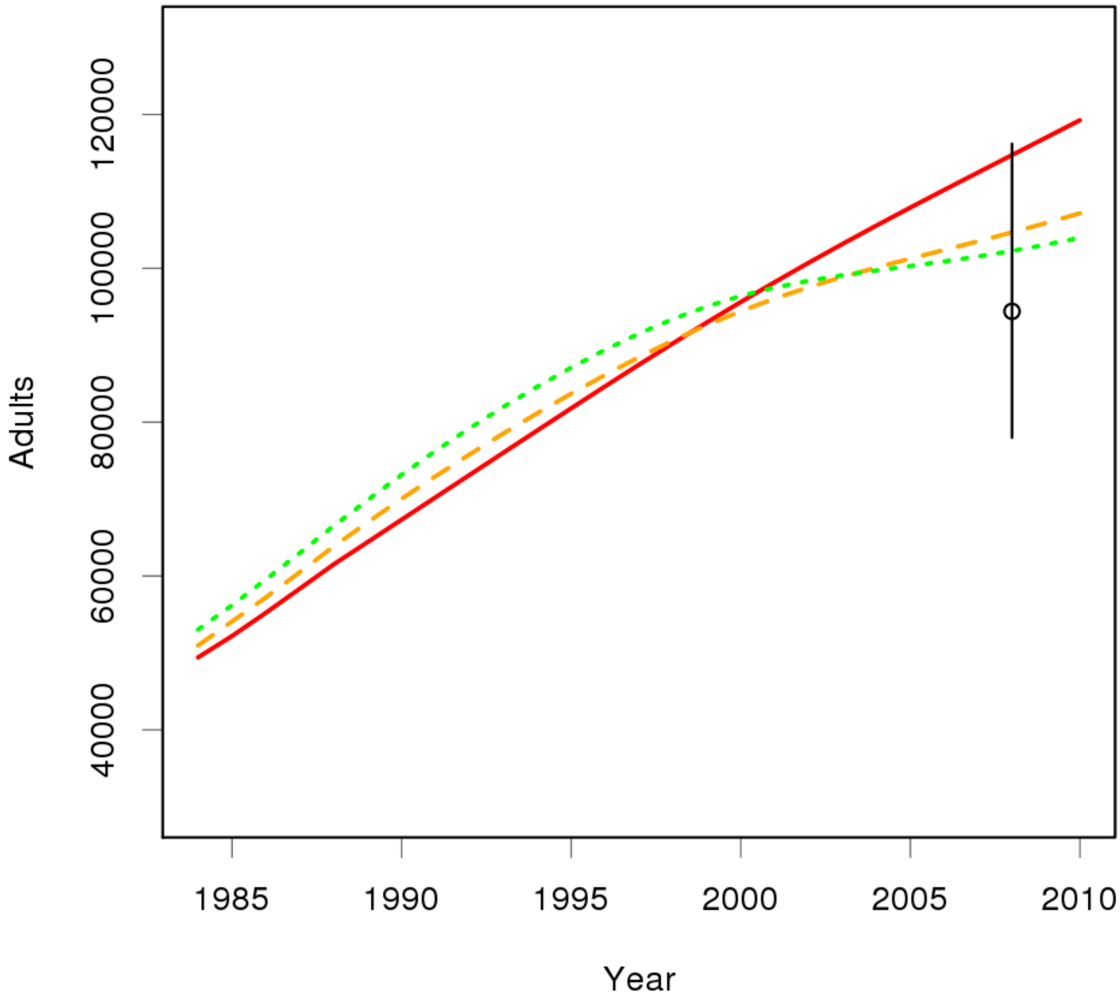

Figure 5. Posterior mean estimates of total population size in 1984-2010 from the model of grey seal population dynamics. Red solid line – main analysis; orange dashed line – additional analysis 1; green dotted line – additional analysis 2. Shown as a circle is the independent estimate from 2008 (horizontal lines indicate 95% confidence interval).
4

Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2017, made using the model of British grey seal population dynamics fit to pup production estimates from 1984-2016 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	4.5 (3.7 5.3)	4.7 (4 5.7)	22.5 (19.4 27.2)	17.8 (14.5 21.8)	49.4 (42.9 58.4)
1985	4.8 (4 5.7)	5 (4.2 6)	23.5 (20.2 28.5)	18.9 (15.5 23)	52.2 (45.5 61.7)
1986	5.1 (4.4 6.1)	5.3 (4.5 6.2)	24.6 (21.3 29.5)	20.2 (16.9 24.4)	55.2 (48.5 65.2)
1987	5.5 (4.7 6.5)	5.6 (4.7 6.6)	25.6 (22.1 30.5)	21.6 (18.3 26)	58.3 (51.4 68.6)
1988	6 (5.1 7)	5.9 (5 7)	26.5 (22.9 31.7)	23.1 (19.7 27.7)	61.5 (54.2 72.1)
1989	6.4 (5.4 7.5)	6.2 (5.3 7.3)	27.1 (23.5 32.4)	24.7 (21.1 29.6)	64.4 (56.8 75.3)
1990	6.9 (5.8 8.1)	6.5 (5.5 7.7)	27.7 (24.1 33)	26.3 (22.5 31.4)	67.3 (59.5 78.6)
1991	7.4 (6.2 8.7)	6.7 (5.8 8)	28.1 (24.5 33.5)	28 (24.1 33.3)	70.2 (61.9 82)
1992	7.9 (6.7 9.3)	7 (6 8.3)	28.5 (24.9 33.8)	29.7 (25.7 35.2)	73.1 (64.4 85.3)
1993	8.5 (7.2 9.9)	7.2 (6.2 8.6)	28.8 (25.2 34.1)	31.5 (27.3 37.2)	76 (67 88.6)
1994	9.1 (7.7 10.7)	7.4 (6.4 8.9)	29.1 (25.5 34.3)	33.2 (29 39.2)	78.9 (69.6 91.9)
1995	9.8 (8.2 11.4)	7.6 (6.6 9.1)	29.3 (25.7 34.5)	35 (30.6 41.3)	81.8 (72.2 95.1)
1996	10.5 (8.8 12.3)	7.8 (6.7 9.3)	29.5 (25.9 34.6)	36.8 (32.3 43.3)	84.6 (74.7 98.3)
1997	11.3 (9.4 13.2)	8 (6.9 9.5)	29.6 (26 34.8)	38.6 (33.9 45.4)	87.4 (77.3 101.4)
1998	12.1 (10.1 14.1)	8.1 (7 9.7)	29.7 (26.1 34.9)	40.3 (35.4 47.3)	90.2 (79.9 104.4)
1999	13 (10.9 15.1)	8.2 (7.1 9.8)	29.8 (26.2 35)	41.9 (36.8 49.2)	92.9 (82.4 107.4)
2000	14 (11.6 16.2)	8.3 (7.1 10)	29.9 (26.2 35)	43.4 (38 50.9)	95.6 (84.8 110.3)
2001	15 (12.5 17.4)	8.4 (7.2 10.1)	30 (26.2 35.1)	44.8 (39.2 52.5)	98.2 (87.2 113.1)
2002	16.1 (13.4 18.7)	8.5 (7.2 10.2)	30 (26.3 35.2)	46.1 (40.2 53.9)	100.7 (89.5 115.8)
2003	17.2 (14.3 20.1)	8.5 (7.3 10.3)	30.1 (26.3 35.3)	47.3 (41.2 55.2)	103.1 (91.7 118.4)
2004	18.5 (15.3 21.5)	8.6 (7.3 10.4)	30.1 (26.3 35.4)	48.3 (42 56.4)	105.5 (93.8 121)
2005	19.8 (16.4 23.1)	8.6 (7.3 10.5)	30.2 (26.3 35.6)	49.3 (42.7 57.5)	107.9 (95.9 123.6)
2006	21.2 (17.5 24.8)	8.7 (7.3 10.5)	30.2 (26.3 35.7)	50.1 (43.3 58.5)	110.2 (98 126.1)
2007	22.7 (18.7 26.5)	8.7 (7.3 10.6)	30.2 (26.3 35.8)	50.8 (43.9 59.5)	112.4 (100 128.6)
2008	24.3 (19.9 28.4)	8.8 (7.4 10.6)	30.3 (26.3 35.9)	51.4 (44.3 60.4)	114.7 (102 131.1)
2009	25.9 (21.3 30.4)	8.8 (7.4 10.7)	30.3 (26.3 36)	52 (44.6 61.3)	117 (103.9 133.7)
2010	27.7 (22.6 32.5)	8.8 (7.4 10.7)	30.3 (26.4 36.1)	52.5 (44.8 62.1)	119.2 (105.9 136.2)
2011	29.5 (24 34.8)	8.8 (7.4 10.7)	30.3 (26.4 36.2)	52.9 (45 62.9)	121.5 (107.8 138.8)
2012	31.4 (25.5 37.2)	8.9 (7.4 10.8)	30.4 (26.4 36.2)	53.2 (45.1 63.7)	123.8 (109.7 141.5)
2013	33.4 (27 39.7)	8.9 (7.4 10.8)	30.4 (26.4 36.3)	53.5 (45.1 64.5)	126.1 (111.6 144.2)
2014	35.4 (28.5 42.4)	8.9 (7.4 10.8)	30.4 (26.4 36.3)	53.8 (45.2 65.3)	128.5 (113.5 146.8)
2015	37.5 (29.8 45.3)	8.9 (7.4 10.9)	30.4 (26.4 36.4)	54.1 (45.2 66.1)	130.9 (115.3 149.6)
2016	39.7 (31 48.3)	8.9 (7.4 10.9)	30.4 (26.4 36.4)	54.3 (45.1 66.8)	133.3 (117 152.4)
2017	41.8 (32.1 51.4)	8.9 (7.4 10.9)	30.5 (26.4 36.5)	54.5 (45.1 67.4)	135.7 (118.5 155.2)

The status of UK harbour seal populations in 2017 including summer counts of grey seals.

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Abstract

In August 2017, during the harbour seal moult, the Sea Mammal Research Unit (SMRU) thermal image surveys on the west coast of Scotland from Cape Wrath to Kyle of Lochalsh, in the Western Isles, the Moray Firth and the Firth of Tay and Eden Estuary. The 2017 survey formed the second year of a new round-Scotland harbour seal survey which started in 2016.

The SMRU fixed-wing surveys in England covered the coast of Lincolnshire, Norfolk and Suffolk. The Tees Seal Research Programme kindly provided information on seal numbers in the Tees Estuary (Bond, 2017). 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 2017, the minimum number of harbour seals counted in Scotland was **26,565** and in England & Wales it was **5092**, making a total count for Great Britain of **31,657**. Including **948** harbour seals counted in Northern Ireland in 2011, the UK harbour seal total count for this period was **32,504**.

From August surveys carried out between 2011 and 2017, the minimum number of grey seals counted in Scotland was **27,526** and in England & Wales **17,031** making a total count for Great Britain of **44,557**. Including **468** grey seals counted in Northern Ireland in 2011, the UK grey seal total count for this period was **45,025**.

The 2017 harbour seal count for the Western Isles was **3,533** (29.0% higher than previous 2014 count of 2,739). The count for West Scotland - North was **479** compared with the 2013 and 2014 count of 390, an increase of 22.8%. In the part of West Scotland – Centre, from Gairloch to Kyle of Lochalsh (including Skye, Rona and Raasay) that was surveyed in 2017, **495** harbour seals were counted compared with 381 counted in 2014, an increase of 29.9%. The 2017 harbour seal count for the West Scotland Seal Management Area in 2017 is **15,889**, compared with the previous 2013-2015 count of 15,184, an overall increase of 4.6%.

The severe decline in the Firth of Tay & Eden Estuary harbour seal SAC showed no sign of recovery, with **29** harbour seals counted in 2017. This represents 4.58% of the mean of counts between 1990 and 2002 (641).

The 2017 harbour seal count for the Moray Firth was **879**, 6.5% lower than the 2016 count of 940.

Introduction

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

Although harbour seals can occur all around the UK coast, they are not evenly distributed. Their main concentrations are in Shetland, Orkney, the Outer Hebrides, the west coast of Scotland, the Moray Firth and in east and southeast England, between Lincolnshire and Kent (Figure 1). Only very small, dispersed groups are found on the south and west coasts of England or in Wales.

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

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

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

Methods

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

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

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

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

In southeast England, from Suffolk to Kent, the Thames Harbour Seal Conservation Project coordinated August surveys by air, from boat and from land between 13th and 16th August 2017 (ZSL unpublished data, see Barker & Obregon, 2015 as example).

Results and Discussion

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

The overall distribution of harbour seals around the British Isles from August surveys carried out between 2011 and 2017 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 2017) for UK Seal Management Areas (SMAs) are provided in Table 1 and are compared with two previous periods (2007 to 2009 and 1996 to 1997).

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

The most recent minimum estimate of the number of harbour seals in Scotland, obtained from counts carried out between 2011 and 2017, is **26,565** (Table 1). This is mid-way between the 2007-2009 count (20,430) and the 1996-1997 count (29,514; Table 1). Since 2001, harbour seal counts have declined in Shetland, Orkney and along the north and east coasts of Scotland (Lonergan *et al*., 2007; Duck & Morris, 2014; 2015; 2016; 2017) while counts in the West Scotland SMA appear to have increased.

The most recent minimum estimate for England & Wales, obtained from surveys carried out mainly in 2017, is **4,991** (Table 1). This is 23.7% higher than the 2007-2009 count (4,032) and 57.9% higher than the 1995-1997 count (3,159; Table 1).

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

The sum of all the most recent counts carried out between 2011 and 2017 gives a UK total of **32,504** 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 2011 and 2017 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 2017 is **27,526** (Table 2). This is 45% higher than the total Scotland count of 18,979 from August surveys between 2007 and 2009.

There were **15,626** grey seals counted in eastern England between 2015 and 2017 and, combined with an estimate of **1,405** in West England & Wales and the 2011 count of **468** in Northern Ireland (Table 2), the most recent UK total count of grey seals in August is **45,025**.

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

The parts of Scotland surveyed in August 2017 were: West Scotland, from Cape Wrath to Kyle of Lochalsh, including Skye, Rona and Raasay, the Western Isles, part of the Moray Firth and the Firth of Tay and Eden Estuary in East Scotland. Details of this survey can be found in the Scottish Natural Heritage (SNH) Commissioned Report No. xxx (Duck & Morris, 2018).

Figure 3 shows the years when different parts of the Scottish coast were last surveyed between 2008 and 2017. Areas surveyed in 2017 are in dark green. The 2017 survey formed the second year of a new round-Scotland survey that started in August 2016.

The most up-to-date distribution of harbour seals in Scotland, from surveys between 2011 and 2017, 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 2017 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 2017, 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 West Scotland, part - harbour seals

West Scotland - North and part of West Scotland - Centre were surveyed between 4th and 9th August 2017. The harbour seal count for West Scotland - North was **1,084** and the count for part of West Scotland - Centre was **5,166**. Combined with previous counts for the remainder of West Scotland, the total for West Scotland Centre was **7,160** and the overall total for the West Scotland SMA was **15,889** (Table 1).

2.2 West Scotland, part - grey seals

The grey seal count for West Scotland - North was **479** and the count for part of West Scotland - Centre was **495**. Combined with previous counts for the remainder of West Scotland, the total for West Scotland Centre was **1,170** and the overall total for the West Scotland SMA was **5,267** (Table 1).

2.3 Western Isles - harbour seals

The 2017 harbour seal count for the Western Isles was **3,533** (Table 1). This was the highest recorded count for the Western Isles and was 29.0% higher than the previous (2011) count of 2,739.

2.4 Western Isles - grey seals

The 2017 grey seal count for the Western Isles was **5,772** (Table 2). This, also, was the highest count for the Western Isles and was 39.3% higher than the previous (2011) count of 4,144.

2.5 Moray Firth, part - harbour seals

The annually surveyed section of coast (Helmsdale to Findhorn) was surveyed on 13th August 2017. The coast between Helmsdale and Duncansby Head was last surveyed in August 2008 and 2011. Between Helmsdale and Findhorn Bay, **831** harbour seals were counted (Table 3). Combined with counts from previous years, the total harbour seal count for the Moray Firth SMA was **879**. This was 6.5% lower than the 2016 count of 940 (Table 3). The majority of these harbour seals (59.8%) were between Culbin and Findhorn.

2.6 Moray Firth - grey seals

In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn Bay) **1,131** grey seals were counted (Table 4). Combined with counts from previous years, a total of **1,189** grey seals were counted in the Moray Firth (Table 4).

2.7 East Scotland, Firth of Tay and Eden Estuary - harbour seals

The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2017 was **29**, equalling the lowest count for this Special Area of Conservation (SAC; Table 2, Table 5).

2.8 East Scotland, Firth of Tay and Eden Estuary - grey seals

In the Firth of Tay and Eden Estuary SAC in 2016, **750** grey seals were counted (Table 2, Table 5).

3. Harbour seal surveys in England and Wales

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

The coast of England and Wales has been divided into three Management Units (Figure 1). The great majority of English harbour seals are found in Southeast England (Figure 1). In 1988, the previously increasing numbers of harbour seals in The Wash declined by approximately 50% as a result of the phocine distemper virus (PDV) epidemic. Following the epidemic, from 1989, the area has been surveyed once or twice annually in the first half of August (Table 7, Figure 14). After recovering to 1988 levels by 2001, the population was hit by another PDV outbreak in 2002. It was reduced by around 20% but recovered to pre-epidemic levels by 2012.

In Northeast England, small numbers of harbour seals are found at Holy Island and in the Tees Estuary. The 2017 count for Northeast England was **87**, a combined count from 2015 (Holy Island) and 2017 (Tees Estuary; Table 7). Harbour seals in the Tees Estuary are monitored by the Industry Nature Conservation Association (INCA). The very slow increase in numbers seems to be continuing, although the August 2016 mean count of 86 was slightly lower than the 2015 mean count (100; Table 7 in Bond & Gibson, 2016).

One aerial survey of harbour seals was carried out by SMRU in Lincolnshire and Norfolk during August 2017 (Table 7). The 2017 count for the coast between Donna Nook and Scroby Sands (**4,170**) was slightly lower (by 4.5%) than the 2016 count (4,367). The Zoological Society of London surveyed the wider Thames Estuary between Hamford Water (in Essex) and Goodwin Sands (off the Kent coast) in 2017 and counted **795** harbour seals (Zoological Society of London, unpublished data), 15% more than in 2016.

The combined counts for the Southeast England Management Unit (Flamborough Head to Newhaven) in 2017 (**4,965**) was 1.9% lower than the 2016 count (5,061; Tables 1 and 7). Although the Southeast England population has returned to its pre-2002 epidemic levels, it is still lagging behind the rapid recovery of the harbour seal population in the Wadden Sea where counts increased from 10,800 in 2003 to 26,788 in 2013 (Reijnders *et al*., 2003; Trilateral Seal Expert Group, 2013), equivalent to an average annual growth rate of 9.5% over the ten years. For the fourth successive year, there was a slight decline in the Wadden Sea total harbour seal count in 2017 (25,936; Galatius *et al*., 2017). In August 2017, part of the Dutch Wadden Sea could not be fully counted due to military restrictions. Although the 2017 count was not complete a correction was included to account for seals missed.

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

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

A single aerial survey of The Wash was carried out during the breeding season on 4th July 2017. The results together with results from previous breeding season surveys are presented in detail in SCOS-BP 18/06b. The 2017 pup count for the Wash was 1268, this was 20% lower than the 2016 peak and 16%lower than the average of the peak counts for the preceding 5 years. Although the counts appear highly variable, a simple exponential growth curve fitted to the counts suggests an average increase of 6.5% p.a. since 2001.

The ratio of pup counts to the all age population index has remained high, at around 0.4. The ratio was 2.3 times higher in 2017 than in 2001 suggesting that the large increase in apparent fecundity after 2001 has been maintained.

3.3 England and Wales – grey seal counts (August)

A total of **8,622** grey seals were counted on the south-east coast of England between Donna Nook and Dover in August 2016 and 2017. This is similar to counts from the previous four years (Table 8).

References

Barker, J. & Obregon, C. (2015). Greater Thames Estuary Harbour Seal Population Survey. UK & Europe Conservation Programme, Report by the Zoological Society of London. 12pp. Available at: https://www.zsl.org/sites/default/files/media/2016-01/Harbour%20Seal%20Survey%20Report%20-%20December%202015.pdf

Bond, I. (2017). Tees Seals Research Programme, Monitoring Report No. 29 (1989–2017). Unpublished report to the Industry Nature Conservation Association (available at: http://www.inca.uk.com/wp-content/uploads/2017/11/Teesmouth-Seals-Report-2017-final.pdf).

Bond, I. & Gibson, J. (2016). Tees Seals Research Programme, Monitoring Report No. 28 (1989–2016). Unpublished report to the Industry Nature Conservation Association (available at: http://www.inca.uk.com/wp-content/uploads/2016/10/Teesmouth-Seals-Report-2016-final.pdf).

Boyle, D. P., (2012). Grey Seal Breeding Census: Skomer Island 2011. Wildlife Trust of South and West Wales. CCW Regional Report CCW/WW/11/1.

Büche, B. & Stubbings, E. (2014). Grey Seal Breeding Census Skomer Island, 2013. Wildlife Trust of South and West Wales. Report to Natural Resources Wales.

Duck, C. (2006). Results of the thermal image survey of seals around the coast of Northern Ireland. Environment and Heritage Service Research and Development Series, No. 06/09.

Duck, C. & Morris, C. (2012). Seals in Northern Ireland: Helicopter survey of harbour and grey seals, August 2011. SMRU Unpublished report to the Northern Ireland Environment Agency.

Duck, C.D. & Morris, C.D. (2014). Surveys of harbour (common) and grey seals on the east north and north-west coast of Scotland and in Orkney, including the Moray Firth and the Firth of Tay, in August 2013. Scottish Natural Heritage (SNH) Commissioned Report 759. http://www.snh.org.uk/pdfs/publications/commissioned_reports/759.pdf.

Duck, C.D. & Morris, C.D. (2015). Surveys of harbour and grey seals on the west coast of Scotland (Ullapool to Scarba), in the Moray Firth and in the Firth of Tay, in August 2014. Scottish Natural Heritage (SNH) Commissioned Report No. 869. http://www.snh.org.uk/pdfs/publications/commissioned_reports/869.pdf.

Duck, C.D. & Morris, C.D. (2016). Surveys of harbour and grey seals on the south-east (border to Aberlady Bay) and south-west coasts (Sound of Jura to Solway Firth) of Scotland, in Shetland, in the Moray Firth and in the Firth of Tay in August 2015. Scottish Natural Heritage (SNH) Commissioned Report No. ??? http://www.snh.org.uk/pdfs/publications/commissioned_reports/???.pdf.

Galatius, A., Brasseur, S., Czeck, R. *et al.* (2015). Aerial surveys of Harbour Seals in the Wadden Sea in 2015. Trilateral Seal Expert Group unpublished report to the Trilateral Wadden Sea Cooperation. http://www.waddensea-secretariat.org/sites/default/files/downloads/tmap/MarineMammals/harbour_seal_report_2015.pdf

Galatius, A., Brasseur, S., Czeck, R. *et al.* (2017). Aerial surveys of Harbour Seals in the Wadden Sea in 2017. Trilateral Seal Expert Group unpublished report to the Trilateral Wadden Sea Cooperation. http://www.waddensea-secretariat.org/monitoring-tmap/topics/marine-mammals

Hilbrebirdobs.blogspot.co.uk (2012). Hilbre Bird Observatory: August 2012. [online] Available at: http://www.hilbrebirdobs.blogspot.co.uk/2012_08_01_archive.html [Accessed 10 July 2014].

Leeny, R.H., Broderick, A.C., Mills, C., Sayer, S., Witt, M.J. & Godley, B.J. (2010). Abundance, distribution and haul-out behaviour of grey seals (*Halichoerus grypus*) in Cornwall and the Isles of Scilly, UK. J. Mar. Biol. Assn., UK. 90:1033-1040.

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

Lonergan, M., Duck, C.D., Thompson, D. & Moss, S. (2011). British grey seal (*Halichoerus grypus*) numbers in 2008; an assessment based on using electronic tags to scale up from the results of aerial surveys. ICES Journal of Marine Science 68: 2201-2209.

Reijnders, P., Brasseur, S., Abt, K., Siebert, U., Tougaard, S. & Vareschi E. (2003). The Harbour Seal Population in the Wadden Sea as Revealed by the Aerial Surveys in 2003. Wadden Sea Newsletter 2003 (2): 11-12.

Sayer, S. (2010). Carracks to St Agnes Seal Photo Identification Project (CASPIP): July 30th (Aug) 2011. A collaborative project between British Divers Marine Life Rescue and Cornwall Seal Group. Unpublished report.

Sayer, S. (2011). Looe Island Seal Photo Identification Project (LISPIP) 2008/9/10: Aug 2010. A collaborative project between the Looe VMCA Marine Volunteers, Cornwall Wildlife Trust and Cornwall Seal Group. Unpublished report.

Sayer, S. (2012a). Polzeath Seal Photo Identification Project (POLPIP7), September 2012. A collaborative project between Cornwall Wildlife Trust, Polzeath Voluntary Marine Conservation Area, Cornish Sea Tours and Cornwall Seal Group. Unpublished report.

Sayer, S. (2012b). Marine Discovery Seal Photo Identification Project (MARPIP1), December 2012. A collaborative project between Marine Discovery and Cornwall Seal Group. Unpublished report.

Sayer, S., Hockley, C. & Witt, M.J. (2012). Monitoring grey seals (*Halichoerus grypus*) in the Isles of Scilly during the 2010 pupping season. Natural England Commissioned Reports, Number 103.

SMRU Ltd (2010). Seals in Northern Ireland: Helicopter surveys 2010. Unpublished report.

Trilateral Seal Expert Group (2013). Aerial surveys of harbour seals in the Wadden Sea in 2013. Unpublished report to the Trilateral Wadden Sea Cooperation. http://www.waddensea-secretariat.org/sites/default/files/downloads/tmap/MarineMammals/trilateral_harbour_seal_counts_2013.pdf

Westcott, S. (2002). The distribution of Grey Seals (*Halichoerus grypus*) and census of pup production in North Wales 2001. CCW Contract Science Report No. 499.

Westcott, S. (2009). The status of grey seals (*Halichoerus grypus*) at Lundy, 2008-2009. Report to Natural England.

Westcott, S.M. & Stringell, T.B. (2004). Grey seal distribution and abundance in North Wales, 2002-2003. Bangor, CCW Marine Monitoring Report No. 13. 80pp.

Table 1. The most recent August counts of harbour seals at haul-out sites in the UK, by Seal Management Area, compared with previous periods.

Seal Management Unit		Harbour seal counts 2013-2017	2007-2009	2000-2006	1996-1997
1 Southwest Scotland		1,200	923	623	929
2 West Scotland	a	15,889	10,626	11,666	8,811
3 Western Isles		3,533	1,804	1,981	2,820
4 North Coast & Orkney		1,349	2,979	4,388	8,787
5 Shetland		3,369	3,039	3,038	5,994
6 Moray Firth		879	776	1,028	1,409
7 East Scotland		346	283	667	764
SCOTLAND TOTAL		**26,565**	**20,430**	**23,391**	**29,514**
8 Northeast England	b	87	58	62 *	54 *
9 Southeast England	c	4,965	3,952	2,964	3,092
10 South England	d	25	15	15	10
11 Southwest England	d	0	0	0	0
12 Wales	d	10	5	5	2
13 Northwest England	d	5	5	5	2
ENGLAND & WALES TOTAL		**5,092**	**4,035**	**3,051**	**3,160**
BRITAIN TOTAL		**31,657**	**24,465**	**26,442**	**32,674**
NORTHERN IRELAND TOTAL	e	**948**	**1,101**	**1,176**	
UK TOTAL		**32,605**	**25,566**	**27,618**	

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, 2017). The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

c Essex & Kent data for 2016 collected and provided by the Zoological Society London (Barker, 2017).

d No dedicated harbour seal surveys in this 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). 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).

*N'umberland coast south of Farne Islands not surveyed in 2005 & 1997; no harbour seal sites known here.

Table 2 The most recent August counts of grey seals at haul-out sites in the UK, by Seal Management Area, compared with previous periods. Grey seal summer counts are known to be more variable than harbour seal summer counts. Caution is advised when interpreting these numbers.

Seal Management Unit		Grey seal counts			
		2008-2017	2007-2009	2000-2006	1996-1997
1 Southwest Scotland		374	233	206	75
2 West Scotland	a	5,267	2,526	2,383	3,435
3 Western Isles		5,772	3,808	3,929	4,062
4 North Coast & Orkney		9,714	8,525	10,315	9,427
5 Shetland		1,558	1,536	1,371	1,724
6 Moray Firth		1,189	1,113	1,272	551
7 East Scotland		3,652	1,238	1,898	2,328
SCOTLAND TOTAL		**27,526**	**18,979**	**21,374**	**21,602**
8 Northeast England	b	7,004	2,350	1,100 *	
9 Southeast England	c	8,716	1,786	2,266	
10 South England	d	5	2	2	
11 Southwest England	d	500	425	425	
12 Wales	d	850	750	750	
13 Northwest England	d	50	30	30	
ENGLAND & WALES TOTAL		**17,125**	**5,343**	**4,573**	
BRITAIN TOTAL		**44,651**	**24,322**	**25,947**	
NORTHERN IRELAND TOTAL	e	**468**	**243**	**272**	
UK TOTAL		**45,119**	**24,565**	**26,219**	

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, 2017). The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

c Essex & Kent data for 2016 collected and provided by the Zoological Society London (Barker, 2017).

d No SMRU surveys in this unit, but some data available. Estimates compiled from counts shared by other organisations (Natural England, Natural Resources Wales, RSPB) or found in various reports & on websites (Boyle, 2012; Büche & Stubbings, 2017; 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; Woodfin Jones, 2017). 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).

* N'umberland coast south of Farne Islands not surveyed in 2005, so count may be incomplete.

Table 3. August counts of harbour seals in the Moray Firth between 1992 and 2017. Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 7 for the 2017 distribution of seals within the Moray Firth and Figure 8 for a histogram of these data.

	Area	1992	1993	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Survey method	fw	fw	fw	ti	fw	fw &ti	fw	2fw	2fw &1ti	fw &ti	fw &ti	fw &ti	fw	fw	ti	fw	fw	fw	fw	ti	fw
(MEAN) COUNTS	Duncansby Head to Helmsdale		2		1					1			1									
(MEAN) COUNTS	Helmsdale to Brora		92		193		188			113	150	54	73	19	101	87	102	70	1	21	40	22
(MEAN) COUNTS	Loch Fleet		16		27	33	59	56	64	71	80	83	82	65	114	113	133	135	156	144	145	138
(MEAN) COUNTS	Dornoch Firth (SAC)	662		542	593	405	220	290	231	191	257	144	145	166	219	208	157	143	111	120	85	39
(MEAN) COUNTS	Cromarty Firth	41		95	95	38	42	113	88	106	106	102	90	90	140	101	144	63	100	22	72	20
(MEAN) COUNTS	Beauly Firth (incl. Milton & Munlochy)	220		203	219	204	66	151	178	127	176	146	150	85	140	57	60	30	37	34	30	5
(MEAN) COUNTS	Ardersier (incl. Eathie)			221	234	191	110	205	202	210	197	154	145	277	368	195	183	199	28	34	36	81
(MEAN) COUNTS	Culbin & Findhorn			58	46	111	144	167	49	93	58	79	92	73	123	163	254	218	260	330	484	526
(MEAN) COUNTS	Burghead to Fraserburgh			0	1					3		0				29		39			47	
TOTALS	Dornoch Firth to Ardersier			1,061	1,141	838	438	759	699	634	736	546	530	618	867	561	544	435	276	210	223	145
TOTALS	Loch Fleet to Ardersier				1,168	871	497	815	763	705	816	629	612	683	981	674	677	570	432	354	368	283
TOTALS	Loch Fleet to Findhorn				1,214	982	641	982	812	798	874	708	704	756	1,104	837	931	788	692	684	852	809
TOTALS	Helmsdale to Findhorn				1,407		829			911	1,024	762	777	775	1,205	924	1,033	858	693	705	892	831
TOTALS	Moray Firth SMA *				1,409		831			915	1,028	763	778	776	1,206	954	1,063	898	733	745	940	879

* For years where only the main area was surveyed (i.e. Helmsdale to Findhorn), the most recent counts for the outlying areas are used to give a total for the Moray Firth Seal Management Area.
fw, fixed-wing survey; ti, thermal imager helicopter survey; SMA, Seal Management Area.

Table 4. August counts of grey seals in the Moray Firth between 1992 and 2017. Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 7 for the 2017 distribution of seals within the SAC and Figure 9 for a histogram of these data.

	Area	1992	1993	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Survey method	fw	fw	fw	ti	fw	fw &ti	fw	2fw	2fw &1ti	fw &ti	fw &ti	fw &ti	fw	fw	ti	fw	fw	fw	fw	ti	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	28	201
	Loch Fleet		0		0	0	0	0	0	0	1	3	1	0	7	7	20	18	7	10	31	22
	Dornoch Firth (SAC)	233		903	456	121	321	79	473	431	748	516	523	819	717	679	74	604	127	716	387	273
	Cromarty Firth	9		0	0	0	0	0	0	0	1	0	0	0	1	2	1	3	1	0	1	0
	Beauly Firth (incl. Milton & Munlochy)	8		2	3	8	0	0	0	0	3	4	0	0	2	3	1	5	2	0	2	0
	Ardersier (incl. Eathie)			36	24	85	0	3	44	55	142	74	142	94	331	74	24	109	2	14	28	87
	Culbin & Findhorn			0	0	0	0	10	0	11	11	28	75	58	58	179	121	218	93	743	717	548
	Burghead to Fraserburgh			30	65					205		61				18		258			43	
	Dornoch Firth to Ardersier			941	483	214	321	82	517	486	894	594	665	913	1,051	758	100	721	132	730	418	360
TOTALS	Loch Fleet to Ardersier				483	214	321	82	517	486	895	597	666	913	1,058	765	120	739	139	740	449	382
	Loch Fleet to Findhorn				483	214	321	92	517	497	906	625	741	971	1,116	944	241	957	232	1,483	1,166	930
	Helmsdale to Findhorn				486		327			608	1,008	677	1,190	1,043	1,751	1,100	557	1,038	259	1,644	1,194	1,131
	Moray Firth SMA †				551		392			872	1,272	797	1,260	1,113	1,821	1,133	590	1,311	532	1,917	1,252	1,189

* 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 and Eden Estuary SAC, 1990-2017. Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 12 for the 2017 distribution of seals within the SAC and Figure 13 for a histogram of these data.

	Area	1990	1991	1992	1994	1997	2000	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Survey method	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	2fw ,1ti	1fw	1fw ,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1ti	1fw
(MEAN) COUNTS	Upper Tay	27	73	148	89	113	115	51	83	91	91	63	49	45	41	16	40	36	21	51	41	28
	Broughty Ferry	77	83	97	64	35	52	0	90	51	31	27	13	28	15	18	16	3	0	2	4	0
	Buddon Ness	13	86	72	53	0	113	109	142	25	96	64	27	8	23	11	8	10	1	3	0	0
	Abertay & Tentsmuir	319	428	456	289	262	153	167	53	63	34	31	50	8	9	0	5	0	0	0	1	0
	Eden Estuary	31	0	0	80	223	267	341	93	105	90	90	83	22	36	32	19	1	7	4	5	1
	SAC total	467	670	773	575	633	700	668	461	335	342	275	222	111	124	77	88	50	29	60	51	29

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

Table 6. August counts of grey seals in the Firth of Tay and Eden Estuary SAC, 1990-2017. Mean values if more than one count per year; red = lowest count, green = highest count per area. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all counts were from digital images obtained using oblique hand-held photography. See Figure 12 for the 2017 distribution of seals within the SAC and Figure 14 for a histogram of these data.

	Area	1990	1991	1992	1994	1997	2000	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Survey method	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	2fw ,1ti	1fw	1fw ,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1ti	1fw
(MEAN) COUNTS	Upper Tay	0	0	18	20	61	64	78	50	42	22	27	26	55	98	16	39	127	62	115	132	78
	Broughty Ferry	0	3	0	9	0	0	0	16	0	8	1	8	0	0	2	3	0	2	0	0	0
	Buddon Ness	0	0	1	104	0	101	0	33	11	25	85	7	0	12	22	13	18	0	2	0	0
	Abertay & Tentsmuir	912	1,546	1,191	1,335	1,820	2,088	1,490	1,560	763	1,267	1,375	483	395	1,406	1,265	1,111	323	531	687	738	596
	Eden Estuary	0	0	16	0	10	0	25	4	27	57	31	33	0	39	17	36	14	39	32	66	76
	SAC total	912	1,549	1,226	1,468	1,891	2,253	1,593	1,663	843	1,379	1,519	557	450	1,555	1,322	1,202	482	634	836	936	750

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

Table 7. August counts of harbour seals on the English east coast, 1988 to 2017. In years when more than one survey was undertaken, values are means with the numbers of surveys in parentheses. Blank grey cells means that no survey was carried out.

	Northeast England			Southeast England				
Year	N'umberland	The Tees	Other sites	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)	
2006		45 (31)		299	1,695	719	71	
2007	7	43 (31)		214	2,162	550		
2008	9	41 (31)		191 (2)	2,011 (2)	581 (2)	81 (2)	319
2009		49 (31)		267 (2)	2,829 (2)	372	165 (2)	
2010		53 (31)		176 (2)	2,586 (2)	391	201 (2)	379
2011		57 (31)		205	2,894	349	119	
2012		63 (31)		192 (2)	3,372 (2)	409	161	
2013		74 (31)		396	3,174	304	148	482
2014		81 (31)		353	3,086	468	285	489
2015	0	91 (31)		228 (2)	3,336 (2)	455	270 (2)	451
2016		86 (31)	0	369 (2)	3,377 (2)	424 (2)	198 (2)	694
2017		87 (31)		290	3,210	399	271	

SOURCE - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
Northumberland - One complete survey in 2008 (funded by DECC (previously DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2017). Single SMRU fixed-wing count in 1994.
Other sites - St Mary's Island, Ravenscar, Filey Brigg (SMRU aerial surveys)
Southeast England - All SMRU aerial surveys, except for Essex & Kent 2013-2016: data from surveys (aerial/by boat/from land) carried out by the Zoological Society of London (Barker & Obregon, 2015, and unpublished). The 130 for 1995 are an estimate based on a partial SMRU aerial survey.

Table 8. August counts of grey seals on the English east coast, 1995 to 2017. In years when more than one survey was undertaken, values are means with the numbers of surveys in parentheses. Blank grey cells means that no survey was carried out.

	Northeast England			Southeast England				
Year	N'umberland	The Tees	Other sites	Donna Nook	The Wash	Blakeney Point	Scroby Sands	Essex & Kent
1988					52	1		
1989		7						
1990		9		115	10			
1991		8			48 (2)			
1992		9		235	35 (2)	6		
1993		9		59	64	7		
1994	100	6		100 (2)	94 (2)	40 (2)	43	
1995		10		123	66 (2)	18 (2)	32	
1996		11		119	60	11	46	
1997	603	10		289 (2)	49 (2)	45 (2)	34 (2)	
1998		11		174 (2)	53 (2)	33 (2)	23	
1999		12		317 (2)	57 (2)	14 (2)	89 (2)	
2000	568	11		390	40 (2)	17	40 (2)	
2001		11		214	111	30	70	
2002		12		291	75 (2)	11 (2)		
2003		11		232 (2)	58 (2)	18	36	96
2004		13		609 (2)	30 (2)	10 (2)	93 (2)	
2005	1,092	12 (31)		927 (2)	49 (2)	86 (2)	106 (2)	
2006		8 (31)		1,789	52	142	187	
2007	1,907	8 (31)		1,834	42			
2008	2,338	12 (31)		2,068 (2)	68 (2)	375 (2)	137 (2)	160
2009		12 (31)		1,329 (2)	118 (2)	22	157 (2)	
2010		14 (31)		2,188 (2)	240 (2)	49 (2)	292 (2)	393
2011		14 (31)		1,930	142	300	323	
2012		18 (31)		4,978	258 (2)	65	126	
2013		16 (31)		3,474	219	63	219	203
2014		16 (31)		4,437	223	445	509	449
2015	6,767	16 (31)		3,766 (2)	369 (2)	528	520 (2)	454
2016		22 (31)	60	3,964 (2)	431 (2)	355 (2)	642 (2)	481
2017		27 (31)		6,526	688	502	425	

SOURCE - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
Northumberland - One complete survey in 2008 (funded by DECC (previously DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2017). 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.
Other sites - St Mary's Island, Ravenscar, Filey Brigg (SMRU aerial surveys)
Southeast England - All SMRU aerial surveys, except for Essex & Kent 2013-2016: data from surveys (aerial/by boat/from land) carried out by the Zoological Society of London (Barker & Obregon, 2015, and unpublished).

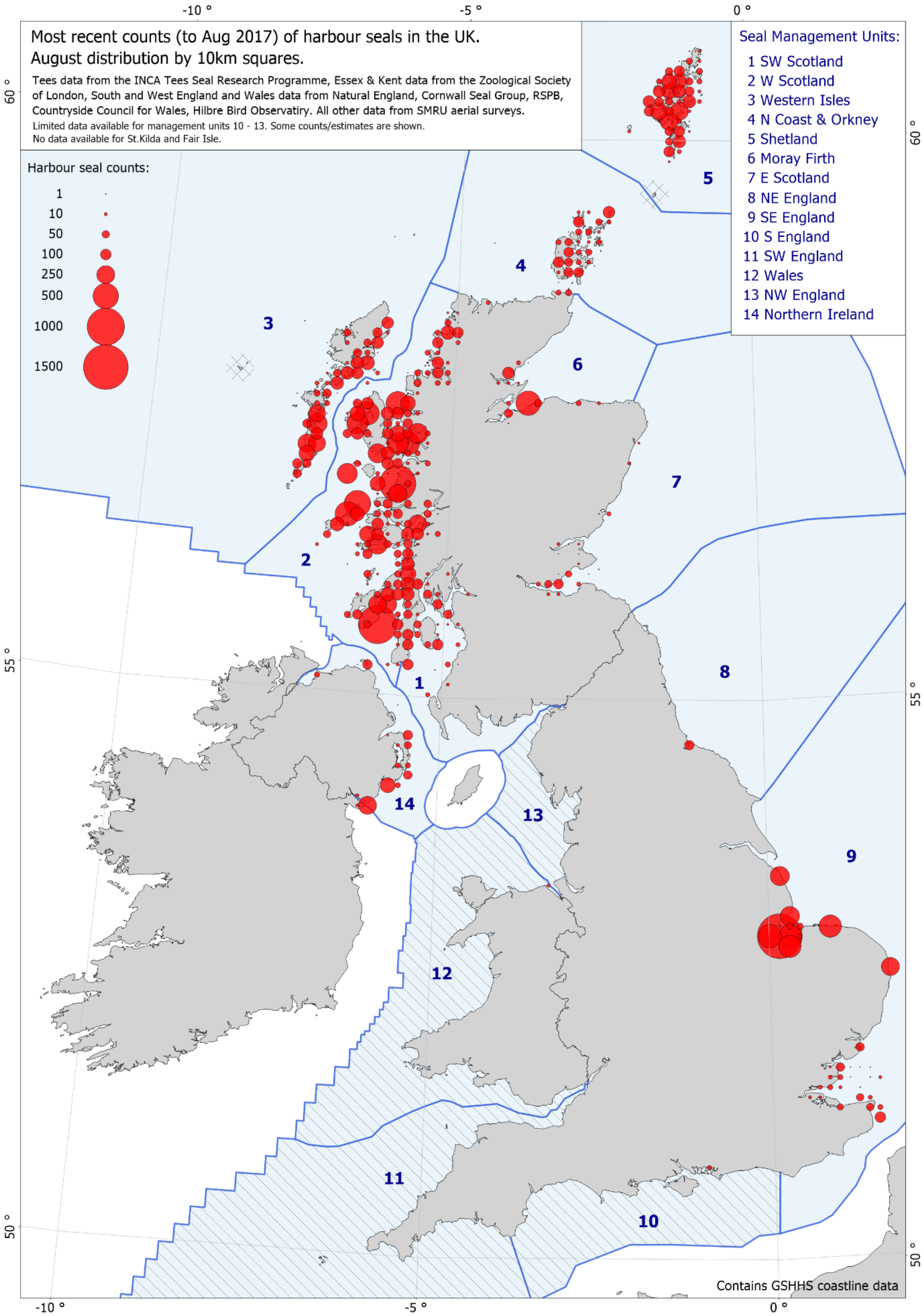

Figure 1. August distribution of harbour seals around the British Isles.

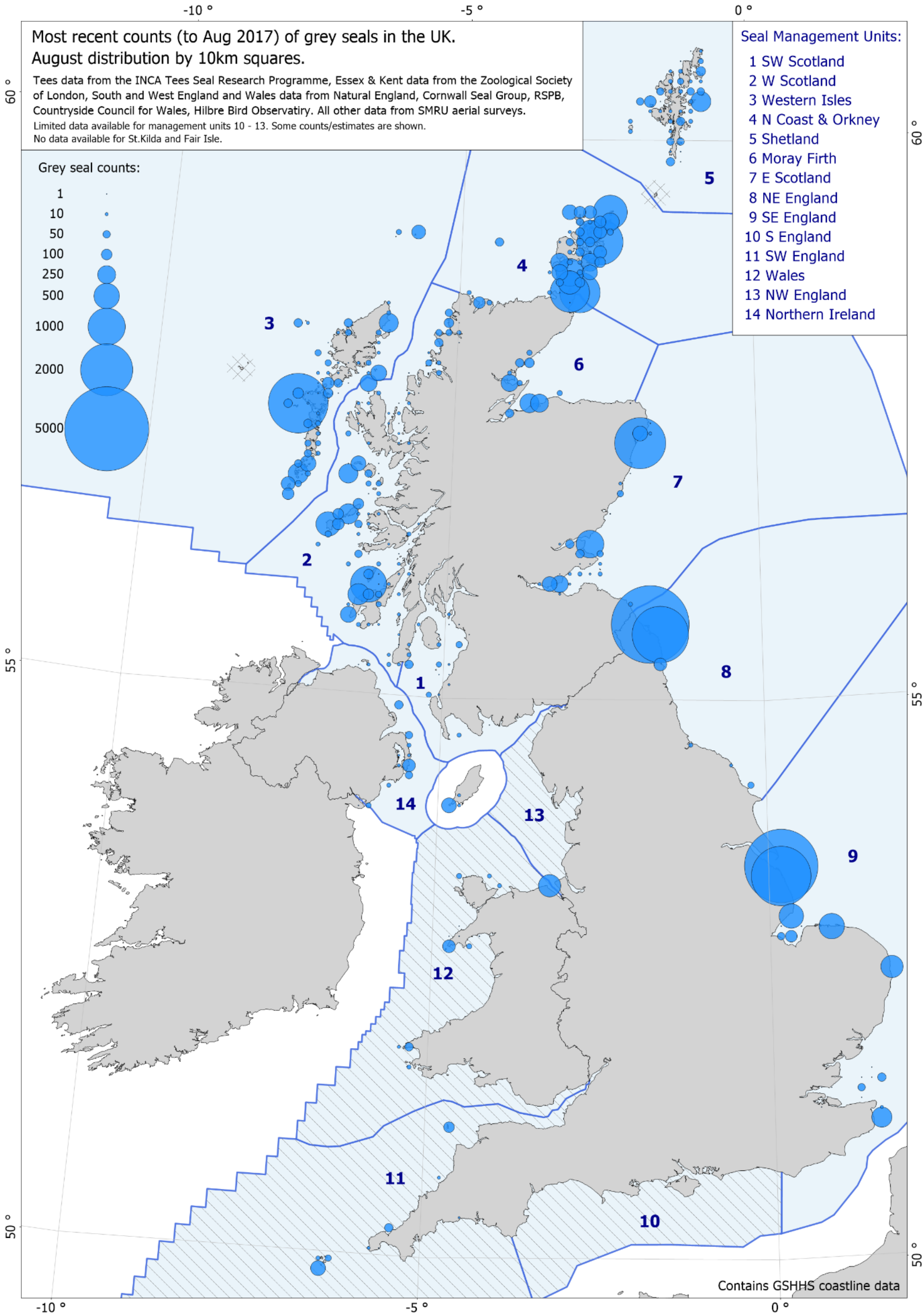

Figure 2. August distribution of grey seals around the British Isles.

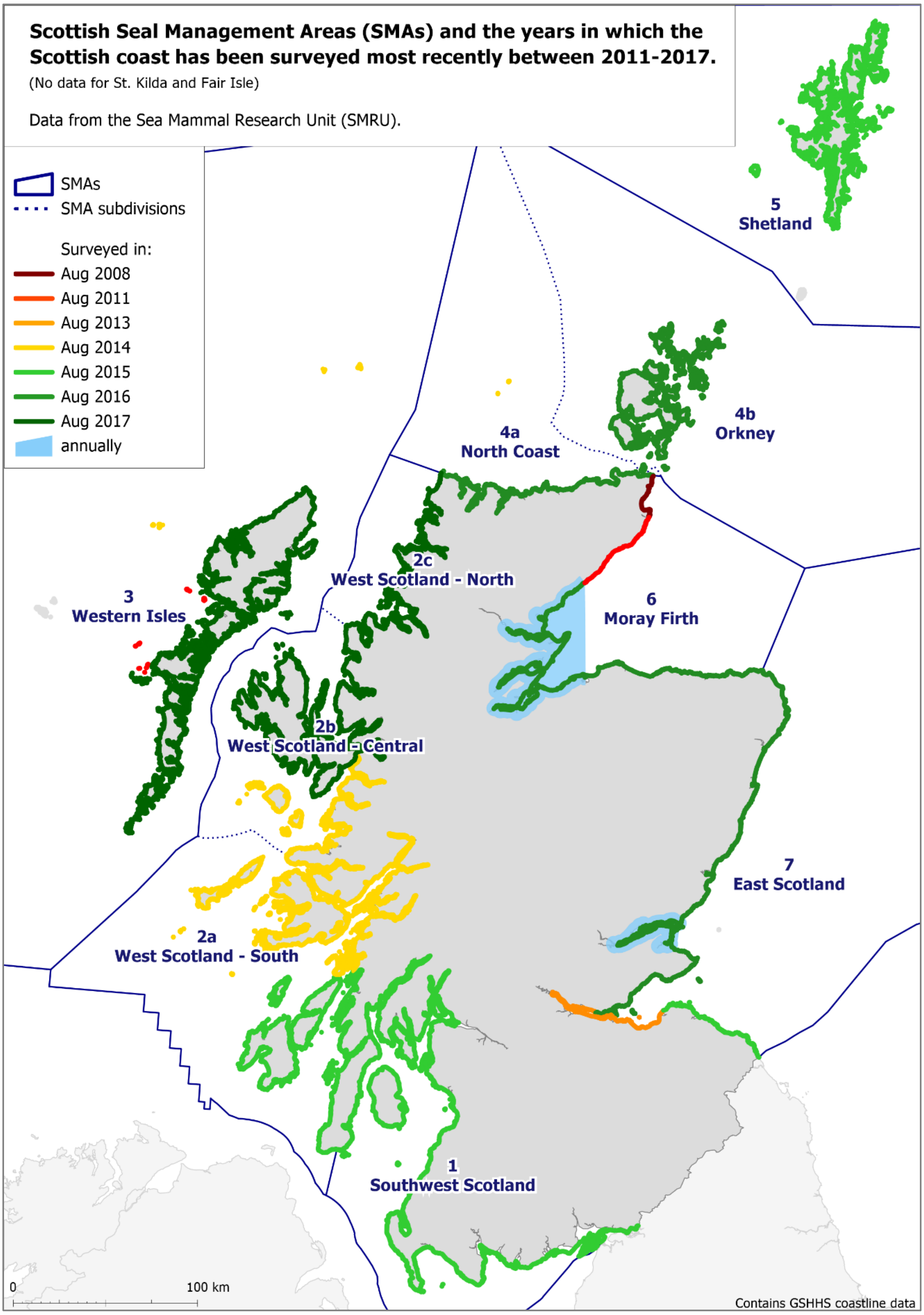

Figure 3. Years in which different parts of Scotland were surveyed most recently by helicopter using a thermal imaging camera. Most areas were surveyed between 2013 and 2017. The blue shaded areas of the Firth of Tay and the Moray Firth (between Findhorn and Helmsdale) are surveyed every year, usually by fixed-wing aircraft.

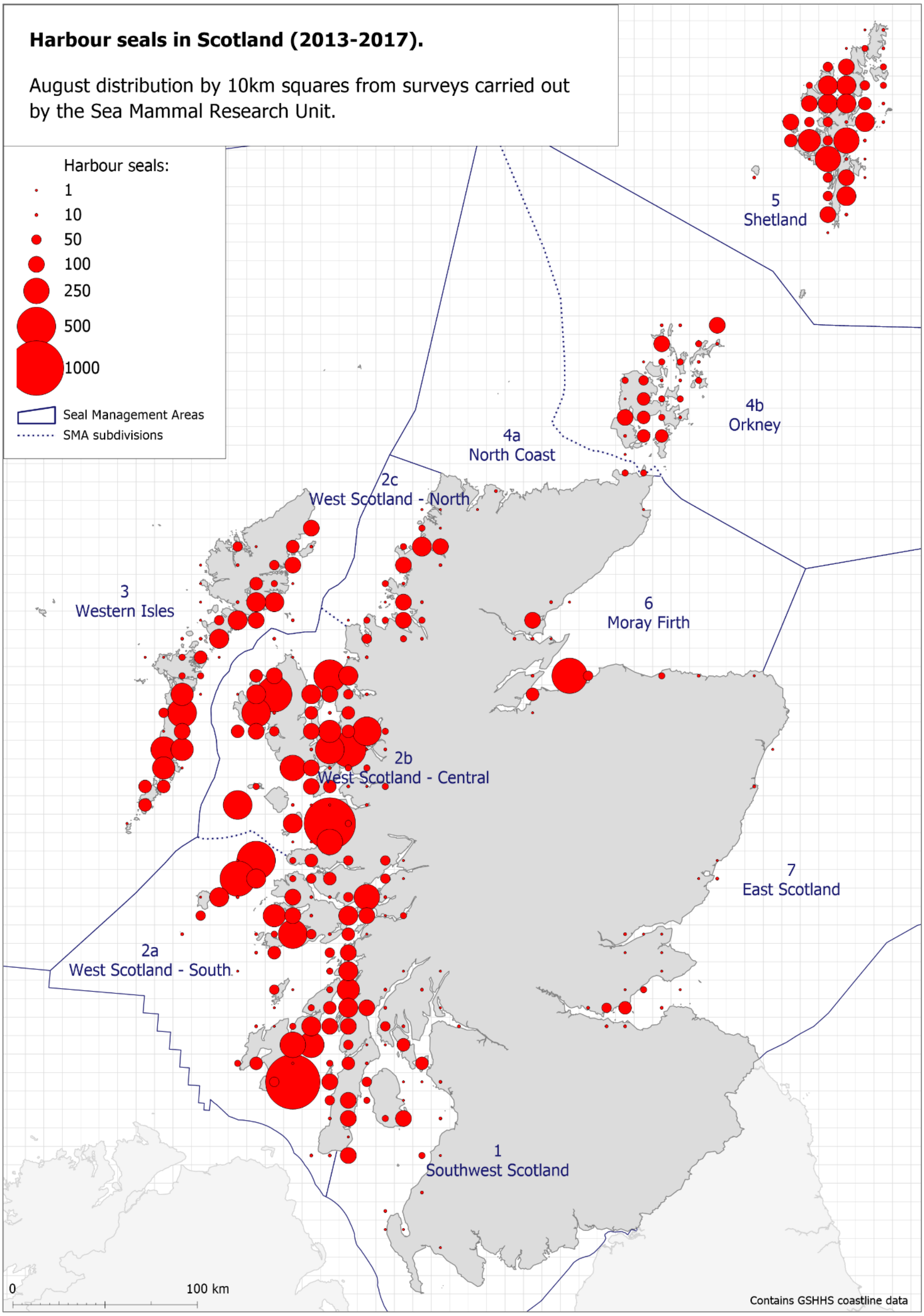

Figure 4. August distribution of harbour seals in Scotland. Most areas were surveyed by helicopter using a thermal imaging camera. The Moray Firth area between Helmsdale and Findhorn, and the Tay and Eden estuaries were surveyed by fixed-wing aircraft without a thermal imager.

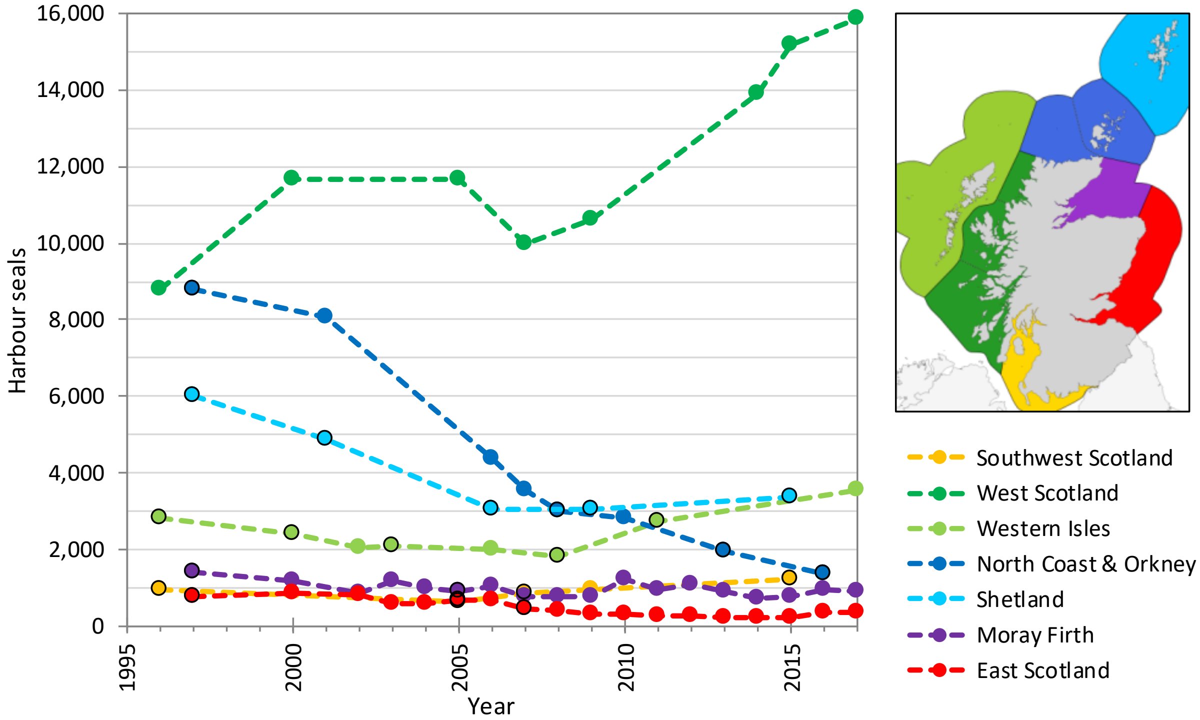

Figure 5. August counts of harbour seals in Scottish Seal Management Units, 1996-2017. Data from the Sea Mammal Research Unit. Note that because these data points represent counts of harbour seals distributed over large areas, individual data points may not be from surveys from only one year. Points are only shown for years in which a significant part of the SMA was surveyed. Points with a black outline are counts obtained in a single year. Trajectories and Seal Management Areas are colour coordinated.

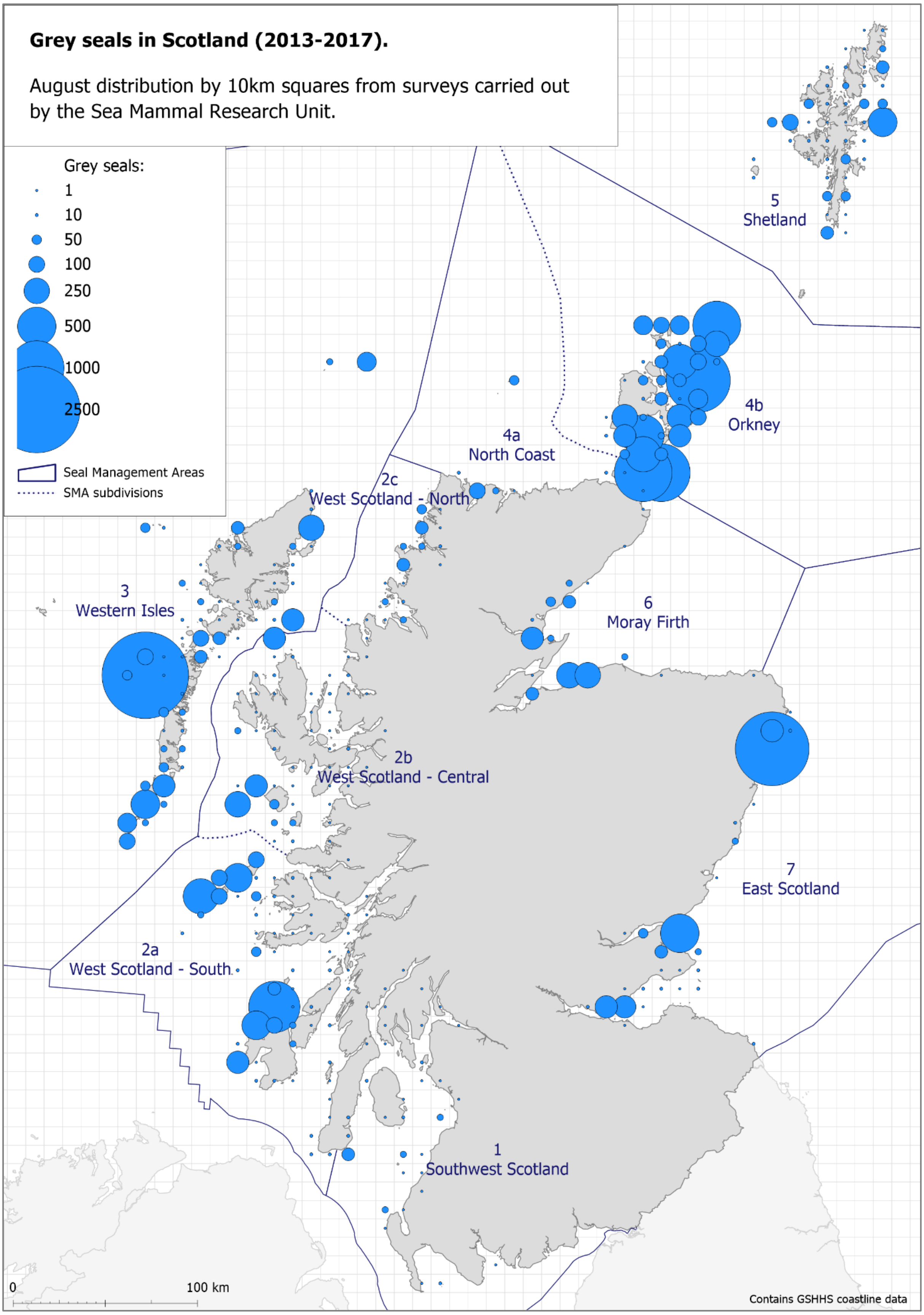

Figure 6. August distribution of grey seals in Scotland. Most areas were surveyed by helicopter using a thermal imaging camera. The Moray Firth area between Helmsdale and Findhorn, and the Tay and Eden estuaries were surveyed by fixed-wing aircraft without a thermal imager.

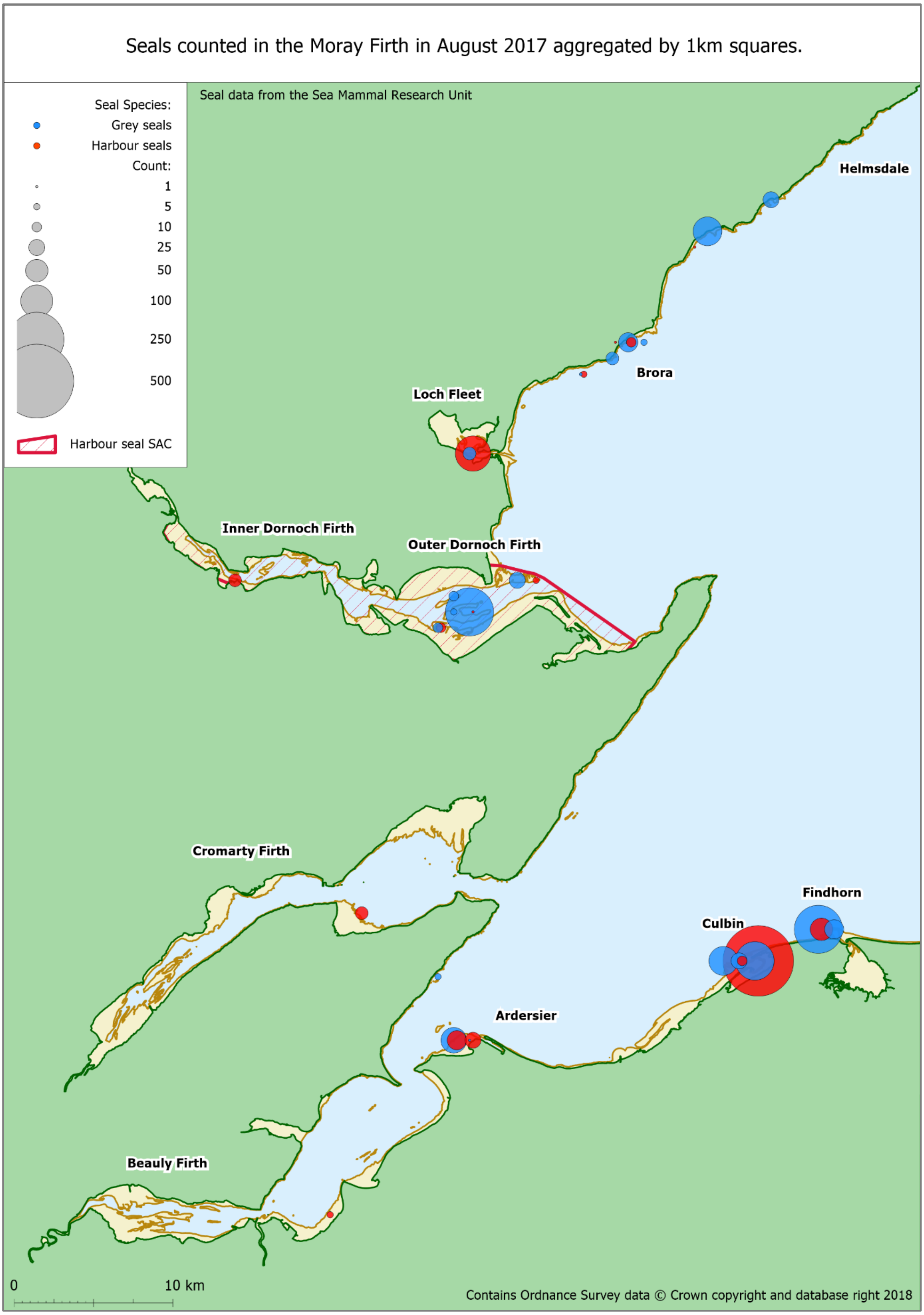

Figure 7. Distribution of harbour (red) and grey seals (blue) in the annually surveyed part of the Moray Firth, between Helmsdale and Findhorn, from an aerial survey carried out on 13th August 2017.

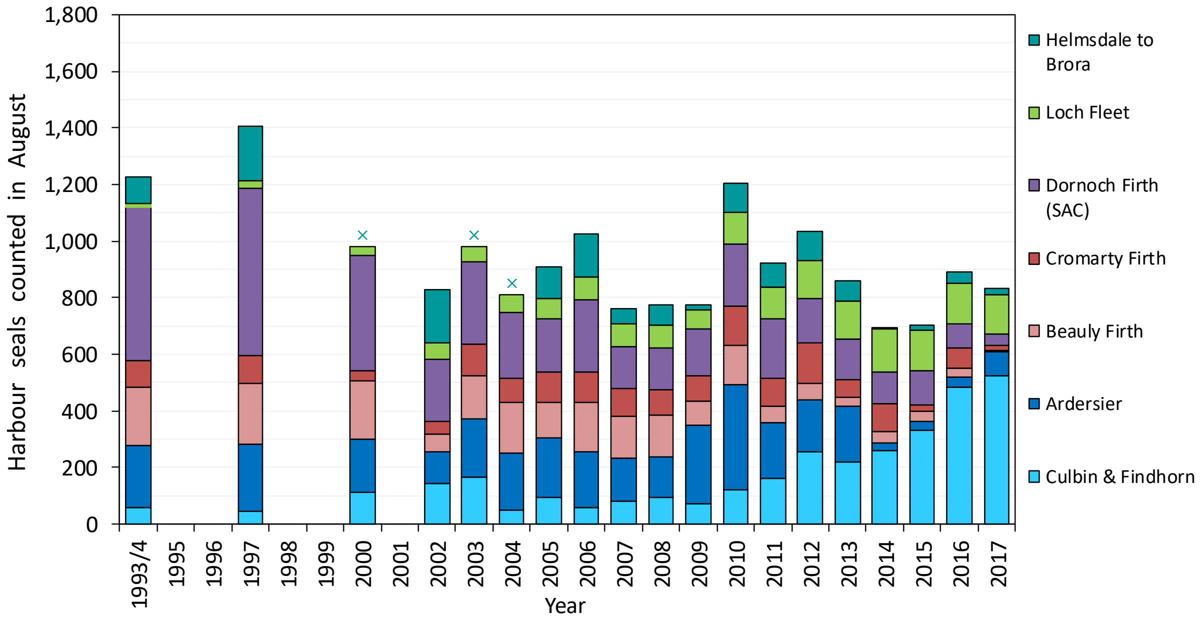

Figure 8. August counts of harbour seals in different areas of the Moray Firth, 1994-2017. The mean is shown for years with more than one survey. Data are from the Sea Mammal Research Unit. x: Helmsdale to Brora not surveyed in 2000, 2003 or 2004.

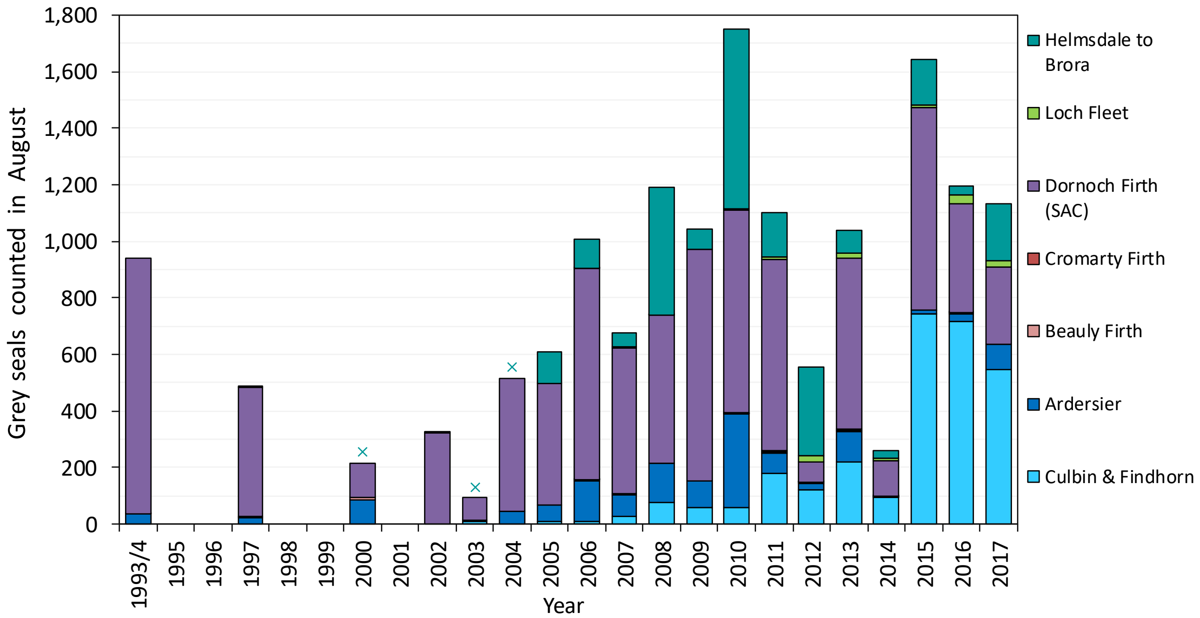

Figure 9. August counts of grey seals in different areas of the Moray Firth, 1994-2017. The mean is shown for years with more than one survey. Data are from the Sea Mammal Research Unit. x: Helmsdale to Brora not surveyed in 2000, 2003 or 2004.

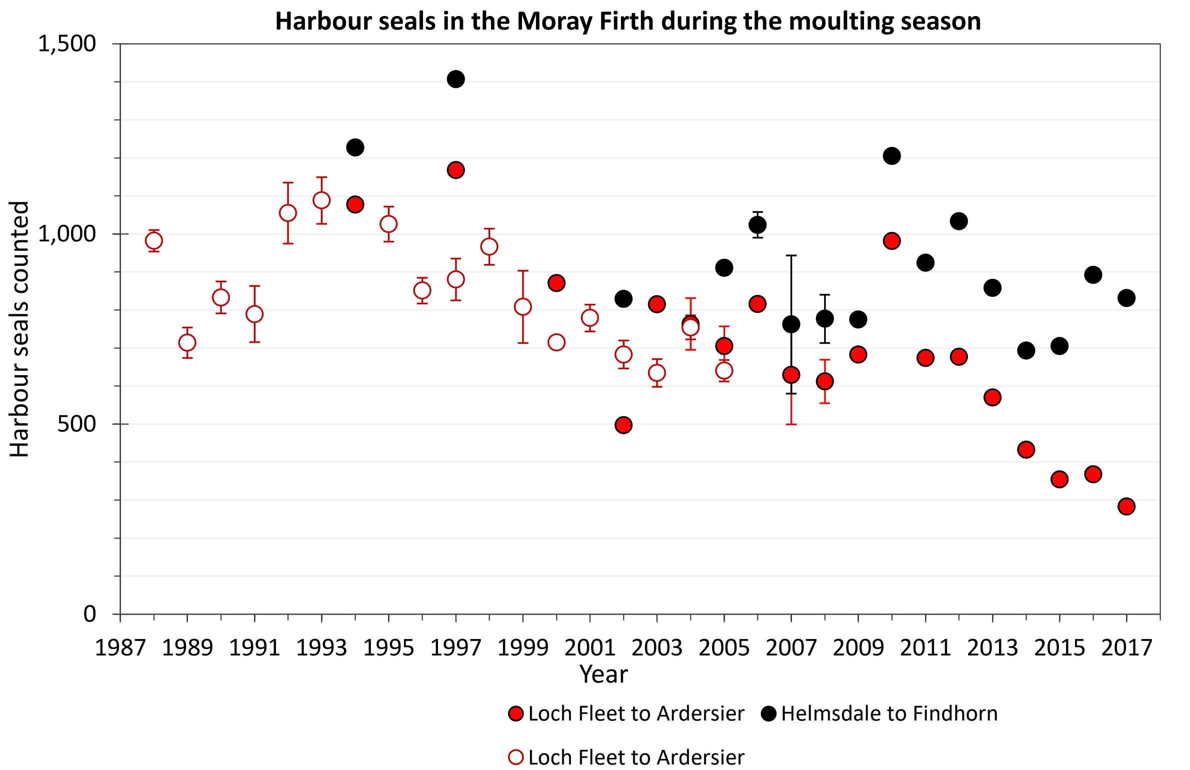

Figure 10. Counts of harbour seals in the Moray Firth during the moult season (August), 1988-2017. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

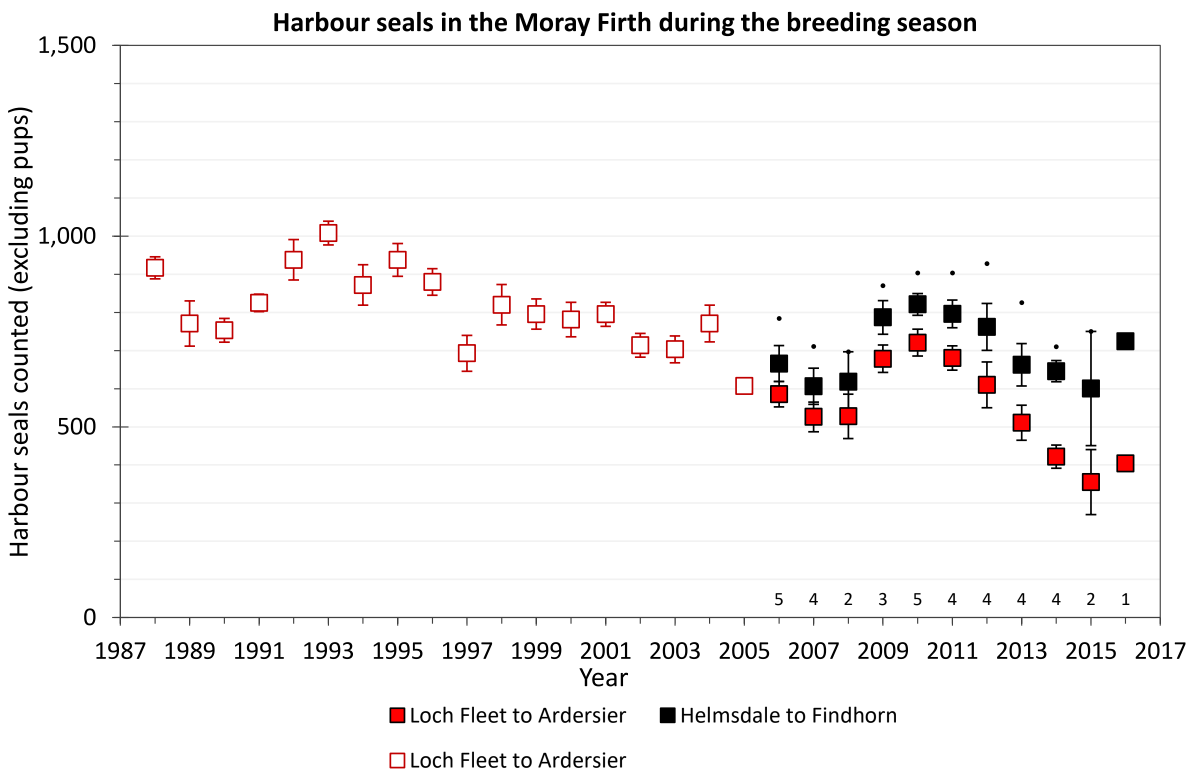

Figure 11. Counts of harbour seals in the Moray Firth during the breeding season (June/July), 1988-2016 (no survey in 2017). Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

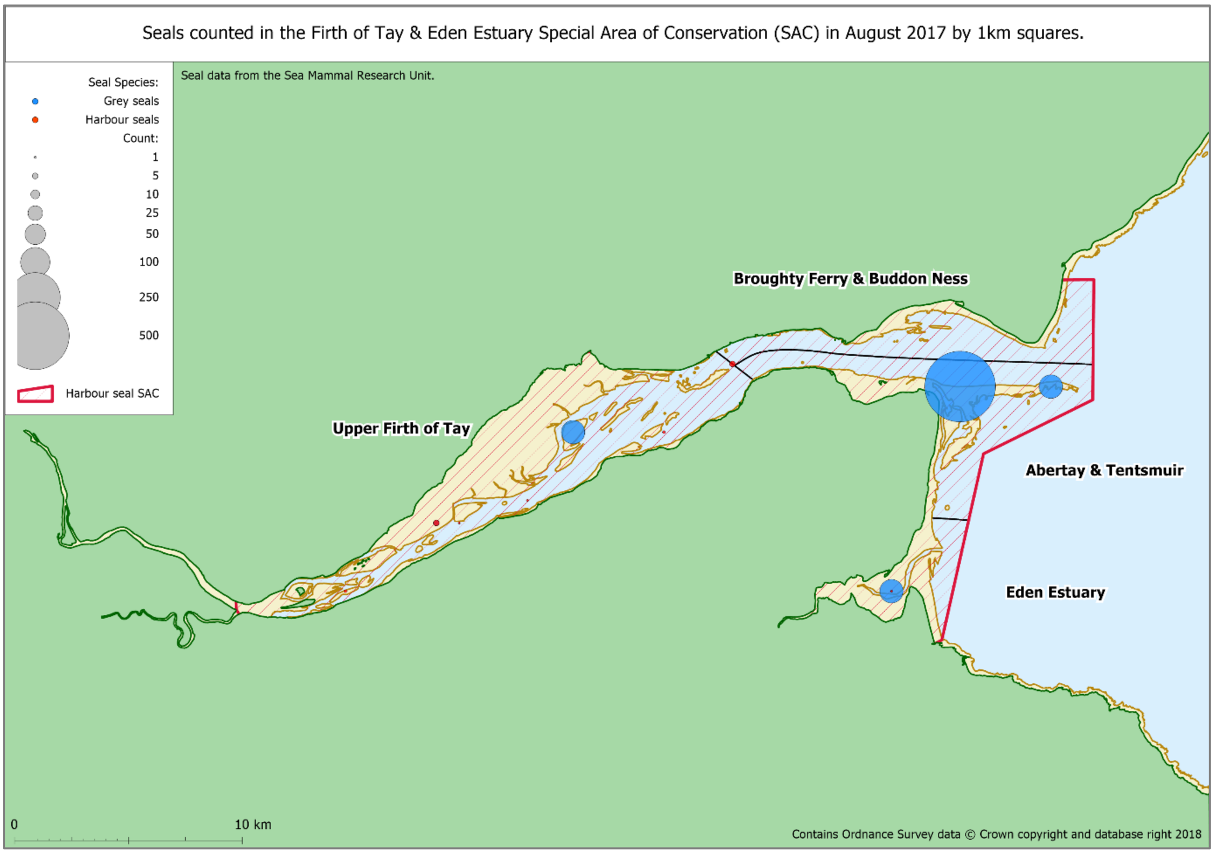

Figure 12. The distribution of harbour (red) and grey seals (blue) in the Firth of Tay and Eden Estuary on 9th August 2016.

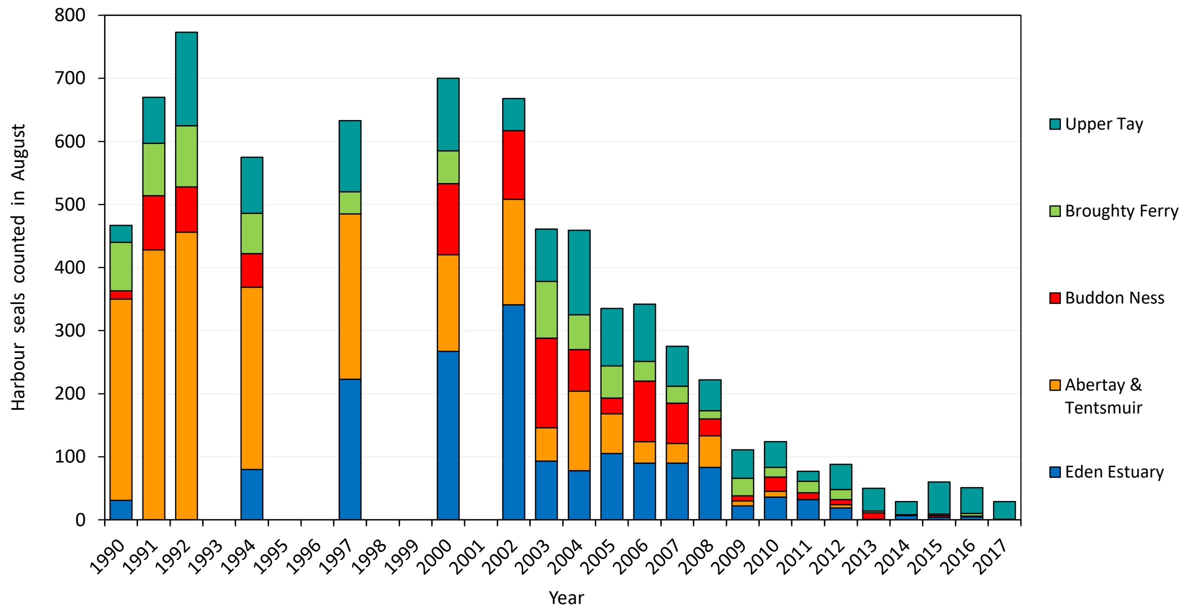

Figure 13. August counts of harbour seals in the Firth of Tay and Eden Estuary, 1990 to 2017.

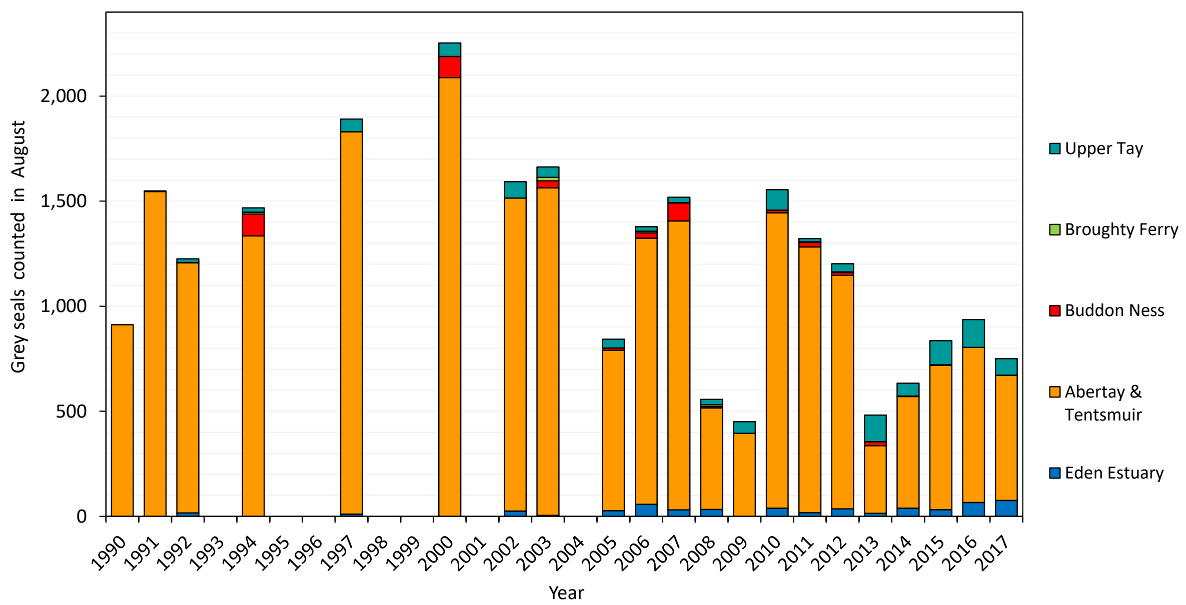

Figure 14. August counts of grey seals in the Firth of Tay and Eden Estuary, 1990 to 2017.

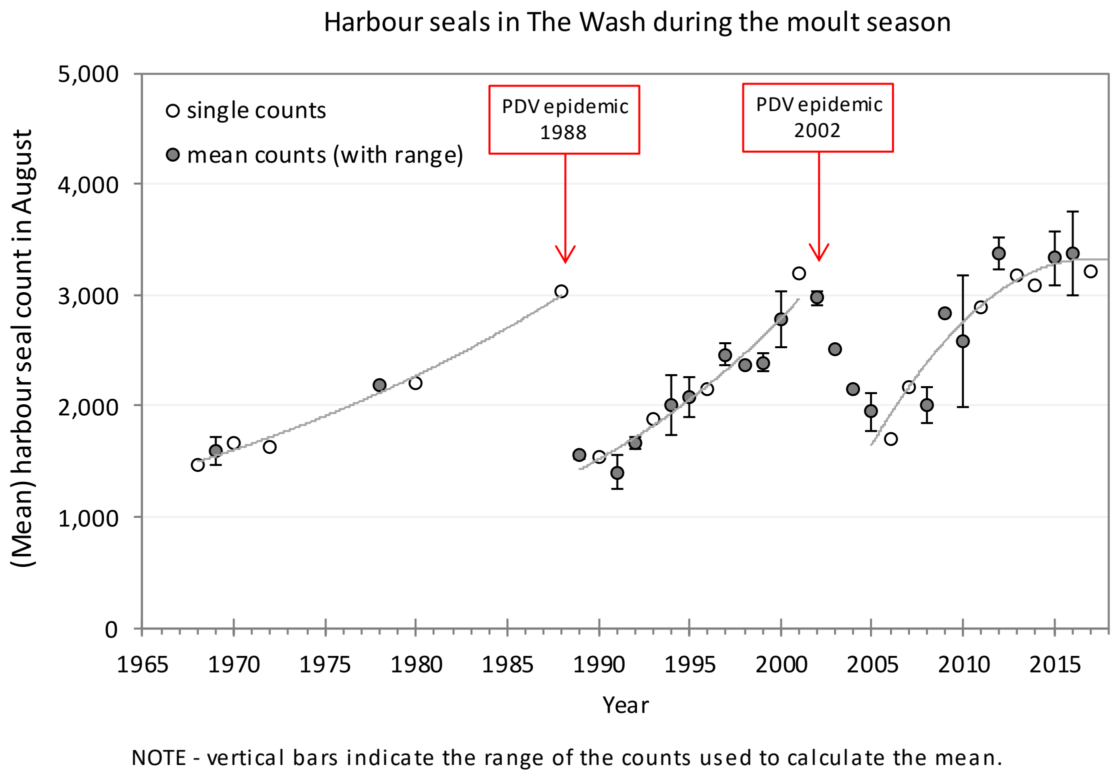

Figure 15. August counts of harbour seals in The Wash between 1967 and 2017 from surveys by the Sea Mammal Research Unit.

Preliminary report on the distribution and abundance of harbour seals (Phoca vitulina) during the 2017 breeding season in The Wash

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Abstract

This report presents preliminary results of a breeding season aerial survey of the harbour seal population along the English east coast between Donna Nook in Lincolnshire and Scroby Sands off the Suffolk coast on 4th July 2017.

The 2017 pup count for the Wash was 1268, this was 20% lower than the 2016 peak and 16%lower than the average of the peak counts for the preceding 5 years.

Although the counts appear highly variable, a simple exponential growth curve fitted to the counts suggests an average increase of 6.5% p.a. since 2001.

The ratio of pup counts to the all age population index has remained high, at around 0.4. The ratio was 2.3 times higher in 2017 than in 2001 suggesting that the large increase in apparent fecundity after 2001 has been maintained.

Introduction

The Wash is the largest estuary in England, and holds the majority of the English harbour seal (*Phoca vitulina*) population (Vaughan, 1978). This population has been monitored since the 1960s, using counts of animals hauled out as indices of population size. The initial impetus for monitoring this population was to investigate the effects of intensive pup hunting. When this hunt ceased in 1973 the monitoring program was reduced

In the summer of 1988 an epidemic of phocine distemper virus (PDV) spread through the European harbour seal population. More than 18000 seal carcasses were washed ashore over a 5 month period, many of them in areas with high levels of human activity (Dietz, Heide-Jorgensen & Härkönen, 1989). Mortality in the worst affected populations, in the Kattegat-Skagerrak, was estimated to be around 60% (Heide-Jorgensen & Härkönen, 1992). After the end of 1988, no more cases of the disease were observed until the summer of 2002, when another epidemic broke out (Harding *et al.*, 2002). Mortality in the European population during the 2002 epidemic was 47%, similar to that seen in 1988 (Harkonnen et al. submitted). However, on the English East coast the mortality rate estimated from pre and post epidemic air survey counts was much lower, approximately 22% (Thompson, Lonergan & Duck, 2005). The pre-epidemic population in 2002 was similar in size to the pre-epidemic population in 1988 and the disease hit the English population at the same time of year, so to date there is no clear explanation for the lower mortality rate.

In general, harbour seal population monitoring programmes have been designed to track and detect medium to long-term changes in population size. As it is difficult to estimate absolute abundance, monitoring programmes have usually been directed towards obtaining indices of population size. If consistent, such time series are sufficient to describe populations' dynamics and have been used to track the long-term status of the English harbour seal population. However, these indices are based on the numbers of individuals observed hauled out, so their utility depends on this being constant over time and unaffected by any changes in population density or structure.

Counts are usually carried out during the annual moult, when the highest and most stable numbers of seals haulout. Unfortunately such counts do not provide a sensitive index of current population health. It is generally accepted that breeding success is a more sensitive index. 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.

Most of the UK harbour seal population breeds on rocky shore habitats, where identifying and counting pups is both difficult and expensive. However, on the English east coast harbour seals breed on open sand banks where pups are relatively easy to observe and count. As a first step towards improving the monitoring program (to increase its sensitivity to short term changes), we identified a need for a baseline survey to map the distribution of breeding harbour seals. In June 2001 Fenland District Council commissioned Sea Mammal Research Unit to conduct an aerial survey 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 as well as 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. In 2008, 2010, 2015 and 2016 additional funds were provided to obtain time series' of counts within single breeding seasons to estimate the parameters of the pupping curve. In addition to confirming the date of the peak number of pups ashore and available to be counted, these results were expected to provide an estimate of the ratio between peak pup counts and pup production and provide an indication of the likely error on estimates of pup production. Large inter-annual differences in the temporal pattern of the pup counts have so far prevented fitting a standard birth curve. However, the data have allowed estimation of the timing of the peak number of pups ashore (Thompson et al, 2016) which confirm that the peak count occurs during the first week in July.

In addition to the pup counts, routine annual moult surveys cover the coast from Donna Nook in Lincolnshire to Scroby Sands off Great Yarmouth in Suffolk. There are known to be smaller groups of seals at various sites along the Essex and the north and east Kent coasts. These sites have been surveyed sporadically during the moult since 2002. In 2011 the Wash pup survey was extended to cover all sites between Scroby Sands and the Goodwin Sands off eastern Kent.

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% pa (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 (Comparison of regression coefficients for small samples with unequal residual variances (Bailey 1972)).

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 approximately 30% lower than the mean count in 2002. After 2006 the counts increased such that by 2010 and 2011 the numbers were similar to the pre epidemic counts. The 2017 count of 3203 was close to the average since 2010 suggesting little change. 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. The apparent lack of recovery or continued decline immediately after the epidemic contrasts with the rapid recovery of the Wadden Sea population that increased at around 12% p.a. from 2002 to 2011. Since 2014 the Wadden Sea population has shown clear signs of a slow-down in growth.

Previous breeding season surveys 2004 to 2016

Based on a preliminary assumption that the peak number of pups would be encountered at the end of June or beginning of July we have surveyed the breeding population between 27th June and 4th July in each year from 2004 to 2016. In addition in 2008, 2010, 2015 and 2016 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 10 animals were photographed using either colour reversal film in a vertically mounted 5X4" format, image motion compensated camera in 2004 & 2005 or with a hand held digital SLR camera since. The equipment and techniques are described in detail in 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.

2017 survey results

In 2017 we surveyed the entire coast and offshore banks from Donna Nook in Lincolnshire to Blakeney Point in Norfolk on 4th July. A total of 1289 pups and 3443 older seals (1+ age classes) were counted in the Wash. No pups were observed at Donna Nook, and only 1 pup was seen at Blakeney point. The Wash count compares with the previous peak counts of 1586 pups and 3905 older seals (1+ age classes) during the 2016 breeding season survey and 1351 pups and 4539 older seals (1+ age classes) during the 2015 breeding season survey. 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 3 shows the distribution of haulout sites in the Wash. Figure 4 shows the detailed route taken in The Wash during the 2017 breeding season survey. The GPS track in combination with the photographs and the observers' knowledge of locations of seals on the beach have been used to confirm the positions of all the sites given in Table 1. In some area, e.g. along the banks of the Lynn channel and the River Nene the groups are highly variable in size and location between surveys. In those cases the counts are pooled and a single count is given at a point in the centre of the distribution of observed groups. Figure 5 shows the counts of pups at each site obtained during the 2017 breeding season survey. Table 1 presents the data for 2015 to 2017. All the raw pup count data from 2004 to 2017 are presented in the appended Excel spreadsheet along with similar data from a survey carried out in 2001 for Fenland District Council and additional counts funded by Statoil in 2015 and 2016. Pups were widely distributed throughout the Wash. In 2017 pups were present at all occupied sites, with the exception of three sites with 5, 8 and 15 1+ age class animals. The proportion of pups in the counts at sites on the inner banks and in tidal creeks in the southern end of the Wash was generally high indicating the importance of these sites during the pupping season (Figure 6).

The 2017 survey produced the lowest pup count since 2011 (Table 2). It was 20% lower than the previous year and 16% lower than the mean of the previous five years. Figure 7 indicates that the trend in the counts can still be approximated by an exponential increase at an annual rate of increase of 6.5% p.a. since 2001. Despite the large inter-annual increase, inclusion of the 2017 count had little effect on the estimated growth trajectory.

The time series indicates that there was no evidence of a major decline in pup production after the 2002 PDV epidemic. The counts increased at around 9% p.a. during the 10 years following the PDV epidemic. This continued increase in pup production contrasts with the apparent decrease in the moult counts between 2003 and 2006 (Figure 1). The moult count increased between 2006 and 2010-2011, but the overall rate of increase for pup counts exceeded that of the moult population index counts (Figure 8). The different trajectories of the pup counts and the independent index of population size represented by the moult count means that the apparent productivity or apparent population fecundity has changed over the period (Figure 9). An index of productivity, i.e. the maximum pup count in each year divided by the moult count in that year shows a major increase from approximately 0.25 at the start of the series between 2001 and 2005 up to an average of 0.45 since 2006.

Discussion

The 2017 breeding season survey counts for both pups and associated 1+ age classes at the estimated peak of the breeding season were lower than during the previous five years. This may indicate that the apparent continuous increase since the first survey in 2001 is slowing or stopping. However, the high degree of variability in the pup counts and the inconsistencies in the shapes of the pupping curves seen in 2008, 2010, 2015 and 2016 means that it is still too early to confirm this apparent slow down. At present, the fitted exponential growth curve indicating a 6.5% p.a. increase should be seen as the best descriptor of the pup production trajectory. The increase in the counts during the annual moult, which are regarded as a more stable indicator of population size, also appears to have slowed after a period of growth since 2005. Again, the variability in these counts means it is too early to confirm this slow down.

Both the population and pup production estimates are high relative to the pre-epidemic counts obtained in 2001. Numbers over the last five years represent the highest populations recorded in the Wash. A reduction in growth rate is therefore not likely to indicate any adverse effects on the population

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 6.5% p.a. increase in pup count should be a reliable indication of the rate of increase of pup production.

The recent low intensity pup survey effort has produced two interesting results that highlight the advantage of a two pronged approach to seal monitoring. Although there was a well-documented decline of over 20% in the population as a result of the 2002 PDV epidemic and a continued decline in the moult counts until 2006, there was no apparent decrease in pup production between the pre and post epidemic counts. There are several potential explanations for the lack of a decline. If there was differential mortality, the number of adult females lost to the epidemic may have been small. Alternatively any decrease in adult female population could have been masked by variations in fecundity. Alternative scenarios involving temporary immigration were thought to be less likely.

Although the moult counts in Wash continued to decline after the 2002 epidemic they had clearly stabilised around 2005 or 2006 and then increased rapidly until around 2012. Interestingly, although the moult counts in recent years, 2012 to 2017 have been similar to the 2001 pre-epidemic count, the estimated peak pup count in 2017 was 2.3 times greater than in 2001 and the number of 1+age class animals counted in the breeding season was approximately double the 2001 estimate. If the moult count is a consistent index of the total population size then the apparent fecundity of the Wash population has increased by a factor of 2.5 since 2001.

The fact that pup production varies much more than the moult population index and more rapidly than could be accounted for by changes in adult female numbers, means that there must be wide fluctuations in fecundity and or short term immigration and emigration. At present we do not have information on pregnancy rates in any UK harbour seal population. Telemetry data from both the English and Netherlands populations suggests that there is limited movement between the two areas that is unlikely to be sufficient to account for these changes. However, to date the telemetry studies have been primarily targeted on seals in the early spring or post moult so there are few data on movements of female seals in the period immediately before pupping and none during the post pupping period. These studies therefore have little power to detect such movements.

The observed large increase in pup production in the absence of an equivalent increase in the moult counts is unexplained at present. It could be generated in various ways:

1. Immigration of a large number of adult females. The absence of any substantial populations on the east coast means that the source of seals would have to be either the Wadden Sea or the Scottish East coast. Data on seal movements suggest that immigration from Scotland is unlikely and that movement between the English and European populations is unlikely to be frequent enough to explain these changes.
2. A continual increase in fecundity. This seems unlikely given the scale of the increase since 2005, although rapid changes in both directions may suggest wide variation in fecundity rates.

At present we have no information to allow us to differentiate clearly between these options and it is likely that a combination of some or all could be operating. However, in each case the explanation would represent a major change in harbour seal demographics. Targeted studies of survival and fecundity in Wash harbour seals would be needed to identify the likely causes of these changes.

The results of the 2001 pup survey suggested that there had been a significant shift in spatial distribution of breeding seals over the preceding 30 years. The 2004 and 2005 distribution was similar to the 2001 distribution, suggesting that there has been a real shift in distribution with a much higher proportion of pups being found in the south eastern corner of the Wash. At present we do not know why this distributional change is occurring but the results through to 2017 indicate that the relative importance of the SE corner of the Wash is still increasing.

References

BOWEN, W.D., BONESS, D.J., & IVERSON, S.J. (1999) Diving behaviour of lactating harbour seals and their pups during maternal foraging trips. *Canadian Journal of Zoology - Revue Canadienne de Zoologie*, **77**, 978-988.

HIBY, A. R., THOMPSON, D. & WARD, A. J. (1987). Improved census by aerial photography - an inexpensive system based on non-specialist equipment. *Wildl. Soc. Bull.* **15**, 438-43.

LONERGAN, M., DUCK, C.D., THOMPSON, D., MACKEY,B.L., CUNNINGHAM,L. & I L BOYD (2007) Using sparse survey data to investigate the declining abundance of British harbour seals."; *Journal of Zoology*; 271(3):261-269

REIJNDERS, P.J.H. & FRANSZ, H.G. 1978. Estimation of birth rate and juvenile mortality from numbers of juveniles in a seal population with normally dispersed reproduction. I.C.E.S. C.M. 1978/N:7

REIJNDERS, P.J.H. (1978) Recruitment in the harbour seal (*Phoca vitulina*) population in the Dutch Wadden Sea. Neth. J. Sea. Res. **12(2)**: 164-179

THOMPSON, D, LONERGAN, M & DUCK, C.D. (2005) Population dynamics of harbour seals (*Phoca vitulina*) in England: growth and catastrophic declines. *J. Appl. Ecol*. 42 (4): 638-648

THOMPSON, D., ONOUFRIOU, J., & PATTERSON, W. (2016) REPORT ON THE distribution and abundance of harbour seals (phoca vitulina) during the 2015 and 2016 breeding seasons in The Wash. Report number: SMRUC-DOW-2016-016, DECEMBER 2016 (UNPUBLISHED).

VAUGHAN, R. W. (1978). A study of common seals in the Wash. *Mammal Rev.* **8**, 25-34.

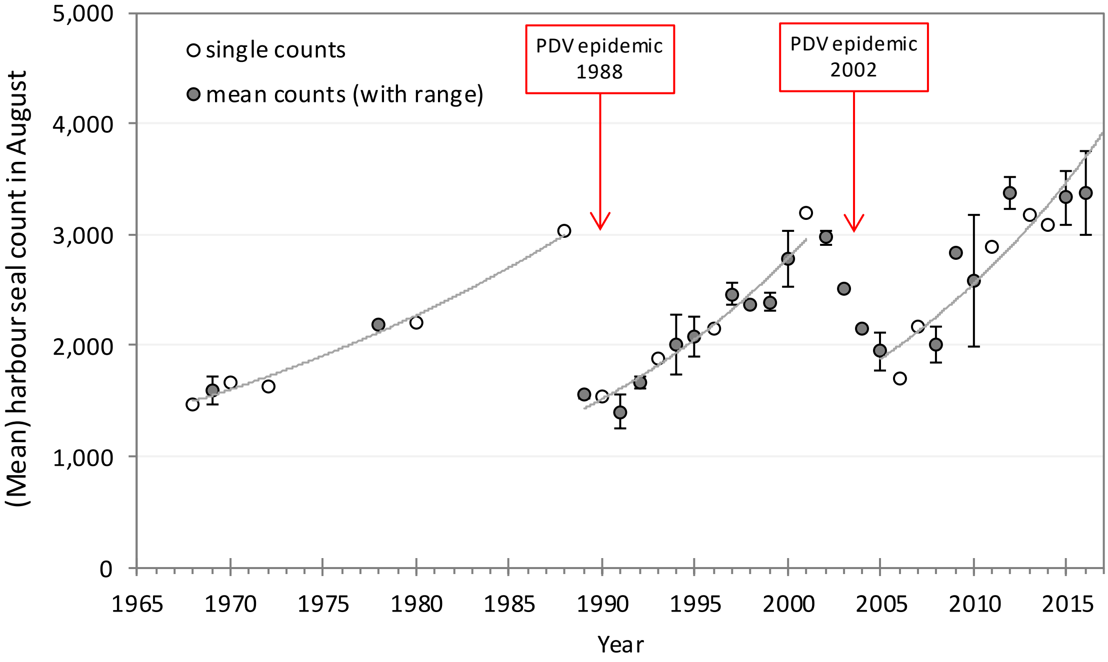
Table 1. Counts of harbour seal pups and 1+ age classes in the Wash from 2001 to 2017.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351	1586	1289
1+ age classes	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	4539	3905	3443

Table 2. Counts of harbour seal pups and 1+ ages at haulout sites in the Wash, 2015-2017.

			4-July 2017		2-July 2016		27-June 2015	
			harbour seals		harbour seals		harbour seals	
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups
Inner & Outer Knock	53.082	0.364	81	15	157	31	193	22
Inner Dogs Head	53.036	0.376	24	3	44	7	37	2
Friskney	53.034	0.309	69	15	81	20	81	18
Friskney Middle	52.997	0.225	32	17	8	7	79	26
Friskney South	52.953	0.119	9	2	22	15	23	8
Long Sand N/E End	53.019	0.334						
Long Sand Middle	53.005	0.297	59	15	101	22	84	15
Ants	52.978	0.264	0	0	1	0		
Rodger	52.963	0.217	5	0	1	0	4	1
NW total			279	67	415	102	501	92
Black Buoy	52.924	0.117	34	1	41	8	51	8
Boston Channel	52.900	0.029	143	35	180	88	319	65
Herring Shoal	52.904	0.064	49	4	43	12	100	14
Toft East	52.932	0.153	16	3	19	6	32	2
Toft West	52.920	0.133	15	0			3	0
Mare Tail	52.917	0.152			28	11	5	4
Main End	52.907	0.193					70	22
Gat End	52.912	0.203						

Gat Sand	52.935	0.198	53	5	44	8	40	7
SW total			310	48	355	133	620	122
			4-July	2017	2-July	2016	27-June	2015
			harbour	seals	harbour	seals	harbour	seals
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups
Puff	52.899	0.121	32	9	55	20	50	22
Kenzies Creek	52.900	0.106	148	93	159	110	185	97
Fleet Haven Marsh	52.877	0.152						
Fleet Haven Middle	52.884	0.157	173	114	295	156	396	139
Fleet Haven Lower	52.909	0.157						
Fleet Haven Mouth	52.922	0.158	48	26				
Evans Creek	52.878	0.169	182	89	101	58	104	58
Dawesmere Creek	52.859	0.191	46	28	110	35	162	46
Creeks total			629	359	720	379	897	362
OWMK 1	52.875	0.233	24	12				
OWMK 2	52.867	0.250	7	2				
Nene Channel 1	52.875	0.220			104	64	169	20
Nene Channel 2	52.867	0.216	198	60	223	68	65	24
Nene Channel 3	52.860	0.214	47	16	88	55	28	8
Nene Channel 4	52.845	0.206	83	37			2	1
Nene Channel 5	52.827	0.219					127	26
IWMK	52.852	0.235	40	19	28	20	135	56
Scalmans Sled	52.857	0.258	74	43	159	87		
Breast Sand	52.828	0.275	78	58	137	71	174	98
Thief West	52.878	0.273	19	1	37	5	23	2
Thief East	52.878	0.273	6	1	5	1	3	2
Seal Sand (W)/Black Shore	52.875	0.312	113	42	51	22		
Seal sand (E)	52.881	0.352	148	23	245	60	178	56
Seal Sand/Daseleys	52.882	0.351	79	31	138	68		
Hull Sand	52.840	0.307	719	193	563	232	558	198
Bull Dog Sand	52.866	0.378	222	49	38	29	133	73
Pandora	52.862	0.355	87	23	235	60	17	0
Black Guard	52.883	0.372	3	0				
Old Bell	52.900	0.372			22	2		
Stylemans Middle	52.887	0.380	8	0	15	7		
Pie Corner	52.834	0.327	30	7			78	47
Lynn Channel	52.810	0.367	276	177	176	121	521	164
Sunk Sand	52.975	0.493	5	0	6	0	9	0
East total			2266	794	2270	972	2220	775
Wash Total			3484	1268	3760	1586	4238	1351



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

Figure 1. Aerial survey counts of harbour seals in the Wash during the annual moult in August for the period 1968 to 2016. Dramatic declines in 1988 and 2002 were the result of epidemics of Phocine Distemper Virus. Fitted lines are exponential growth curves.

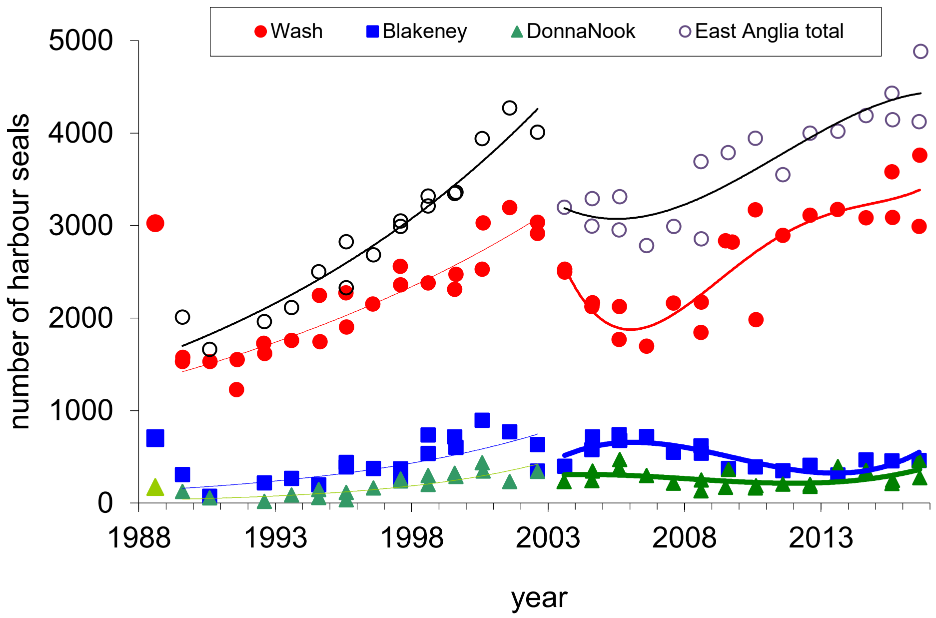


Figure 2. Aerial survey counts of harbour seals at major sites in East Anglia during recovery from the 1988 and 2002 PDV epidemics. 1989 to 2002 fitted line is a simple exponential. The fitted polynomial from 2003 is included simply for illustration.

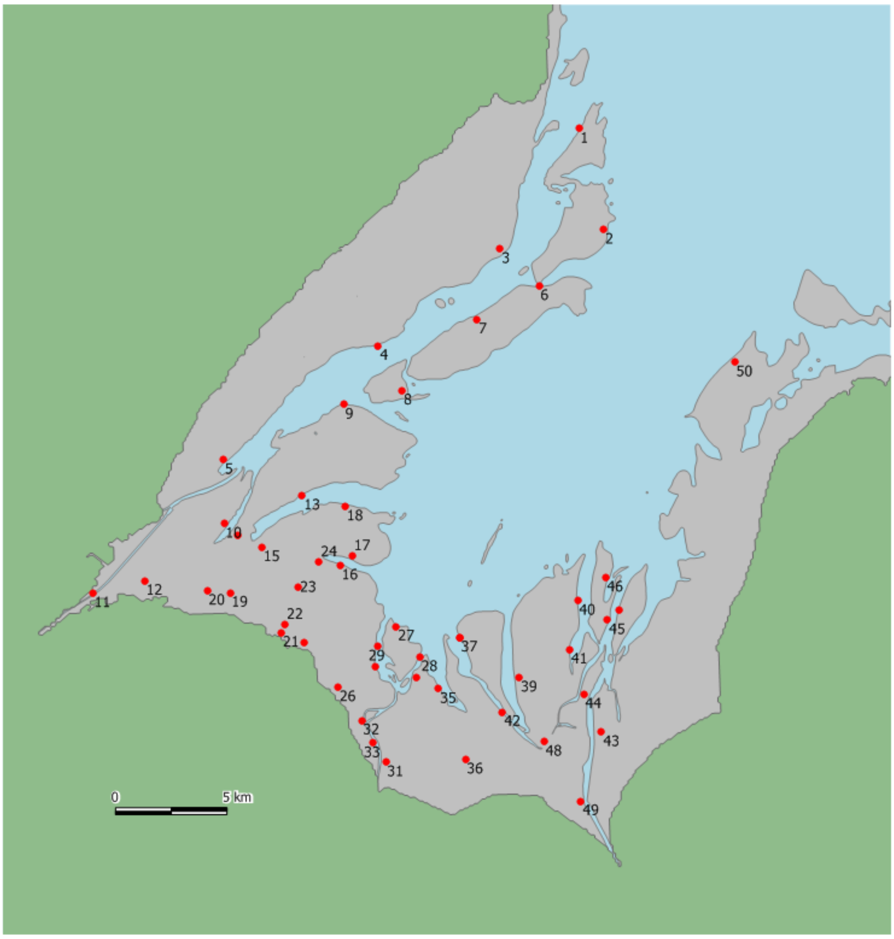


Figure 3. Locations of seal haulout sites during the pupping season in the Wash. Numbers correspond to counts in Table 1.

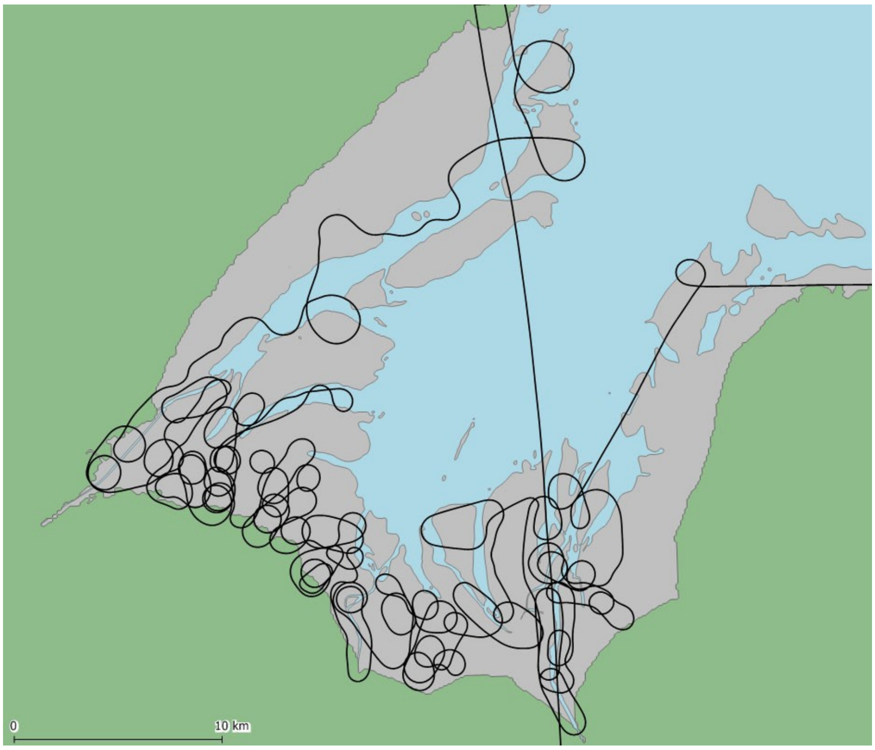


Figure 4. Survey flight path over the Wash during the breeding season survey (4/7/2017). The approximate locations of the groups are derived from a combination of the positions of the tight turns and our observations of the location of seals within the turn.

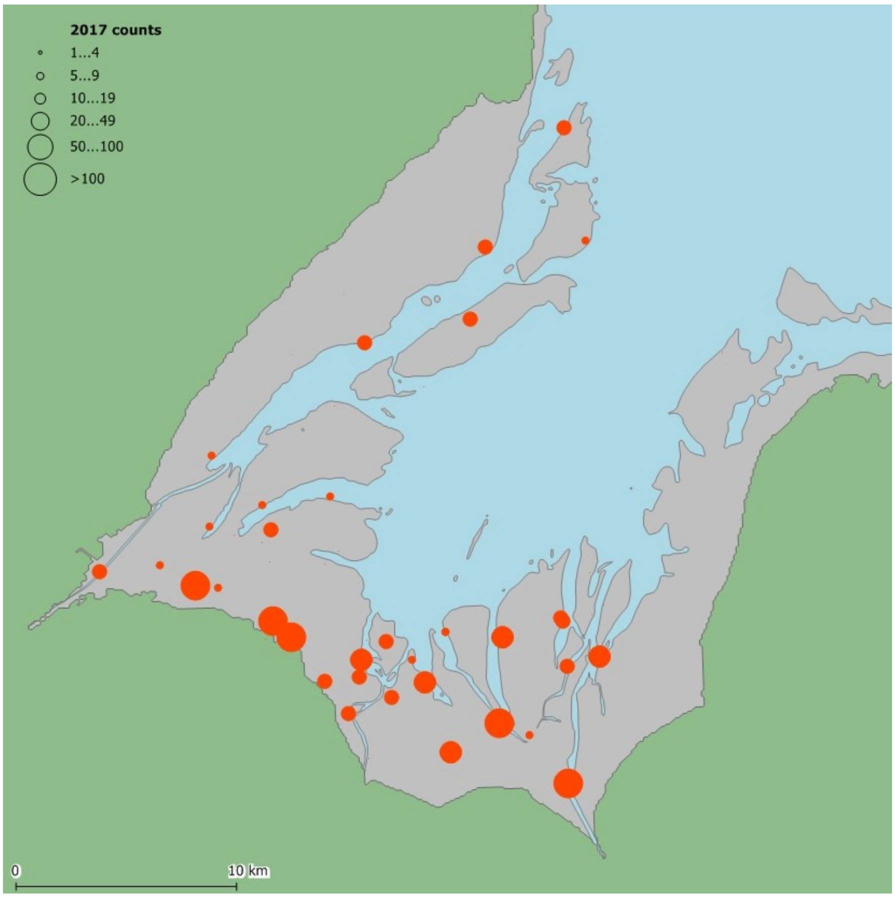


Figure 5. Distribution of pups in the Wash on 4/7/2017. Numbers of pups are represented by the areas of the circles on each site. Locations given to nearest 50m. Names of haulout sites together with latitudes and longitudes and numbers of seals at each site are given in Table 1 and Figure 3.

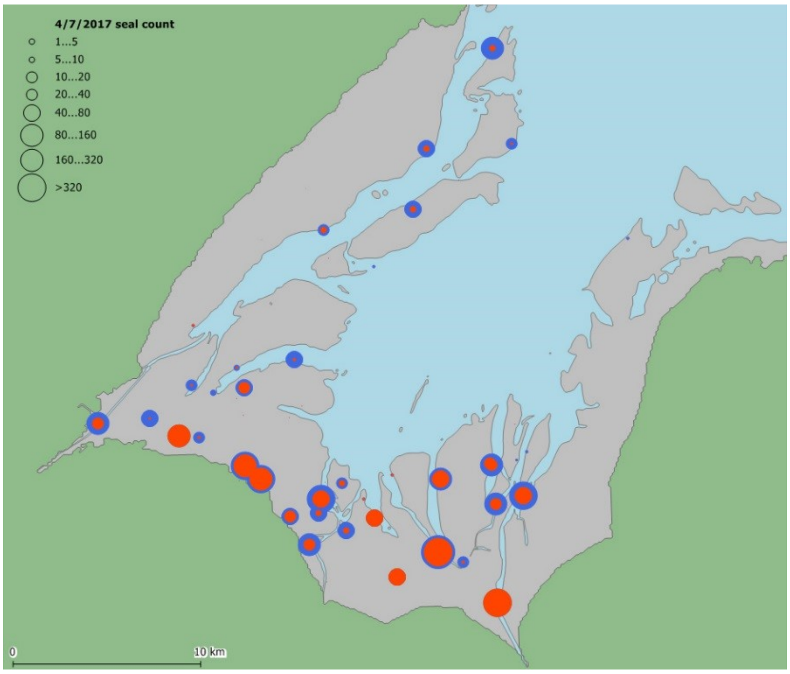


Figure 6. Distribution of harbour seal pups (RED) and older seals (1+ age classes BLUE) in the Wash on 4/7/2017. Numbers of seals are represented by the areas of the circles on each site. At four sites, shown as simple red dots, the number of pups equalled or slightly exceeded the number of older seals.

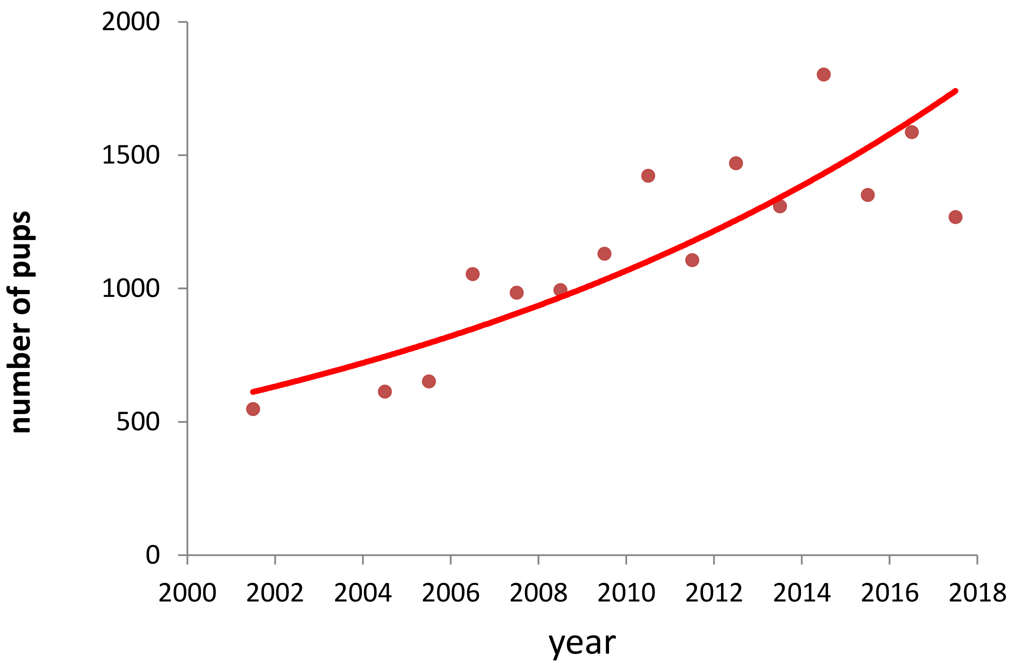


Figure 7. Maximum counts of pups in The Wash between 2001 and 2017. The fitted line is a simple exponential. Pup counts have increased at an average rate of approximately 6.5% p.a.

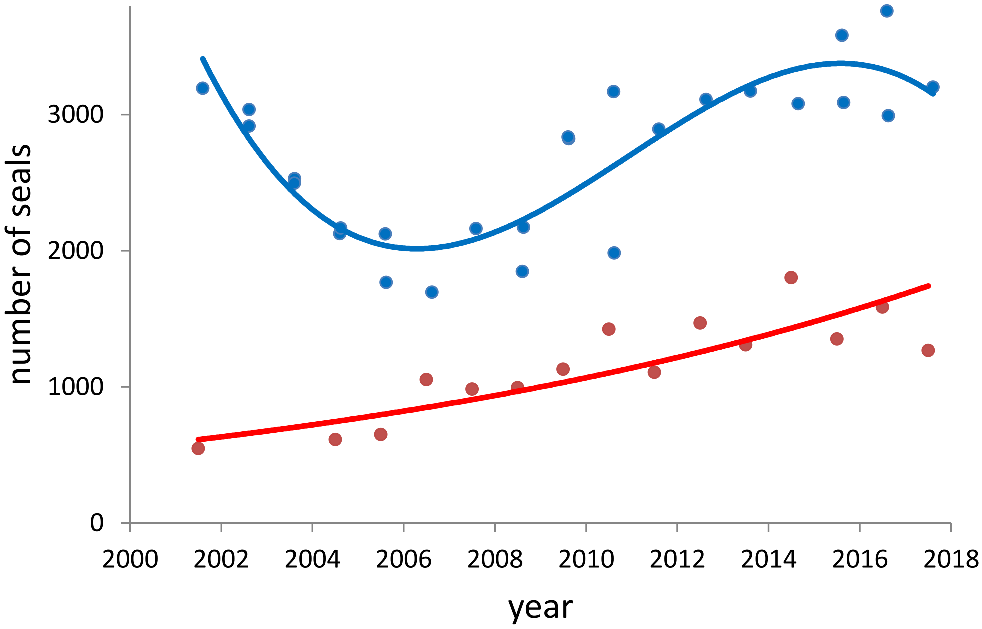


Figure 8. Maximum counts of pups in The Wash between 2001 and 2017 alongside the annual moult count over the same period.

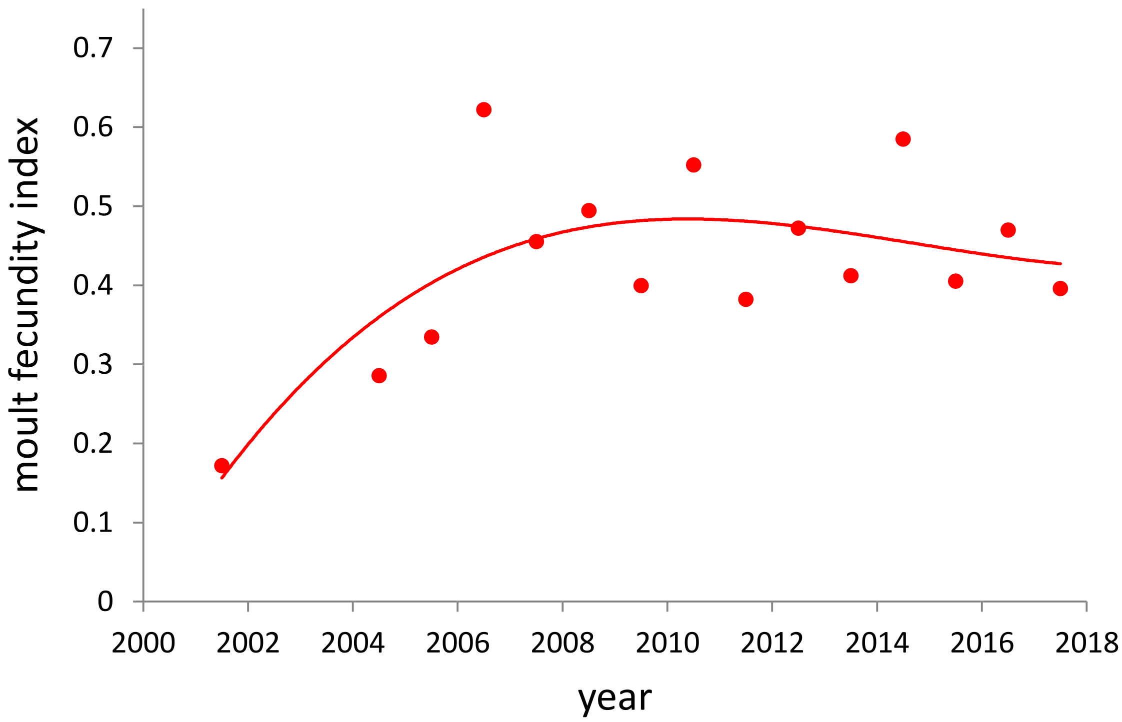


Figure 9. An index of fecundity, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size).has increased over the period of surveys. The fitted line is a cubic polynomial through the moult counts for illustration only.

Provisional Regional PBR values for Scottish seals in 2019

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Abstract

This document estimates PBR values for the grey and harbour seal "populations" that haul out in each of the seven Seal Management Areas in Scotland. Sets of possible values are tabulated for each area using the equation in Wade (1998) with different values of that equation's recovery factor. A value is suggested for this parameter in each population, the resulting PBR is highlighted, and a rationale is provided for each suggestion. The PBR values are calculated using the latest confirmed counts in each management area.
Changes since last year: The latest harbour seal survey counts for the Western Isles management region was approximately 25% higher than the previous estimate, resulting in a 25% higher PBR for harbour seals in that management region. The recovery factor (F_R) for harbour seals in the West of Scotland region was increased from 0.7 to 1.0 to make it consistent with F_R values for grey seals. The resulting PBR was 42% higher than previous estimates. Recovery factors have been held constant for both species in all other management regions.
The grey seal count for the Western Isles was approximately 40% higher than the previous estimate, resulting in a 40% higher PBR for grey seals in that management region.

Introduction

Potential Biological Removal is a widely used way of calculating whether current levels of anthropogenic mortality are consistent with reaching or exceeding a specific target population, chosen to be the Optimum Sustainable Population. It is explicitly given, in an amendment to the US Marine Mammal Protection Act, as the method to be used for assessing anthropogenic impacts in the waters around that country. The method has been supported by simulations demonstrating its performance under certain assumptions (Wade 1998). The formulation of the equation allows for small anthropogenic takes from any population, however much it is depleted or fast it is declining. Scottish Government uses PBR to estimate permissible anthropogenic takes for each of the ten seal management regions and uses this information to assess licence applications for seal control and for other licensable marine activities.

Materials and Methods

The PBR calculation:

PBR = Nmin.(Rmax/2).FR
where:

PBR is a number of animals considered safely removable from the population.
Nmin is a minimum population estimate (usually the 20th percentile of a distribution)
Rmax is the population growth rate at low densities (by default set 0.12 for pinnipeds), this is halved to give an estimate of the growth rate at higher populations. This estimate should be conservative for most populations at their OSP.

FR is a recovery factor, usually in the range 0.1 to 1. Low recovery factors give some protection from stochastic effects and overestimation of the other parameters. They also increase the expected equilibrium population size under the PBR.
The approach and calculation is discussed in detail in Wade (1998).
Data used in these calculations
Nmin values used in these calculations are from the most recent summer surveys of each area, for both species:

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

- Grey seals: Analysis of telemetry data from 107 grey seals tagged by SMRU between 1998 and 2016 shows that around 23.9% (95% CI: 19.2 - 28.6%) were hauled out during the survey windows (Russell et al. 2016 SCOS-BP 16/03). The 20th centile of the distribution of multipliers from counts to abundances implied by that data is 3.86. This represents a 50% increase over the previous estimates due to a revised estimate of the proportion of time seals spend hauled out and available to be counted during the aerial survey window. This estimate is substantially lower than the estimate used in calculations prior to 2017 and has narrower confidence intervals. In combination these factors have raised the Nmin value and hence the PBR estimate for any given grey seal count.

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

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) Western Isles (F_R = 0.5)

Population was apparently undergoing a protracted but gradual decline during the 2000s, but the 2011 count was close to the pre-decline numbers and a trend analysis suggested no significant change since 1992. 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. The most recent count for the Western Isles was 25% higher than the previous count. On that basis there may be an argument for increasing the recovery factor to bring it in line with the other western Scottish management areas. However, there is an existing conservation order in place for the management unit and it is therefore recommended that the recovery factor is left at 0.5 and reviewed again when a new count is available for the larger, adjacent West Scotland region.

4) West Scotland (F_R = 1.0)

The population is largely closed, likely to have limited interchange with much smaller adjacent populations. The most recent count was the highest ever recorded and the population is apparently stable or increasing.

4) South West Scotland (F_R = 0.7)

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

5) Moray Firth (F_R= 0.1)

Counts for 2016 in the Moray Firth were 7% lower than in 2016. This follows a large increase the previous year and confirms the absence of any overall trend over the past 15 years. The neighbouring Orkney and Tay populations are continuing to undergo unexplained rapid and catastrophic declines in abundance. Data available from electronic telemetry tags suggest there is movement between these three areas. In the absence of a significant increase in the Moray Firth counts it is recommended that the F_R should be left at its previously recommended value of 0.1.

Grey seals

All regions (F_R = 1.0)

There has been sustained growth in the numbers of pups born in all areas over the last 30 years. All UK populations are either increasing or apparently stable at the maximum levels ever recorded and therefore assumed to be at or close to their carrying capacities (Lonergan et al. 2011b). Available telemetry data and the differences in the regional patterns of pup production and summer haul-out counts (Lonergan et al. 2011a) also suggest substantial long-distance movements of individuals.

References

Bowen WD, McMillan J, Mohn R (2003) Sustained exponential population growth of grey seals at Sable Island, Nova Scotia. ICES Journal of Marine Science 60**:** 1265-1274

Lonergan M, Duck CD, Thompson D, Mackey BL, Cunningham L, Boyd IL (2007) Using sparse survey data to investigate the declining abundance of British harbour seals. Journal of Zoology 271: 261-269

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

Lonergan M, Thompson D, Thomas L, Duck C (2011b) An Approximate Bayesian Method Applied to Estimating the Trajectories of Four British Grey Seal (*Halichoerus grypus*) Populations from Pup Counts. Journal of Marine Biology 2011, 7p.

Lonergan M, Duck C, Moss S, Morris C, Thompson D (2012) 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 23:135-144

Reijnders, P.J.H., Brasseur, S.M.J.M., Tougaard, S., Siebert, U., Borchardt, T. and Stede, M. (2010). Population development and status of harbour seals (*Phoca vitulina*) in the Wadden Sea. NAMMCO Scientific Publications 8**:** 95-106

Russell, D.J.F., Duck, C.D., Morris, C.D. & Thompson, D. 2016 Independent estimates of grey seal population size: 2008 and 2014. SCOS Briefing Paper 2016/03. Available at: http://www.smru.standrews.ac.uk/documents/scos/SCOS_2016.pdf pp 61-68.

Wade PR (1998) Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14(1):1:37

Boyd IL, Thompson D, Lonergan M (unpublished) Potential Biological Removal as a method for setting the impact limits for UK marine mammal populations. Draft briefing paper to 2009 SCOS meeting.

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

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

.

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 2019

Seal Management Area	2008-2017 count	Survey years	N_{min}	PBRs based on recovery factors F_R ranging from 0.1 to 1.0										selected F_R	PBR
				0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0		
1 Southwest Scotland	1,200	(2015)	1,200	7	14	21	28	36	43	50	57	64	72	0.7	50
2 West Scotland	15,889	(2014-2015; 2017)	15,889	95	190	286	381	476	572	667	762	858	953	0.7	953
3 Western Isles	3,533	(2011; 2014; 2017)	3,533	21	42	63	84	105	127	148	169	190	211	0.5	105
4 North Coast & Orkney	1,349	(2014; 2016)	1,349	8	16	24	32	40	48	56	64	72	80	0.1	8
5 Shetland	3,369	(2015)	3,369	20	40	60	80	101	121	141	161	181	202	0.1	20
6 Moray Firth	879	(2008; 2011; 2016; 2017)	879	5	10	15	21	26	31	36	42	47	52	0.1	5
7 East Scotland	346	(2013; 2015-2017)	346	2	4	6	8	10	12	14	16	18	20	0.1	2
SCOTLAND TOTAL	**26,565**	(2008; 2011; 2013-2017)	**26,565**	**158**	**316**	**475**	**634**	**794**	**954**	**1,112**	**1,271**	**1,430**	**1,590**		1143

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

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 2019

	2008-2017			PBRs based on recovery factors F_R ranging from 0.1 to 1.0										selected	
Seal Management Area	**count**	**Survey years**	N_{min}	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	F_R	**PBR**
1 Southwest Scotland	374	(2015)	1,444	8	17	25	34	43	51	60	69	77	86	1.0	86
2 West Scotland	5,267	(2014-2015; 2017)	20,331	121	243	365	487	609	731	853	975	1,097	1,219	1.0	1,219
3 Western Isles	5,772	(2011; 2014; 2017)	22,280	133	267	401	534	668	802	935	1,069	1,203	1,336	1.0	1,336
4 North Coast & Orkney	9,714	(2014; 2016)	37,496	224	449	674	899	1,124	1,349	1,574	1,799	2,024	2,249	1.0	2,249
5 Shetland	1,558	(2015)	6,014	36	72	108	144	180	216	252	288	324	360	1.0	360
6 Moray Firth	1,189	(2008; 2011; 2016; 2017)	4,590	27	55	82	110	137	165	192	220	247	275	1.0	275
7 East Scotland	3,652	(2013; 2015-2017)	14,097	84	169	253	338	422	507	592	676	761	845	1.0	845
SCOTLAND TOTAL	**27,526**	(2008; 2011; 2013-2017)	**106,250**	**633**	**1,272**	**1,908**	**2,546**	**3,183**	**3,821**	**4,458**	**5,096**	**5,733**	**6,370**		**6,370**

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

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

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

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

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

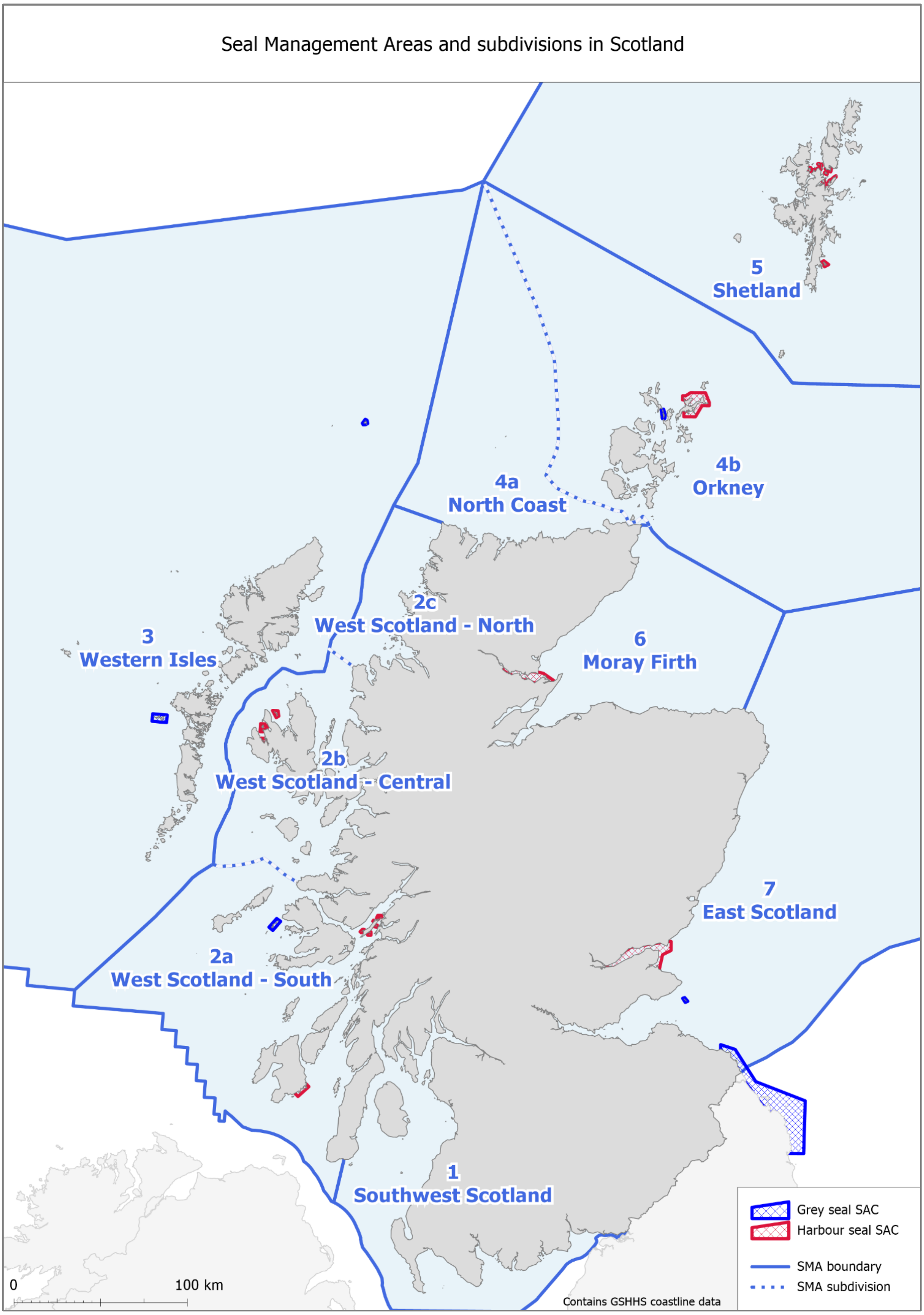

Figure 1.Seal management areas in Scotland. For purposes of PBR calculations West Scotland is treated as a single management area.