Scientific Advice on Matters Related to the Management of Seal Populations: 2019

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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 2019, 32 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 6,700 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 65,400 (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 2019. The pup production model is currently under review and being updated. The population model provided an estimate of **152,800 (approximate 95% CI 135,300-173,800)** UK grey seals (1+ aged population) in 2018.

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

Location	Pup production in 2016
England	**8,550**
Wales	**2,000**
Scotland	**54,750**
Northern Ireland	**100**
Total UK	**65,400**

There is evidence for regional differences in grey seal demographics but detailed information on vital rates is 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 (2015-2018) gives a total of 33,000 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 2018 of **45,800 (approximate 95% CI: 37,500-61,100)**.

Overall, the UK population has increased since the late 2000s and is close to the previous high observed during the 1990s. 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 Phocine Distemper Virus (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), but now show clear signs of reaching an asymptote.

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 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. In Northern Ireland, populations appear to have declined slowly throughout.

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

Location	Most recent count (2015-2018)
England	**5,100**
Wales	**<10**
Scotland	**26,900**
Northern Ireland	**1,000**
Total UK	**33,000**

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 Scottish 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 Southwest Scotland SMU was approximately 40% higher, for both harbour and grey seals, than the previous estimate, resulting in a 40% higher PBR for both species in that management region. Grey seal counts in West Scotland and Moray Firth SMUs were lower reducing the grey seal PBRs by 20% and 36% respectively.

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. There has been good progress in understanding how seals use tidally energetic habitats and on how seals respond to the presence of turbines at ranges of 10s to 100s of metres but understanding the fine scale underwater movements (at a scale of metres) of individual seals around operating turbines remains a critical knowledge gap.

Interactions with Fisheries

SCOS discussed the current state of knowledge on interactions between seals and fisheries, specifically examining the question of impacts of seal populations on fish stocks. SCOS consider that there are three aspects to this question.

1) *Are seal populations increasing in areas where fish stocks are declining*? SCOS noted that seal population increases over the past decade have been confined to the Central and Southern North Sea. Consumption by seals as a percentage of estimated stock size in the North Sea was estimated to be small and North Sea cod stocks rose steadily from 2006 to 2017, which would not be the case if seal predation was significant and increasing.

2) *What are the diets of seals in UK waters?* Both grey and harbour seals are known to consume a wide range of prey including commercially exploited species such as sandeels, cod, other gadoids, flatfish, herring and mackerel, and a large number of non-commercial species including benthic fish such as dragonet

3) *Is there evidence that seal predation is having detectable effects on fish mortality?* Seal predation can have significant impacts on particular fish stocks. For example grey seal predation has been identified as a major source of mortality on cod stocks in the North West Atlantic and off Western Scotland, and in the Wadden Sea, harbour seal predation has been shown to be a major contributor to demersal fish mortality.

SCOS discussed the likelihood that seal predation was a factor in the declines in salmon rod and line catches in 2018. As seal populations around Scotland have not increased significantly over the past decade there is unlikely to be a direct link between population size and the rapid decline in rod and line catches of salmon in 2018.

The issue of seal bycatch in commercial fisheries was discussed. The most recent estimate of seal bycatch in UK fisheries is 474 animals (95% CI 354-911). 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 2017 estimate, the estimated bycatch levels in the Celtic Sea in 2018 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 2019. 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). Briefing papers which provide additional scientific background for the advice are appended to the main report.

SMRU's long-term funding has recently seen a substantial reduction. 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. 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.

SCOS 2019: Questions from Marine Scotland, Department for Environment, Food and Rural Affairs and Natural Resources Wales.

Questions for SCOS 2019 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.

Seal Populations

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

Based on the 2016 pup production estimates, the total UK grey seal population of at the start of the 2018 breeding season (before pups are born) is estimated at 152,800 individuals (approximate 95% CI 135,300-173,800). Details are provided in SCOS-BP 19/01 and below, and estimates by country are presented in Tables 1 & 2.

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 these aerial surveys together with the 2016 estimates from the annually ground counted sites in eastern England, produced an estimate of pup production of 58,700. An additional 6,700 pups were estimated to have been born at less frequently surveyed colonies in Shetland and Wales as well as other scattered locations throughout Scotland, Northern Ireland and South-west England. When combined, this resulted in an estimate of 65,400 (approximate 95% CI 58,200-72,200) pups born throughout the UK (Table 1).

The regional pup production estimates for 1984 to 2016 are converted to estimates of total population size (1+ aged population, referred to as 'adult population') using a mathematical model and projected forward two years to the start of the 2018 breeding season. The stages in the process and the observed trends are described below and presented in SCOS-BPs 19/01, 18/01, 18/02, Russell *et al. (*2019) and Thomas *et al. (*2019). The pup production model is described in detail in Russell *et al. (*2019) 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 2018 was 137,200 (95% CI 121,500-156,100). When combined with data on pup production at less frequently monitored sites, the total, adult grey seal population in 2018 in the UK was estimated to be 152,800 (approximate 95% CI 135,300-173,800). Details are presented in SCOS-BP 19/01 and below.

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 biennially monitored colonies around Scotland.

Table 1 ***Grey seal pup production, by country, in 2016 and total population estimates at the start of the 2018 breeding season.***

Location	Pup production in 2016	2018 Population estimate**
England	**8,550**	**25,300**
Wales	**2,000***	**4,700**
Scotland	**54,750**	**122,500**
Northern Ireland	**100***	**300**
Total UK	**65,400**	**152,800**

*Estimated production for less frequently monitored colonies, see Table 2 and SCOS-BP 18/01 for details. Populations associated with these estimates were based on the average ratio of pups to total population for the regularly monitored sites.
** Populations derived from the pup production in each country.

The aerial survey programme in 2018 was curtailed due to a combination of poor weather and aircraft availability issues that occurred at the mid point of the survey programme. An analysis of the impact of an extended gap in the middle of the survey programme and a reduced number of surveys overall, was carried out to estimate the maximum delay that could be accepted without compromising the result. The results indicated that missing the third survey in a planned sequence of 5 or 6 surveys had only a small impact on the size or the coefficient of variation (CV) of the pup production estimate, if the resulting inter-survey interval was less than 24 days. Unfortunately, the problems with weather and aircraft availability meant that even this gap would be exceeded and the 2018 survey programme for the Inner and Outer Hebrides, Orkney and the North Coast Mainland colonies was abandoned.

Pup productions at the major colonies on the East coast of England are estimated annually from ground counts by the bodies responsible for those sites. Differences between ground counts and a preliminary air survey count in 2014, as well as differences between the counting methodologies at the main sites in England (the Farne Islands, Donna Nook, Blakeney and Horsey) make it difficult to incorporate these data into the population estimation models. The cancellation of the late survey flights over the main Scottish breeding sites provided an opportunity to carry out a full aerial survey programme for the English breeding sites, to provide a direct comparison with the ground count data for 2018. Using the previous ground count data to estimate the optimum survey dates, we extended the Firth of Forth site surveys to cover the four English east coast colonies. Four surveys were carried out for each site and results from these surveys will be presented at SCOS 2020.

The ground count data, combined with estimates from less frequently aerially surveyed colonies, indicated that the total number of pups born in 2016 across all UK colonies was approximately 65,400 (approximate 95% CI 57,800-71,800).

Regional pup production estimates in 2016 at biennially surveyed colonies were 4,500 (approximate[1] 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 6,700 pups were estimated to have been born in Wales and at less

[1] 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

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 65,400.

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) for details). Interpretation of the trends in pup production are complicated by a change in survey methodology 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). 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 both the Inner and Outer Hebrides, the estimated pup production increased between 2014 and 2016 at 6% p.a. and 5% p.a. respectively. 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.

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). A series of sensitivity analyses are under way.

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 before the last ice age.

The estimated pup production at the Farne Islands increased dramatically, by >18% p.a. between 2014 and 2016, while 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.

Pup production estimates from 2016 at Ramsey Island and in the Skomer Marine Conservation Zone (MCZ) have 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 (Stringell *et al., 2014*); 465 pups in North Pembrokeshire in 2016 (Strong *et al., 2006*; Lock *et al., 2017*) and 345 pups born on Skomer and adjacent mainland sites in 2016 (Lock *et al., 2017*). For consistency with the Scottish surveys, the 2016 estimates for England and Wales have been used in the UK total population estimate. More recent counts are available for the Skomer MCZ, showing a continued increase with a pup production estimate of 395 pups for 2018 (Büche & Stubbings, 2019). The relative size of pup production at the different breeding colonies by region is shown in Figure 2.

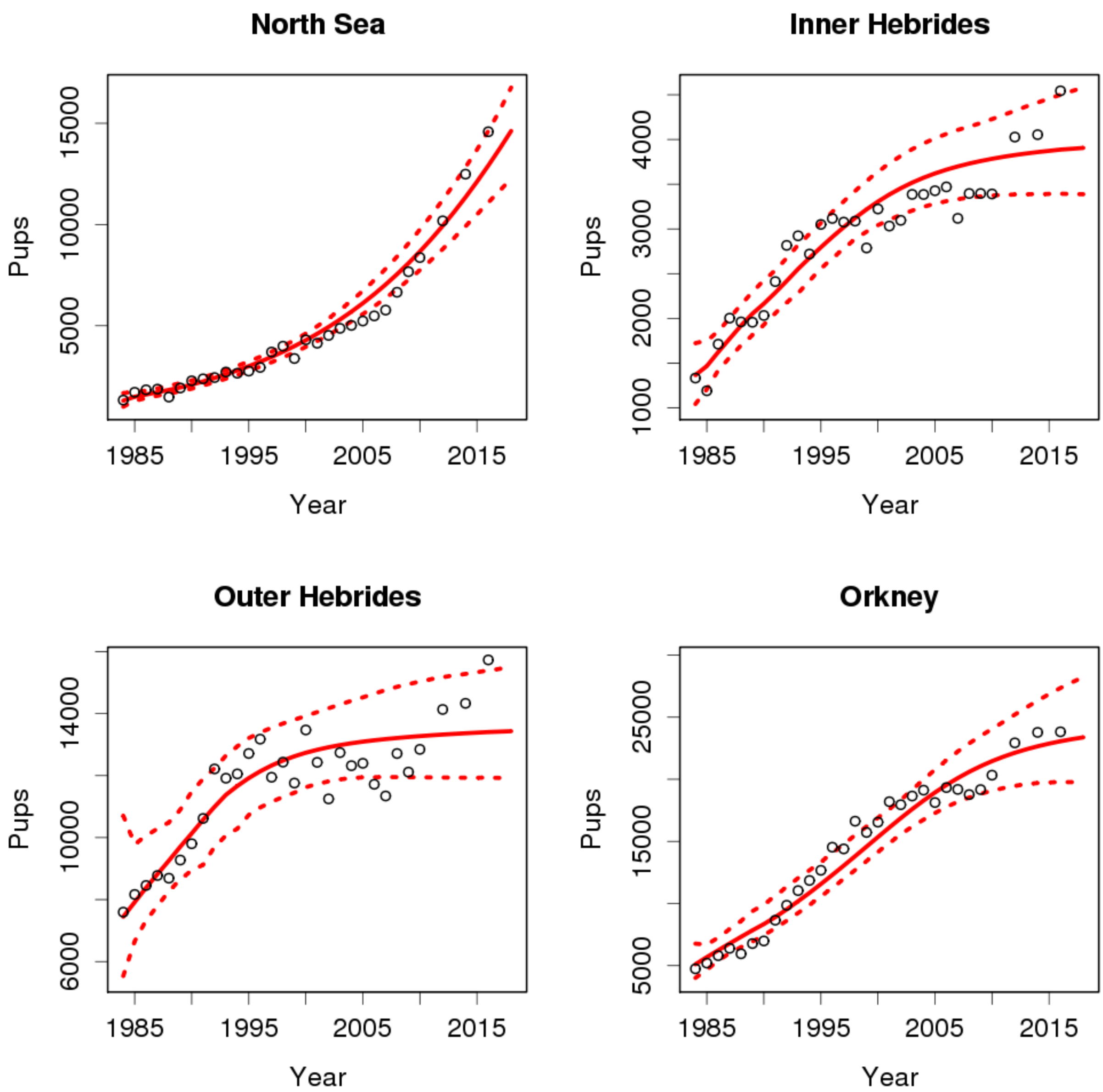

Figure 1. *Mean estimates of pup production (solid lines) and 95% Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates for regularly monitored colonies (SCOS-BP 18/01 and Table 2 below), from 1984-2016 (circles) and two independent total population estimates from 2008 and 2014 (see text for details).*

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 biennially 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)	380 [2]	250 [3]	
Total England	**8,537** [2]	**6,877** [3]	
Total Wales	**2,000**	**1,650**	**+10.1%**
Total Northern Ireland	**100** [3]	**100** [3]	
Total UK	**65,378**	**60,490**	**+3.7%**

1 Estimates derived from ground counts in Shetland and aerial surveys of sites on the mainland coast and smaller Hebridean Islands. Data collected in different years

2 Combination of survey counts of most colonies in 2016 to 2018 and an estimate for other colonies based on a multiplier derived from 2004 survey results. These numbers differ from those in *SCOS-BP 18/01*

3 Includes estimated production for colonies that are rarely monitored

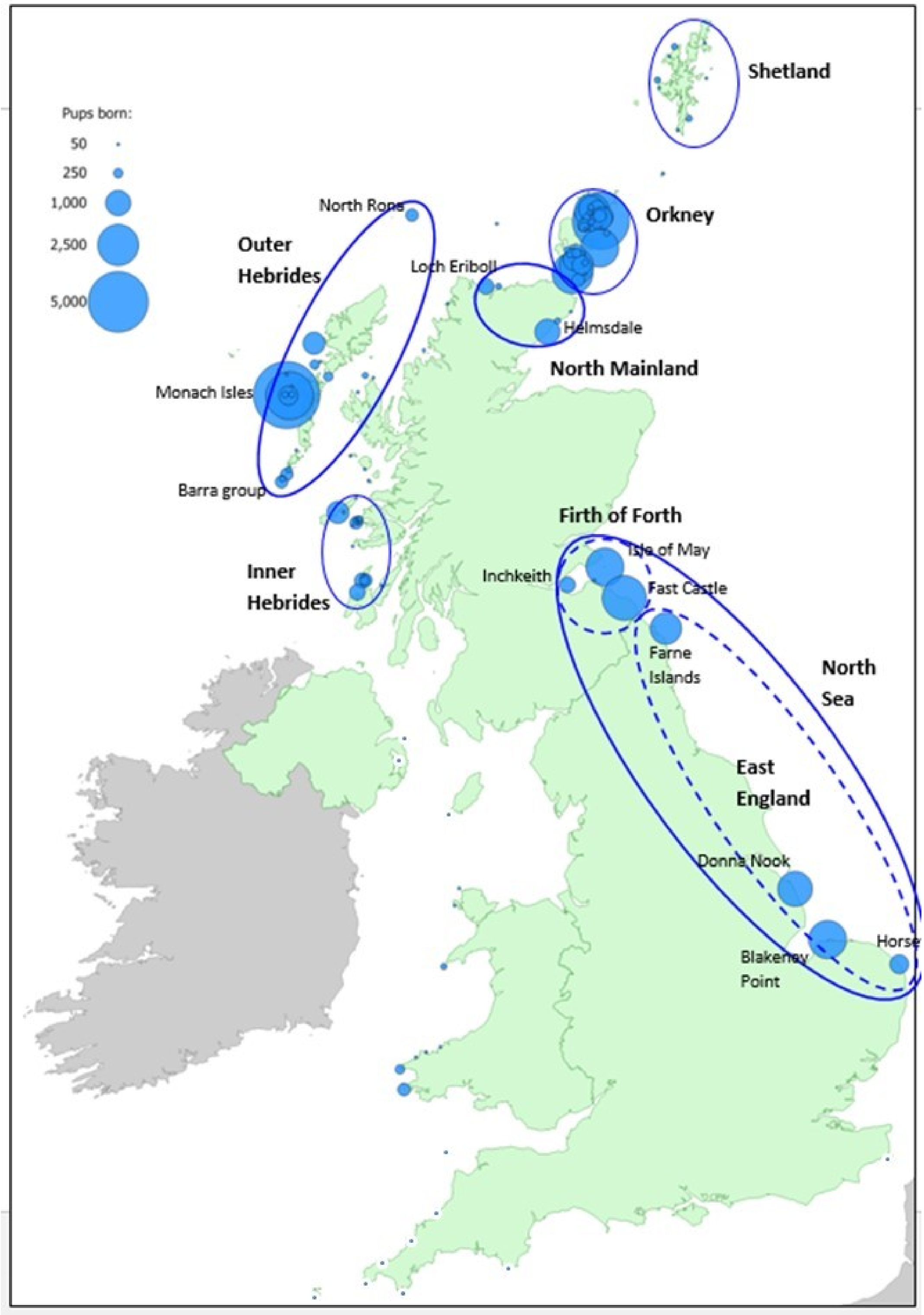

Figure 2. *Distribution and size of the main grey seal breeding colonies. Blue ovals indicate groups of regularly monitored colonies within each region.*

Population size

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

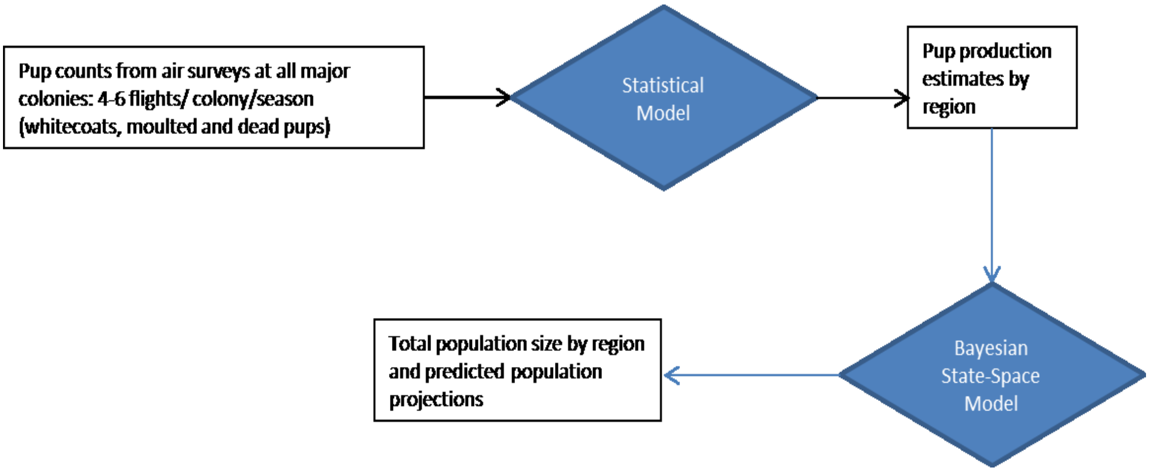

Figure 3. *Schematic diagram of steps involved in estimating total grey seal population size from pup counts (see also SCOS BP-09/02, SCOS BP-10/02).*

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 that provides an estimate of the proportion of the population available to be counted during the aerial surveys (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 (Lonergan *et al., 20*11). Assuming 4% of the population were in southwest UK, this led to a UK independent population estimate in 2008 of 91,800 (95% CI: 78,400 - 109,900).

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

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

The revised analyses resulted in an 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.

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 19/02 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 the upper bound of the adult survival prior was increased slightly to 0.98 in line with revised survival estimates detailed in SCOS-BP 19/02.

This year, an identical model equivalent to the main analysis in 2018 was fitted to the 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.

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 0.80-0.98. The prior revised prior on North Sea carrying capacity of 20,000 was used as the population produced over 14,000 pups but continues to increase rapidly, indicating that it was not close to its carrying capacity.

Grey seal population estimate

From the standard model run the estimated adult class population size (here taken to mean the total 1+ age population) in the regularly monitored colonies at the start of the 2018 breeding season was 137,200 (95% CI 121,000-156,100) for the model incorporating density dependent pup survival, using the revised priors and including the independent estimates for 2008 and 2014 (details of this analysis and posterior estimates of the demographic parameters are given in SCOS-BP 19/01 and SCOS-BP 19/02). 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). These estimates including a revised pup production estimate for Welsh and SW English colonies provide a total pup production estimate of at these sites was estimated to be approximately 6,670. The total population associated with these sites was then estimated using the average ratio of 2016 pup production to 2018 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 15,600 (approximate 95% CI 13,800 to 17,700). Combining this with the annually monitored sites gives an estimated 2018 UK grey seal population of 152,800 (approximate 95% CI 135,300-173,800).

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). 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 in 2018 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. These were reported in SCOS-BP 18/03

Briefly, the estimated pup production trajectories were 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.

In 2018, the mode of the posterior distribution on adult survival from the population dynamics model was 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 were higher than this upper bound (0.976, SE 0.001) (denHeyer & Bowen, 2017). Hence, the prior for adult female survival was increased to 0.98 for this year's model runs.

Thomas *et al. (*2019) discussed how sensitive the estimate of total population size may be to the parameter priors, and concluded 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 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 set of four aerial surveys were carried out for each of these ground-counted North Sea colonies. Counts and comparison with the 2018 ground counts will be presented to SCOS 2020. A revised pup production model is being developed with the aim of re-estimating pup production for the entire count data set.

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 2014 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 shows the relative sizes and status of grey seal populations throughout their range. Pup production estimates are used as indices of population size because they represent a directly observable/countable section of the population and comparable data are available for the grey seal populations in each of the range states. Total population estimates are derived from population dynamics models fitted to time series of pup productions in the two largest populations, i.e. Canada and the UK (Hammill *et al*., 2017; Thomas *et al*., 2011, 2019). However, although the models are similar, the published total population estimates are derived differently: in the Canadian population, total population refers to the number of 1+ age class animals alive at the end of the breeding season plus the total pup production for that year; in the UK the total population is given as the total number of seals alive at the start of the breeding season, i.e. does not include any of that year's pup production. The published estimates therefore differ by around 20 to 30% for the same pup production estimate. It is not clear how the total population is derived in several populations. To avoid confusion, only the pup production values are presented here.

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	1,700	2018[2]	Increasing
France	50	2016	increasing
Norway	700	2014-17[3]	Possible decline
Russia	800	1994	Unknown
Iceland	1,500	2017[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. N.B. the pup count in the Netherlands was 10 days earlier than the expected peak, suggesting that it may be a significant under-estimate of the peak number.
[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] Granquist, S.M. and Hauksson, E. 2019. Aerial census of the Icelandic grey seal (*Halichoerus grypus*) population in 2017: Pup production, population estimate, trends and current status. Marine and Freshwater Research Institution, HV 2019-02. Reykjavík 2019. 19 pp. https://www.hafogvatn.is/static/research/files/1549015805-hv2019-02pdf.

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. The estimated total population for the UK and Northern Ireland in 2018 was 45,800 (approximate 95% CI: 37,500-61,100). This is derived by scaling the most recent composite count of 33,000, (based on surveys between 2014 and 2018) by the (Table 4) by the estimated proportion hauled out during the surveys (0.72 (95% CI: 0.54-0.88)). 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 2018, 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.

Recent trends, i.e. those that incorporate the last 10 years show significant growth in both SMUs on the east coast of England. Populations in Orkney & North Coast and East Scotland SMUs are continuing to decline and in Shetland and the Moray Firth, the current population size is at least 40 % below the pre-2002 level with no indication of recovery. Populations in western Scotland are either stable or increasing. In Northern Ireland counts have declined slowly.

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 19/xx. 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 population estimates based on counts during the moult; rounded to the nearest 100.***

Location	Most recent count (2014-2018)	Population estimates
England	**5,100**	**7,100**
Wales	**<10[1]**	**<15**
Scotland	**26,900[2]**	**37,300**
Northern Ireland	**1,000**	**1,400**
Total UK	**33,000**	**45,800**

[1] *There are no systematic surveys for harbour seals in Wales*
[2] *Compiled from most recent surveys, see Table 5 for dates and details*

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[2]. 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 (Lonergan *et al., 20*13).

The most recent counts of harbour seals by region are given in Table 5 and Figures 4, 5 & 6. These are minimum estimates of the British harbour seal population. Results of surveys conducted in 2018 are described in more detail in SCOS-BP 19/04. 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 (2014-2018) at all sites, approximately 33,000 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 ~36,500 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 (Thompson *et al.,* 2016). These flights confirmed that the peak number of pups ashore occurred around the beginning of July. In 2018 a survey was carried out on 29th June but was curtailed by low cloud and was completed on 2nd July. The 2018 count was 17% higher than the 2017 count and similar to the average for the preceding 5 years. This continues the pattern of high inter annual variability (SCOS-BP 19/04). 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 5.6% p.a. since surveys began in 2001 although the rate of increase may have slowed and may be reaching an asymptote (SCOS-BP 19/04).

The ratio of pups to the moult counts remained high in 2018, more than double the same ratio in 2001. This ratio can be seen as an index of the productivity of the population. Until recently, the index for the Wash was higher than for the larger Wadden Sea population. However, the ratio has increased rapidly in the Wadden Sea population since 2008 as moult counts stopped increasing while pup counts continue to grow, and is now at a similar level to the Wash population. Previous attempts to explain the apparently high Wash fecundity/productivity as a result of seasonal movements between these populations can no longer explain the increase. If the change is real, it suggests that either the fecundity has increased in both the Wash and Wadden Sea populations or that the ratio between the moult counts and the total population has changed. We do not have any information to determine to what extent either of these metrics has changed. SCOS recommends further investigation to identify the underlying changes.

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

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, 2007-2013 and 2015-2018.*** *Details of sources and dates of surveys used in each compiled regional total are given in SCOS-BP 19/03.*

Seal Management Unit / Country		Harbour seal counts			
		2015-2018	**2007-2013**	**2000-2006**	**1996-1997**
1	Southwest Scotland	1,709	923	623	929
2	West Scotland	15,600	11,072	11,666	8,811
3	Western Isles	3,533	2,739	1,981	2,820
4	North Coast & Orkney	1,349	1,938	4,388	8,787
5	Shetland	3,369	3,039	3,038	5,994
6	Moray Firth	962	898	1,028	1,409
7	East Scotland	342	214	667	764
SCOTLAND TOTAL		**26,864**	**20,823**	**23,391**	**29,514**
8	Northeast England	79	83	62	54
9	Southeast England	4,961	4,504	2,964	3,092
10	South England	40	20	13	5
11	Southwest England	0	0	0	0
12	Wales	10	10	4	2
13	Northwest England	5	5	5	2
ENGLAND & WALES TOTAL		**5,095**	**4,622**	**3,051**	**3,160**
BRITAIN TOTAL		**31,959**	**25,445**	**26,442**	**32,674**
NORTHERN IRELAND TOTAL		**1,012**	**948**	**1,176**	
UK TOTAL		**32,971**	**26,393**	**27,618**	
REPUBLIC OF IRELAND TOTAL		**4,007**	**3,489**	**2,955**	
BRITAIN & IRELAND TOTAL		**36,978**	**29,882**	**30,573**	

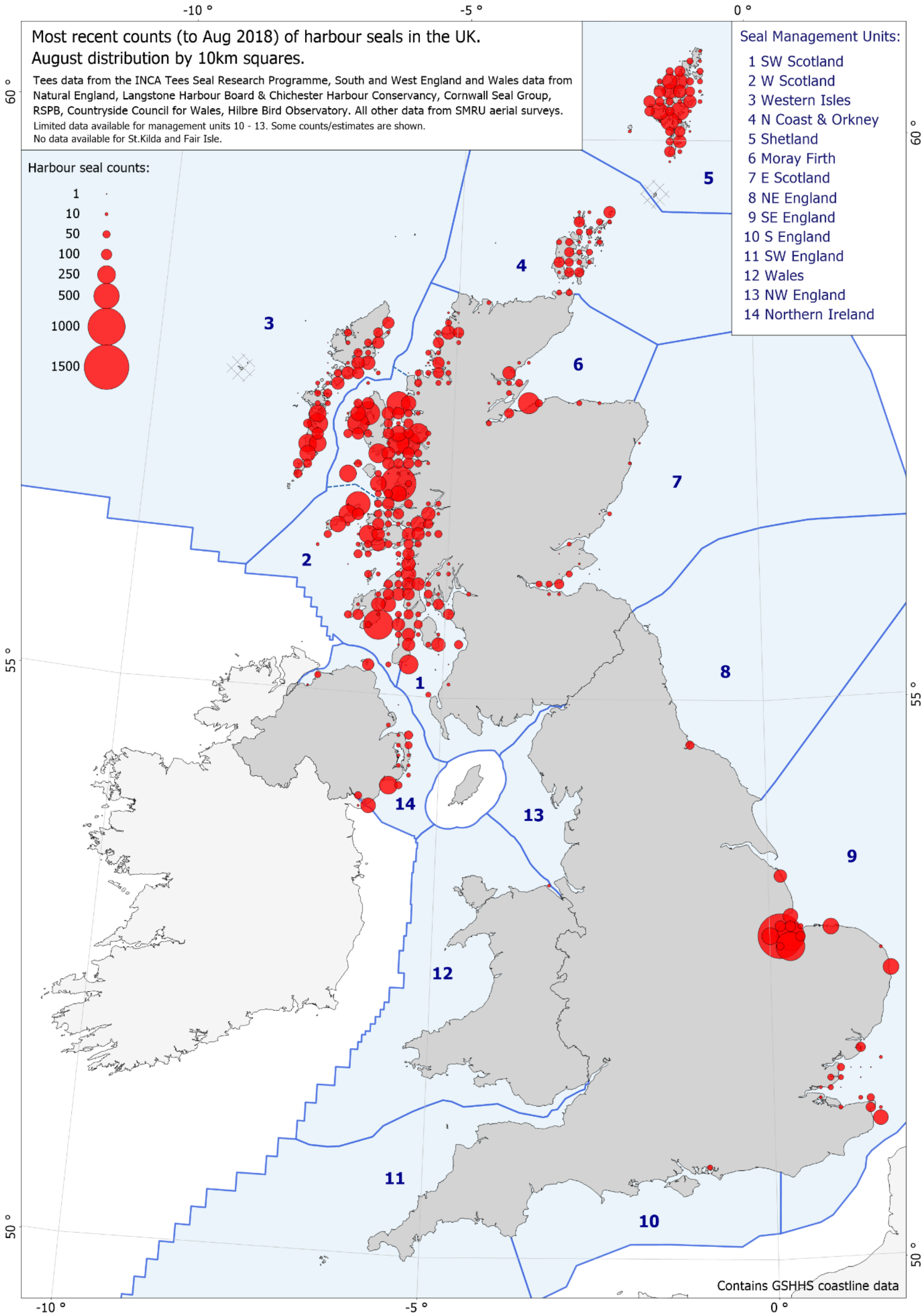

Figure 4. *August distribution of harbour seals around the British Isles. Small numbers of harbour seals (<20) are anecdotally reported for the West England & Wales SMUs, but are not included on this map. Estimates are composites of the most recent survey counts in each region between 2015 and 2018.*

Population trends
The overall UK harbour seal population has increased over the last decade. Counts increased from 26,400 (rounded to the nearest 100) in the 2007-2013 period to 33,000 during the 2015-2018 period. As no count was available in Northern Ireland in the 1990s, a UK wide comparison is not possible, but the 2015-2018 count of 32,000 harbour seals in Great Britain (i.e. UK minus Northern Ireland) was effectively the same as the 1996-97 count of 32,700 (Table 5). However, as reported in SCOS 2008 to 2018, 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).

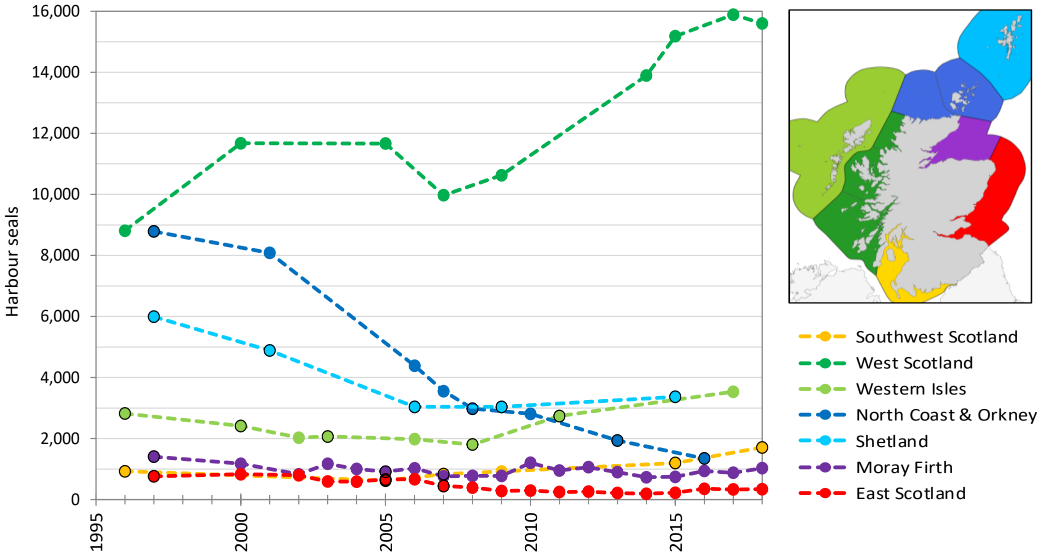

Figure 5. *August counts of harbour seals in Scottish Seal Management Areas, 1996-2018. Note that because these data points represent counts of harbour seals distributed over large areas, individual data points may be from surveys from more than one year. Points are only shown for years in which a significant 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.*

***Trends by Seal Management Unit* (SMU).**
Details of regional and local trend analyses, and model selection for each are given in Thompson *et al. (*2019) and the results are briefly described here.

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 (2000, 2003, and 2008) showed a decline but the most recent count in 2017 was approximately 40% higher than the average between 1993 and 2017 and was almost as high as the count in 1996. A simple intercept only Generalized Linear Model (GLM) 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 SMU (North and part of Centre) were surveyed in 2017 and the remainder was surveyed in 2018. The harbour seal count for West Scotland - North was

1,084, for West Scotland - Centre was 7,447 and for West Scotland – South was 7,053, and the overall total for the West Scotland SMU was 15,600 (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 for the period from the 1990s to 2015, implying no significant change. The composite 2017-18 count is similar to the 2015 count.

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 (Thompson *et al., 20*19):

- In the north of the region (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). The composite 2017-2018 count is consistent with a continued 4% p.a. increase. 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, with counts varying between approximately 5,000 and 7,000 over the period 1990 to 2018. Counts for both the Southeast Islay Skerries SAC and the Lismore SAC have also remained stable over the same period.

Southwest Scotland: All of the Southwest Scotland SMU was surveyed in August 2018. A total of 1,700 harbour seals were counted compared with 1,200 in 2015 and 923 in 2009 (Table 5). This was the highest count of harbour seals for the Southwest Scotland SMU, approximately three times higher than the 1990's count. Despite this apparent increase, the trend analysis selected a simple intercept only model suggesting that there was no detectable trend in the data. The 2018 count represents a further 12% p.a. increase since 2015, suggesting that the population may now be increasing rapidly.

North Coast and Orkney: The North coast and Orkney 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 5) 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.

Shetland: A complete survey was carried out in 2015. 3,369 harbour seals were counted compared with 3,039 in 2009. The count was 11% 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. 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).

Moray Firth: The count in the regularly surveyed region was 884 in 2018, and when combined with counts of the outer Moray Firth from previous years, the total harbour seal count for the entire Moray Firth SMU was 962. This was 9% higher than the 2017 count but only 2% higher than the 2016 count. The majority of these harbour seals (48%) were observed between Culbin and Findhorn, confirming the continued importance of these sites after a 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 in 2017 and 2018 are consistent with a relatively stable population. 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 2018 count of 117 was three times higher than the extremely low count in 2017, and similar to the count in 2015.

East Scotland: The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2018 was 42, equal to the mean of the previous 4 years' counts for this SAC. This represents a 93% decrease from the mean counts recorded between 1990 and 2002 (641). The low numbers of harbour seals in this area remain a concern to Marine Scotland.

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.

South east England: The combined counts for the Southeast England SMU (Figure 6) in 2018 (4,944) was similar to counts for 2014 to 2017. This may be a further indication that the population in SE England SMU is approaching its carrying capacity.

The combined counts for The Wash, Donna Nook and Blakeney Point, taken here to represent the Southeast England SMU, are available from 1988 to 2018. 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 2018. 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.3,000 (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 Generalised Additive Model (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 2018 count is the second highest ever recorded in the Wash and represents a 13% increase over the 2017 count. The recent counts for The Wash are similar to the levels in 1988 and 2002 immediately before the two PDV epidemics.

The Thames population, here taken to include all haulout sites between Hamford Water in Essex and Goodwin Sands off the Kent coast, have been surveyed sporadically since 2002 and annually since 2008. A formal analysis of the Thames data is currently underway, but a preliminary examination shows that a simple exponential fits well, indicating a 12% p.a. increase in counts since 2002.

Although the Southeast England population increased after the 2002 PDV epidemic, and has apparently levelled off at a similar size to its pre-2002 epidemic population, it grew at a much lower rate than the Wadden Sea harbour seal population, the only other major population in the southern North Sea. Counts in the Wadden Sea increased from 10,800 in 2003 to 26,788 in 2013, equivalent to an average annual growth rate of 9.5% over ten years. Counts since 2014 indicate that the rapid growth since the 2002 PDV epidemic has stopped. Although there was an influenza-A epidemic that killed at least 1600 seals in 2014 it now seems highly likely that cessation of the previously rapid increase in the Wadden Sea population indicates that it has reached its carrying capacity. The coincidence of the timing of the slowdown in the Wadden Sea and SE England is notable.

Northern Ireland: Only two synoptic surveys have been carried out of the entire harbour seal population in Northern Ireland. However, a subset of the population from Carlingford Lough to Copeland Islands has been monitored more frequently from 2002 to 2011. This area contained 80-85% of the total in the two years with complete coverage. This subset of the population has declined slowly over the period at an average rate of 2.7% p.a. (95% CIs: 1.8, 3.5).

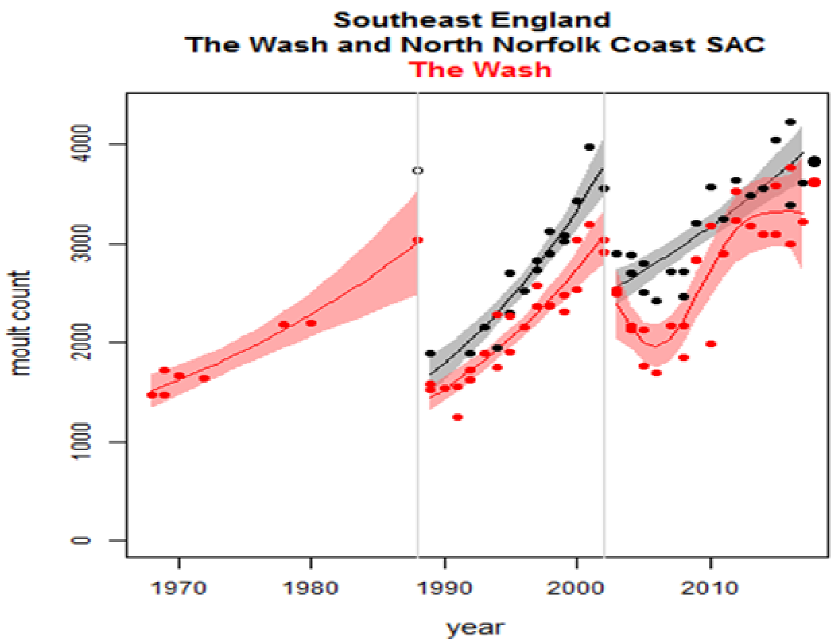

Figure 6*. Trends in harbour seals counts in The Wash (red) and the combined Wash and North Norfolk SAC, between 1967 and 2017 (shaded areas indicate the 95% confidence intervals for the fitted curves). For further explanation see text and Thompson et al. (2019).*

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	**26,900**	2015-2018
England	**5,100**	2018[2]
Northern Ireland	**1000**	2018
UK	**33,000**	
Ireland	3,500	2011-12
France	1,100	2018
Wadden Sea-Germany	16,900	2017-18[3]
Wadden Sea-Denmark	2,700	2018
Wadden Sea-NL	7,900	2018[4]
Delta-NL	700	2016
Limfjorden	1,100	2017
Kattegat	9,400	2016
Skagerrak	6,200	2016
Baltic (Kalmarsund)	1,100	2016
Baltic Southwestern	1,000	2017
Norway	6,900	2011-18
Barents Sea	1,900	2010
Iceland	7,700	2016
Europe excluding UK	**68,100**	
Total	**101,100**	

[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] Includes an estimate of 55 seals for south England, Wales and north-west England compiled from sporadic reports
[3] 2018 partial count in Lower Saxony combined with 2017 Schleswig-Holstein count, areas hold similar numbers of seals.
[4]Partial count of the Netherlands' Wadden Sea in 2017 due to military restriction, count corrected by adding 900 for area missed.

Data sources

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

Grey seals

There is evidence for regional differences in grey seal demographics (Smout *et al.,* 2019) but detailed information on vital rates are lacking. New resources should be identified to address questions around fecundity and first-year survival as they are likely drivers of UK grey seal population dynamics.

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

Age and sex structure

While the population was growing at a constant (i.e. exponential) rate, 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 19/01). 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 19/02).

<u>Adult female survival</u>: Estimates of annual adult survival in the UK, obtained by aging teeth from shot animals were between 0.93 and 0.96 (Harwood & Prime, 1978; Hewer, 1964; SCOS-BP 12/02). Capture-mark-recapture (CMR) of adult females on breeding colonies (Smout *et al.*, 2019) has been used to estimate female survival on North Rona and the Isle of May of 0.87 and 0.95 (SCOS-BP19/02 - Table 2). The population dynamics models fitted to the pup production time series, produced estimates of adult female survival close to the upper limit of that range (SCOS-BP 19/01). Interestingly, recent estimates from Sable Island suggest that adult female survival during the main reproductive age classes (4 to 24 years old) may be even higher. 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 (den Heyer & Bowen, 2017). 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 (Hewer, 1964; Boyd, 1985) and Canada (Hammill & Gosselin, 1995) 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(den Heyer & Bowen, 2017; Bowen *et al., 20*06). UK estimates of 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 (Smout *et al.*, 2019).

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 19/01).

A recent study in Finland (Kauhala *et al., 20*19) based on shot animals showed pregancy rate can fluctuate significantly (between c0.6 and c0.95) and was significantly related to herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) quality (weight), which, in turn were influenced by sprat and cod (*Gadus morhua*) abundance, as well as zooplankton biomass. Their results suggest strong trophic coupling over three trophic levels in the Baltic. Smout *et al. (*2019) reported a similar link between likelihood of breeding and environmental conditions during the preceding year. In a parallel study, Hanson *et al. (*2019) (showed high levels of variation in individual postpartum maternal body composition at two grey seal breeding colonies (North Rona and Isle of May) with contrasting population dynamics. Although average composition was similar between the colonies, it increased at the Isle of May where pup production increased and declined at North Rona where pup production decreased.

SCOS recommends continued investigations into the effects of environmental variation on fecundity and the potential effects of such links on population projections for UK grey seal populations.

First year survival: In the context of the population estimation model, first year survival is used to describe the probability that a female pup, will 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) (Table 2). Mean estimates of pup survival were between 0.54 – 0.76.

The fitted value for maximum unconstrained pup survival was 0.43 (SE 0.07) (SCOS-BP19/01) from the standard model run on the 1984-2016 dataset.

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 0.43, 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 (Thomas *et al., 20*19 estimated that pup survival for a population at carrying capacity will be around 0.1-0.14).

Sex Ratio: The sex ratio effectively scales up the female population estimate derived from the model fit to the pup production trajectories, to the total population size. 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 (2017) estimated survival rates of male and female branded seals at Sable Island, Canada. 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.

Investigations using the grey seal population dynamics model suggested that changes in first year survival rather than changes in fecundity are the main mechanisms through which density dependence acts on UK grey seal populations (Thomas, 2010). Fecundity at an increasing population at the Isle of May was only marginally higher than in a declining population at North Rona colony in Scotland, and fecundity has not changed as the Sable Island grey seal population reaches a density dependent limits (den Heyer *et al.*, 2017; Smout *et al., 20*19). Variation in fecundity may become increasingly important in areas where populations have reached carrying capacity, e.g. age of first recruitment appears to increase as populations reach carrying capacity (Bowen *et al., 20*06).

Regional data on fecundity and survival rates would allow us to further examine the drivers of population trends. Such data would feed into the population dynamics model, improving confidence in model predictions and enhancing our ability to provide advice on population status. Furthermore, such data could inform effective management by identifying the relative sensitivities associated with different life stages, in terms of population dynamics. SCOS recommends that new resources should be identified to investigate regional patterns and the effects of environmental covariates on both first year survival and fecundity in UK grey seal populations.

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 (Walton & Stanley, 1997) and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona (Allen *et al., 19*95). There is therefore some indication of sub-structure within the UK grey seal population, but it is not strong.

Recent genetic data from the Baltic grey seals (Fietz *et al.*, 2016) 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 (Brasseur *et al.*, 2015). Similar immigration appears to be driving growth in southern colonies on the west side of the Atlantic. On the basis of mDNA haplotype information Wood *et al. (*2011) could not differentiate between US and Canadian grey seal populations and concluded although grey seals are regarded as philopatric, their results indicate that the genetic structure of the northwest Atlantic grey seal population is not different from the null hypothesis of panmixia.

A PhD project based at the Galway-Mayo Institute of Technology (GMIT) is currently investigating the genetic structure of both grey and harbour seals occupying Irish haul-out sites and coastal/marine waters and their relationship to wider regional populations across Western Europe. The results of this study are intended to inform the possible identification of appropriate Assessment/Management Units for seals in Ireland.

Harbour seals

Knowledge of UK harbour seal vital rates is limited and inferences about the population dynamics rely on count data from moulting surveys. Information on vital rates would improve our ability to provide advice on population status, but estimates for UK harbour seals are only available from one long term study at Loch Fleet in northeast Scotland. Additional studies are underway to obtain similar data from new sites in Orkney and western Scotland.

Indices of fecundity in both the Wash and Wadden Sea have increased suggesting that either demographic rates, or our indices of those rates, are changing and require further investigation.

Recent genetic 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 (Olsen *et al.*, 2017) 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 were collected from approximately 300 harbour seals at 18 sites throughout the UK and the Wadden Sea (Olsen *et al.*, 2017) and were genotyped at 12 micro-satellite loci. Results suggested three distinct groups, one in in the south equivalent to Southeast England SMU and the Wadden Sea, and a northern cluster that was further divided into a north-western cluster equivalent to the West Scotland, Southwest Scotland and Western Isles SMUs, and a north-eastern cluster equivalent to Shetland, Orkney, Moray Firth and the East Scotland SMUs.

The UK harbour seal population can be divided into similar regional sub-divisions to those seen in the genetics data on the basis of the observed population trends. The southern UK population equivalent to the English east coast shows continual rapid increase punctuated by major declines associated with PDV epidemics in 1988 and 2002. 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 (Hall *et al*., 2019).

Survival and fecundity rates

A long term photo-ID study of harbour seals at Loch Fleet, NE Scotland produced survival rate estimates of 0.95 (95% CI 0.91-0.97) for adult females and 0.92 (0.83-0.96) for adult males (Cordes & Thompson, 2014; Mackey *et al.*, 2008).

A study investigating first year survival in harbour seal pups, using telemetry tags was carried out in Orkney and on Lismore in 2007. Battery life of the transmitters limited the study duration, but survival was not significantly different between the two regions and expected survival to 200 days was 0.3 (Hanson *et al.*, 2013). Harding *et al. (*2005) showed that over winter survival in harbour seal young of the year was related to body mass and to water temperature.

In South-east England there is evidence for changing demographic parameters in harbour seals. The apparent fecundity, i.e. the peak count of pups (as an index of pup production) divided by the moult survey count (as an index of total population size) of the large harbour seal population in The Wash has shown large 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 19/04). The fact that apparent fecundity of the much larger population in the Wadden Sea has now also increased, suggests that this is a real effect and not due simply to movement between breeding and moulting populations in the two areas. This is a crude metric for the productivity of a population of seals and may be influenced by changes in the timing or the pattern of haulout during the moult. It does however indicate that demographic rates, or our indices of those rates, are changing and require further investigation.

Growth.

If harbour seal dynamics are the consequence of resource limits, e.g. because of reduced prey density or increased competition, it is likely that the growth rates of individuals would carry some signal of those effects. Resource limitations are likely to result in slower growth and later age at sexual maturity.

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 from fitted von-Bertalanffy growth curves, across all regions (Hall *et al.*, 2019), 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 (Harding *et al.*, 2018). 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 of seals, 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.

3. 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?	NRW Q1

The timing of the pupping season at sites in Pembrokeshire and around Scotland show a range of patterns with some becoming earlier and others showing no trend or becoming later. Increasing age and/or body mass influences timing of birth of individual seals and changes in age composition of breeding groups may account for the observed changes in timing.

Patterns of timing of breeding in grey seals have been reported for Skomer Island and the Marloes Peninsula (Bull *et al., 20*17a & b, Lock *et al., 20*17), two colonies within a kilometre of each other in Pembrokeshire. The patterns of timing of first births differ between these colonies, with pupping apparently becoming earlier at Marloes over the past 20 years but no apparent trend at Skomer. These two Pembrokeshire colonies are much closer together than some individual breeding groups on what are regarded as single colonies in Scotland or eastern England. Because the two sites are so close together, seals at each would be expected to be experiencing very similar environmental conditions. The apparent differences in timing may simply reflect the gradual spread of seals in the area as the population grows and differing proportions of young females at the two sites. Additional analyses of these and a more extensive data set for other Welsh sites are underway (Bull pers com.) and progress will be reported to SCOS 2020.

Interestingly, the timing of breeding based on "week of peak pup production" at the Marloes colonies does not appear to show the same consistent trend as the timing of the first birth (Lock *et al.,* 2017) but on Skomer the two metrics show similar temporal patterns. The apparent timing of the pupping season may therefore differ depending on the descriptor/metric chosen. The occurrence of the first birth would be expected to advance to some extent as the pup production increases even if the mean pupping date did not change. Interestingly, the duration of the pupping season at Skomer did not increase even though pup production trebled during the study. The date of the initial birth is likely to be inherently more variable than the mean or median pupping date and could be influenced for periods of several years by the behaviour of one individual seal as females tend to pup on or around the same date in consecutive years (Pomeroy *et al.,* 2005).

Timing of the pupping has been studied on two Scottish colonies: North Rona (NR) in the Outer Hebrides and Isle of May (IM) in the Firth of Forth. The colonies are widely separated (>450km by sea) and little effective breeding exchange is thought to occur between them (Allen *et al.*, 1995). Pup production at NR has declined while IM increased and stabilised. With some annual variation, over the last 3 decades, the mean pupping date at NR has become later by around 10d. Over the same period, the mean pupping date at IM has fluctuated without showing a clear trend.

Preliminary mixed model analyses of pupping dates of known female seals at NR and IM (Pomeroy *et al.*, in prep) reveal a complex situation. At both colonies, pupping date was highly variable between individuals but tended to become earlier with increasing maternal mass. However, the effects of age were different at NR and IM, possibly because of differences in the age ranges of the respective animals. As the study animals' average pupping dates tracked the colony average pupping dates, we assume the study animals at each are representative of their colony.

Estimation of the pup production model at Scottish colonies involves deriving a birth curve and thus allows mean pupping date to be estimated. A new pup production model is currently being developed to deal with issues around the parameters associated with the detection and classification of pups. Once this pup production model is completed, the mean birth dates of all regularly monitored colonies in England and Scotland will be available for the period 1987 to date. These data will allow a detailed analysis of changes in timing of pupping at colonies representing over 85% of the UK's pup production.

4. Are the current management areas for harbour and grey seals fit for purpose given the differences between the species? In particular, it would be helpful for SCOS to advise whether the management areas should continue to be identical for both species, and whether they need to be biologically relevant to be effective for management purposes?	MS Q 14
Does SCOS see a benefit to making seal management units (MUs) and seal assessment units (AUs) consistent, and reviewing them in 2019?	Defra Q 3

SCOS advises that SMUs should be the same for both species and, at the moment, SCOS does not see any not biologically relevant reason why seal management units and seal assessment units should be coalesced.
The raw data that go into the estimates of SMU totals are collected at very fine spatial resolution, and as such could be combined in any way to provide totals for SMU or AU scales.

At present seals in the UK are managed on the basis of seal management units (SMU). 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. The SMUs were designed to allow local and regional management of seal populations in response to local environmental effects or anthropogenic impacts. Particularly for grey seals, there will probably be substantial movement of animals between these areas.

At present the same SMU boundaries (Figure 4 and SCOS-BP 19/05) are used to report population size and trend information for harbour seals and to set management targets such as PBRs for both species. The resolution of the survey data mean that the basic counts and pup production estimates could be combined to match whatever management structure was required.

The grey seal pup production data used in the population dynamics models are pooled in a geographical structure based on what were originally discrete breeding assemblages. This structure differs slightly from the SMU structure. Breeding sites are currently pooled into four large populations units, the Inner Hebrides, Outer Hebrides, Orkney and the North Sea and the population dynamics model treats each as a discrete population with no interchange.

The Inner Hebrides, Outer Hebrides and Orkney populations each breed within one SMU, West Scotland, Western Isles and Orkney and North Coast SMUs respectively. However, the North Sea population breeds at sites from the Firth of Forth in SE Scotland down to Norfolk, in SE England, a range that includes three SMUs; East Scotland, NE England and SE England.

The spatial scale at which seal populations are managed depends on the management goals. For example, management advice in the form of PBR estimates are currently provided for each SMU around Scotland for both species (see SCOS-BP 19/05). The distribution of harbour seals at the scale of SMUs is not thought to change with season. For grey seals however the foraging distribution, is very different from the breeding distribution. Interactions with anthropogenic activities such as fisheries or industrial activities will occur at sea or close to haulout sites. Managing on the basis of breeding distributions could lead to inappropriate control or protection measures. PBRs for both grey and harbour seals are derived for each SMU on the basis of counts obtained during the August harbour seal moult surveys (see SCOS-BP 19/05). These counts are scaled up by the probability of being hauled out, derived from telemetry data in the same way as the independent grey seal population estimate (see SCOS-BP 19/02).

A proportion of the grey seals found in any particular SMU during the summer originate from and return to breed at sites in other SMUs and in some cases may be a mix of seals from several breeding sites in different SMUs. As a consequence, management actions that are applied on the basis of the summer distribution will potentially have impacts on breeding populations in other SMUs. This can be avoided by coalescing the SMUs into larger units, but at the expense of being able to address local issues and without any increased protection for the seal population.

Such management targets can easily be coalesced to provide targets for larger regions if and when necessary. SCOS therefore recommend that seal population monitoring and provision of management advice, such as PBRs, continue to be collected/provided at the scale of the current SMUs.

5. 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

The most recent composite count for Scotland, for surveys in 2015 to 2018, was 25% higher than for the previous round of surveys (2007-2013). Declines are continuing in Orkney and along the East coast of Scotland. Counts in the Moray Firth and Shetland have apparently remained stable after experiencing large reductions around 2002. Counts also appear stable in the Western Isles and Southwest Scotland management units and are increasing in the north and central parts of the West Scotland SMU. The most recent count in the West Scotland management area is the highest to date.
The current UK harbour seal population is at a similar size to the estimates from the late 1990s, but there have been significant population declines in some regions and similar increases in others.

As reported in SCOS 2008 to 2018, 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 SCOS-BP 19/03 and Thompson *et al. (*2019).

The composite count for all of Scotland, based on recent (2015-2018) surveys in all areas, is approximately 30% higher than the previous composite count based on 2007-2013 surveys, representing approximately 3% p.a. increase (Figure 5; Table 5) and has returned to levels similar to those in the mid-1990s.

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 has been a continuing decline in the Firth of Tay and Eden Estuary SAC. The 2018 count of 40 represents a 93% decrease from the mean counts before 2002. In Orkney the most recent count of 1,349 in 2016 represents an 85% 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 entire time series but the 2016 count was 25% higher. The 2018 count was similar to the 2016 count and overall there has been no significant trend in the counts of the Moray Firth since 2000.

The 2017-2018 composite count of 15,600 in the large West Scotland Management Area was 40% higher than the 2007-2013 composite 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 2018 (4,961) was similar to the previous five years' counts. The Southeast England population has returned to its pre-2002 epidemic levels (Figure 6) but the last five counts suggest it may be at or near its carrying capacity. Pup production in the Wash continues to increase, but the rate of increase has slowed (SCOS-BP 19/04).

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.

6. In the 2018 SCOS advice, a number of potential causes for the harbour seal decline were presented (e.g., competition with grey seals for prey resources, predation by grey seals or/and killer whales, reduction in prey availability). Can SCOS advise on the outcomes of work progressed, with specific focus on any gaps that require further consideration /exploration?	MS Q4

The research on the potential causes for the harbour seal decline is a 5 year programme funded by Scottish Government. This programme is due to complete in 2020 after which time the findings will be available. The results, and the additional study funded by SNH to investigate migration and

source-sink dynamics and genomic variation in Scottish harbour seals, will indicate where the knowledge gaps remain.

The Sea Mammal Research Unit has been funded by Scottish Government to investigate the causes of the declines and this project will be completed in 2020. The focus remains the priority potential causes (predation, effects on prey and toxin exposure) and the investigation of the survival and fecundity rates in areas with contrasting population trajectories in order to determine which vital rates are being impacted and to therefore assist in narrowing down the potential drivers. The population model being developed indicates that adult survival is being affected, not just fecundity and pup survival. The model will therefore be further refined when the fecundity and survival parameters for Orkney and the control sites are available. For information, Table 7 contains a list of potential factors involved and the current assessment of their importance (modified from SCOS 2018).

Table 7. ***The current view of the potential major 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 declines.
2.	Pollution	unlikely	Levels of persistent organic pollutants are low in the areas of decline and highest in regions where populations are increasing[1].
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[2], although temporary relocation between regions may be frequent.
6.	Entanglement in marine debris	no	Data from stranded seals and faecal samples indicate that entanglement in marine debris or ingestion of plastics are not major issues for UK seals.
7.	Legal control	no	Introduction of the Marine (Scotland) Act 2010 and the licensing system is ensuring the declining populations are protected from directed takes.
8.	Infectious disease and parasites	unlikely	No evidence of an unusual mortality from strandings. Live captures show no evidence of disease in areas of decline. No evidence that Brucella infection is responsible[3]. However, other esoteric or secondary disease agents may be factors.
9.	Prey quality and availability	possible	It is not possible to rule out changes prey quantity or quality as factors in the harbour seal decline, 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[4] and killer whales is still being reported at several locations. Recent anecdotal reports from Shetland suggest that predation rates may be very high in some locations.
12.	Toxins from harmful algae	possible	Domoic acid, saxitoxins and okadaic continue to be detected in seals[5] 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.
15	Disturbance	unlikely	Possible local re-distribution effects. Most sites are remote and rarely disturbed. Occasional disturbance does have severe effects. Population trends at sites with high levels of tourism/military aircraft activity show no signs of negative impacts.

[1]Hall, A.J. & Thomas, G.O. 2007. Polychlorinated biphenyls, DDT, polybrominated diphenyl ethers and organic pesticides in UK harbor seals - mixed exposures and thyroid homeostasis. *Environmental Toxicology Chemistry*, 26, 851-861.
[2]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.
[3] 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
[4]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.
[5]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.

7. Has there been any further progress in describing the prevalence and spatio-temporal trends of grey seal predation on other seals and harbour porpoises?	NRW Q4

There has been limited progress in determining the prevalence and extent of grey seal predation on seals and porpoises around the UK.

There are cetacean stranding schemes in all countries in the UK and as a consequence, any harbour porpoise carcasses reported in the UK are examined where practicable. Records from the UK Cetacean Strandings Investigation Programme (CSIP) and the Scottish Marine Animal Stranding Scheme (SMASS)of porpoises with trauma, suggest that grey seal predation of harbour porpoises occurs sporadically around the entire UK coast. To date there has been no attempt to extrapolate from the number of reported cases to produce population scale mortality rates.

There has been limited progress in determining the prevalence and spatio-temporal trends in grey seal predation on seals around the UK.

Numbers of seals reported with characteristic lesions indicating grey seal predation are being logged in Scotland and Wales. A detailed report of the seal strandings records from 2009 to 2018 is presented in SCOS-BP 19/06. The distribution and temporal patterns of seal strandings and necropsy results identifying cause of death are presented for the Scottish coast. A total of 2804 seals were found dead stranded between 2009 and 2018. These comprised of 1471 grey seals, 533 harbour seals, and 800 animals where the species could not be determined.

At present there is no formal reporting or post-mortem exam of seals in England, but additional funding from Defra has been requested, to include seals in the English and Welsh strandings scheme.

Grey seal infanticide and cannibalism is reported annually at breeding sites in the UK and Germany where large numbers of pups were concentrated on or very close to shore. Recent observations in the Firth of Forth show that adult male grey seals can and do prey on juvenile grey seals in open water, away from haulout sites and throughout the year.

These observations indicate that grey seals can be effective open water predators and that grey seal predation may be more widespread than previously identified. Wound patterns on carcasses known to be victims of grey seal attacks suggest that those previously identified as indicative of grey seal predation will likely underestimate the scale, and geographical and temporal spread of such predation.

8. Scientific advice from SCOS that would aid policy consideration of whether or not too review any existing Seal Conservation Areas (e.g., Western Isles). **Notes in response to the driver/rational for MS Q6.**	MS Q6b:

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

The Seal Conservation Areas were established in response to observed declines in several harbour seal populations. Harbour seal populations in Shetland, Orkney and North Coast, Moray Firth and East Scotland SMUs are all either continuing to decline or are stable at population sizes 40% below their 1990s levels. There is therefore no reason to consider that the threat to those populations has been removed. SCOS therefore recommends that existing conservation orders remain in place in these SMUs.

Conservation areas are currently designated for the Western Isles, Northern Isles and down the Scottish 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 recent survey results and trend analyses are presented briefly in answer to Q1 above, and in detail in SCOS-BP 19/03 and Thompson *et al. (*2019). There is no evidence that the threats to those populations have been removed and SCOS therefore recommends that existing conservation orders remain in place in these SMUs.

The 2017 survey in the Western Isles was the highest yet recorded and was approximately 25% higher than the equivalent count in the mid-1990s and more than 75% higher than the lowest count obtained in 2008. 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. Inclusion of the 2017 result did 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 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 requirement to extend the conservation orders to the West Scotland or Southwest Scotland management areas.

In addition to the specific conservation orders, the potential biological removal (PBR) is calculated for each region for each year (SCOS-BP 19/05) and region specific recovery factors are assigned each year on the basis of current/recent population status. These are discussed in answer 10 below.

Seal Legislation

9. Does the Committee consider that there is a significant scientific requirement or advantage to updating the Conservation of Seals Act 1970, For example, definitions and applications of closed seasons, the netsmen's defence and the potential for the introduction of mandatory recording and/or licensing of shooting?	Defra Q9a

SCOS again recommend that reporting of seals killed should be mandatory

SCOS cannot advise on the need for introducing any additional conservation areas.

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. In Scotland, the licensing of shooting, allows the targeted management of seals and requires an assessment of the need for and consequences of that management. Applying similar procedures in England and Wales would potentially overcome a problem with the Conservation of Seals Act, whereby the netsman's defence currently takes precedence over seal conservation orders.

SCOS note that it is possible that shooting seals to protect fisheries and salmon aquaculture activities could trigger actions under the US Marine Mammal Protection Act. This may result in sanctions against the importation of salmon farm produce from the UK into the USA. Any such actions are expected to be imposed from 2021.

For long-lived, annually breeding species such as grey and harbour seals, with consistently high pregnancy rates, the enforcement of closed seasons associated with the breeding seasons has little effect on the population consequences of removals. However, 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

10. What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system?	MS Q5

Provisional regional PBR values for Scottish seals for 2020 are given in SCOS-BP 19/05. Those PBR calculations assume that the method and the chosen values for F_R and R_{max} are unchanged from SCOS 2018, so any changes are the result of changes in population N_{min} estimates.

The only substantive change for harbour seals since 2018 is the 40% increase in the count for the Southwest Scotland SMU, leading to a commensurate increase in PBR, from 50 to 71.
The grey seal count for the West Scotland was 20% lower than the previous estimate, leading to a reduction in PBR from 1219 to 966. The Moray Firth grey seal count was 36% lower leading to a reduction in PBR from 275 to 175. The grey seal count in the Southwest Scotland SMU was almost 40% higher than previous counts leading to an increase in PBR from 86 to 119.

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 19/05. Sets of possible values are tabulated for each area with different values of recovery factor. The recovery factor (F_R) 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.

F_R has been held constant in all management regions.

In 2018 SCOS recommended increasing the F_R for the West Scotland SMU to 1.0 but recommended a review of that decision in light of the 2018 surveys results. Adding in the 2018 results brought the total down very slightly, but not enough to negate the arguments for raising F_R to 1.0.

In 2018 SCOS recommended that the Western Isles management area PBR be re-examined in light of the results of the 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 25% higher than the 2011 count. Despite this high count, a trend analysis (see Q2 above) suggested no significant change between the early 1990s and 2017.

In practical terms, the 2020 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 2018 recommended that the recovery factor be left at 0.5.

The PBR calculation includes a scalar for intrinsic rate of increase (R_{max}), i.e. the rate at which a population is assumed to increase if it is far below carrying capacity. By default this is set at 0.12 for both grey and harbour seals. The value has been previously identified as an appropriate value for pinnipeds because several populations of both phocid and otariid seals have been observed to increase at this rate.

Regional pup production estimates for the UK grey seal population have shown maximum growth rates in the range 5-10% p.a. (Lonergan *et al., 20*11b). However the large grey seal population at Sable Island in Canada has grown at nearly 13% p.a. (Bowen *et al., 20*03). The UK grey seal population in the North Sea has been increasing since structured surveys began in the 1960s. At no time during that period has the growth rate approached 12% p.a. except for particular subsets of the population where it is impossible to rule out immigration. If as seems likely the achievable intrinsic rate of increase is less than 12%p.a. it may be sensible to reduce the value in the PBR calculations. As R_{max} is a scalar in the calculation, any reduction in R_{max} would produce an equivalent reduction in the recommended PBR.

11. Has there been any new information on harbour seal trends that would lead to a change in the recovery factor used in the PBR calculation for any of the Scottish seal management areas? In light of this information, do SCOS recommend any changes to the recovery factors for any of the management areas?	**MS Q6a**

SCOS does not consider that the recent survey results change the status of any of the harbour or grey seal populations around the UK sufficiently to require a change in any of the F_R values. SCOS therefore recommend that recovery factors used in the PBR calculations should be left unchanged at present.

Harbour seal populations in Shetland, Orkney and North Coast, Moray Firth and East Scotland SMUs are either continuing to decline or are stable at population sizes >40% below their 1990s levels. SCOS therefore recommends that existing conservation orders remain in place in these SMUs.

Results of recent surveys and a detailed description of the status of harbour seal populations in each SMU are given in SCOS-BP 19/03 and in answers 1 and 5 above. SCOS does not consider that the recent survey results change the status of any of the harbour or grey seal populations around the UK sufficiently to require a change in any of the F_R values (see previous answer above and for more detail).

Seals and Marine Renewables

12. Has there been any further progress on improving our understanding of how seals behave around tidal energy devices?	NRW Q 2

There has been good progress in understanding how seals use tidally energetic habitats and on how seals respond to the presence of turbines at ranges of 10s to 100s of metres but

understanding the fine scale underwater movements (at a scale of metres) of individual seals around operating turbines remains a critical knowledge gap.

The risk of an individual seal being hit by a turbine blade will depend on the likelihood of seals being in the vicinity of turbines, i.e. whether or not the turbines are located in foraging habitats or on transit routes used by seals and, if they are, whether or not the seals will alter their behaviour to avoid those locations. This risk will then be scaled by whether seals approach operating turbines and if so whether they are able to evade the rapidly rotating blades.

There has been good progress in understanding how seals and other wildlife use tidally energetic habitats (Hastie *et al.*, 2016; Lieber, Nimmo-Smith, Waggitt, & Kregting, 2018) and on how seals respond to the presence of turbines at ranges of 10s to 100s of metres (Hastie *et al., 20*17; Joy *et al., 20*18). However, there has been no published information on evasion responses of seals to moving turbine blades. In the absence of direct observations to inform evasion estimates, current guidance from regulators suggests using a range of values of 0, 50, 90, 95, 98 & 99% evasion (SNH 2016)

Two recent studies report evidence of avoidance behaviour. Joy *et al. (*2018) showed that seals avoided the operating Sea Gen tidal turbine in Strangford Narrows. Harbour seals with GPS/GSM location tags showed a mean 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. Hastie *et al. (*2017) showed that GPS tagged harbour seals exhibited significant spatial avoidance of acoustic playbacks of tidal turbine sounds, resulting in a 27% (95% C.I., 11%, 41%) reduction in usage by seals at the playback location. These empirical changes could be used to estimate preliminary avoidance rates for use in collision risk models but it should be noted that the responses were to a single point source and additional work is needed to determine the effects of multiple sources equivalent to operational tidal arrays.

Scottish Government funded work to determine the probability of severe trauma in seals from collisions with tidal turbine blades has recently been published (Onoufriou *et al*., 2019). Pathological consequences of direct collisions with tidal turbines at a range of speeds, were estimated using seal carcasses and physical models of tidal turbine blades. A dose–response model was developed with associated uncertainty to determine an impact speed threshold of severe trauma. Results showed that severe trauma was restricted to the thoracic region, with no evidence of injury to the lumbar or cervical spine. Severe trauma was only predicted to occur in collision speeds in excess of 5.1 ms^{-1} (95% C.I. 3.2 ms^{-1}, 6.6 ms^{-1}) and was affected by body condition; increasing blubber depth reduced the likelihood of severe trauma (Onoufriou *et al.*, 2019). The collision trials used a blade profile equivalent to the tip of a typical tidal turbine blade and therefore represented the worst case collision scenario. Collisions with wider sections of the blade would be expected to cause less damage at the same collision speeds.

Other data gaps relevant to the impacts of tidal turbines 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.

Seals and Fisheries

13. What is the evidence of impacts of an increasing seal population on wild fish populations and fish stocks? It would be particularly helpful if SCOS could consider this in the context of other potential pressures acting on the fisheries. Where the evidence	MS Q8

base is limited, it would be helpful if SCOS could identify knowledge gaps.	

SCOS consider that there are three aspects to this question.
1) Are seal populations increasing in areas where fish stocks are declining?

- **SCOS noted that seal population increases over the past decade have been confined to the Central and Southern North Sea. Consumption by seals as a percentage of estimated stock size in the North Sea was estimated to be small and North Sea cod stocks rose steadily from 2006 to 2017, which would not be the case if seal predation was significant and increasing.**

2) What are the diets of seals in UK waters?

- **Both grey and harbour seals are known to consume a wide range of prey including commercially exploited species such as sandeels, cod, other gadoids, flatfish, herring and mackerel, and a large number of non-commercial species including benthic fish such as dragonet**

3) Is there evidence that seal predation is having detectable effects on fish mortality.

- **Seal predation can have significant impacts on particular fish stocks. For example grey seal predation has been identified as a major source of mortality on cod stocks in the North West Atlantic and off Western Scotland, and in the Wadden Sea, harbour seal predation has been shown to be a major contributor to demersal fish mortality.**

1) Are seal populations increasing in areas of fish stock collapse?

Although there has been continued increase in the overall UK grey seal population in terms of both pup production (SCOS-BP 18/01) and total population (SCOS-BP 19/01), the majority of the increase in pup production over the past 20 years has been at colonies in the North Sea and in the past 10 years that has been concentrated at colonies in the southern North Sea. Grey seals disperse widely from their breeding sites to forage, but on a regional scale, the resulting distribution of foraging grey seals reflects the regional patterns in pup production. Based on the distribution of hauled out seals during the summer, the numbers of grey seals foraging around Scotland have remained relatively stable. The numbers of grey seals foraging in the central and southern North Sea have increased particularly at sites along the east coast of England (figure 7) and recently, the majority of this increase has been in the southern North Sea. Harbour seal populations around the north and east of Scotland have undergone dramatic declines over the same period. It is clear that there has been no general increase in the population of seals foraging around Scotland.

In the absence of a rapidly increasing seal population in Scotland and the lack of any apparent large scale re-distribution within Scotland it is unlikely that seal population growth is a major factor driving recent fish stock declines. Seal population increases over the past decade have been confined to the Southern North Sea. Consumption of cod by seals in the North Sea was estimated to represent a small percentage of estimated stock size, and North Sea cod stocks rose steadily from 2006 to 2017, which would not be the case if seal predation was significant and increasing.

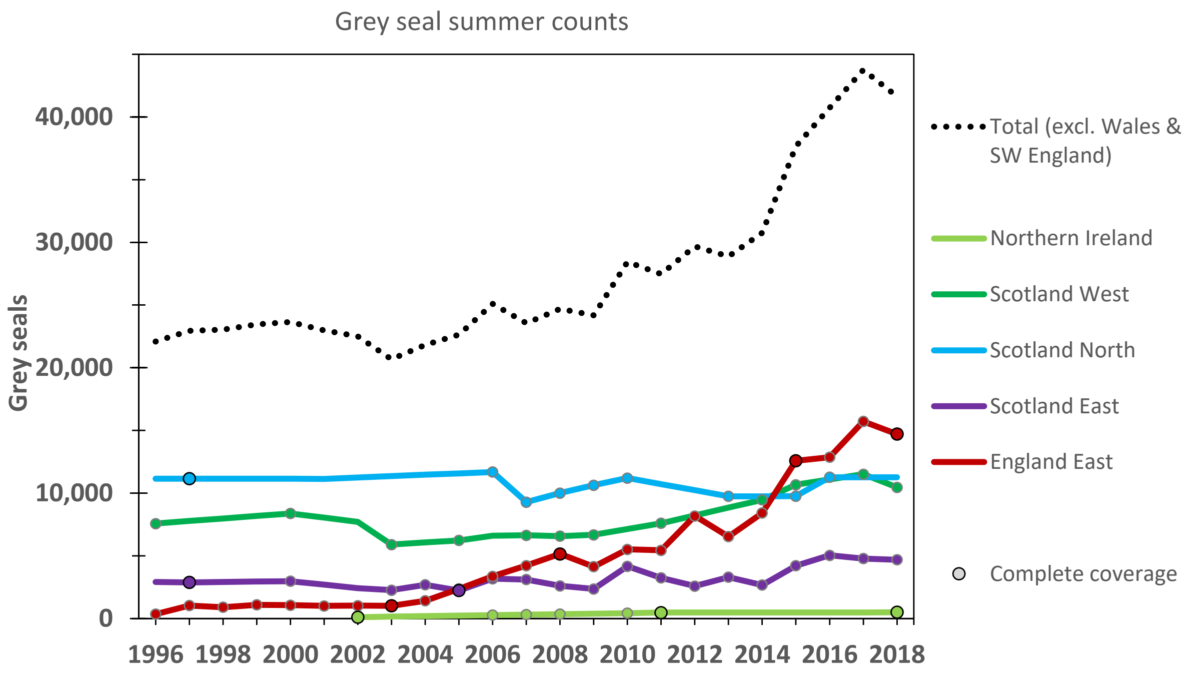

Figure 7. Summer haulout counts of grey seals around the UK coast, by region.

UK seal population trends should be seen against a background of major long-term changes in the productivity of key ecosystem components of the North Sea, Celtic Sea and adjacent waters. Phytoplankton, zooplankton, and demersal and pelagic fish have all exhibited episodic cycles in variability (ICES, 2017). Managers should expect change and ensure that management plans have the potential to respond to new circumstances. Examples of these changes include the gadoid 'outburst' in the 1970s and reduced productivity of gadoid stocks since the mid-1980s, as well as reduced productivity of herring (*Clupea harengus)* since 2002. Large-scale ecosystem changes appear tightly linked to sea water temperature trends. Whilst the mechanisms underlying these links are not known, it is clear that the temperature cycle of the North Atlantic (the Atlantic Multi-decadal Oscillation, AMO) affects the North Sea and adjacent waters (Nye *et al.*, 2013).

Fishing pressure has reduced the number of large fish in the North Sea ecosystem (mostly cod *Gadus morhua*, saithe *Pollachius virens*, ling *Molva molva*, and various elasmobranchs). Whilst the impact of these removals on the ecosystem functioning is not clearly understood, it should be assumed that the North Sea ecosystem is currently in a perturbed state. However, it is clear that fishing effort has reduced in the North Sea since the 2002 Common Fishery Policy (CFP) reforms; this can now be detected in the reduction of fishing mortality in most assessed fish stocks and an increase in the amount of larger fish present (ICES, 2018). The majority of assessed fish stocks are now fished at or below MSY fishing mortality targets (F_{MSY}; ICES, 2018).

2) **What are the diets of seals in UK waters?** Both grey and harbour seals are known to consume a wide range of prey including commercially exploited species such as sandeels, cod, other gadoids, flatfish, herring and mackerel, and a large number of non-commercial species including benthic fish such as dragonet (Wilson & Hammond 2016). A growing seal population has the potential to impact fish populations through predation mortality (the seals can be thought of as a competing fishery). Estimates of seal diet can be combined with knowledge of their daily energetic requirements, to estimate the quantities of different fish that are consumed by whole populations of seals.

SMRU has carried out three major diet studies in the mid-1980s, 2002, and 2010/11 to sample scats seasonally around the coast of Scotland and eastern England and estimate diet composition and prey consumption of grey seals and, in 20110/11, harbour seals. Estimates of prey consumed were compared with fish stock sizes to estimate percent predation mortality.

In addition, captive seal studies have allowed analyses to account for the effects of partial and complete digestion of the hard parts recovered from faecal samples, which would otherwise generate results that were subject to considerable bias. Results of all these studies have been presented to SCOS in the past and are described in detail in a series of recent reports to Scottish Government (Hammond & Wilson, 2016; Wilson *et al., 20*16; Wilson & Hammond, 2016a,b).

The most recent study collected 2,200 grey seal scats containing 68,465 otoliths and beaks. Results indicated that:

- In the Western Isles, estimated diet was dominated by sandeel and gadid prey, particularly cod and ling.
- In the Northern Isles, the diet was also dominated by sandeel and gadid prey, particularly saithe and cod.
- In the Northern Isles sandeel made up around a quarter of the diet in Shetland and around half of the diet in Orkney.
- In the central North Sea, diet was heavily dominated by sandeel but was more varied in the southern North Sea.

Overall, grey seals were estimated to have consumed 129,200 t (95% c.i: 114,800-149,400t) of prey in the North Sea (ICES Subarea IV) and 70,300 t (95% conf. interval: 60,000-84,000 t) of prey west of Scotland (ICES Division VIa) in the 12 months from April 2010 to March 2011; a grand total of 199,500 t (95% conf. interval: 181,200-225,500 t).

Diet composition appears to have changed little in the Western Isles from 1985 to 2002 to 2010/11. In the Northern Isles, changes in diet composition were characterised by a marked decline in the contribution of sandeel in Shetland and a more gradual decline in Orkney, and an increase in the contribution of gadids. In the central North Sea, however, the change in the contribution of sandeel and gadids was the reverse of that seen in the Northern Isles. Gadids declined markedly but sandeel increased steadily between 1985 and 2010/11.

In 2010/11 harbour seal diets were also sampled by SMRU, and there have also earlier harbour seal diet studies in restricted areas e.g. Shetland, the Moray Firth and the Tay Estuary. The consumption of fish by harbour seals is of interest particularly in the context of harbour seal declines in some areas.

3) **Is seal predation large enough to have detectable effects on fish mortality?**

In the North Sea (ICES Subarea IV), consumption by seals as a percentage of estimated stock size was estimated to be small; the highest figure was for cod (5% in 2010). North Sea cod stocks (for example) rose steadily from 2006 to 2017, which would not be the case if seal predation was significant and increasing.

However, in the West of Scotland (ICES Division VIa) estimated consumption by seals as a percentage of estimated stock size was larger for whiting (10% in 2010) and very large for cod (> 100% in 2010). These figures increase to ~50% and > 200%, respectively, if harbour seal consumption is also included. The partial coverage of west coast cod by the stock assessment and the lack of overlap between the area of the fishery and the area where seals forage provide at least a partial explanation for how the estimated consumption by seals can be so large relative to the size of the assessed stocks. Seals are therefore more likely to have an impact on the West Coast than in the North Sea, but even on the West Coast the area of seal distribution does not coincide with the main areas of commercial fishing, and it is likely that predated fish are from different functional stocks than commercial-caught fish (particularly for cod).

Cook & Trijoulet (2016) showed that seal predation rate on the depleted West of Scotland cod stock was consistent with a type II functional response and included seal predation with this functional response in a model of cod stock dynamics. Projections of a model under varying levels of fishing and seal population size suggested that stock recovery was possible under current conditions although there was a small probability that cod population would decline with small increases in either fishing or seal predation. The dynamics were sensitive to relatively small changes in mortality rates, and sensitive to some of the basic assumptions of the shape of the fishing mortality curve (Cook*, 20*19).

Trijoulet, Holmes & Cook (2018) used a Bayesian state-space model to investigate stock trends in the presence of grey seals and estimate predation mortality on haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) and cod in the West of Scotland. Grey seal predation mortality on cod was higher than the natural mortality rates used in the ICES cod stock assessments, but seal predation mortality is low for haddock and whiting. Estimates of $F_{0.1}$ and F_{MSY} were sensitive to seal predation for cod and whiting but not for haddock in the West of Scotland stocks. In all cases, MSY decreases with increased seal predation.

Grey seals have been implicated in the failure of the Northwest Atlantic cod to recover from the stock collapse in the early 1990s. The grey seal population increases corresponded with increases in estimated natural mortality (M) of cod. However, the diet information available suggests that seals consume mainly juvenile cod, whereas the available evidence indicates an increase in M for larger cod (Chouinard, *et al., 20*05). Incorporating grey seal predation in a population model for Gulf of St Lawrence (GSL) cod via a functional response, indicated that predation mortality of adult Atlantic cod increased sharply during the stock collapse and has continued to increase (Neuenhoff *et al., 20*17). Seal predation is estimated to have comprised the majority of cod mortality since the late 1990s. Although grey seals were not shown to have driven the initial collapse, seal predation was estimated to be the main factor preventing recovery and their model predicted continued declines in the sGSL Atlantic cod unless there is a large decline in the abundance of grey seals.

Clearly predation by grey seals is large enough to be a potential factor in the dynamics of some stocks. However uncertainties in several factors, e.g. in the diet composition, in the total consumption and overlaps between seals and fisheries at sea, mean that confidence in predictions of effect levels will be low.

Aarts *et al. (*2019) combined seal diet data, estimates of seal metabolic rates and telemetry tracking data to estimate the impact of the harbour seal predation on the fish community in the Wadden Sea and nearby coastal waters. They concluded that harbour seals apparently acquired the majority of their prey in the adjacent North Sea, and only spend 14% of their diving time in the Wadden Sea. Despite this, seal predation was still estimated to cause an average annual mortality of 43% of the remaining fish in the Wadden Sea and 60% in the nearby shallow coastal waters (<20 m).

Data gaps

The results of the UK grey seal diet studies suggest substantial variation in diet between regions, seasons, and years. In some years and places, seals appear to have removed appreciable quantities of commercial fish especially cod (Hammond & Wilson, 2016)

It is now almost a decade since the last comprehensive diet survey and there is a pressing need to update this information in light of the changes in the foraging distributions of seals around the UK. A research priority is therefore a comprehensive diet survey covering the same regions as the previous studies.

However, diet studies are expensive and time consuming and therefore will be infrequent, so it is important to develop our ability to estimate the likely quantities of commercial fish consumed in intervening years, and predict quantities that might be consumed in future. SMRU has previously developed models based on the data, linking diet composition to prey availability (e.g. Smout *et al., 20*13). To clearly understand the implications of seal predation for commercial fish stocks such as North Sea cod, we need to

a) Model seal-prey interactions
    a. Improve estimates of fish abundance and distribution
    b. Compare seal foraging distribution with fish distribution
    c. Address a major knowledge gap about the changing abundance and distribution of sandeels in UK waters.
    d. Model how seal diet changes in response to prey availability – the multi-species functional response of the seals (MSFR)
b) Link MSFR model to models of fish populations, to better understand if the impacts of seal predation are important, compared with the impacts (for example) of fishing and predation by other species such as predatory fish and cetaceans, and of competition between species. This work requires multi-species models of the marine food web so that the important trophic links can be accounted for and the relative importance of different sources of fish mortality can be understood.

14. Can SCOS advise on what practical options are available to manage an increasing seal population to address any potential impacts to fish populations/fish stocks, and what ethical considerations there are (if applicable) for these approaches? It would be particularly helpful to understand whether these options have been employed previously, and their success rate and applicability to Scottish seal populations.	MS Q9

The answer below assumes that a case for population reduction has been made.
Two methods of population control are discussed.
1) Mass contraception using a previously tested porcine zona pellucida (PZP) vaccine.
2) Population reduction by targeted killing of pups or adult female grey seals.

SCOS discussed the practical aspects of control, including the sex and age structure of the culls, the effects of population status, geographical spread and time frame of culling programmes to achieve specific management goals and discussed the risks and monitoring requirements associated with such actions.

The question assumes that seal populations are having an impact on fish populations/fish stocks, that issue is discussed in answer to Q13 above. The answer below assumes that a case for population reduction has been made.

It may be possible to dissuade seals from preying on particular fish at specific locations (e.g. by use of ADDs in rivers and estuaries, or around fixed/static fishing gear) and it may be feasible to develop anti predator devices and methods for other mobile fishing gear. However, SCOS is not aware of any feasible/practicable methods to control or alter the feeding habits of individual seals in the open sea, nor any method to alter the foraging behaviour/prey preferences at a population scale.

SCOS consider that the only remaining option for controlling seal populations in order to reduce prey consumption, is to kill seals to reduce the population or reduce the growth rate so that the population approaches some target level defined by the management goals. Reducing the growth rate of a population can only be achieved by reducing either survival or fecundity or some combination.

Reducing fecundity: Reducing grey seal fecundity through a program of mass contraception at breeding sites has been proposed. The Canadian Senate's Standing Committee on Fisheries and Oceans (2012) suggested that when considering ethics, social good, public perception, and international market implications, the use of contraceptive methods to manage the grey seal population is believed to be more acceptable than killing large numbers of seals.

Brown *et al.* (1997) reported a field trial of PZP vaccine as a long-term, single application contraceptive for grey seals. They showed that pup production of the test group was reduced by approximately 90% between two and five years after immunization. There was no temporal pattern in antibody titres between two and five years post immunization so the contraceptive effect was long lasting and may have been effectively permanent.

The production of birth control vaccine, its administration to a large proportion of the adult female grey seal population and the population monitoring requirements for assessing its effects would be a major undertaking.

The effectiveness of reducing fecundity as a management tool would depend critically on the status of the population in question. The population dynamics model used to produce grey seal population estimates (SCOS BP 19/01) indicates that density dependence acts mainly through reduced pup survival. In such populations, e.g. the Inner and Outer Hebrides and Orkney, few pups survive to recruit into the breeding population. Reducing fecundity in such a population would have little effect on the absolute number of pups surviving to age one, since pup survival is already low. Any reduction in population would also eventually lead to increased pup survival thereby further damping the effect of reducing fecundity. Conversely, in the North Sea population where pup survival is relatively high, reducing fecundity could have significant effects.

Monitoring the effects of a large scale contraception programme would be labour intensive. It would require several years of monitoring of the breeding behaviour of a known, i.e. permanently marked group of adult female grey seals.

The apparent long term effect of the PZP contraceptive vaccine are not fully understood. If the contraceptive is effective for many years, the effect on the population will be similar to that of killing the adult females. However, removal of breeding females would also mean that they were no longer consuming prey whereas contraception or sterilization would leave the female seal alive and therefore feeding. Further studies of the effects of PZP, or any other potential contraceptive, on long term fecundity would be required before their potential impact on populations could be predicted and before its widespread use in the wild could be considered as a population control measure.

Reducing survival: An apparently simpler method of population reduction would be to kill a proportion of the population in a structured culling programme. Determining the number of seals that would need to be killed to produce a particular reduction in population, and the number that would then need to be removed to stabilize the population at that new level requires a reliable population dynamics model to rigorously test a range of harvest strategies and a structured population monitoring programme to assess the realised effects of the culling.

The Scientific Advisory Committee of the UNEP Marine Mammal Action Plan drew up a protocol for the scientific evaluation of proposals to cull marine mammals (UNEP, 1999). Such an evaluation must consider the complexity of ecological interactions among the marine mammal population(s), the relevant fish stocks and the fisheries which catch them. The protocol defines the information which must be provided to allow a scientific evaluation of the biological and ecological aspects of a proposed cull and the simulation modelling approaches that should be adopted to predict the ecological effects.

An essential part of the evaluation of the ecological effects of the proposed cull is an estimate of the impact of the cull on the abundance of the marine mammal. Thomas *et al. (*2011) and Hammill *et al. (*2017,) presented harvest advice that predicts the effects of different age and sex structures and magnitudes of removals from the Canadian grey seal population. A modified version of these assessment approaches would be relatively easy to apply to UK grey seals.

15. Could the Committee provide further information on how the killing of grey seals and harbour seals affects the rest of the UK ecosystem?	Defra Q8

Reported levels of seal killing are not sufficient to cause significant changes in national or regional populations. There is uncertainty around the total numbers of seals killed, particularly in England and Wales where licences and reporting are not required.

The removal of a small number of seals is unlikely to result in detectable large scale effects on the wider ecosystem (see answer 13 above).

Large scale population reduction will have obvious consequences for the target species, but the consequences for the ecosystem or even for individual prey populations will be complex and hard to predict. Recent reduction in fishing mortality for many stocks, means that natural mortality is becoming the dominant source of mortality in the North Sea. Improving estimates of consumption of fish by top predators, such as seals and cetaceans, is increasingly important, particularly when these predator populations are expected to increase further.
As seal predation usually represents a small proportion of natural mortality, the removal of a part of that predation is unlikely to result in detectable large scale effects on the wider ecosystem, but assessing the likely impacts will require an integrated ecosystem modelling approach.

At present, the reported number of seals being killed in the UK is low relative to the national or regional populations. In Scotland where seals can only be legally killed under licences issued under the Marine Scotland Act the numbers of licences issued is informed by estimates of the potential biological removals (PBR) (see answers 10 & 11 above). These are designed to allow seal populations to stabilise at the Optimum Sustainable Population (OSP). For large long lived mammals such as seals the expected shape of the density dependent population growth curve means that OSP should be quite close to the carrying capacity. In practice few grey seals are shot, generally less than 5% of the PBR, and for harbour seals the declining populations have zero takes or “conservative” PBRs to minimise potential increased rates of decline and relatively conservative PBRs are set for the rest of the Scottish harbour seal population. Again, in these larger populations the number of reported seal kills is generally less than 5% of the PBR.

For the rest of the UK there is no requirement to report the numbers of seals shot and therefore no data to estimate the impact of such removals. However, reports of shot seals stranding on the English and Welsh coasts are relatively rare and there is no indication that seals are being killed in large enough numbers to have a significant effect on population trajectories.

On a local scale and for specific parts of the ecosystem, even relatively small numbers of seals being killed could have detectable effects on both the seal and prey populations. For example, a large scale shooting programme in the Moray Firth was identified as the likely cause of a decline in the harbour seal population and led to the development of a seal management plan (Butler *et al., 20*08)

The targeting of specific seals involved in depredation of particular fish populations can reduce predation mortality. For example, in the USA targeted removal and killing of particular individual sea lions and harbour seals from rivers with endangered salmonid runs is permitted. Salmon escapement up-river has increased as a consequence.

For large scale population reduction, the results in terms of effects on seal populations will depend on the scale, sex and age structure, and timing of any such reduction. The effects would be different for grey and harbour seals because of their different movement and foraging strategies. Removing large numbers of harbour seals could have local effects on the ecosystem but effects of removing grey seals would be more dispersed over a much large area.

The effects of large scale population reduction measures in terms of the effects on seal populations are addressed in answer 14 above. Such removals would be aimed at reducing predation pressure on specific parts of the ecosystem, primarily commercial fish stocks. The effectiveness and the medium to long term consequences of such actions are unclear. As seal predation usually represents a small proportion of natural mortality, the removal of a part of that predation is unlikely to result in detectable large scale effects on the wider ecosystem. However, in some areas and for some fish stocks, seal predation may be an important mortality factor. Reducing this predation will have effects on prey populations, but such effects may be complicated and, for most prey species, are likely to be swamped by small changes in fishing pressure or changes in other fish populations.

Determining the ecosystem-level impacts of removing a proportion of the seal population will require an integrated ecosystem modelling approach with inputs on the drivers of distribution for key components of the ecosystem. Several such models are already in use, e.g. Romagnoni *et al.* (2015) used a spatial food web model "Ecospace" for the North Sea, based on the Ecopath with Ecosim (EwE) software. The model was validated against trends in time series of fish biomass and fishing effort for a system with 12 fish species and three fishing fleets and successfully predicted the fish species distribution. Ecospace has recently been improved to include the impacts of variable habitat quality on the distribution of populations and could be modified to investigate the ecosystem effects of changing predator populations.

The reduction in fishing mortality for many stocks, means that natural mortality is becoming the dominant source of mortality in the North Sea. Improving estimates of consumption of fish by top predators, such as seals and cetaceans, is increasingly important, particularly when these predator populations are expected to increase further (ICES, 2013).

16. Is seal predation a contributing factor to declines in rod and line catches in 2018?	MS Q10

Seal populations around Scotland, have not increased significantly over the past decade so there is unlikely to be a direct link between population size and the rapid decline in rod and line catches of salmon in 2018.

Studies of diet of seals in salmon rivers produced results that vary between heavy predation on salmonids to zero evidence of predation. It is clear that there is no simple/obvious correspondence between numbers of seals observed close to or even within salmon rivers and the levels of predation on salmonids. Further work on identifying salmon in diets where no hard parts are found may help clarify this issue..

Seal populations around Scotland, have not increased significantly over the past decade so there is unlikely to be a direct link between population size and the rapid decline in rod and line catches of salmon in 2018 (see answer 13).

Relocation of haulout groups and local changes in foraging distribution may be more important than overall population size when considering impacts on salmonid catches within rivers. With the exception of the Moray Firth and the Tay and Eden estuaries we do not have enough survey data to allow us to assess the local redistribution of seals on an annual basis. Where there are regular counts of seals at haulout sites associated with or within salmon rivers the patterns are variable. There has been a major shift in the distribution of haulout use in the Inner Moray Firth over the past decade, with numbers of harbour seals declining dramatically in the Beauly and Cromarty Firths (few grey seals have ever been recorded there) while there has been a commensurate increase in numbers of both harbour and grey seals using haulout sites at Ardersier and Culbin. Numbers of harbour seals in the estuaries of the Tay and Eden have declined substantially, but numbers of grey seals hauling out within the estuaries have increased to match the declines.

However, recent work suggests that the numbers of seals counted on haulout sites may not be a relevant index of local salmon predation rates. Photo i.d. data collected during a 12-month observational study of Aberdeen Harbour and the River Dee in 2016-2017 (as part of the Scottish Government funded Marine Mammal Scientific Support Research Programme MMSS/002/15) identified 19 individual grey seals and 17 individual harbour seals using the river system. Of these, 14 were categorised as salmonid specialists (9 grey seals, 5 harbour seals), 15 as regular users of the river system (6 grey seals, 9 harbour seals), and seven (4 grey seals, 3 harbour seals) as transient, based on the frequency of occurrence and their behaviour. Seals were seen throughout the year in the harbour and most often during winter months higher up the river. Observations of predation events were highest during the first half of the year and increased with increasing river flow.

Results of a diet study of harbour seals using scats collected at a haulout near the River Dee (Harris & Northridge, 2017) show that the diet was dominated by whiting and flatfish otoliths, with only one scat containing salmonid otoliths, which were of smolt size. The fact that 5 photo identified harbour seals in the River Dee were classed as salmonid specialists on the basis of observed predation events and the low level of salmonid remains in the diet samples indicates that the numbers of seals seen at haulout sites within or close to the river may not be indicative of the level of predation on salmonids within that river. Granquist & Haukson (2016) also found no evidence of seal predation on salmonids in scat samples from haulout sites in the estuaries of three salmon rivers in Iceland, where flatfish, sandeels and capelin were the most important species in the diet.

Conversely, Sharples *et al. (*2009) found potentially important levels of predation by harbour seals on salmon in the vicinity of the Tay estuary, (a SAC designated for both harbour seals and salmon). Within the Firth of Tay, sandeels were prevalent in winter, but salmon comprised 64% of the diet by weight in summer and sea trout comprised 40% of the diet in autumn. Although harbour seal predation was likely impacting local salmon stocks, the high uncertainty in estimates of seal diet and salmon stock size precluded the provision of management advice at that time. Since that study, the population of harbour seals in the Tay has fallen by >70%. Diet based on scat samples in the outer estuary did not indicate any predation on salmonids.

Telemetry tags deployed on four harbour seals from the haulout site close to the River Dee revealed that most of the seals spent their time travelling and foraging close to the coast, but outside the estuary. Only one seal spent time within the River Dee, and this was an individual that had already been identified and categorised as a regular user of the river. The tag data for this individual has provided further insight into the behaviour of seals that regularly use the river but that are not salmonid specialists, highlighting that estuaries are used by seals to forage on species other than salmonids.

Bottlenose dolphins were also recorded during the Dee study, and observations were highest between January and June (coinciding with the period of highest probability of a salmonid predation event by seals).

Continuing seal diet work in conjunction with seal observation studies should improve estimates (or confidence in estimates) of salmonid consumption.

It is clear that there is no simple/obvious correspondence between numbers of seals observed close to or even within salmon rivers and the levels of predation on salmonids. Further work on identifying salmon in diets where no hard parts are found may help clarify this issue.

17. a) Reports from some fishermen in S and SW England of bycatch of rescued, tagged seal pups that appear to have been snagged in nets by their tags. **b) Some fishermen also complain that the numbers of seal pups being rescued is increasing and they're being released in same area and increasing local population and conflict. Can SCOS comment on these observations?**	Defra Q6

a) SCOS is aware that standard Jumbo-Roto (J-R) tags pose a risk of entanglement, although there is no hard evidence to estimate the scale of the problem. However, to minimize the risk SMRU have designed and tested a new closed loop tag that is flexible enough to accommodate post tagging growth of the flipper. The smooth curved design, absence of any significant lip and the narrow rounded profile means that snag risk has been eliminated. SCOS recognises the potential usefulness of the new closed loop tags on these grounds.
b) Rehabilitated grey and harbour seals, shortly after release, have been shown to behave like wild seals. If stranded pups are released in areas close to their capture sites there should be little effect on local seal densities.

a) The widely used Jumbo-Roto (J-R) flipper tags comprise a single post inserted through the flipper with two trapezoidal shaped plates on either side of the flipper web. This poses a potential entanglement risk. There are a few anecdotal but reliable reports of such events (R. Deaville, CSIP, pers. com.). In most cases, the tag attachment is unlikely to be strong enough to hold a seal, it would likely pull out of the flipper. However the reaction of a seal to snagging a tag on a net would be to turn and or twist and this greatly increases the chances of becoming entangled.

Partly in response to this perceived risk, but also because of high tag loss rates for standard J-R tags, SMRU have trialled two alternative marking techniques. Successful trials of a tattooing technique have been carried out on both grey and harbour seals. This technique however requires significant handling and restraint of the seal and has so far only been carried out on anaesthetised seals. Tattooing may be suitable for targeted observation studies but is unlikely to be applicable to the large numbers of seals released from rehabilitation centres.

SMRU have also designed a new closed loop tag that is flexible enough and long enough to accommodate post tagging growth of the flipper. The tag is a two part design that clips together requiring a single hole in the flipper web, of a much smaller diameter than the holes for current JR tags. The smooth curved design, absence of any significant lip and the narrow rounded profile means that snag risk has been eliminated, abrasion risk should be dramatically reduced and drag minimised. Tag prototyping has been completed and SMRU are trying to identify resources to allow field testing of the designs in the near future.

b) The effects of releasing large numbers of rehabilitated juvenile seals can be significant. In the Wadden Sea, for several years, a large proportion of the pup production of both grey and harbour seal populations were brought into rescue centres and later released. It is thought that this activity made a significant contribution to the rapid growth of both populations. The release programmes in the UK are on a much smaller scale but have caused some controversy in some areas.

It is extremely hard to assess the effects of such releases on local fisheries. Most of the information required to make such an assessment is missing. However there have been several studies of the efficacy of rehabilitation which may provide some insight into the likelihood of negative impacts.

The behaviour of a small sample of rehabilitated harbour and grey seals has been studied using a combination of visual marks, flipper tags and telemetry (VHF and satellite transmitters). Six rehabilitated harbour seals released in the Wash were fitted with satellite tags and their movements and dive behaviour over the following four months were similar to those of seals caught, tagged and immediately released in the same area (Morrison *et al.,* 2011). A larger sample of rehabilitated grey seals were monitored after release in France (Vincent *et al.*, 2002). Seals dispersed widely. Although tag resightings were concentrated in western Brittany near their release sight, sightings were also scattered along the Brittany and Normandy coasts and western Cornwall, with one recovery in Pembrokeshire and one in SE Ireland.

Of four satellite tagged seals, two remained in the Molene Archipelago close to the release site although one swam almost to the Devon coast. Another travelled along the English south coast to an area south of the Isle of Wight (a 480 km swim) and one travelled to Dunay Point in NE Ireland (a 630km swim). All seals appear to have dived like typical grey seals. These movement patterns are similar to those seen in wild grey seal pups (Bennet *et al.,* 2010; Carter *et al.,* 2017).

The fact that rehabilitated seals behaved like typical wild seals soon after release suggests that if they are released in areas close to their capture sites there should be little effect on local seal densities. The natal sites of the seals released in France are not known, but their wide dispersal in the few months after release suggest that any concentration effect is likely to be limited.

18. 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. Could SCOS advise on how to structure a study to investigate and address these issues?	Defra Q7

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 levels of damage.

SCOS is not able to recommend any particular research programme. The structure and methods used in any study of interactions between seals and fisheries will be determined by the nature of the fishery and the specifics of the interaction. A necessary first step will be to determine the importance, extent and scale of the perceived interaction. The initial assessment should be designed to inform the decision to go ahead with a study and should provide sufficient information to allow a targeted research programme to be designed.

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.

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.

19. What advice can be provided on the relocation of seals as **1) a non-lethal method to deal with seal predation in aquaculture, and** **2) a mitigation measure in marine development to avoid disturbance or injury to seals. It would be particularly useful if**	MS Q7

SCOS could consider these issues in the context of capturing seals in the water, and the feasibility and any ethical concerns and/or considerations that there may be with this approach.	

The relocation of seals from established foraging habitat is at best a temporary solution. The disturbance during capture and relocation will be substantial and likely outweigh any possible benefits to the seal.

Catching seals in rivers is, in most cases, extremely difficult and poses some risk to the target animals. Relocation trials in the USA have been ineffective with seals returning to the capture sites even from distant release sites. Such activity has been abandoned and seals and sea lions are now removed and killed.

The adopted mitigation strategy for each aquaculture site and each marine development site is likely to differ depending on the characteristics of the site, 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 have established foraging sites in harbours etc. or those that specialise on salmon in rivers or at aquaculture sites.

The use of relocation to avoid disturbance to the seals is not sensible. At some ongoing marine development/construction sites, seals are remaining in the vicinity of the human activity, suggesting they are disturbed less than they would if they were caught, manhandled and transported away from the site.

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 site (NOAA-NWFSC Tech Memo-28) 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 (Oliver *et al.*, 1998).

Capture and relocation is therefore likely to be only a temporary solution, would involve significant risk to the individual seal, would be expensive in terms of both effort and financial cost, and is constrained by lack of suitably experienced staff.

<u>Seals and River Fisheries</u>

20. In 2016 and 2018, advice was provided in relation to non-lethal options to address seal predation in both river fisheries and aquaculture. In light of the upcoming review of the operation of the seal licensing system in 2020, it would be helpful for SCOS to provide updated advice on practical non-lethal options available to river fisheries and aquaculture to address seal predation.	MS Q13

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.
New netting materials (e.g. HDPE) appear to reduce or even eliminate predation in early trials.

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 (Coram *et al.*, 2017). Several broad approaches are explored. While Acoustic Deterrent Devices (ADDs) have been 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. So far they have shown that the methods tried were generally impractical, often resulting in undesired or counterproductive effects on salmonids. 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 following is a summary of the relevant information in Coram *et al.* (2014 & 2016) with slight changes where recent anecdotal information is deemed relevant. There have been no published studies of the extent and intensity of use of AHDs or other non-lethal methods since the publication of these two reports.

Anti-predator measures are employed to protect salmonid aquaculture sites in Ireland, Canada, the USA, Chile, Norway, South Africa, and Australia. Measures include lethal removal, antipredator nets and acoustic deterrent devices (ADDs). Nowhere has the effectiveness of these measures been assessed rigorously.

As listed in the Coram *et al.* (2014) review, new netting solutions seem to be very promising, with some companies reporting elimination of predation after switching to HDPE ('sealpro') netting. There have been suggestions that the Tasmanian aquaculture industry may be attempting to isolate compounds from fur seal scent glands, to see if they could be used to elicit any useful behaviour (e.g. for deterring animals or trapping big males), but it is unclear whether this has progressed. Use of predator call and presence of life sized models of killer whales have been trialled with little success, although MOWI (formerly Marine Harvest) are considering another trial of a killer whale model with killer whale calls in Scotland.

Initial attempts to develop pulsed electric fields to prevent seals attacking the bottom of salmon cages have been fairly unsuccessful, although again there is little information available to allow a rigorous assessment. Ace-Aquatec report very good results from the 2nd generation of their 'electric fish' (dummy salmon with electrodes protruding which fire pseudo-randomly).

Conditioned taste aversion trials are currently being discussed with Marine Harvest and it is hoped that a series of trials with captive seals may be carried out.

There is little available published information on the methods used or the extent of their use in other countries. To the best of our knowledge, the following represents the current state of knowledge for other salmon producing countries.

Ireland. ADDs and anti-predator nets are used in Ireland to limit seal damage. There is no published estimate of the number of farms using these methods. Shooting of seals can only be carried out under licence and requires evidence of damage to pens for a licence to be granted. Few such licences appear to be granted.

Chile. Salmon farms in Chile frequently subject to predation by South American sea lions (*Otaria flavescens*). Anti-predator nets are widely used in Chile, and fibreglass models of killer whales were also tried, but were not deemed efficient (Sepulveda and Oliva, 2005). ADDs have been widely used in the past, but the present situation is less clear. There is no published information about the number of salmon farms currently using ADDs/AHDs in southern Chile. However, Chilean marine mammal biologists familiar with the salmon farming industry consider that very few farms are currently operating ADDs/AHDs due to their poor long term effectiveness against sea lions. At present only one company is thought to be testing them and has apparently reported poor results. The current best guesstimate is that less than 2-3% of the centres are now using ADDs/AHDs.
Sea lions in Chile are officially protected from hunting, but derogations exist allowing hunting or live capture under certain conditions, such as if the population in a certain area is shown to be excessive. The Chilean national Fisheries Service issues permits to kill sea lions that are known to cause problems (Kemper *et al.*, 2003; Vilata *et al.*, 2010). There is no information available on current shooting levels, but there are reports of around 5000 - 6000 South American sea lions being shot annually in the 1980s and 1990s. Most of these were taken illegally.

Norway. ADDs and anti-predator nets are used to some extent, but reliable figures are not available.
Unlike Scotland, seal hunting is allowed in Norway. Licences are available to those who already possess a 'huntsman's' licence. Quotas and licensing are administrated regionally: each area council has a total maximum limit, which is dictated by the Fisheries Directorate and based on advice from experts at the Institute of Marine Research. Certain time and area closures are applied, depending on the reproductive cycles of the relevant species.
Researchers in Norway familiar with the industry suggest that seal depredation is not considered a significant problem facing the industry. Compared to Scotland, seal populations are relatively low and highly dispersed.

Canada. Work in Canada concluded that although ADDs can be effective deterrents in the short-term, they are largely ineffective in the long-term, and there is no evidence they alleviate the need for lethal removal of predators. Given their ineffectiveness as deterrents and far-ranging impacts on non-target species, including SARA-listed species, DFO recommended that AHD use at fish farms be prohibited (Olesiuk *et al.,* 2012). AHDs are not used in British Columbia, and their use is being or has been phased out in the rest of Canada.

Anti-predator netting (Fisheries and Oceans Canada, 2015) is used at aquaculture sites in Canada. This is not a truly non-lethal control method as seals and sea lions become entangled and drown: between 1 and 13 harbour seals per year since 2011; 51 sea lions were reported to have drowned in anti-predator nets in one incident in 2007. Nylon netting for cages is now being phased out of use, in favour of HDPE based nets due to perceived benefits reducing depredation (Knox Nets, pers. comm., 2015).

Since 2010, Canadian aquaculture site licences include a provision authorising the humane destruction of 'nuisance seals' under certain conditions (Fisheries and Oceans Canada, 2015), although there are discussions ongoing to eliminate shooting at aquaculture sites. These provisions under the Pacific Aquaculture Regulations replace the previous 'nuisance seal licences' and describe the conditions under which a seal may be shot, including the presence of, and compliance with, a Predator Management Plan. 'All reasonable methods' must be used to deter seals and sea lions from coming into conflict with the facility. Regular site audits by DFO biologists ensure compliance with licence conditions and the Predator Management Plan. The number of harbour seals recorded as being removed fell consistently from a peak of 577 in 1995 to 556 in 2010. A similar pattern occurred for the California sea lion with a lower peak of 243 animals removed in 2000, down to <10 per year from 2004 – 2008. There was, however, a more recent increase up to 170 animals in 2010 (Coram *et al., 20*14).

USA. Nelson *et al. (*2006) reported that salmon farms in the Gulf of Maine routinely use anti-predator nets and ADDs to deter seal depredation. Killing any marine mammal in the USA is illegal under the Marine Mammal Protection Act. Under Section 120 of the Act, and shooting at aquaculture sites is therefore not an option.

Lethal removal of individually identifiable pinnipeds can only be authorised if they are shown to be having a significant negative impact on "endangered", wild salmonid stocks and only after all other options have been exhausted. Attempts to relocate harbour seals feeding on salmonids at Ballard Locks in Seattle to Hood Canal (>50km) were abandoned because seals returned to the capture site; harbour seals have been recorded returning to capture sites from release sites between 21 and 421km distant on the west coast of North America. Capture and relocation has also been attempted for California sea lions (*Zalophus californianus)* but were also deemed unsuccessful due to animals returning to their capture sites. Although California sea lions are still caught in the Columbia River in Oregon and Washington they are no-longer released back into the wild. In 2016 this resulted in the removal and euthanasia of 59 California sea lions

Australia. Depredation by fur seals and sea lions at Australian fish farm sites has long been a significant problem, accounting for the loss of c. 2% of stock in 1997/1998, valued at AUD$ 1.5 (Schotte and Pemberton, 2002). All seals species are protected by the 1999 Environment Protection and Biodiversity Conservation Act. Governmental permits can be issued for their removal, but these do not appear to be granted for the protection of aquaculture sites. A 2007 report acknowledged a problem with illegal shooting, but numbers were not known (Anon, 2007).

Relocation of seals has been employed extensively in Tasmania, where more than 4500 fur seal relocations were undertaken (Robinson *et al., 20*08). 56% were recaptured seals with 3% trapped more than 20 times. Recapture intervals were highly variable, ranging from days to years and within the same year, recapture intervals ranged from 4 to 258 days, mean 36 days.

A 2002 study (Schotte and Pemberton, 2002) assessed the use of flexible oceanic pens and recommended maximising of weight hung on the predator netting (minimum 2.4 T for a 120 m circumference circle). They also recommended the use of 'separation sticks' to maintain the distance between the growth and predator nets. In 2013 a Tasmanian company began using Dyneema® netting hoping to reduce seal predation (ABC News, 2013), and their website states that no escapes occurred in the last three years, though no further details have been reported.

Seals and Fish Farms

21. Can SCOS advise on what non-lethal measures are currently available to remove seals caught within fish farm cages?	MS Q15

SCOS is not aware of any non-lethal measures specifically designed to, or currently used to remove seals from fish farm cages.

Providing an escape route would seem to be an appropriate method, however it is not clear how this could be done in practice and would probably require re-engineering of the containment system in most cases.

Lowering a section of the barrier net to the surface level and providing an escape route may be practicable in some circumstances. Providing an escape route for a seal that does not allow salmon to escape may be difficult.

Once inside a cage, a seal has the potential to damage a large number of fish very rapidly. It is therefore imperative that whatever means is employed to remove the seal, it must act quickly. Attempts to drive a seal towards an escape route may also prove difficult as a stressed seal in a cage is unlikely to behave cooperatively. Deploying an ADD may force a seal to search for and use an escape route, but would potentially harm the animal in the process, and there is no guarantee that a distressed animal would find or use an escape route. Allowing a seal to find and use an available escape route may work eventually, but such a passive approach could leave the seal free to attack and damage fish for long periods and would likely be unacceptable to farm operators and could not be condoned from a fish welfare perspective.

Catching a seal within a fish cage would be extremely difficult and dangerous for both the seal and the farm operators. If a purpose built, large mesh net could be deployed within the cage and below the seal, it is conceivable that the seal could be brought to the surface by raising the net. A system for controllably raising the net would need to be designed. The seal could then either be restrained and moved or shepherded to an escape point.

Deploying such a system reactively would be difficult. SCOS is not aware of any attempts to develop such a system. To date anaesthesia of free swimming grey and harbour seals has not been successful.

The infrequent and sporadic nature of these events, combined with the practical difficulty of catching seals or manipulating their behaviour in such circumstances means that it is unlikely that an effective non-lethal solution to this very rare occurrence will be available in the short term. It would be better to ensure all cages are adequately protected from possible seal ingress with physical barriers around walkways and cage perimeters.

Seal Bycatch

22. What is the latest information on levels of seal bycatch across the UK? 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?? **Has there been any progress on investigating the reasons why the estimated rate of grey seal bycatch is higher than the PBR for this region, despite increasing seal populations? Can the committee recommend what can be done to investigate this further, particularly on the origins of bycaught seals in the South West, and identify ways that NRW could assist?**	Defra Q5 NRW Q3

The estimated bycatch of seals in UK fisheries in 2018 was 474 animals (95% CI 354-911). This was lower than in 2017 because of a continuing reduction in fishing effort between 2016 and 2018.

Approximately 85% of the bycatch estimate occurs in the south-west, in ICES area VII, where the UK gillnet fishery is concentrated. 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.

Future research priorities include increased monitoring of coastal vessels in Wales, improved monitoring/reporting of bycatch by other EU vessels fishing off the south west. Genetic studies to identify the source populations for bycaught grey seals are a research priority.

Seal bycatch estimates

Seal bycatch estimates are made for both species of seal (grey and common/harbour) combined. Most seals that have been examined were young grey seals which can be hard to differentiate from harbour seals. All seals taken in gillnets were thought to be grey seals and were taken in the southwest where harbour seals are rare. The numbers of harbour seals recorded are too low to generate a useful bycatch estimate so for expedience a single combined seal bycatch total is calculated. Although it is reasonable to assume that the majority of these are grey seals, in the North Sea at least, some proportion will likely be harbour seals.

The total seal bycatch estimate for UK waters in 2018 is 474 animals (CV = 0.07; 95% confidence limits 354-911) which is once again lower than the previous year (572), because of the continuing decline in recorded fishing effort (Northridge *et. al.,* 2019). Estimates of seal bycatch have fluctuated over the past few years, but are generally in the region of 400-600 seals per year, with no clear trend (Table 8). .

Table 8: ***Recent estimates of annual seal bycatch in UK gillnet fisheries with 95% confidence limits***

Year	Estimated number	95% confidence interval
2013	469	285-1369
2014	417	255-1312
2015	580	423-1297
2016	610	449-1262
2017	572	429-1077
2018	474	354-911

Table 9 shows the estimates by ICES Division and general area. All four seals caught in tangle nets by boats with observers 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 82% of the bycatch (390 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, (300 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 88 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).

Six grey seals were reported caught in sandeel trawls in 2018, the first such records from a trawl fishery for some years. Although this appears to be a high rate, seal bycatch records in trawl fisheries are clumped, often involving several individuals in one location, but are overall very rarely recorded events in both the targeted marine mammal bycatch programme and Cefas/AFBINI discard monitoring programmes. The overall observed mean bycatch rate is therefore very small and will have extremely wide confidence intervals, so without a clearer understanding of the spatial and other factors that lead to such bycatch events, these numbers have not been included in the 2018 seal bycatch estimates.

Although the total bycatch estimate of 474 is not large compared to the entire UK grey seal population of over 150,000 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 300 (Table 9), approximately 6% greater than the conservative PBR.

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

Table 9. ***Seal bycatch estimates by ICES Division 2018 (from Northridge et. al 2019)***

Region	ICES Division	Estimated total bycatch	Two-Sided 95% LCL	Two-Sided 95% UCL	One-sided 90% UCL
North Sea	4a	19	15	24	23
	4b	4	3	6	6
	4c	49	38	105	95
West Scotland offshore	6b	9	8	11	11
Irish Sea	7a	3	2	8	7
Eastern Channel	7d	88	52	248	219
Western Channel and Celtic Sea	7e	159	122	287	264
	7f	122	98	181	171
	7g	4	3	14	12
	7h	9	7	13	12
	7j	5	4	10	9
Biscay	8abcd	2	2	3	3

Despite the fact that the recorded bycatch levels are high relative to local population estimates, the grey seal pup production in the region continues to increase. For example, regularly monitored colonies in Pembrokeshire are increasing by around 6% p.a. (Bull *et al.,* 2017 a,b, Lock *et al., 20*17, Morgan *et al., 20*18). 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. Ongoing telemetry studies with grey seals at Islay, the Monach Isles and the Welsh Dee Estuary do not indicate large scale movements between the south-west and north-west populations in the UK and Ireland. However, these studies have concentrated on adult seals. The bycatch is almost exclusively young grey seals for which we have no useful telemetry information with which to examine movements from the potential source populations in the Hebrides. 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.

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, the estimate of UK vessel bycatch and the existence of an unknown but likely large foreign vessel bycatch in the region, the western channel and Celtic Sea would seem to be an appropriate area for additional work.

Future research recommendations
Although the scale of inshore fisheries around the Welsh coast is not large and some dedicated monitoring has already been carried out, the specific interest in bycatch in the southwest suggests that effort to monitor bycatch in these fisheries closest to breeding sites should be increased. Increased marine mammal bycatch monitoring on French, Irish and other EU registered vessels fishing in this region would also be helpful. The potentially large takes in these fisheries mean that the bycatch rates presented above may significantly under-estimate the scale of the problem.

Identifying the source of bycaught seals in the southwest is a priority. Samples 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 substantial additional funding.

Tracking movements of juvenile grey seals from sites in the Inner and Outer Hebrides would also potentially provide estimates of migration rates into the southwest. Again, substantial additional funding would be required for such a study.

23. Can SCOS consider the current methodology used to identify seal haul out sites and make suggestions and provide their rationale for any potential changes to the methodology?	MS Q11

SCOS consider that the current methodology is effective,

SCOS considered the current methodology for identifying seal haul out sites in 2012 following submission and review of a briefing paper (SCOS BP12/07) detailing the method. In brief, virtual observation points were placed at 100m intervals along the coast of Scotland (a total of 186,442) and sighting histories of both species from the summer air survey data for each individual point and with a 300m buffer radius out from each observation point, were compiled. A time weighted averaged (TWA) for each point by species was calculated using the data from 1996 – 2010 to allow for fluctuations in site usage and for the sparsity of surveys in some regions.

All Seal Management Units (SMUs) were examined and haulout sites ranked by the TWAs starting from those with TWA >50 and gradually declining until a minimum of 50% of the populations of each species in each SMA was included. This was a minimum figure requested by Marine Scotland and SNH to achieve a balance between maximising seal protection and minimising implications for other sustainable activities. All identified sites were listed, and a target population proportion to be protected set for each SMA, which in some cases was >50% where populations had declined. All seal SACs were included and all haulout sites that contained ≥5% of the harbour seals for that SMA and all sites that contained ≥10% of the grey seals. In addition, all known grey seal breeding sites that are regularly surveyed and where at least 20 pups are born each year were included.

The limitations of this method were also detailed in SCOS BP12/07. These were that the site selection is based on surveys carried out during August so seasonal variability is not considered. The process favours large sites and the potential risk of harassment at each of the sites is also not accounted for. The weighting factor of 0.8, used to calculate all the TWAs (see SCOS BP12/07 for more details on the impact of this) is a value that gives appropriate relative weight to the data collected over the 14 year time period. Finally, it is often difficult to define boundaries to decide where a site starts and ends, particularly in areas of high density or fluidity.

The list of designated sites is currently under review. Whilst it is desirable for these not to change over time, unfortunately, particularly due to the major changes in seal population abundance, any threshold-based designation method will result in a revision of the list depending on the rate of change and the review time-scale (currently five yearly). Using the same approach but including data collected up to 2016, has resulted in some sites disappearing from the list and others having to be included, particularly in regions of harbour seal decline such as Orkney. There is the potential to cluster smaller sites and designate them as a single site, but this could have implications for designating very large areas in regions with a high density of individual haul-out sites (such as the Western Isles). In any case, the arbitrary decision on where to draw site borders remains. Increasing the minimum threshold from 50% could also result in less change over time but this could produce a major change in the current list. Thus, compromises are required in order to provide a workable approach that results in minimal change in site designation whilst accounting for any population and haulout site usage change.

24. Does SCOS consider that the Scottish nationally designated haul out sites have been of benefit and could the methods used to identify sites be briefly detailed, to consider their use in England?	Defra Q9b

The designated haulout sites are chosen to protect as high a proportion of the seal population as possible with the minimum number of sites. This is considered to have been successful. The method of site designation is described in detail in answer #23 above. With necessary changes to legislation this method could be applied in exactly the same way to sites in England.

25. Have there been any significant studies done in looking into how macroplastics, microplastics, abandoned (ghost) fishing gear and other plastic pollution are affecting seal populations? Is there a need for more research to be done on this subject area?	Defra Q11

The number of studies investigating the effect of microplastics, macroplastics, abandoned fishing gear and other forms of plastic pollution on seals is limited. Although there have been studies on discarded fishing gear and on the trophic transfer, retention and excretion of microplastics and ongoing research on the impact of plastic contaminants and plasticizers on UK seals, the population consequences of these forms of marine debris are not known. There are significant information gaps and current research will help shape future studies.

The potential impact on seals of different types of plastic marine debris at the individual and population level varies due to their sources and different size ranges.

Microplastics (defined as plastic particles <5mm long) can be translocated across the gastro-intestinal membranes via endocytosis-like mechanisms (Alimba and Faggio, 2019) in invertebrates. They are also capable of adsorbing organic contaminants (such as persistent organic pollutants), metals and pathogens which will add to their toxicological profile as these will be in addition to their inherent plasticizer compounds. Nelms *et al. (*2019a) investigated the occurrence of microplastics in the gastrointestinal tracts of 50 marine mammals of 10 different species that stranded around the UK coast. Microplastics were ubiquitous being found in every animal examined but at relatively low numbers per animal (mean = 5.5) suggesting the particles were transitory. Stomachs were found to contain a greater number than intestines, indicating possible temporary retention. However, only 3 grey seals and 4 harbour seals were included in this study. A follow-up study by Nelms *et al. (*2019b) found that in 2 g subsamples from 15 grey seal scats, 53% had 1-5 microplastics. The samples were all from adults collecting during the breeding season on Skomer Island off the Welsh coast, so they may only represent near-shore exposure. Nelms *et al. (*2018) also found grey seals readily excreted microplastics in their faeces and a feeding study in SMRU's captive facility, to determine the passage time of prey in grey seals, found all the polystyrene balls (3 mm) fed to the animals as tracers to determine fish otolith recovery rates, were recovered within six days (Grellier and Hammond, 2006). Bravo Rebolledo *et al. (*2013) analysed 107 stomachs, 100 intestines and 125 scats of harbour seals from the Netherlands for the presence of plastics. They reported the occurrence of plastic in 11% of the stomachs, 1% of the intestines, and 0% of the scats.

The potential toxicological impact of microplastics at the population level for seals has not been reported in the literature. Whilst microplastics may be readily excreted by seals, retention in the stomach and intestine prior to egestion may facilitate the release of the chemical compounds and plasticizers during the digestive process. Further studies, particularly into the impacts of the phthalates, a major group of plastic additives, on seal health are currently being carried out by the University of Abertay and SMRU. Their findings will be reported at SCOS 2020.

The ingestion of larger plastic debris, the macroplastics, may cause blockage in the gastrointestinal tract and injury to the gut mucosa. However, the prevalence of this as a cause of morbidity or mortality in UK seals is not known. It is rarely reported as a proximate or ultimate cause of death in seals by the Scottish Marine Animal Strandings Scheme (http://www.strandings.org/smass/).

Entanglement in marine and plastic debris, particularly discarded fishing gear may increase the risk of drowning but perhaps more commonly, may restrict feeding or cause deep blubber and skin abrasions (particularly around the head and neck). Allen *et al. (*2012) used sightings records and a photo identification catalogue from a haul out site in southwest England to investigate the prevalence of entanglement in grey seals. Between 2004 and 2008 the annual mean entanglement rates varied from 3.6% to 5% (n= between 83 and 112 animals). Of the 58 entangled cases in the catalogue, 64% had injuries that were deemed serious. Of the 15 cases where the entangling debris was visible, 14 were entangled in fisheries materials. In a review Butterworth (2016) concluded that globally pinnipeds are at the visible end of the spectrum of animals which become entangled, snared, trapped or caught in marine debris, particularly plastics in the form of net, rope, monofilament line and packing bands, with severe consequences. This is in line with a study by Unger and Harrison (2016) who used the beach litter based on a data set established by the Marine Conservation Society (MSC) beach-watch weekends. Debris collected around the UK was divided into three main types of debris: (1) plastic, (2) fishing, and (3) fishing related plastic and rubber on a total of 1023 beaches. Debris attributable to fishing was identified on clusters of beaches mainly located on the coasts of Scotland and along the English Channel. They concluded that the fishing industry is responsible for a large proportion of the marine debris on UK beaches, particularly in areas with adjacent fishing grounds.

26. Is marine litter a concern for grey and harbour seals in terms of entanglement or ingestion?	MS Q 12

Marine litter especially in the form of plastic rings, packing bands, netting and nylon lines pose a risk of entanglement to both grey and harbour seals in UK waters. Such entanglement with associated wounds has been recorded in at least six phocid and five otarid seal species everywhere from the Arctic to the Antarctic to the tropics.

The issue of entanglement in marine debris is addressed in answer 25 above.

27. Can SCOS comment on the effects of seal tourism (including seal watching and interactions in the water with swimmers or divers)? Is there an official code of conduct for any of these activities, and is there a need for more control??	Defra Q11

There are established seal watching activities (e.g. grey seals at Donna Nook, Lincolnshire and Horsey in Norfolk and harbour seals at Blakeney Point, Norfolk and Dunvegan in Skye), which show that controlled wildlife tourism can be conducted throughout the year including during the breeding season without causing obvious problems to the animals.

However, in other areas the same species may react very differently, being easily disturbed and tending to become sensitized rather than habituated to repeated disturbance. There is growing concern among NGO groups that such disturbance will negatively impact individual seals and pose potential threats to the continued use of sites for hauling out and/or breeding.

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. Local site managers and NGOs have developed their own guidelines and in some cases they monitor disturbance events.

There is no formal licencing or recording system for swimming encounters with seals. SNH's guide to best practice for watching marine wildlife states that swimming with seals is not considered best practice and highlights that seals are large wild animals that are potentially dangerous. Swimming with any seals poses a clear bite risk and health risk. Seals bites can cause Seal Finger a dangerous infection (probably due to Mycoplasma phocacerebrale), that can lead to severe necrosis and requires urgent medical attention and specific antibiotic treatment. The fact **that large male grey seals are known to be predators of other marine mammals means that they pose a particular risk.**

SCOS advises that where a problem of disturbance has been identified, effective control measures should be applied.

Seals are spectacular and appealing wild animals that can be easily observed and appear to be approachable. The populations of both grey and harbour seals are increasing in the central and southern North Sea, in an area with a very dense human population, dramatically increasing the opportunity for human seal interactions. Environmental tourism is also increasing rapidly in the UK, and watching wildlife, especially large, spectacular and apparently passive animals like seals is a rapidly growing sector. There are thriving seal tourism industries at various sites around the UK coast. More recently there has been an increase in interest in swimming with seals, primarily scuba divers interacting with grey seals at various locations around the coast.

Until the 1980s it was generally regarded that human presence was likely to cause sufficient disturbance to prevent seals from hauling out at sites with frequent human visitors. However, there are now clear examples where obvious human presence, in some cases involving close approaches to seals, is not acting as a deterrent to hauling out (e.g. Horsey) or breeding (e.g. Blakeney and Donna Nook) by grey seals. Philipp *et al. (*2016) recorded repeated, frequent approaches by tourists to less than 30m from hauled out grey and harbour seals without overt signs of disturbance. It is also apparent that hauled out seals of both species can habituate to the presence of, and tolerate close approaches by tourist boats, e.g. tourist boats at Dunvegan, the Farne Islands and Blakeney Point now regularly approach to within 20-30m of seals on haulout sites without causing apparent disturbance response. The ability of seals to habituate to even severe visual and acoustic disturbance is shown by the presence of large haulout groups within the active military firing and bombing ranges on the east coast (Wash, Moray Firth, and Dornoch Firth).

Such examples clearly demonstrate that controlled wildlife tourism can succeed without causing obvious problems to the animals. However, in other areas the same species may react very differently, being easily disturbed and tending to become sensitized rather than habituated to repeated disturbance.

Conversely, there are regular press and social media reports of repeated disturbance of seal haulout sites and growing concern among NGO groups that such disturbance will negatively impact individual seals and pose potential threats to the continued use of sites for hauling out and/or breeding (Cornwall Seal Group 2019).

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 (e.g. Cornwall Seal Group. 2019).

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. Specific guidance on the offence of harassment at seal haul-out sites has been published[3] Although such restrictions do not apply in the rest of the UK, guidance on general seal watching has been published by the Marine Management Organisation[4] and information notes on the effects of wildlife watching and non-motorised boat based disturbance on seals at haulout sites have been published by Natural England[5]. Guidance notes to provide advice on best practice

[3] https://consult.gov.scot/marine-environment/ /user_uploads/guidance-on-the-offence-of-harassment-at-seal-haul-out-sites.pdf
[4] https://marinedevelopments.blog.gov.uk/2016/08/11/seals-protected-illegal-touch-feed/
[5] Natural England Evidence Information Note EIN028 & EIN030

for wildlife watchers and wildlife tourism operators have been published by both government and voluntary organisations (e.g. Scottish Natural Heritage[6], National Trust[7], Cornwall Seal Group[8]). There is now an established UK national training scheme for minimising disturbance to marine wildlife. The WiSe Scheme[9] aims to promote responsible wildlife-watching, through training, accreditation and raising awareness through a simple modular training course aimed primarily at wildlife cruise operators, dive and service boats and yacht skippers.

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 and harbour seal pup tagging studies.

Repeated disturbance may lead to abandonment of specific haulout sites, but a recent study suggested that even repeated boat-based disturbance, did not increase the likelihood of harbour seals moving to a different site and had little effect on their movements and foraging behaviour (Patterson *et al.*, 2019). Despite the very close approaches by large numbers of people and anecdotal reports of severe disturbance, the haulout site on the public beach at Horsey continues to be used year round and the grey seal pup production there continues to increase rapidly.

Swimming with seals, usually grey seals, has become a popular activity at certain sites around the UK. To date there have been thousands of such encounters, both as part of deliberate swim with seals programmes and incidental encounters as part of normal leisure diving activities. There are no estimates of the numbers of such encounters, but they will number in the hundreds or thousands over the past 20 years (Van Neer *et al.,* 2017) and such encounters have so far been generally benign.

However, although rare, there have been anecdotal, press and social media reports from the UK in 2016, 2017 and 2019 where seals have bitten swimmers. Grey seals at sites around the UK coast have been recorded attacking, killing and eating other seals and harbour porpoises. The prey animals, which are primarily caught and killed in the water, range in size from juvenile harbour seals up to fully grown adult harbour seals. These prey are themselves large, marine predators that are heavier, more agile, powerful and adept in the water than are human divers/swimmers.

28. Several related questions around understanding population estimates for OSPAR/MSFD assessments and measures: **a. Is it necessary to have more reliable estimates of the grey/harbour seal populations for S England, SW England and NW England in order to determine the population and conservation status (GES) of grey/harbour seals? If so, can SCOS advise on how to structure a study to investigate this?**	Defra Q12

[6] https://www.nature.scot/professional-advice/land-and-sea-management/managing-coasts-and-seas/scottish-marine-wildlife-watching-code

[7] https://www.nationaltrust.org.uk › godrevy › documents › how-to-watch-seals.pdf

[8] https://www.cornwallsealgroup.co.uk/2016/08/admire-from-a-distance/

[9] https://www.wisescheme.org/

b. **Does the Committee consider that it is necessary to introduce seal conservation measures to protect vulnerable harbour seal populations along the English coast?** c. **The two common seal indicators, M3 (harbour and grey seal abundance and distribution) and M5 (grey seal pup production) will be assessed in 2020 for the OSPAR region. There is particular interest within OSPAR to include the distribution element of the indicator in this assessment. Can SCOS make any recommendations on how to meaningfully assess distribution of harbour and grey seals within the relevant UK assessment units, while enabling consistency with the UK and wider OSPAR Contracting Parties' monitoring programmes?**	

(a) To determine the population and conservation status of grey and harbour seals at a UK or English level, it is not necessary to have more reliable estimates of populations S England, SW England and NW England. It is likely than < 1 % and < 5% of the UK harbour and grey seal populations, respectively, are in these areas.
(b) The harbour seal population on the east coast of England has been increasing since the last PDV epidemic and has stabilised in recent years. Frequent monitoring is required so any declines are quickly noticed and appropriate actions can be taken. However, currently there is no need to introduce seal conservation measures here.
(c) Changes is distribution can be examined in terms of (1) change in the proportion of an area occupied, (2) shifts in occupancy, and (3) spatial shifts in abundance. The first two were considered in the Intermediate Assessment as a 'surveillance indicator'. To meaningfully assess changes in distribution, a consistent spatial resolution is required. The habitat and survey protocol in the UK result in data being available on a regular grid which lends itself to such assessment. It may not be possible to be consistent across all the wider Contracting Parties.

(a) There are no known and established haul outs of harbour seals in NW or SW England. The main haulouts in S England are at Chichester and Langstone harbours. Regular counts of these sites are conducted by Chichester Harbour Conservancy and Langstone Harbour Board, and have been shared with SMRU. However, August counts of both grey and harbour seals are still low (< 50). Grey seal data are available for a subset of sites in the NW and SW of England. Numbers in the NW England are still reasonably low but do seem to be increasing. The main haulout sites in the NW England are South Walney (also a small breeding site) and the Dee Estuary (shared with Wales). Numbers at these sites are monitored by Cumbria Wildlife Trust and Hilbre Bird Observatory, respectively.

In Wales and SW England, comprehensive and regular August counts and pup production, which would allow the SMRU population model to be extended to these areas, are not available. The prevalence of hauling out and pupping in caves prohibits aerial survey methods. However, the coast has been covered over multiple years. Along with a smaller number of indicator areas which were surveyed more frequently trends in these populations could be assessed.

At a UK level, these regions account for < 1% and < 5% of the harbour and grey seal populations respectively, and thus for the purposes of determining population and environmental status on a UK scale, population estimates for these regions are not required.

(b) Currently the east coast is covered by an existing seal conservation order. Harbour seal moult counts in Southeast England have been increasing since 2002 (the last PDV epidemic) at a rate of 2.8% p.a. (95% CIs: 1.3, 4.3). However, more surveys were conducted in The Wash (c. 65% of the Southeast England count) and these show that the trend has levelled off in recent years, presumably upon reaching carrying capacity. It is not clear to if and to what extent carrying capacity will be impacted by the increasing grey seal foraging population (increasing at c. 16% p.a.). It is possible that the harbour seal population may decline. Thus frequent monitoring is required to ensure that any decline is detected quickly and appropriate management action taken. Currently it is not necessary to introduce new seal conservation measures in this region.

Harbour seal populations along the rest of the English and Welsh coasts have historically been very small.

(c) Changes is distribution can be examined in terms of (1) change in the proportion of an area occupied, (2) shifts in occupancy, and (3) spatial shifts in abundance. The first two were considered in the Intermediate Assessment as ‘surveillance indicator’, and were based on an approach developed for marine birds. To meaningfully assess changes in distribution, a consistent spatial resolution is required over which effort should be constant (or at least known). The habitat and survey protocol in the UK result in data being available on a regular grid (5 x 5 km) which lends itself to such assessment. In other countries, data are available by individual haulout, and there may be difficulties in determining effort where no seals were recorded. In the Dutch Wadden Sea, counts are recorded on a subunit scale (of which there are ten). For the Dutch Wadden Sea, seals are present on most sandbanks and thus assessing change in distribution may not be a useful indicator. These variations in survey protocol and habitat would also prohibit examining spatial shifts in abundance in a consistent way across countries.

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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 J. Armstrong	Marine Scotland, Science, Aberdeen;
Dr M. Biuw	Institute of Marine Research in Norway. Tromso;
Dr G. Englehardt	Centre for Environment Fisheries and Aquaculture Science, Lowestoft;
Professor B. Wilson	Scottish Association for Marine Science, Dunstaffnage, Oban
Dr J. London	National Marine Mammal Lab. Seattle;
Dr K. Bennett	Abertay University, Dundee;
Dr O. Ó Cadhla	National Parks and Wildlife Service, Ireland;
Dr G. Townsend (Secretary)	UKRI Natural Environment Research Council, Swindon.

ANNEX II   Questions to SCOS.

Questions from Marine Scotland
Organisation: *Scottish Government*

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

19/01 Estimating the size of the UK grey seal population between 1984 and 2018.
Thomas, L.

19/02 2018 Annual review of priors for grey seal population model.
Russell, D.J.F., Thompson, D. and Thomas, L.

19/03 The status of UK harbour seal populations in 2018 including summer counts of grey seals.
Duck, C., Morris, C.D. Lonergan, M., Empacher, F., Thompson, D. and Harwood, J.

19/04 Preliminary report on the distribution and abundance of harbour seals (Phoca vitulina) during the 2018 breeding season in The Wash. Thompson, D.

19/05 Provisional Regional PBR values for Scottish seals in 2020.
Thompson, D., Morris, C.D. and Duck, C.D.

19/06 Pinniped strandings in Scotland 2009-2018
. ten Doeschate, M. & Brownlow, A.

Estimating the size of the UK grey seal population between 1984 and 2018.

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Abstract

We fitted a Bayesian state-space model of British grey seal population dynamics to two sources of data: (1) regional estimates of pup production from 1984-2016, and (2) independent estimates assumed to be of total population size just before the breeding season in 2008 and 2014. 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 the prior distribution on adult survival has been slightly altered, with the upper bound increased from 0.97 to 0.98.

Estimated population size in regularly monitored colonies in 2018 was 137,200 (95% CI 121,000-156,100). The population overall is estimated to be increasing at a rate of 1.9% per year.

In last year's briefing paper (Thomas 2018) we found 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. We therefore caution that estimates of population size in 2018 may change once an ongoing review of pup production estimation has been completed.

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 and are described in detail in Thomas et al. (2019). The data are the same as those used in the main analysis presented last year (Thomas et al. 2018): pup production estimates for 1984-2016 (Duck and Morris 2018), plus independent estimates of total population size from 2008 and 2014 (Russell et al. 2016). The prior distributions on model parameters are the same as those used last year, except that the upper bound on adult survival has been increased from 0.97 to 0.98.

We present estimates of population size at the start of the 2018 breeding system (i.e., projected forward two years from the last data point). 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 Thomas et al. (2019). 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 Russell et al. (2019) and summarised in Table 1. As noted earlier, one minor change was made to the priors previously used: the upper bound on the scaled shifted beta distribution used as a prior for adult survival was increased from 0.97 to 0.98. This is to account for the observation made by den Heyer & Bower (2017) of adult female survival in Canada, based on mark-recapture estimate of 0.976 (SE 0.001).

Input data was pup production estimates for 1984-2016 (Duck and Morris 2018), plus independent estimates of total population size from 2008 and 2014 (Russell et al. 2016).

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. Here, 3 billion simulations were used, which gave results accurate to 3 significant figures in most cases (2 for some parameters).

Results

Main analysis

As would be expected given the near-identical inputs (the only difference being a small change in the prior on adult survival), estimated model fit to the pup production data is indistinguishable from that presented in last year's briefing paper. Estimated pup production by region from the model matches 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).

Total population size is estimated to have grown steadily, although at a slightly decreasing rate; population size is estimated to have been larger than the independent estimate from 2008 and smaller than that from 2014 (Figure 2). Posterior mean population size in regularly monitored colonies in 2018 was 137,200 with 95% credible interval (CI) 121,000-156,100. Estimates by region are given in Table 2 and estimates for all years 1984-2018 are given in the Appendix. The estimated growth in population size between 2017 and 2018 is 1.9%.

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) – the same as reported by Thomas (2018) to 2 significant figures (but very slightly higher when more significant figures are considered). However, with the prior upper bound of 0.97 used in last year's analysis, the mode of the posterior was close to the maximum (Thomas 2018, Figure 3); with the higher bound used this year the mode is slightly lower than the maximum, which is more satisfactory. Pup survival is estimated to be lower than the prior (mean 0.43 SE 0.07) – this is slightly lower than the estimate of 0.45 (SE 0.07) given in Thomas (2018), as would be expected if the posterior on adult survival is slightly higher, given the strong correlation between these two parameters (Figure 4). Fecundity is somewhat higher than the prior (mean 0.92 SE 0.50) and indistinguishable from that reported last year. As with the results reported last year, 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 again unchanged from the prior.

Discussion

Estimated population size is nearly identical to that reported in last year's briefing paper (Thomas 2018) for a comparable year – for example the estimate derived here for 2017 is 134,700 (95% CI 119,300-153,000), while that of Thomas (2018) was 135,700 (95% CI 118,500-155,200), a difference of only 0.7%. We conclude that the change in prior on adult survival made no meaningful difference to the population size estimate.

Estimating pup production from aerial survey data requires several assumptions, as described by Russell et al. (2018), and these have some influence on the resulting pup production estimates. There has been discussion of the appropriate value to use for the probability of correctly classifying moulted pups as moulted, especially with the transition in 2012 from film to digital aerial photography. Thomas (2018) undertook an analysis of pup production estimates arising from different scenarios, and documented up to a 13% difference in resulting estimated total population size. An investigation of pup production estimation methods is ongoing; in the meantime we suggest treating the estimates reported here with appropriate caution.

Currently the two additional estimates of total population size, from 2008 and 2014, are assumed to be statistically independent. Although they are based on separate aerial surveys of hauled-out seals, in scaling up from counts of seals hauled out to total population size both rely on the same estimate of the proportion of seals hauled out. Future work will account for this in the population estimation methods used here; we anticipate the effect will be to increase the estimated population size. This is because estimates from the population model and pup count data alone are higher than those from the independent estimate (Thomas 2018), and the effect of accounting for the dependence will be to increase the influence of these estimates.

Thomas et al. (2019) 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.

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Russell, D.J.F., D. Thompson and L. Thomas. 2019. Annual review of priors for grey seal population model 2019. SCOS Briefing Paper 19/02.

Thomas, L. 2018. Estimating the size of the UK grey seal population between 1984 and 2017. SCOS Briefing Paper 18/04.

Thomas, L., D.J.F. Russell, C. Duck, C.D. Morris, M. Lonergan, F. Empacher, D. Thompson and J. Harwood. 2019. Modelling the population size and dynamics of the British grey seal. Aquatic Conservation. DOI: 10.1002/aqc.3134

Table 1. Prior parameter distributions and summary of posterior distributions. Be denotes beta distribution, Ga Gamma distribution (with parameters shape and scale, respectively). Analysis uses both 1984-2016 pup production estimates, and the 2008 and 2014 total population estimates.

Parameter	Prior distribution	Prior mean (SD)	Posterior mean (SD)
adult survival ϕ_a	0.8+0.17*Be(1.79,1.53)	0.90 (0.04)	0.96 (0.01)
pup survival ϕ_{pmax}	Be(2.87,1.78)	0.62 (0.20)	0.45 (0.07)
Fecundity α	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.92 (0.05)
dens. dep. ρ	Ga(4,2.5)	10 (5)	3.02 (0.66)
NS carrying cap. χ_1	Ga(4,5000)	20000 (10000)	34200 (12500)
IH carrying cap. χ_2	Ga(4,1250)	5000 (2500)	3930 (354)
OH carrying cap. χ_3	Ga(4,3750)	15000 (7500)	13300 (914)
Ork carrying cap. χ_4	Ga(4,10000)	40000 (20000)	24500 (3320)
observation CV ψ	Ga(2.1,66.67)	140 (96.6)	73 (16.3)
sex ratio ω	1.6+Ga(28.08, 3.70E-3)	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 2018 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	43.8 (32.1 - 54.1)
Inner Hebrides	8.9 (7.4 - 10.8)
Outer Hebrides	30.5 (25.8 - 35.9)
Orkney	54.0 (44.5 - 65.9)
Total	137.2 (121.0 - 156.1)

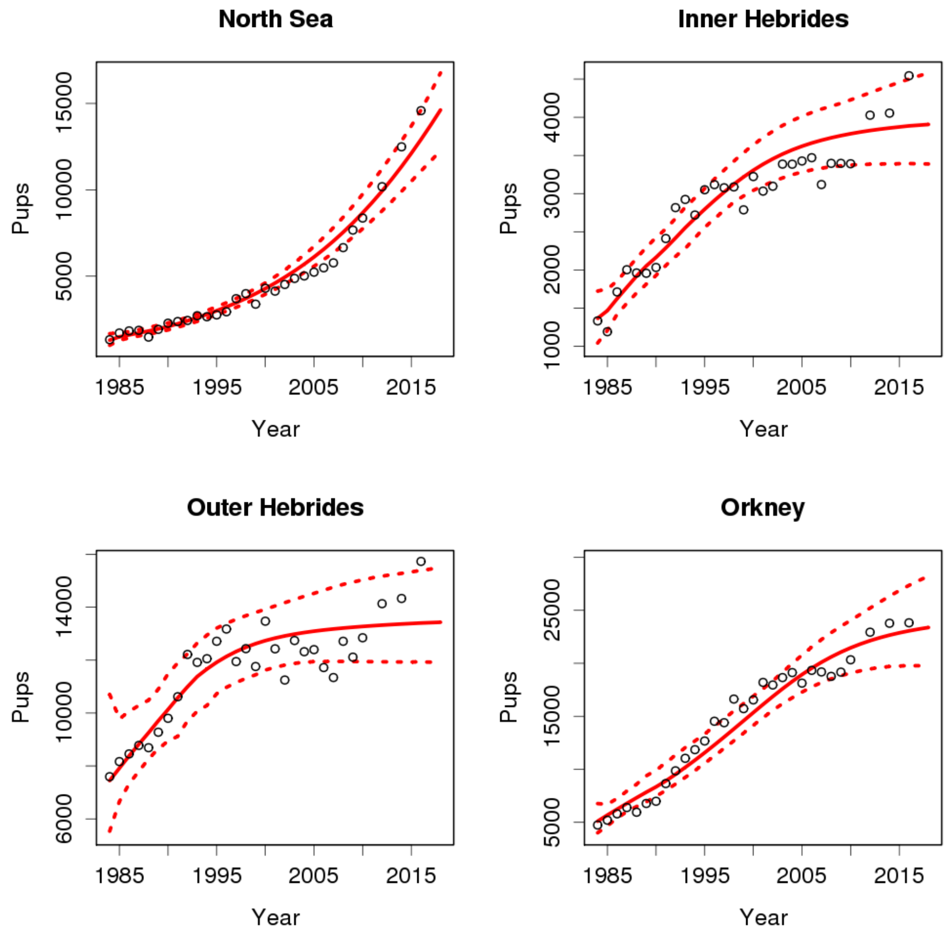

Figure 1. Posterior mean estimates of pup production (solid lines) and 95%CI (dashed lines) from the model of grey seal population dynamics, fitted to pup production estimates from 1984-2016 (circles) and the total population estimates from 2008 and 2014.

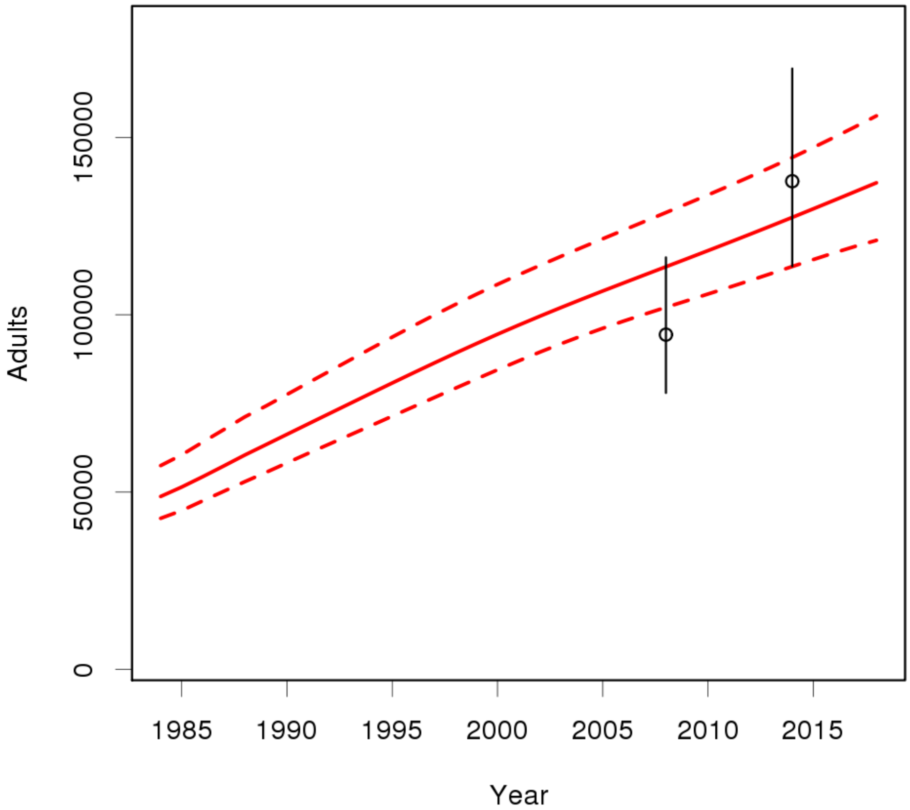

Figure 2. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2018 from the model of grey seal population dynamics, fit to pup production estimates from 1984-2016 and total population estimates from 2008 and 2014 (circles, with vertical lines indicating 95% confidence interval on the estimates).

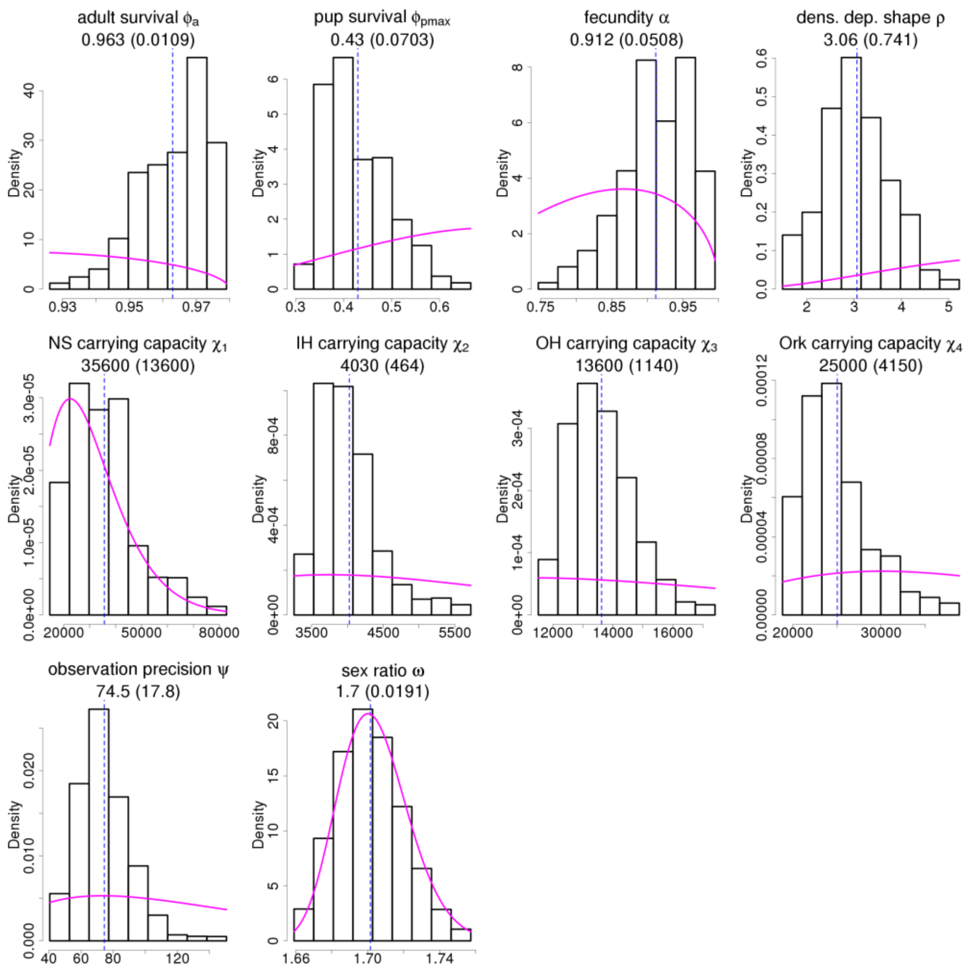

Figure 3. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1984-2016 and total populations estimate from 2008 and 2014. The vertical dashed line shows the posterior mean; its value is given in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

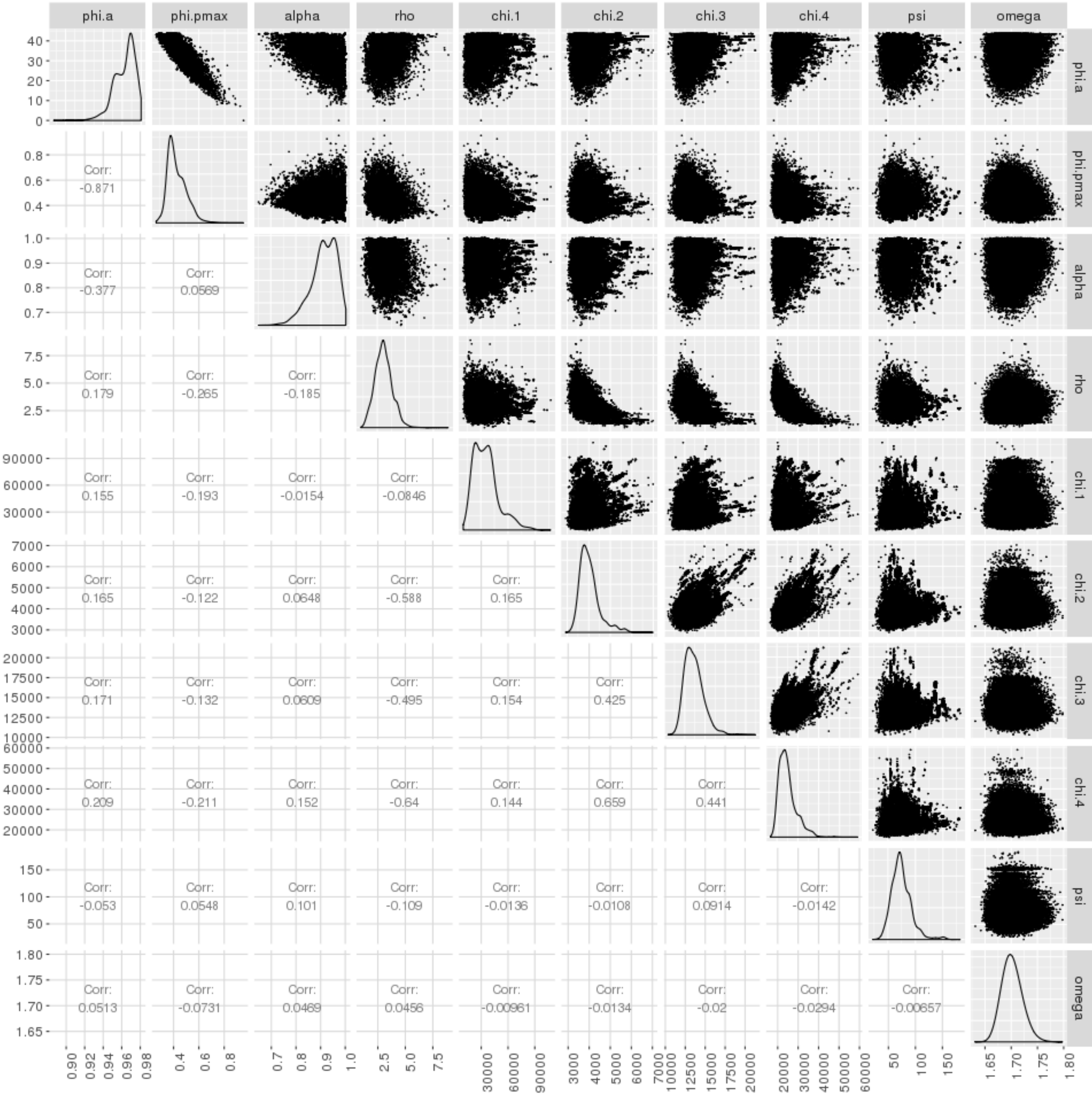

Figure 4. Pairwise scatterplots and correlation coefficients for posterior parameter distributions of the state-space model of grey seal population dynamics, fitted to pup production estimates from 1984-2016 and the total population estimate from 2008 and 2014. Diagonal elements are univariate marginal posterior densities. (Note that, for presentational reasons, a subset of 10,000 posterior samples were selected at random for display.)

Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2018, 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	4.4 (3.8 5.3)	4.6 (3.9 5.6)	22 (18.8 26.5)	17.7 (15 22)	48.8 (42.6 57.5)
1985	4.7 (4.1 5.6)	4.9 (4.1 5.9)	22.9 (19.5 27.7)	18.9 (16 23.2)	51.4 (44.8 60.5)
1986	5.1 (4.4 6)	5.2 (4.4 6.2)	23.9 (20.5 28.8)	20.1 (17.1 24.9)	54.3 (47.5 64.1)
1987	5.5 (4.8 6.4)	5.5 (4.7 6.6)	24.9 (21.4 29.9)	21.5 (18.2 26.6)	57.4 (50.2 67.6)
1988	5.9 (5.2 6.9)	5.8 (4.9 6.9)	25.8 (22 31)	23 (19.5 28.3)	60.5 (52.9 71.2)
1989	6.3 (5.5 7.4)	6.1 (5.2 7.2)	26.4 (22.6 31.7)	24.6 (20.9 29.8)	63.4 (55.6 74.3)
1990	6.8 (6 7.9)	6.3 (5.4 7.6)	27 (23.2 32.3)	26.2 (22.3 31.5)	66.3 (58.2 77.5)
1991	7.3 (6.4 8.5)	6.6 (5.7 7.9)	27.5 (23.7 32.8)	27.8 (23.9 33.3)	69.2 (60.9 80.8)
1992	7.8 (6.9 9.1)	6.8 (5.9 8.2)	27.9 (24.1 33.2)	29.5 (25.4 35.1)	72.1 (63.5 84)
1993	8.4 (7.4 9.8)	7.1 (6.1 8.4)	28.3 (24.5 33.6)	31.2 (27 36.9)	75 (66.1 87.3)
1994	9 (7.9 10.5)	7.3 (6.3 8.7)	28.6 (24.9 33.9)	33 (28.6 38.8)	77.9 (68.8 90.5)
1995	9.7 (8.5 11.3)	7.5 (6.5 8.9)	28.8 (25.1 34.2)	34.7 (30.2 40.6)	80.8 (71.4 93.7)
1996	10.4 (9.1 12.1)	7.7 (6.7 9.2)	29 (25.3 34.3)	36.5 (31.8 42.6)	83.6 (74 96.9)
1997	11.2 (9.7 13)	7.8 (6.8 9.4)	29.2 (25.5 34.5)	38.2 (33.4 44.5)	86.4 (76.7 99.9)
1998	12 (10.4 14)	8 (6.9 9.5)	29.4 (25.6 34.6)	39.8 (34.9 46.4)	89.2 (79.3 102.9)
1999	12.9 (11.1 15)	8.1 (7 9.7)	29.5 (25.7 34.7)	41.4 (36.2 48.2)	91.9 (81.9 105.8)
2000	13.8 (11.9 16.1)	8.2 (7.1 9.8)	29.6 (25.7 34.8)	42.8 (37.4 49.9)	94.5 (84.5 108.6)
2001	14.8 (12.8 17.3)	8.3 (7.2 9.9)	29.7 (25.8 34.9)	44.2 (38.6 51.5)	97.1 (87 111.3)
2002	15.9 (13.6 18.6)	8.4 (7.2 10)	29.8 (25.8 35)	45.5 (39.6 52.9)	99.6 (89.4 113.9)
2003	17.1 (14.6 19.9)	8.4 (7.3 10.1)	29.9 (25.8 35.1)	46.6 (40.5 54.2)	102 (91.8 116.4)
2004	18.3 (15.6 21.4)	8.5 (7.3 10.1)	30 (25.8 35.1)	47.6 (41.3 55.4)	104.4 (94 118.9)
2005	19.6 (16.7 22.9)	8.6 (7.3 10.2)	30 (25.8 35.2)	48.5 (41.9 56.5)	106.7 (96.2 121.4)
2006	21 (17.8 24.6)	8.6 (7.3 10.3)	30.1 (25.8 35.3)	49.3 (42.4 57.5)	109 (98.2 123.9)
2007	22.5 (19 26.3)	8.7 (7.4 10.3)	30.1 (25.8 35.3)	50 (42.8 58.5)	111.3 (100.2 126.3)
2008	24 (20.3 28.1)	8.7 (7.4 10.4)	30.2 (25.8 35.4)	50.6 (43.2 59.3)	113.5 (102.1 128.8)
2009	25.7 (21.7 30.1)	8.7 (7.4 10.4)	30.2 (25.8 35.4)	51.2 (43.5 60.1)	115.8 (104 131.3)
2010	27.4 (23 32.2)	8.8 (7.4 10.5)	30.3 (25.9 35.5)	51.7 (43.8 60.9)	118.1 (105.8 133.8)
2011	29.2 (24.4 34.4)	8.8 (7.4 10.5)	30.3 (25.9 35.6)	52.1 (44 61.6)	120.4 (107.7 136.3)
2012	31.1 (25.8 36.7)	8.8 (7.4 10.6)	30.3 (25.9 35.6)	52.5 (44.2 62.4)	122.7 (109.7 138.9)
2013	33.1 (27.1 39.2)	8.8 (7.4 10.6)	30.4 (25.9 35.7)	52.8 (44.3 63.1)	125.1 (111.6 141.6)
2014	35.1 (28.2 41.9)	8.8 (7.4 10.7)	30.4 (25.9 35.7)	53.1 (44.4 63.7)	127.4 (113.6 144.3)
2015	37.2 (29.3 44.7)	8.9 (7.4 10.7)	30.4 (25.9 35.8)	53.3 (44.4 64.3)	129.9 (115.6 147.2)
2016	39.4 (30.4 47.7)	8.9 (7.4 10.8)	30.5 (25.8 35.8)	53.6 (44.5 64.8)	132.3 (117.5 150.1)
2017	41.6 (31.3 50.8)	8.9 (7.4 10.8)	30.5 (25.8 35.9)	53.8 (44.5 65.4)	134.7 (119.3 153)
2018	43.8 (32.1 54.1)	8.9 (7.4 10.8)	30.5 (25.8 35.9)	54 (44.5 65.9)	137.2 (121 156.1)

Annual review of priors for grey seal population model 2019

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Summary

Prior distributions (Table 1) for the grey seal population model (Thomas 2019) 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 are shown in Figure 1 and Table 1. These distributions are identical to those used in the previous year's analysis (Thomas 2018), except that the upper bound on ϕ_a has been increased from 0.97 to 0.98. 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. (2019).

Table 1. Prior parameter distributions input in Thomas (2019). 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+0.18*Be(1.79,1.53)	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)

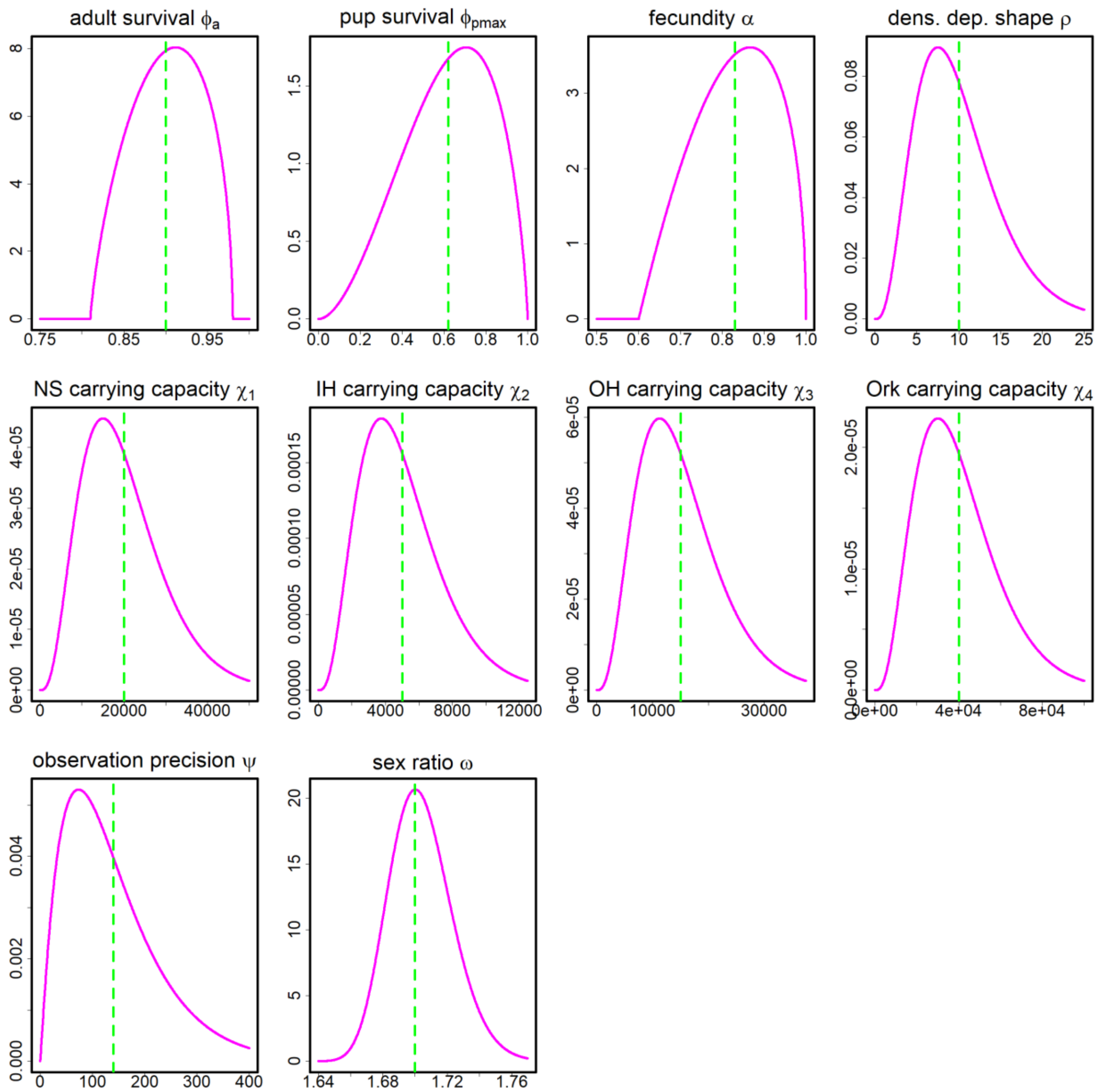

Figure 1. Prior probability density functions for each model parameter input in Thomas (2019), drawn from the distributions specified in Table 1. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions, respectively. Prior means are shown as green dashed 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 was specified to allow non-zero probability density only between 0.8 and 0.97 (Thomas 2018). 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+). Thus, as agreed by SCOS, the upper limit has been increased to 0.98; the resulting distribution is a beta distribution Be(1.79, 1.53) which is scaled (multiplied by 0.18 and added to 0.8) to allow non-zero probability density only between 0.8 and 0.98. The resulting distribution has mean 0.90 and SD 0.04.

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). A recent study in Finland (Kauhala *et al.* 2019) based on shot animals showed pregancy rate can fluctuate significantly (between c0.6 and c.95) in relation to the environment (prey quality). 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% and 20%).

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 above	0.970	SE = 0.002	As above	As above	As above	As above	As above	As 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	Canada	Aged ≥ 6 years old	Hammill & Gosselin 1995
Pregnancy	0.83			2011-2016	Shot samples	Finland	Age 6-24 years old	HELCOM 2018
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
Birth	0.83			2011-2016	Shot samples	Finland	Age 7-25 years old	HELCOM 2018

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The status of UK harbour seal populations in 2018 including summer counts of grey seals.

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Abstract

In August 2018, during the harbour seal moult, the Sea Mammal Research Unit (SMRU) carried out thermal image surveys on the west coast of Scotland from Kyle of Lochalsh to the Solway Firth, the east coast of Scotland from the upper Forth (above the bridges) to the Border by Berwick on Tweed including Holy Island and the Farne Islands. Part of the Moray Firth and the Firth of Tay and Eden Estuary SAC were surveyed by fixed-wing. The 2018 survey formed the third year of a new round-Scotland harbour seal survey which started in 2016. Note that a small section of the Moray Firth (Helmsdale to Wick) was last surveyed in 2011 and another small section (from Wick to Duncansby Head) in 2008.

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, 2018).

From August surveys carried out between 2015 and 2018, the minimum number of harbour seals counted in Scotland was **26,864** and in England & Wales it was **5,095**, making a total count for Great Britain of **31,959**. Including **1,012** harbour seals counted in Northern Ireland in 2018, the UK harbour seal total count for this period was **32,971**.

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 2015 and 2018, the minimum number of grey seals counted in Scotland was **26,266** and in England & Wales **16,226** making a total count for Great Britain of **42,492**. Including **505** grey seals counted in Northern Ireland in 2018, the UK grey seal total count for this period was **42,997**.

The harbour seal count for Southwest Scotland in 2018 was **1,709** (42% higher than the previous 2015 count of 1,200.

The harbour seal count for West Scotland - south was **7,053**, 7.6% lower than the previous 2015 count of 7,629. The count for West Scotland - Central was **7,447**, 15.9% higher than the 2014 count of 6,424. The new total count for West Scotland (2017-2018) was **15,600**, 2.7% higher than the previous (2013-2015) total count of 15,184.

The harbour seal count for the Moray Firth was **962**, 9.4% higher than the 2017 count of 879.

The harbour seal count for East Scotland was **342**, 2.4% higher than the 2017 count of 334. The severe decline in the Firth of Tay & Eden Estuary harbour seal SAC showed no sign of recovery, with **40** harbour seals counted in 2018. This represents 8.7% of the mean of counts between 1990 and 2002 (641).

In Northern Ireland, the 2018 total count of **1,012** harbour seals was 6.8% higher than the previous 2011 count of 948.

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 third year of a new survey that started in August 2016 and should be completed in August 2019.

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 survey of harbour and grey seals in Northern Ireland and the Republic of Ireland was completed in 2017 and 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. Groups of both harbour and grey seals were digitally photographed and the images used to classify the species composition of all 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).

Since August 2016, a new custom-built, 3-camera system, based on Trakka System's SWE-400, has been used to survey seals in August. 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 together with 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.

Seals in Southeast England (from Suffolk to Kent) was surveyed by the Thames Harbour Seal Conservation Project coordinated August surveys by air, from boat and from land between 2015 and 2017 (ZSL unpublished data, see Barker & Obregon, 2015 as example). In 2018, SMRU's survey of The Wash was extended to cover Suffolk and Kent.

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 2015 and 2018 is shown in Figure 1. For ease of viewing at this scale, counts have been aggregated by 10km squares. Most of the Scottish coast was surveyed between 2016 and 2018. A small section, Helmsdale to Duncansby Head, was last surveyed in 2008 (Wick to Duncansby Head) and in 2011 (Helmsdale to Wick).

The most recent minimum harbour seal population estimates (i.e. counts between 2008 and 2018) for UK Seal Management Areas (SMAs) are provided in Table 1 and are compared with three previous periods (2007 to 2010, 2000-2006 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 2015 and 2018, is **26,864** (Table 1). This is mid-way between the 2007-2013 count (20,823) 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 2018, is **5,095** (Table 1). This is 10.2% higher than the 2007-2013 count (4,622) and 61.2% higher than the 1995-1997 count (3,160; Table 1).

The 2018 count for Northern Ireland of **1,012** was 6.8% higher than the previous complete count from 2011 (948).

The sum of all the most recent counts carried out between 2015 and 2018 gives a UK total of **32,971** 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 2007-2008 and 2013-2015 have been used to calculate an independent estimate of the size of the grey seal population (Lonergan *et al*. 2011; Russell *et al*., 2016). August grey seal counts will be used similarly in future.

The overall UK and Ireland distribution of grey seals from August harbour seal surveys carried out between 2008 and 2018 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 2015 and 2018 is **26,266** (Table 2). This is 30.6% higher than the total Scotland count of 20,113 from August surveys between 2007 and 2013.

There were **14,701** grey seals counted in eastern England between 2015 and 2018 and, combined with an estimate of **1,525** in West England & Wales and the 2018 count of **505** in Northern Ireland (Table 2), the most recent UK total count of grey seals in August is **42,997**.

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

The parts of Scotland surveyed in August 2018 were:

-West Scotland, from Kyle of Lochalsh to the tip of the Mull of Kintyre, including Coll, Tiree, Jura and Islay; Southwest Scotland.

-Moray Firth (part), from Helmsdale to Findhorn.

-East Scotland (part), the Firth of Tay and Eden Estuary, the Firth of Forth upstream of the bridges and the south Forth and Lothian shore to the border at Berwick on Tweed.

-The northern part of Northeast England was also surveyed, from Holy Isle to Coquet Island in Northumbria.

Figure 3 shows the years when different parts of the Scottish coast were last surveyed between 2015 and 2018. Areas surveyed in 2018 are in dark green. The 2018 survey formed the third year of a new round-Scotland survey that started in August 2016. Shetland remains the only area yet to be surveyed for the current round.

The most up-to-date August distribution of harbour seals in Scotland, from surveys between 2015 and 2018, 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 2018 are shown in Figure 5. Harbour seal counts from the most recent surveys and from three previous survey periods (2015-2018, 2007 to 2013, 2000-2006 and 1996 to 1997) are in Table 1.

The most up to date August distribution of grey seals in Scotland, from surveys between 2015 and 2018, is shown in Figure 6. Grey seal counts from the most recent surveys and from three previous periods (2015-2018, 2007 to 2013, 2000-2006 and 1996 to 1997) are in Table 2.

2.1 West Scotland - harbour seals *(10-19 August 2018)*

The harbour seal count for part of West Scotland - Central was **2,281** and the count West Scotland - South was **7,053**. Combined with the previous 2017 count for part of West Scotland - Central, the total for West Scotland - Central was **7,447.** The total count for the West Scotland SMA was **15,600** (Table 1).

2.2 West Scotland - grey seals *(10-19 August 2018)*

The 2018 grey seal count for part of West Scotland - Central was **279** and the count for West Scotland - South was **2,922**. The total for West Scotland - Central was **773**. The overall total grey seal count for the West Scotland SMA was **4,174** (Table 1).

2.3 Southwest Scotland - harbour seals *(19, 23 August 2018)*

The harbour seal count for the Southwest Scotland in 2018 was **1,709** (Table 1). This was the highest recorded count for the Southwest Scotland and was 42.4% higher than the previous (2015) count of 1,200.

2.4 Southwest Scotland - grey seals *(19, 23 August 2018)*

The grey seal count for Southwest Scotland in 2018 was **517** (Table 2). This, also, was the highest count for Southwest Scotland and was 64.6% higher than the previous (2015) count of 374.

2.5 Moray Firth, part - harbour seals *(19 August 2018)*

Between Helmsdale and Findhorn Bay, **914** harbour seals were counted in 2018 (Table 3). Combined with counts from previous years, the total harbour seal count for the Moray Firth SMA was **962**. This was 9.4% higher than the 2017 count of 879 (Table 3). Almost half of these harbour seals (46.2%) were between Culbin and Findhorn. The coast between Helmsdale and Duncansby Head was last surveyed in August 2008 and 2011. The coast between Findhorn and Fraserburgh was surveyed in August 2016.

2.6 Moray Firth - grey seals *(19 August 2018)*

In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn Bay) **711** grey seals were counted (Table 4). Combined with counts from previous years, a total of **798** grey seals were counted in the Moray Firth (Table 4).

2.7 East Scotland, Firth of Tay and Eden Estuary, upper Forth and south shore of Firth of Forth - harbour seals (21 August 2018)

The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2018 was **40**. There is still no real sign that this population is recovering 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, upper Forth and south shore of Firth of - grey seals (21 August 2018)

In the Firth of Tay and Eden Estuary SAC in 2018, **765** grey seals were counted (Table 2, Table 5). The revised 2018 grey seal count for East Scotland was **3,762**.

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 2018 count for Northeast England was **79**, a combined count from Holy Island the Tees Estuary (Table 7). Harbour seals in the Tees Estuary are monitored by the Industry Nature Conservation Association (INCA). The overall slow increase in numbers seems to be continuing, although the August 2018 mean count of 76 was slightly lower than the 2017 mean count of 86 (Bond, 2018).

One aerial survey of harbour seals was carried out by SMRU in Lincolnshire and Norfolk during August 2018 (Table 7). The 2018 count for the coast between Donna Nook and Scroby Sands (**4,223**) was slightly higher (by 1.3%) than the 2017 count (4,170). The survey extended to cover the coast of Essex and Kent, where **738** harbour seals were counted compared with795 counted in 2017 by the Zoological Society of London (Zoological Society of London, unpublished data).

The combined counts for the Southeast England Management Unit (Flamborough Head to Newhaven) in 2018 (**4,961**) was virtually the same as the 2017 count (4,965; 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 in two flights on 28th June and 2nd July 2018. The results together with results from previous breeding season surveys are presented in detail in SCOS-BP 19/04. The 2018 pup count for the Wash was 1498, this was 18% higher than the 2017 peak and similar to 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 5.6% p.a. since 2001.

3.3 England and Wales – grey seal counts (August)

A total of **8,199** grey seals were counted on the south-east coast of England between Donna Nook and Dover in August 2018. This is similar to counts from the previous four years (Table 8).

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

Seal Management Unit		Harbour seal counts			
		2015-2018	**2007-2013**	**2000-2006**	**1996-1997**
1 Southwest Scotland		1,709	923	623	929
2 West Scotland	a	15,600	11,072	11,666	8,811
3 Western Isles		3,533	2,739	1,981	2,820
4 North Coast & Orkney		1,349	1,938	4,388	8,787
5 Shetland		3,369	3,039	3,038	5,994
6 Moray Firth		962	898	1,028	1,409
7 East Scotland		342	214	667	764
SCOTLAND TOTAL		26,864	20,823	23,391	29,514
8 Northeast England	b	79	83	62 *	54 *
9 Southeast England	c	4,961	4,504	2,964	3,092
10 South England	d	40	20	15	10
11 Southwest England	d	0	0	0	0
12 Wales	d	10	10	5	2
13 Northwest England	d	5	5	5	2
ENGLAND & WALES TOTAL		5,095	4,622	3,051	3,160
BRITAIN TOTAL		**31,959**	**25,445**	**26,442**	**32,674**
NORTHERN IRELAND TOTAL	e	1,012	948	1,176	
UK TOTAL		**32,971**	**26,393**	**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, 2018). 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 2013 collected and provided by the Zoological Society London (Barker, 2014).

[d] Estimates compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy) or found in various reports & on websites (Boyle, 2012; Hilbrebirdobs blogspot, 2013; Sayer, 2010, 2011; Sayer *et al.*, 2012; Westcott, 2002). Some 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 & 2018 (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			
		2015-2018	2007-2013	2000-2006	1996-1997
1 Southwest Scotland		517	233	206	75
2 West Scotland	a	4,174	2,712	2,383	3,435
3 Western Isles		5,772	4,144	3,929	4,062
4 North Coast & Orkney		9,714	8,195	10,315	9,427
5 Shetland		1,558	1,536	1,371	1,724
6 Moray Firth		769	1,311	1,272	551
7 East Scotland		3,762	1,982	1,898	2,328
SCOTLAND TOTAL		26,266	20,113	21,374	21,602
8 Northeast England	b	6,502	2,354	1,100 *	
9 Southeast England	c	8,199	4,178	2,266	
10 South England	d	25	5	2	
11 Southwest England	d	500	500	425	
12 Wales	d	900	850	750	
13 Northwest England	d	100	50	30	
ENGLAND & WALES TOTAL		16,226	7,937	4,573	
BRITAIN TOTAL		**42,492**	**28,050**	**25,947**	
NORTHERN IRELAND TOTAL	e	505	468	272	
UK TOTAL		**42,997**	**28,518**	**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, 2018). 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 2013 collected and provided by the Zoological Society London (Barker, 2014).

[d] No SMRU surveys, but some data available. Estimates compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Natural England, Natural Resources Wales, RSPB) or found in various reports & on websites (Boyle, 2012; Büche & Stubbings, 2019; Hilbrebirdobs blogspot, 2013, 2018; Leeney *et al*., 2010; Sayer, 2010, 2011, 2012a, 2012b; Sayer *et al*., 2012; Westcott, 2002, 2009; Westcott & Stringell, 2004; Woodfin Jones, 2018). 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 & 2018 (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 2018. 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 2018 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	2018
	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	fw
(MEAN) COUNTS	Duncansby Head to Helmsdale		2		1					1			1										
	Helmsdale to Brora		92		193		188			113	150	54	73	19	101	87	102	70	1	21	40	22	30
	Loch Fleet		16		27	33	59	56	64	71	80	83	82	65	114	113	133	135	156	144	145	138	152
	Dornoch Firth (SAC)	662		542	593	405	220	290	231	191	257	144	145	166	219	208	157	143	111	120	85	39	117
	Cromarty Firth	41		95	95	38	42	113	88	106	106	102	90	90	140	101	144	63	100	22	72	20	43
	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	30
	Ardersier (incl. Eathie)			221	234	191	110	205	202	210	197	154	145	277	368	195	183	199	28	34	36	81	98
	Culbin & Findhorn			58	46	111	144	167	49	93	58	79	92	73	123	163	254	218	260	330	484	526	444
	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	288
	Loch Fleet to Ardersier				1,168	871	497	815	763	705	816	629	612	683	981	674	677	570	432	354	368	283	440
	Loch Fleet to Findhorn				1,214	982	641	982	812	798	874	708	704	756	1,104	837	931	788	692	684	852	809	884
	Helmsdale to Findhorn				1,407		829			911	1,024	762	777	775	1,205	924	1,033	858	693	705	892	831	914
	Moray Firth SMA *				1,409		831			915	1,028	763	778	776	1,206	954	1,063	898	733	745	940	879	962

* 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 2018. 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 2018 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	2018
	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	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	147
	Loch Fleet			0		0	0	0	0	0	0	1	3	1	0	7	7	20	18	7	10	31	22	15
	Dornoch Firth (SAC)		233		903	456	121	321	79	473	431	748	516	523	819	717	679	74	604	127	716	387	273	321
	Cromarty Firth		9		0	0	0	0	0	0	0	1	0	0	0	1	2	1	3	1	0	1	0	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	1
	Ardersier (incl. Eathie)				36	24	85	0	3	44	55	142	74	142	94	331	74	24	109	2	14	28	87	83
	Culbin & Findhorn				0	0	0	0	10	0	11	11	28	75	58	58	179	121	218	93	743	717	548	144
	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	405
TOTALS	Loch Fleet to Ardersier					483	214	321	82	517	486	895	597	666	913	1,058	765	120	739	139	740	449	382	420
	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	564
	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	711
	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	769

* 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, 1990-2018. 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 2018 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	2018
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	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	32
Broughty Ferry	77	83	97	64	35	52	0	90	51	31	27	13	28	15	18	16	3	0	2	4	0	4
Buddon Ness	13	86	72	53	0	113	109	142	25	96	64	27	8	23	11	8	10	1	3	0	0	2
Abertay & Tentsmuir	319	428	456	289	262	153	167	53	63	34	31	50	8	9	0	5	0	0	0	1	0	0
Eden Estuary	31	0	0	80	223	267	341	93	105	90	90	83	22	36	32	19	1	7	4	5	1	2
SAC total	467	670	773	575	633	700	668	461	335	342	275	222	111	124	77	88	50	29	60	51	29	40

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, 1990-2018. 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 2018 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	2018
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	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	52
Broughty Ferry	0	3	0	9	0	0	0	16	0	8	1	8	0	0	2	3	0	2	0	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	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	667
Eden Estuary	0	0	16	0	10	0	25	4	27	57	31	33	0	39	17	36	14	39	32	66	76	46
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	765

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 2018. 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 (11)		290	3,210	399	271	
2018	3	76 (11)		146	3,632	218	210	738

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 (prev. DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015, 2018. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2018). 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 2018. 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
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 (11)		6,526	688	502	425	
2018	6,427	15 (11)		6,288	253	360	497	596

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 (prev. DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015, 2018. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2018). 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).

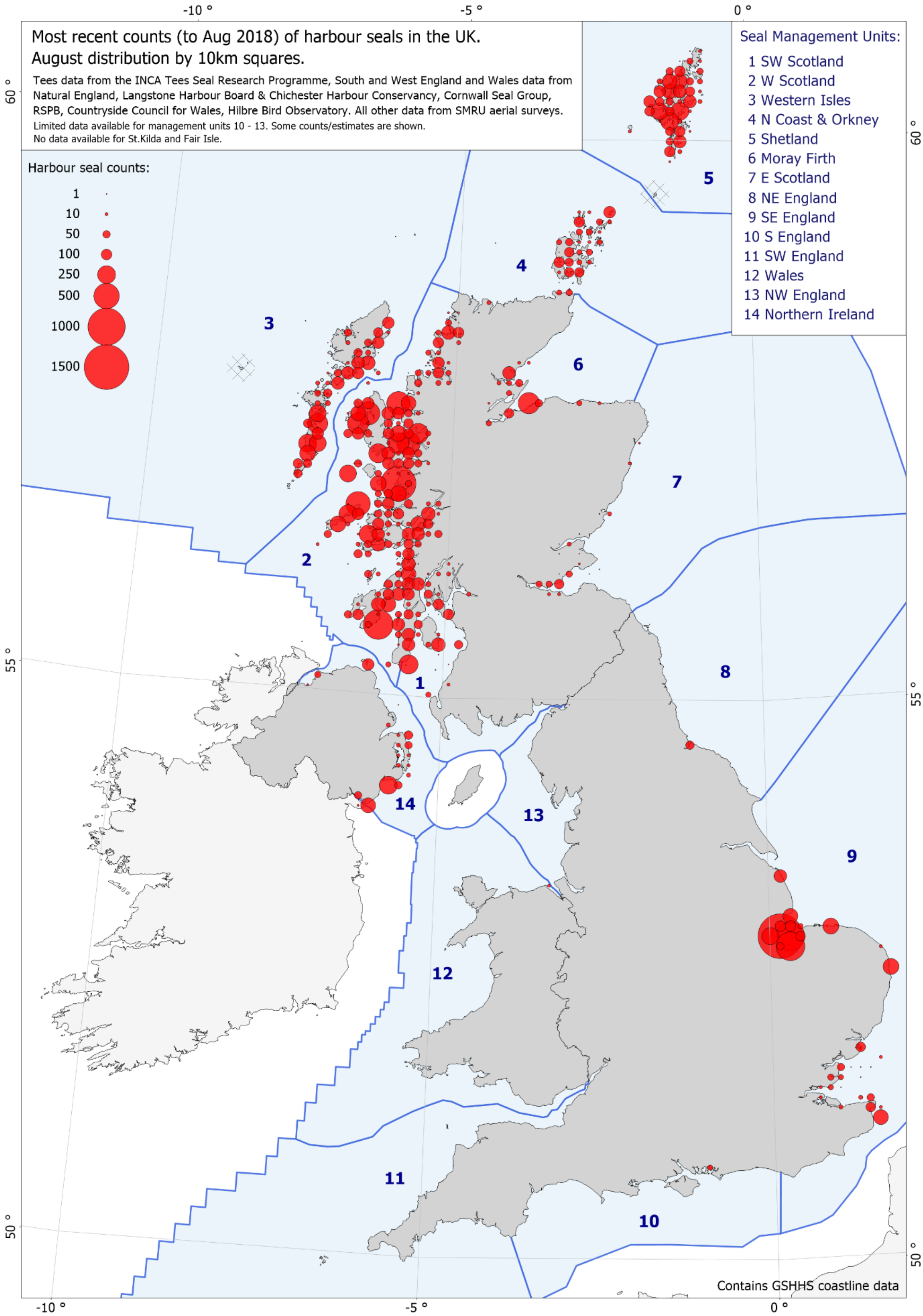

Figure 1. August distribution of harbour seals around the British Isles.

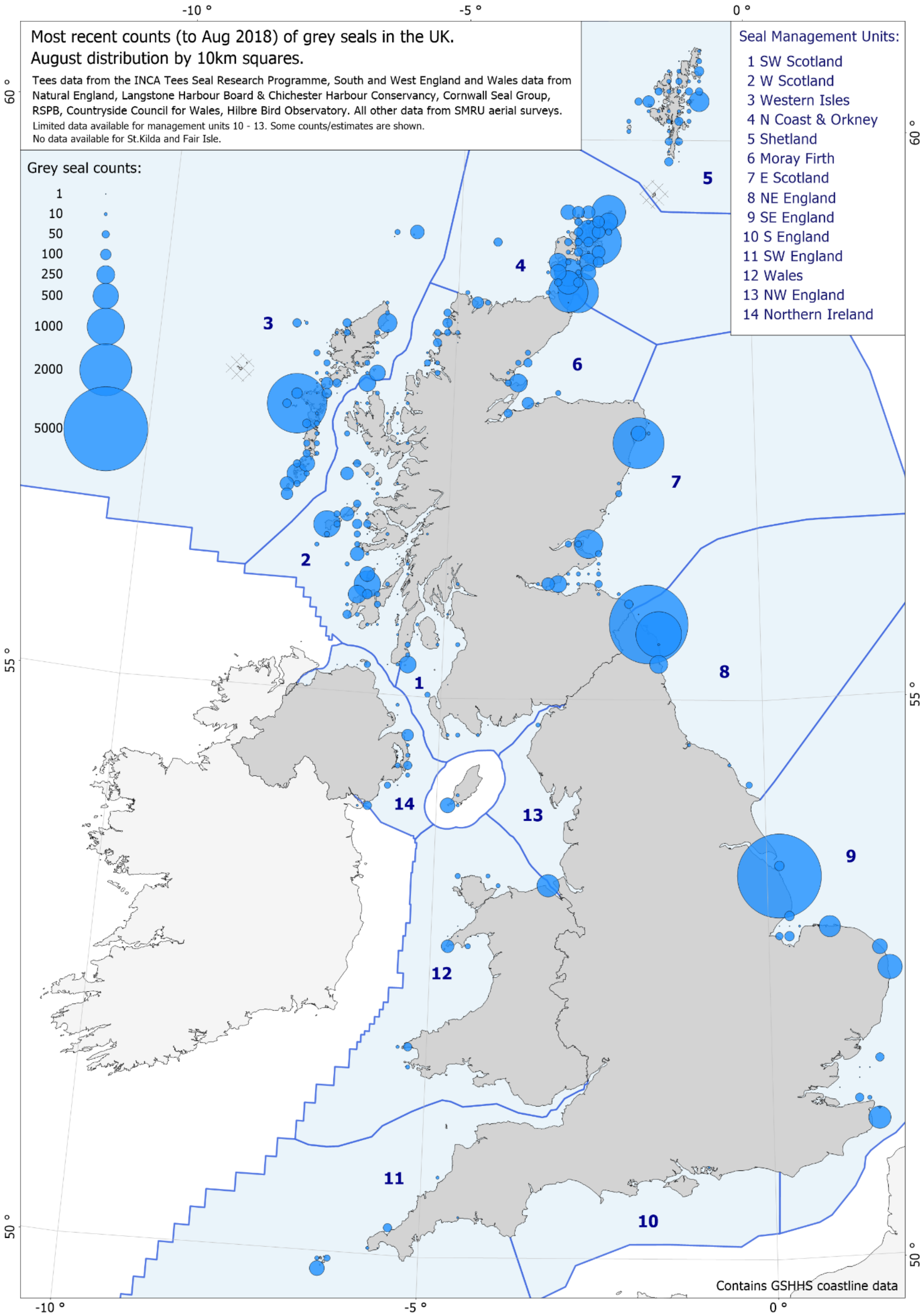

Figure 2. August distribution of grey seals around the British Isles.

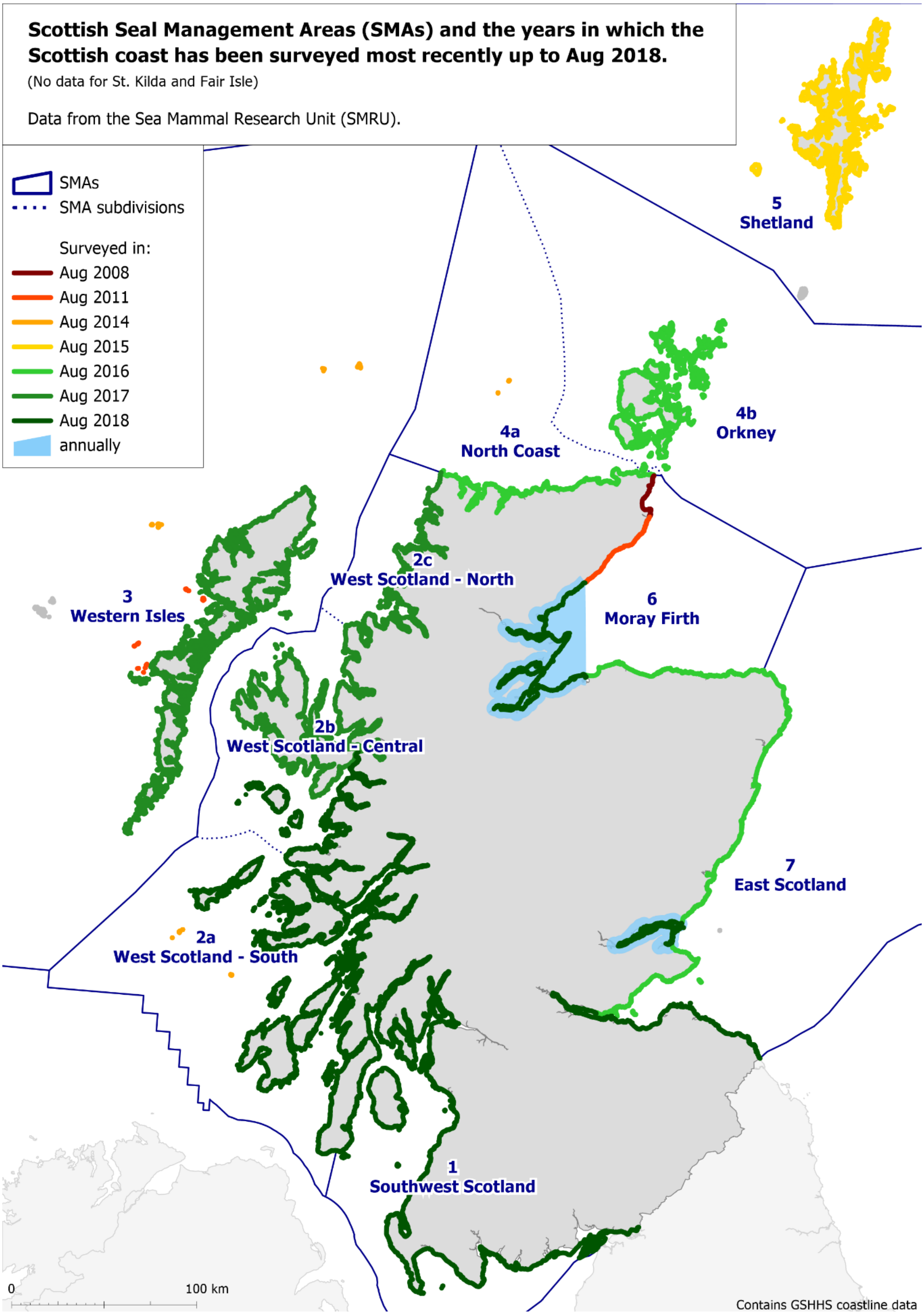

Figure 3. Years in which different parts of Scotland were surveyed most recently by helicopter using a thermal imaging camera. Most areas were surveyed between 2015 and 2018. The blue shaded areas of the Firth of Tay and the Moray Firth (between Findhorn and Helmsdale) are surveyed every year, usually by fixed-wing aircraft.

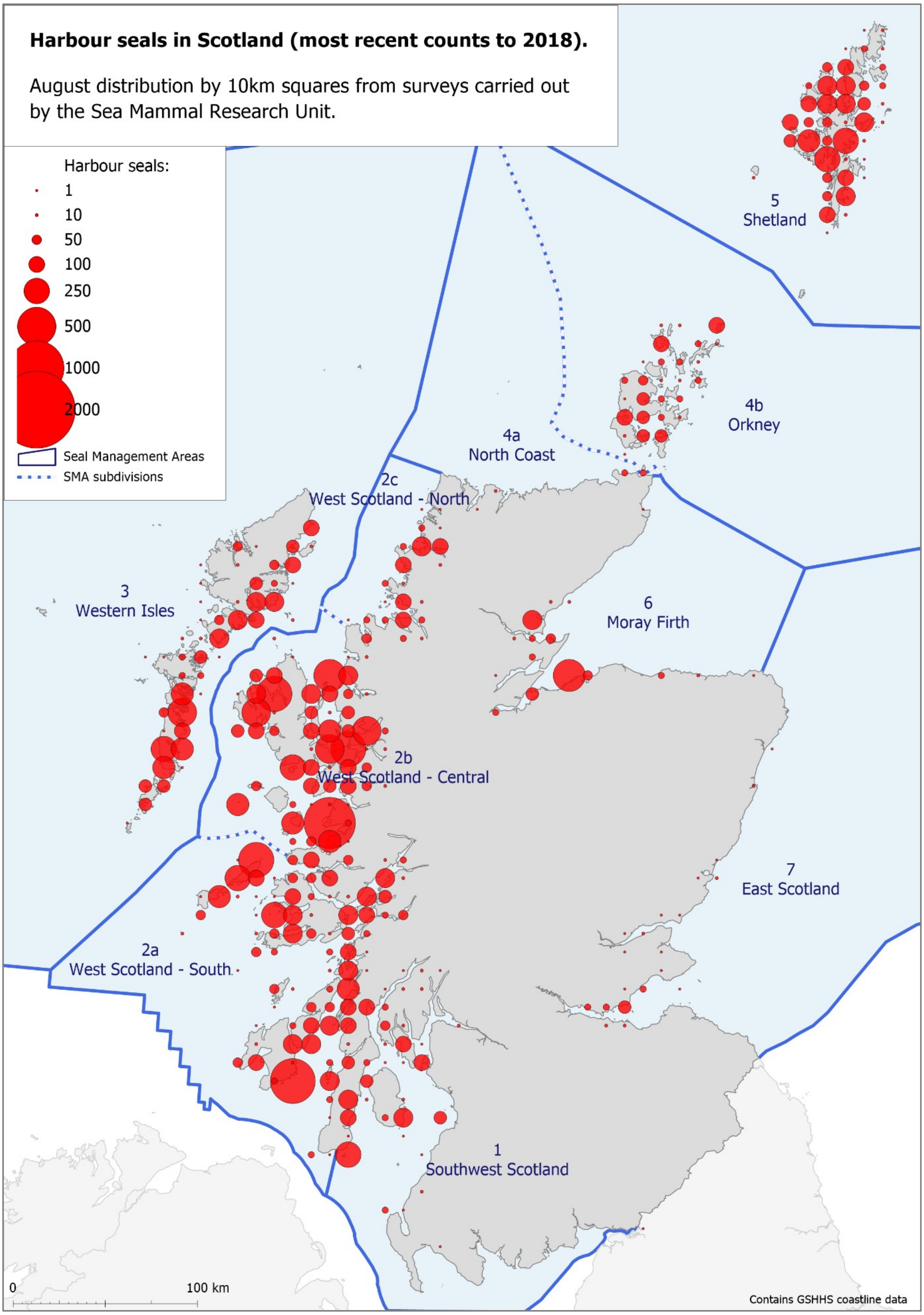

Figure 4. August distribution of harbour seals in Scotland. Most areas were surveyed by helicopter using a thermal imaging camera. The Moray Firth area between Helmsdale and Findhorn, and the Tay and Eden estuaries were surveyed by fixed-wing aircraft without a thermal imager.

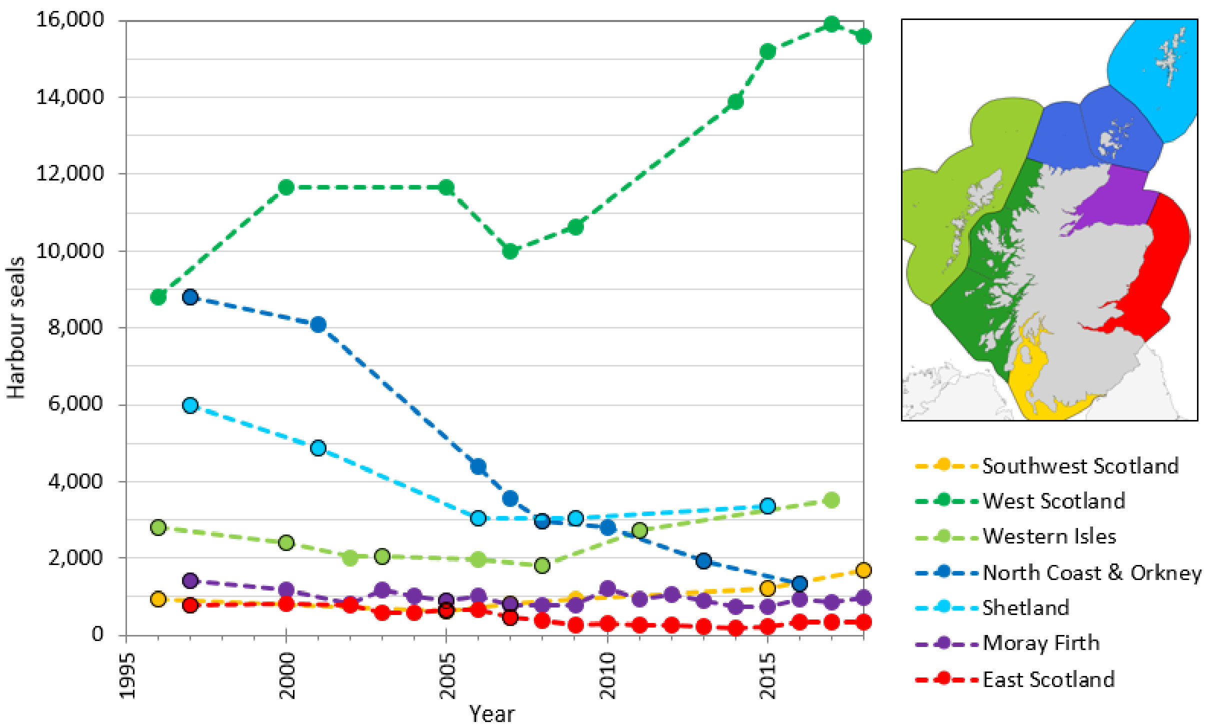

Figure 5. August counts of harbour seals in Scottish Seal Management Areas, 1996-2018. Data from the Sea Mammal Research Unit. Note that because these data points represent counts of harbour seals distributed over large areas, individual data points may not be from surveys from only one year. Points 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.

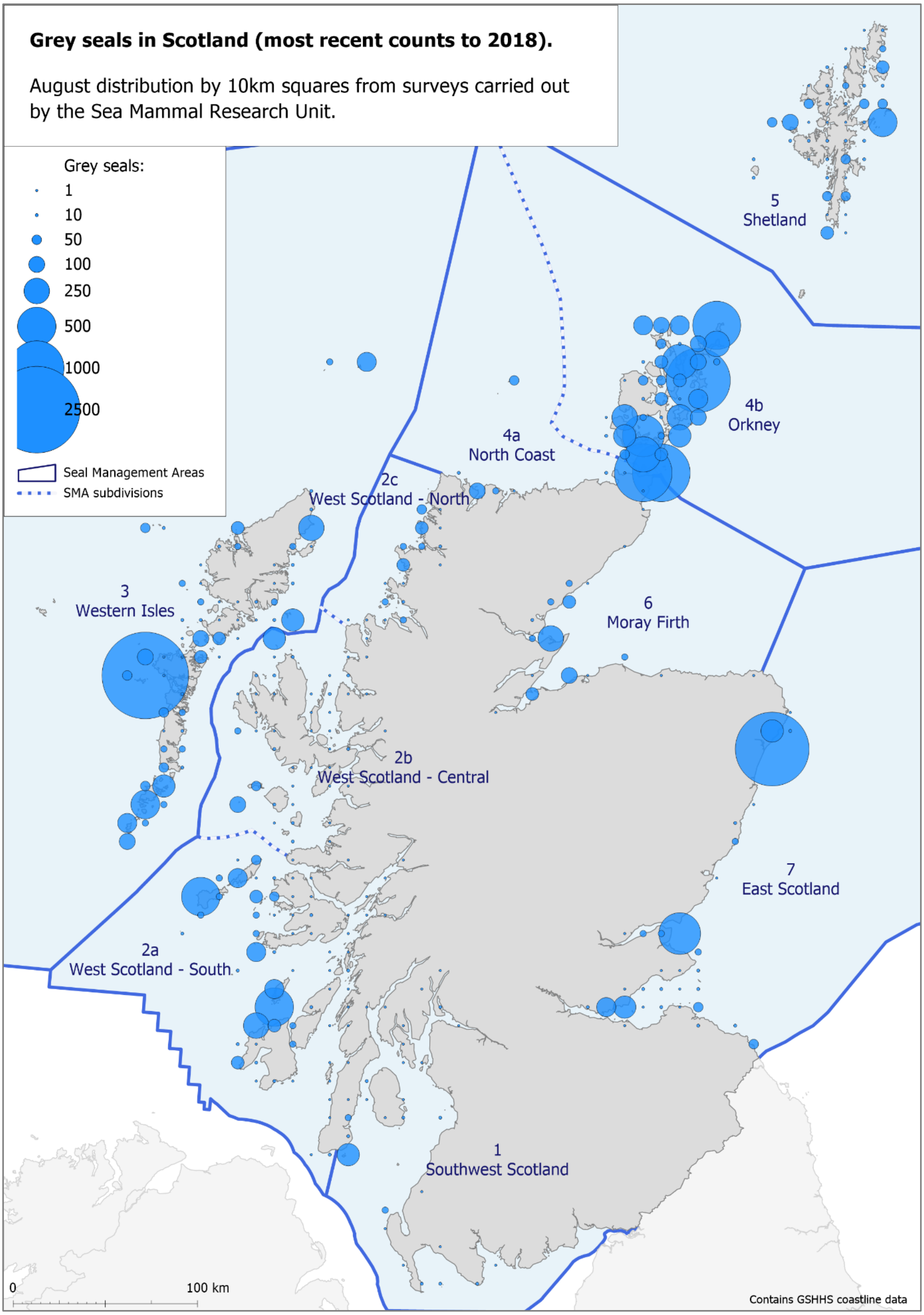

Figure 6. August distribution of grey seals in Scotland. Most areas were surveyed by helicopter using a thermal imaging camera. The Moray Firth area between Helmsdale and Findhorn, and the Tay and Eden estuaries were surveyed by fixed-wing aircraft without a thermal imager.

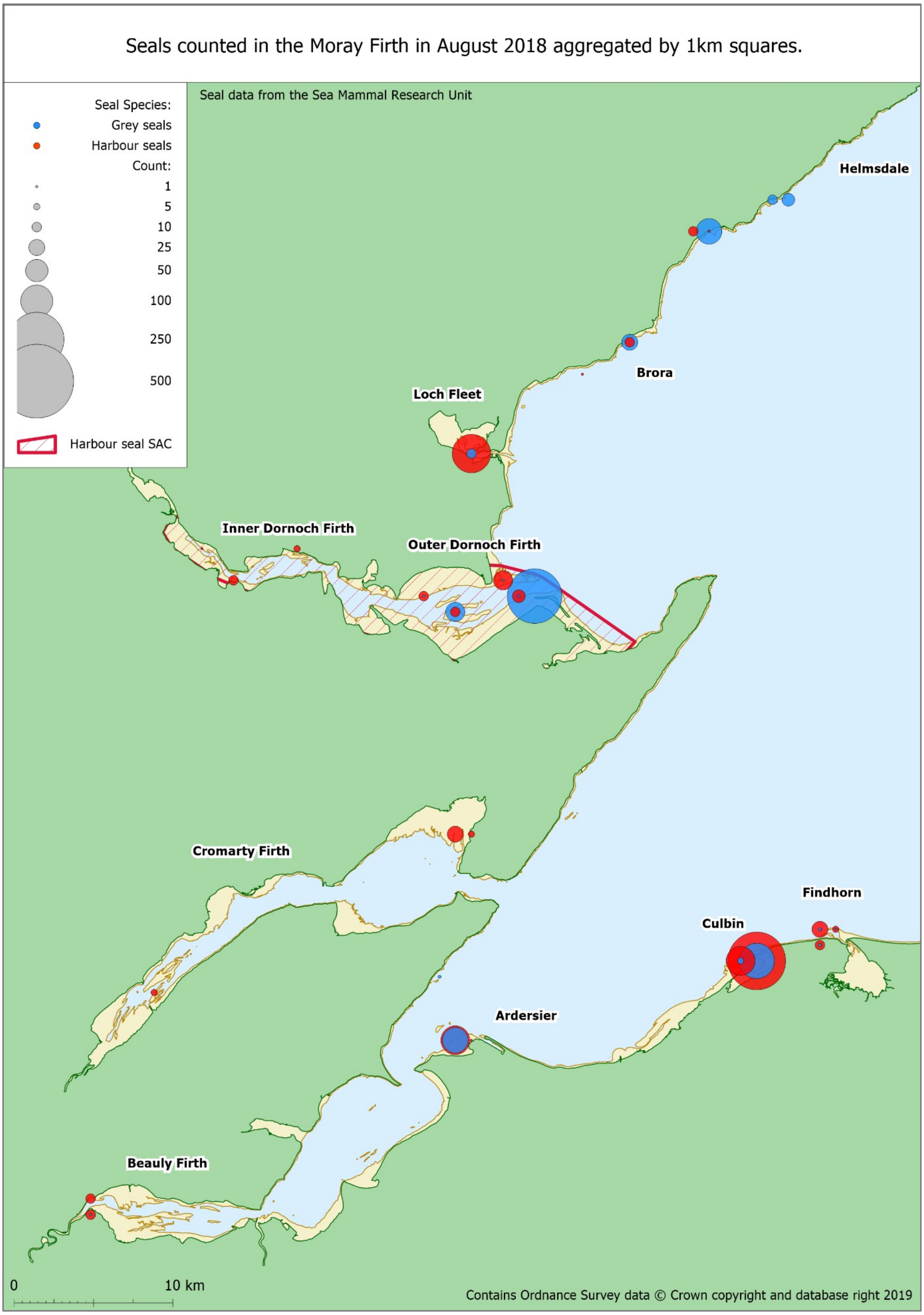

Figure 7. Distribution of harbour (red) and grey seals (blue) in the annually surveyed part of the Moray Firth, between Helmsdale and Findhorn, from an aerial survey carried out on 19th August 2018.

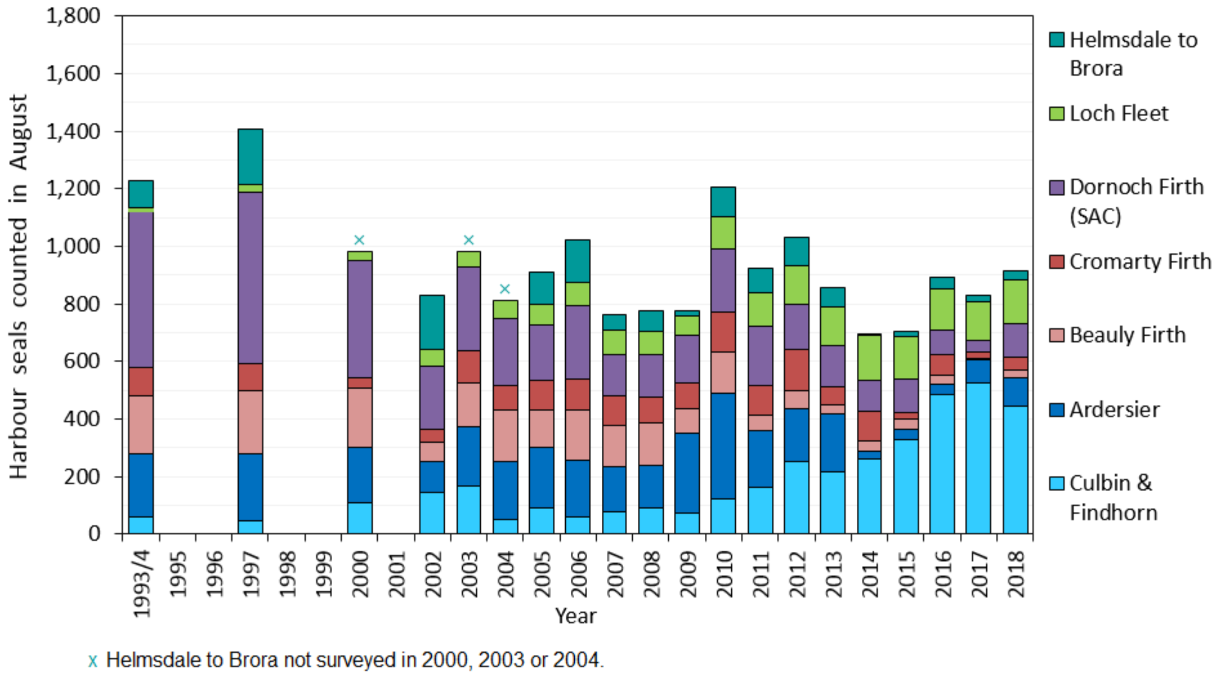

Figure 8. August counts of harbour seals in different areas of the Moray Firth, 1994-2018. The mean is shown for years with more than one survey. Data are from the Sea Mammal Research Unit.

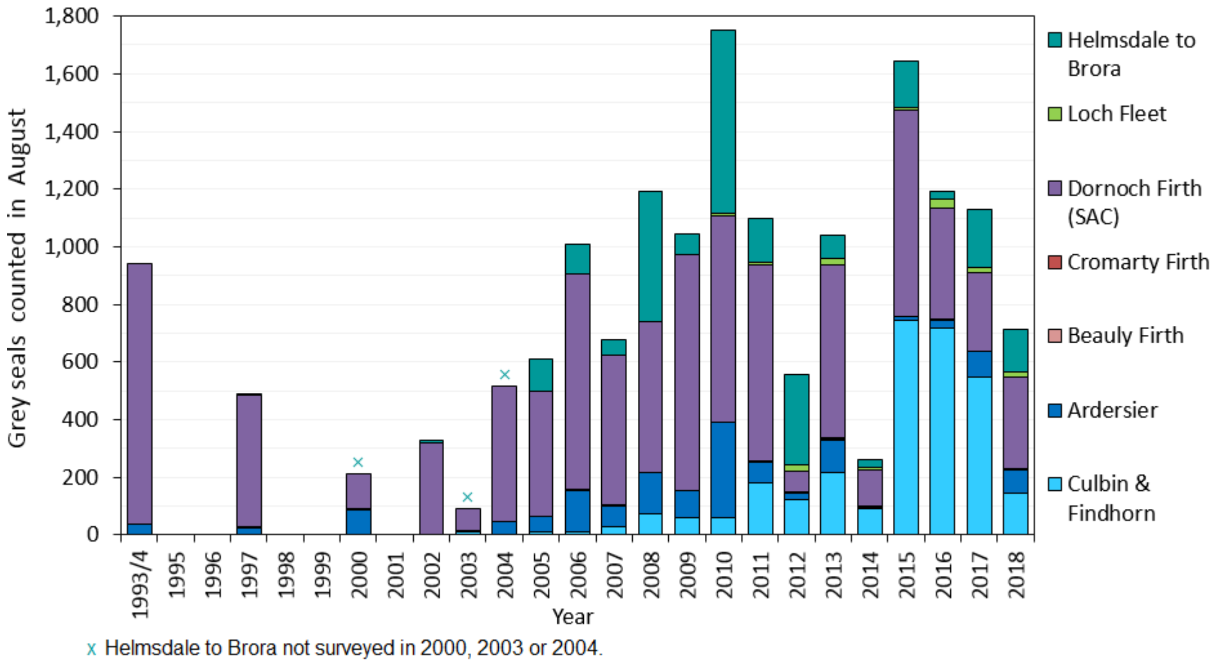

Figure 9. August counts of grey seals in different areas of the Moray Firth, 1994-2017. The mean is shown for years with more than one survey. Data are from the Sea Mammal Research Unit.

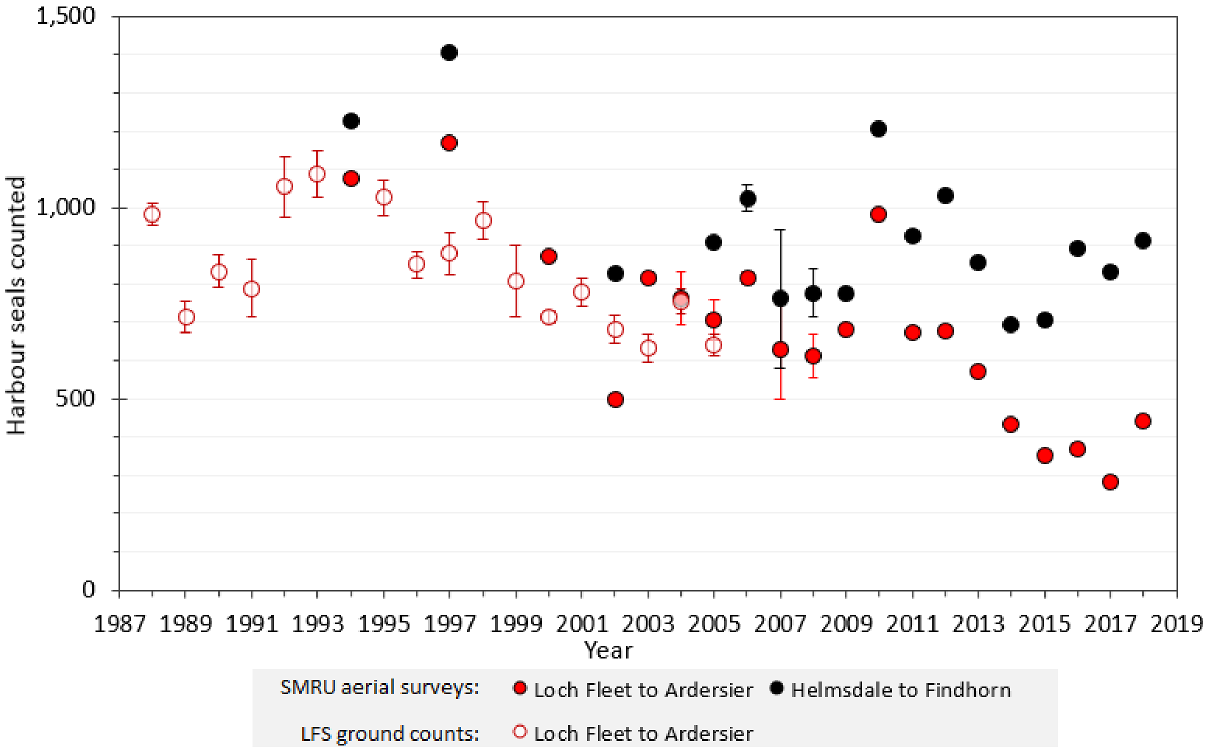

Figure 10. Counts of harbour seals in the Moray Firth during the moult season (August), 1988-2018. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

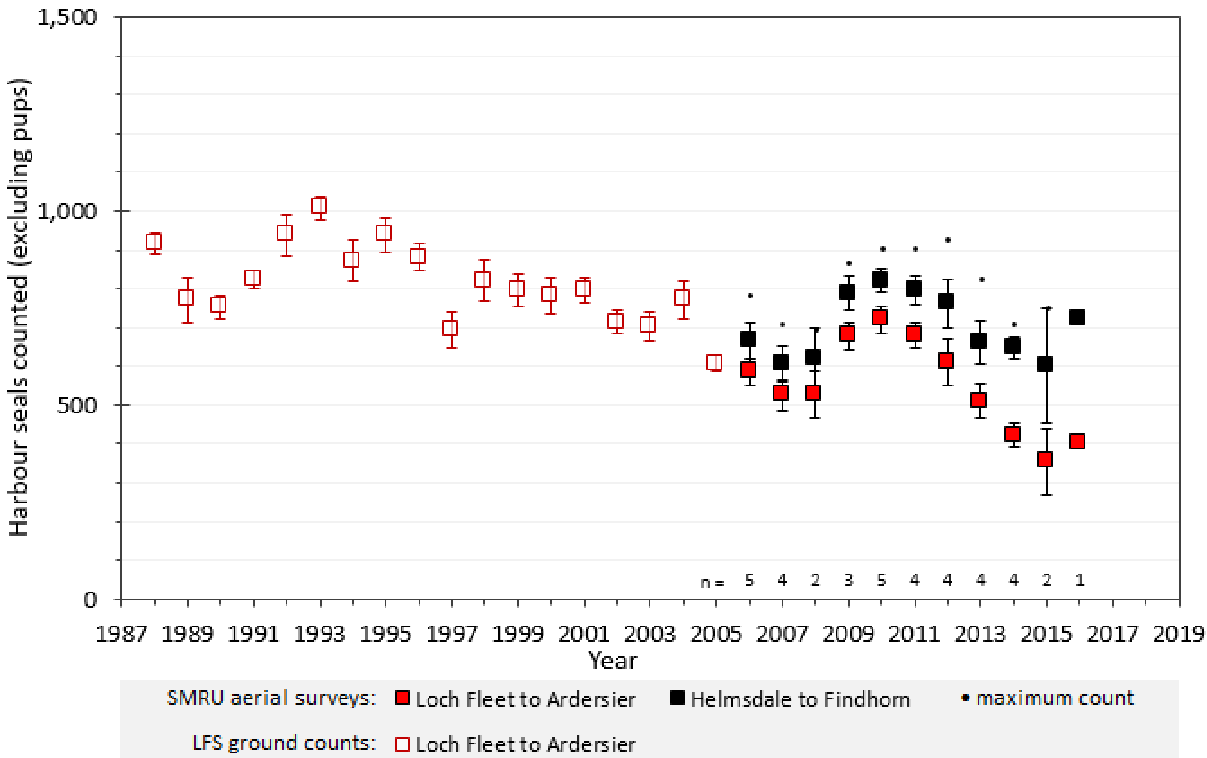

Figure 11. Counts of harbour seals in the Moray Firth during the breeding season (June/July), 1988-2016. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

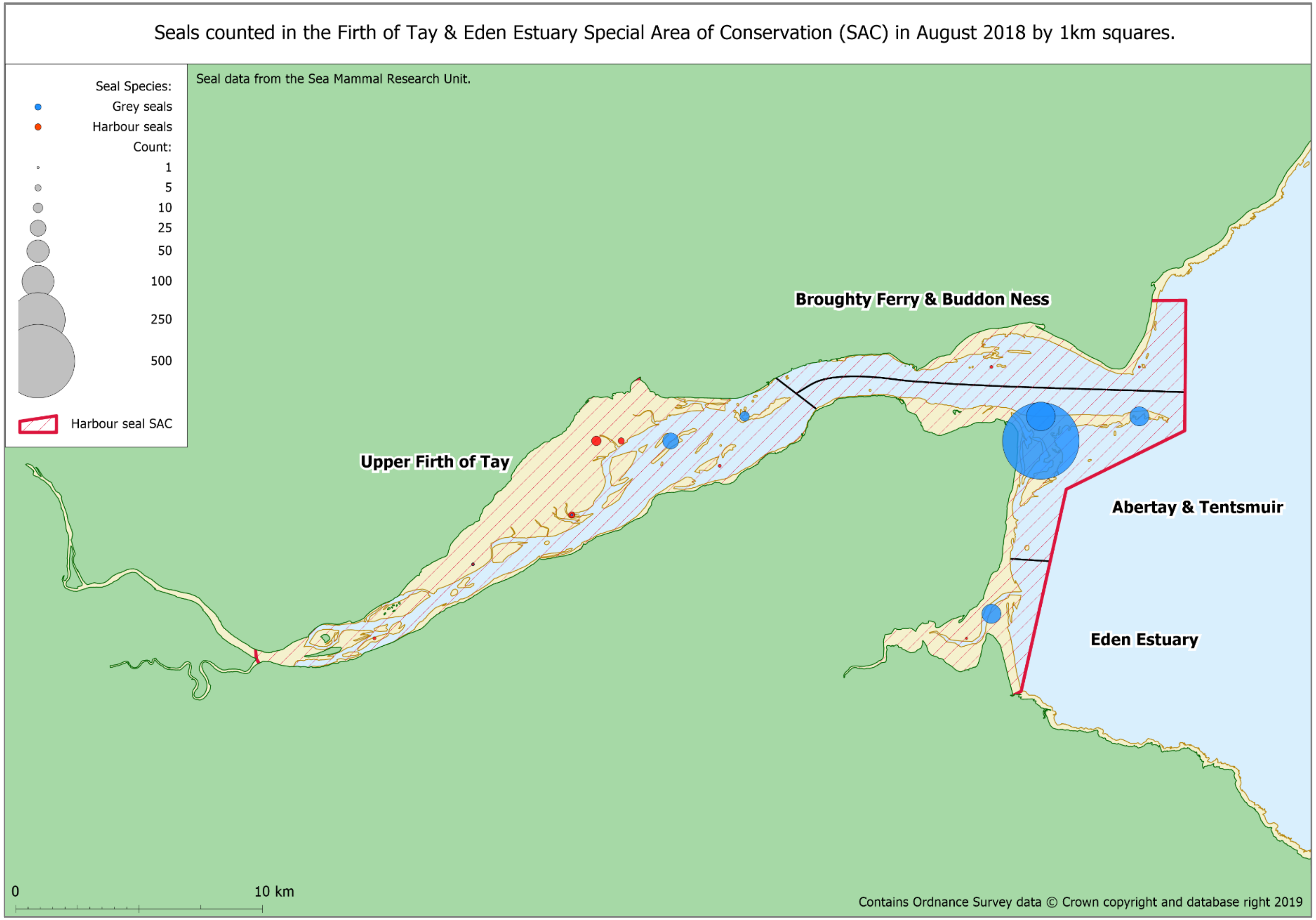

Figure 12. The distribution of harbour (red) and grey seals (blue) in the Firth of Tay and Eden Estuary on 28th August 2018.

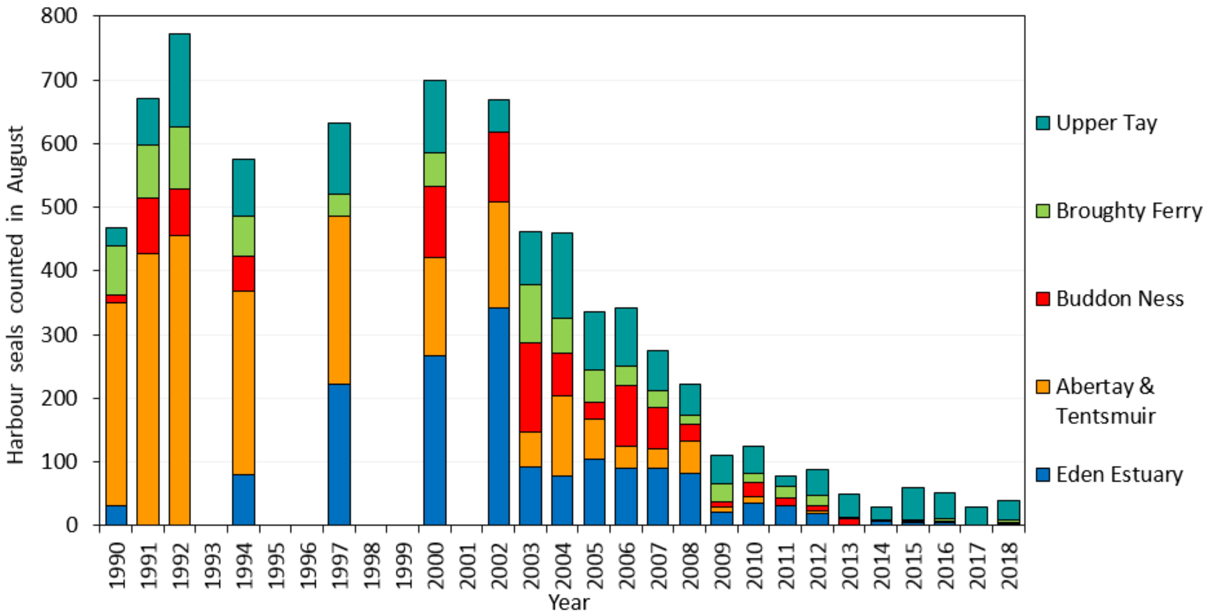

Figure 13. August counts of harbour seals in the Firth of Tay and Eden Estuary, 1990 to 2018.

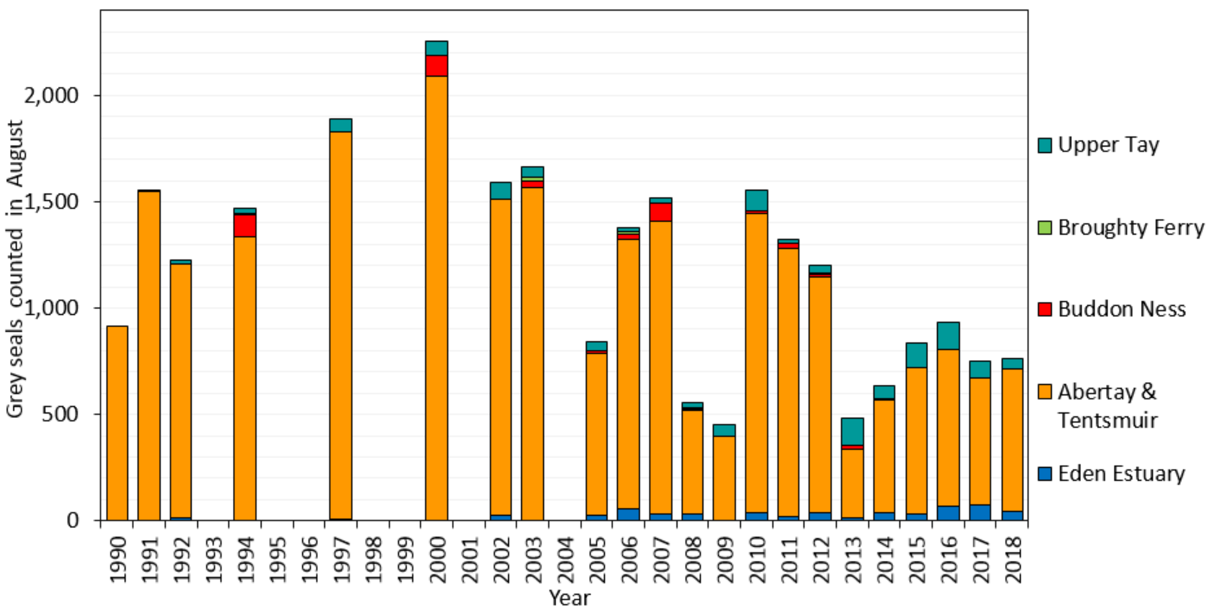

Figure 14. August counts of grey seals in the Firth of Tay and Eden Estuary, 1990 to 2018.

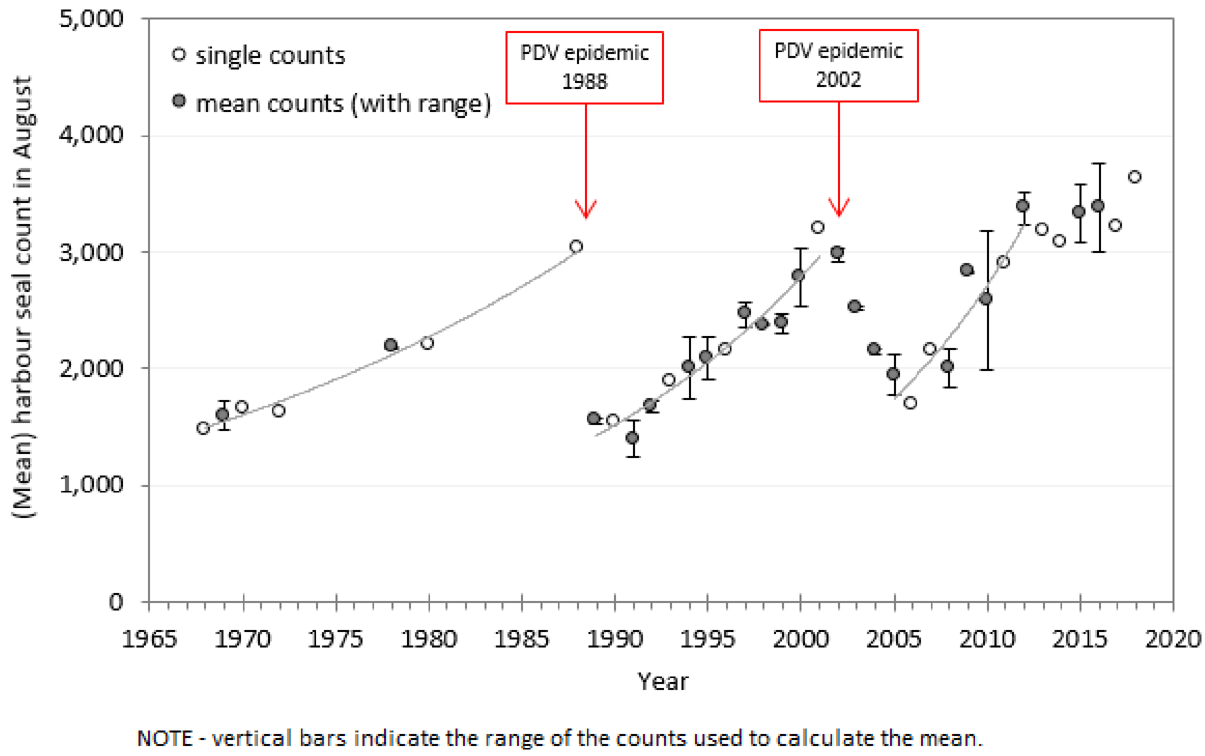

Figure 15. August counts of harbour seals in The Wash between 1967 and 2018 from surveys by the Sea Mammal Research Unit.

Preliminary report on the distribution and abundance of harbour seals (Phoca vitulina) during the 2018 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 The Wash in Lincolnshire and Scroby Sands off the Suffolk coast on 29th June and 2nd July 2018.

Results suggest that:
•The pup count for the Wash was 1498, which was 18% higher than the 2017 peak and similar to 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 5.6% 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 2.7 times higher in 2018 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. 2006). 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 2017

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 2017. 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.

2018 survey results

In 2018 a survey was attempted on 29th June, but was curtailed because of low cloud covering the open coast between Donna Nook and Scroby Sands. The cloud moved west to cover most of the Wash during the survey. As a consequence only around 1/3 of the sites could be surveyed. The rest of the Wash and the haulout at Blakeney Point were surveyed during the late afternoon on 2nd July after the RAF ranges closed. The late timing of the survey dictated by military restrictions meant that Donna Nook was not surveyed. However, given the absence of pups in the previous surveys it is unlikely that any pups were missed.

A total of 1498 pups and 3747 older seals (1+ age classes) were counted in the Wash. As in 2017, only 1 pup was seen at Blakeney point. The 2018 pup count for the Wash was 18% higher than the 2017 count but similar to the average of the peak counts for the preceding 5 years (1463). The non-pup count, i.e. all 1+ age classes, was 7% higher than the 2017 count, but close to the average count during the previous five year's breeding season survey counts.
The 18% difference between the estimated peak pup counts in the 2018 and 2017 surveys continues the pattern of high inter-annual variability (Table 2 and Figure 3). Accounting for the variability there has been little change in the peak count over the past 5 years suggesting that the increase in pup production may have slowed and may be approaching an asymptote after a period of exponential growth since the Phocine Distemper outbreak in 2002 (Figure 3). Both logistic and exponential growth curves were fitted to the pup count data since 2004, i.e. after the last PDV epidemic. The two models fit the data equally well (Exponential AIC = 74.9; Logistic model AIC = 73.6), so it is not possible to conclude that the population growth rate is slowing.
Based on a simple exponential model the pup production is estimated to have increased at an average rate of 5.6% p.a. since the 2002 PDV epidemic.

Pups were recorded in 34 separate haulout groups in the Wash, although the number of sites is to some extent a function of the arbitrary division or pooling of groups (see below). This is the same as in the previous 3 years, indicating no contraction or expansion in number of pupping sites. Figure 4 shows the distribution of haulout sites in the Wash. Figure 5 shows the flight path for the standard East Anglian surveys and Figure 6 shows the detailed track of survey flights over the Wash carried out on 29/06/2018 and 2/07/2018. 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 areas, 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 an arbitrary point in the approximate centre of the distribution of observed groups. Figure 7 shows the counts of pups at each site obtained during the 2018 breeding season survey. Table 1 presents the data for 2015 to 2018. All the raw pup count data from 2004 to 2018 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 carried out in 2015 and 2016 for Statoil.

In 2018 pups were present at all bar five of the sites occupied by harbour seals. The fine scale distribution was similar to that observed in previous years. Most sites that held more than one pup per year over the previous three years also had pups in 2018. Each of the eight sites where this was not the case were within 2 km of a site with pups. Inter-annual movement at that scale is not unusual for harbour seals. 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 8).

The time series indicates that there was no evidence of a major decline in pup production after the 2002 PDV epidemic and the peak counts increased at around 9% p.a. during the 10 years following the PDV epidemic. This continued increase in pup production contrasted 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 initially exceeded that of the moult population index counts (Figure 9). Since 2011 there has been little apparent increase in either the pup or moult counts. The different trajectories of the pup counts and the independent index of population size represented by the moult count since the 2002 PDV epidemic means that the apparent productivity or apparent population fecundity has changed over the period (Figure 10). 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. The productivity index for 2018 is based on the moult count for 2017 and will be updated when the counts for 2018 are available.

Discussion

The 2018 breeding season survey counts for both pups and associated 1+ age classes at the estimated peak of the breeding season were similar to the average counts from surveys during the previous five years. This suggests that the apparent continuous increase in pup production 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 an average increase of 5.6% p.a. 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 and the highest pup production recorded in the Wash. A reduction in growth rate of the population is therefore unlikely to indicate any problem for 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 5.6% 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 resulting in a 50% decrease by 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.

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 2018 was 2.7 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 relative to the moult count index 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 2018 indicate that the relative importance of the SE corner of the Wash is still increasing.

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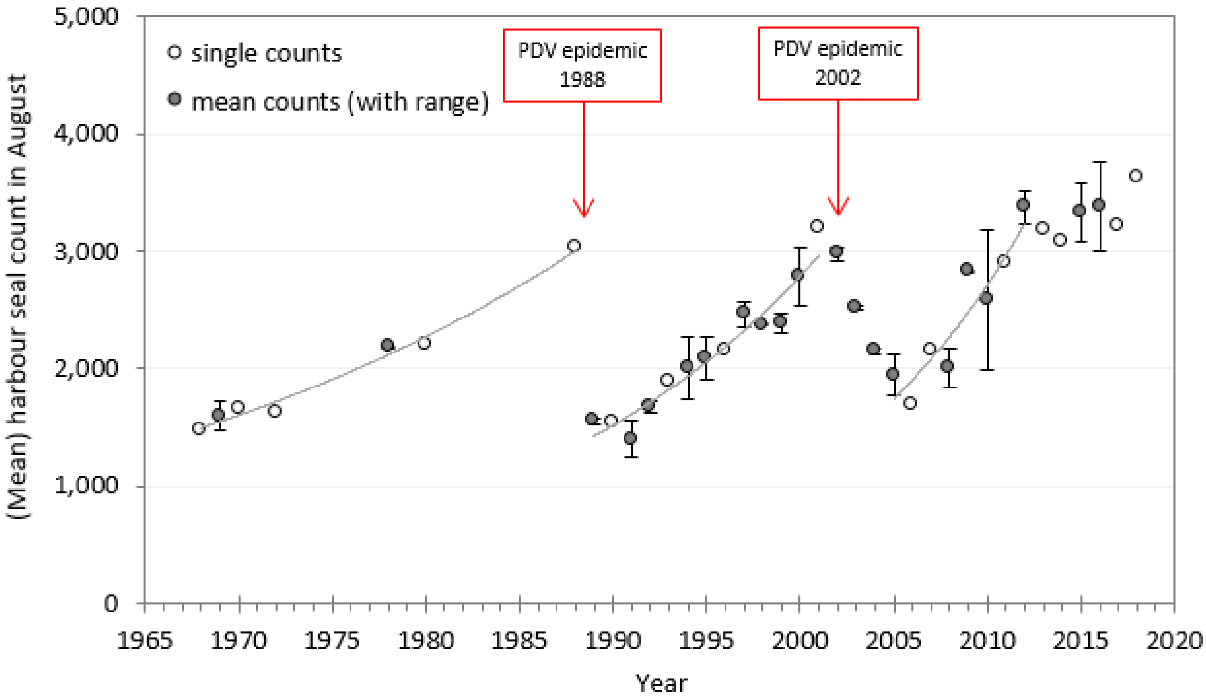
Table 1. Counts of harbour seal pups and 1+ age classes in the Wash from 2001 to 2018.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351	1586	1289	1498
1+ age classes	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	4539	3905	3443	3747942

Table 2. Counts of harbour seal pups and 1+ ages at haulout sites in the Wash, 2016-2017.

			2-July 2018		4-July 2017		2-July 2016	
			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	195	24	81	15	157	31
Inner Dogs Head	53.036	0.376	45		24	3	44	7
Friskney	53.034	0.309	68	16	69	15	81	20
Friskney Middle	52.997	0.225	8	4	32	17	8	7
Friskney South	52.953	0.119	38	16	9	2	22	15
Long Sand N/E End	53.019	0.334						
Long Sand Middle	53.005	0.297	97	25	59	15	101	22
Ants	52.978	0.264	1	1	0	0	1	0
Rodger	52.963	0.217	7		5	0	1	0
NW total			459	86	279	67	415	102
Black Buoy	52.924	0.117	26		34	1	41	8
Boston Channel	52.900	0.029	210	104	143	35	180	88
Herring Shoal	52.904	0.064	66	31	49	4	43	12
Toft East	52.932	0.153	28	5	16	3	19	6
Toft West	52.920	0.133	52	41	15	0		
Mare Tail	52.917	0.152	26	10			28	11
Main End	52.907	0.193						
Gat End	52.912	0.203	9	9				
Gat Sand	52.935	0.198	70	13	53	5	44	8
SW total			487	213	310	48	355	133
			2-July	2018	4-July	2017	2-July	2016
			harbour	seals	harbour	seals	harbour	seals
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups
Puff	52.899	0.121	57	24	32	9	55	20
Kenzies Creek	52.900	0.106	143	94	148	93	159	110
Fleet Haven Marsh	52.877	0.152						
Fleet Haven Middle	52.884	0.157	234	114	173	114	295	156
Fleet Haven Lower	52.909	0.157						
Fleet Haven Mouth	52.922	0.158	25	25	48	26		
Evans Creek	52.878	0.169	137	56	182	89	101	58
Dawesmere Creek	52.859	0.191	167	49	46	28	110	35
Creeks total			763	362	629	359	720	379
OWMK 1	52.875	0.233	74	36	24	12		
OWMK 2	52.867	0.250	27	12	7	2		
Nene Channel 1	52.875	0.220	78	46			104	64

Nene Channel 2	52.867	0.216	165	44	198	60	223	68
Nene Channel 3	52.860	0.214	25	6	47	16	88	55
Nene Channel 4	52.845	0.206	96	56	83	37		
Nene Channel 5	52.827	0.219						
IWMK	52.852	0.235			40	19	28	20
Scalmans Sled	52.857	0.258	145	68	74	43	159	87
Breast Sand	52.828	0.275	174	84	78	58	137	71
Thief West	52.878	0.273	25	2	19	1	37	5
Thief East	52.878	0.273	2		6	1	5	1
Seal Sand (W)/Black Shore	52.875	0.312			113	42	51	22
Seal sand (E)	52.881	0.352	128	26	148	23	245	60
Seal Sand/Daseleys	52.882	0.351			79	31	138	68
Hull Sand	52.840	0.307	369	144	719	193	563	232
Bull Dog Sand	52.866	0.378	64	35	222	49	38	29
Pandora	52.862	0.355	86	23	87	23	235	60
Black Guard	52.883	0.372	4		3	0		
Old Bell	52.900	0.372					22	2
Stylemans Middle	52.887	0.380	13	3	8	0	15	7
Pie Corner	52.834	0.327			30	7		
Lynn Channel	52.810	0.367	563	252	276	177	176	121
Sunk Sand	52.975	0.493			5	0	6	0
East total			2038	837	2266	794	2270	972
Wash Total			3747	1498	3484	1268	3760	1586



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 2017. Dramatic declines in 1988 and 2002 were the result of epidemics of Phocine Distemper Virus. Fitted lines are exponential growth curves between 1968 and 1988 and between 1989 and 2002. A simple polynomial is fitted to the counts from 2005.*

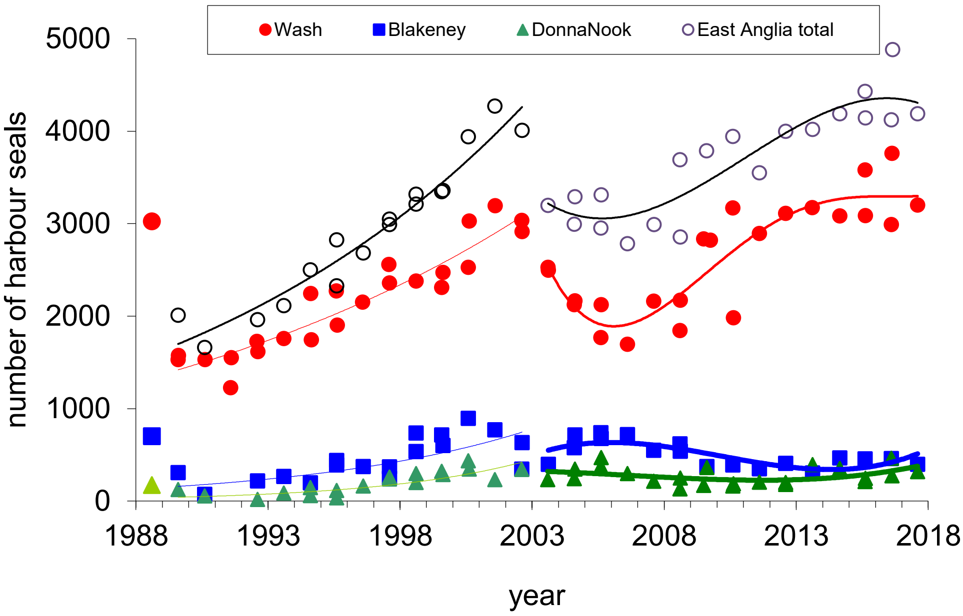
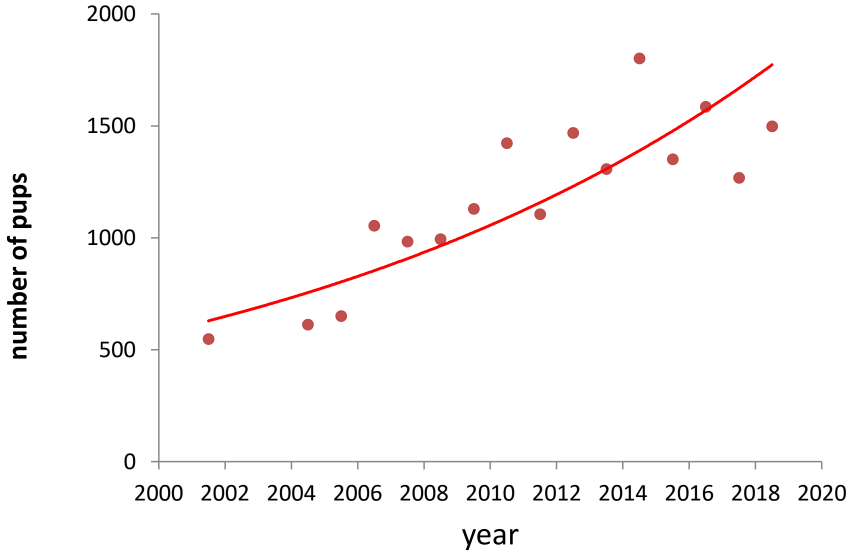


Figure 2. *Aerial survey counts of harbour seals at major sites in East Anglia during recovery from the 1988 and 2002 PDV epidemics. 1989 to 2002 fitted line is a simple exponential. The fitted polynomial from 2003 is included simply for illustration.*

a



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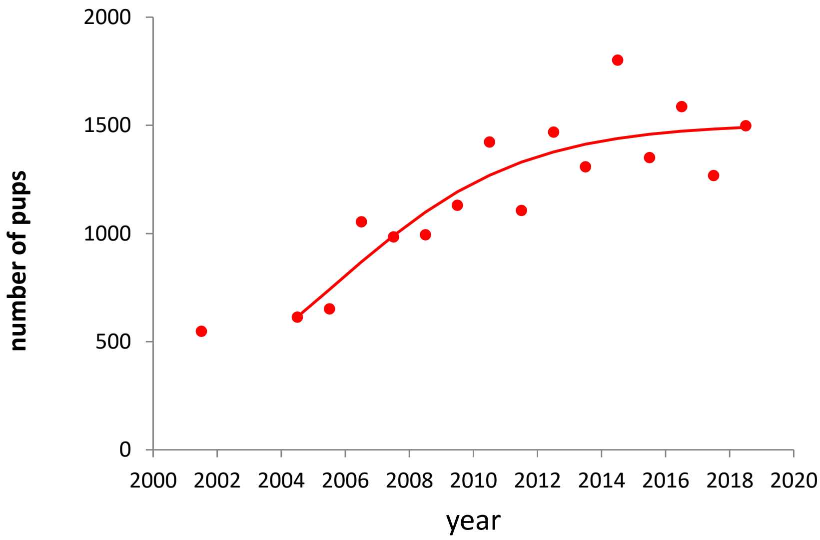

Figure 3. Maximum counts of pups in The Wash between 2001 and 2018. The fitted line in a is a simple exponential which suggests that pup counts have increased at an average rate of approximately 5.6% p.a. since the 2002 PDV epidemic. The fitted line in b is a logistic growth curve indicating a slowdown in the rate of increase in recent years. Both models have equal weight based on AIC model selection criterion.

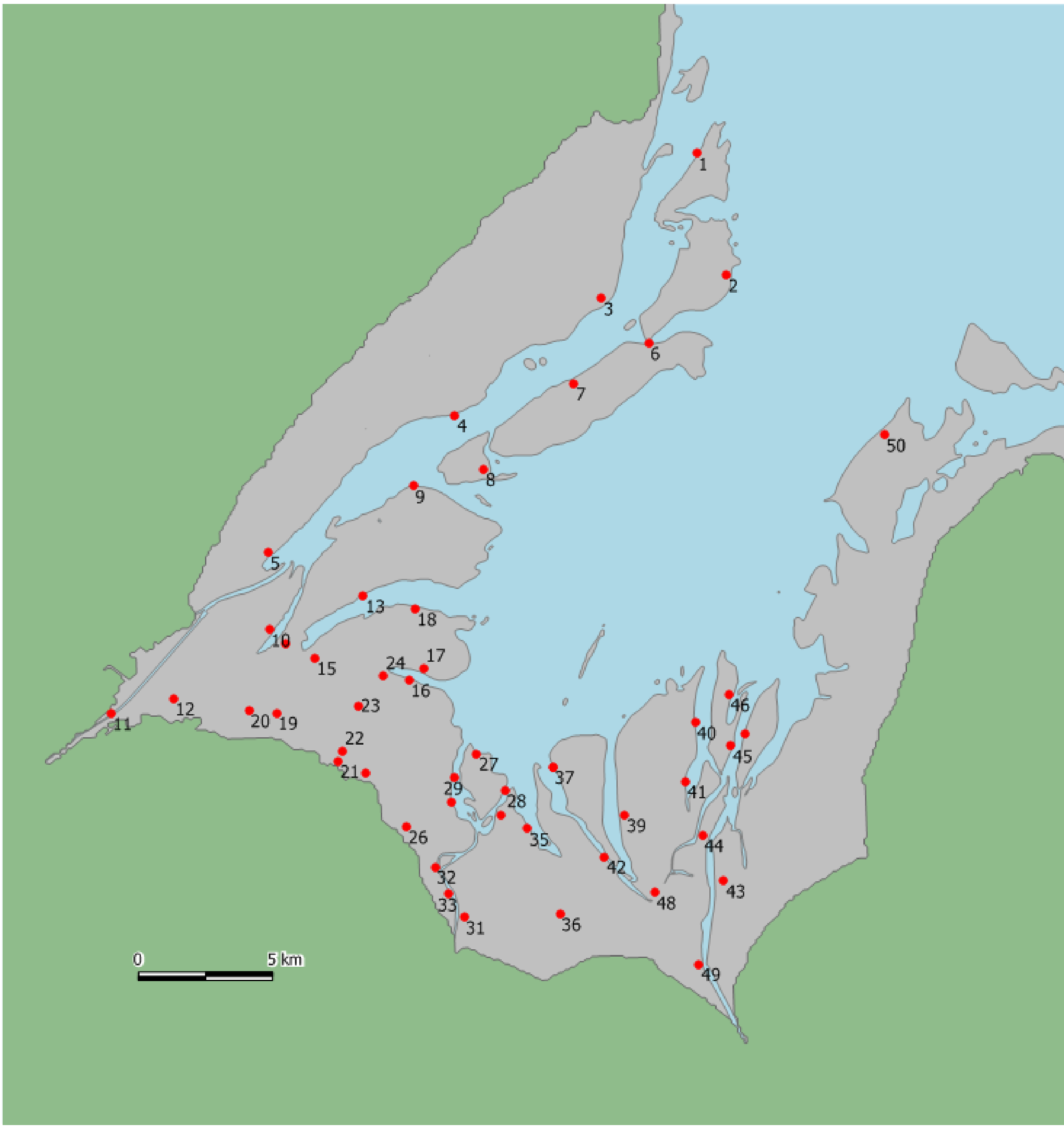

Figure 4. Locations of seal haulout sites during the pupping season in the Wash. Numbers correspond to counts in Table 1. Sites 11 and 49 are composites of several groups that haulout within the lower tidal reaches of the Rivers Welland and Great Ouse respectively. The exact locations and sizes of groups vary widely between surveys so a single composite count is marked at the approximate centre of the distribution of sites.

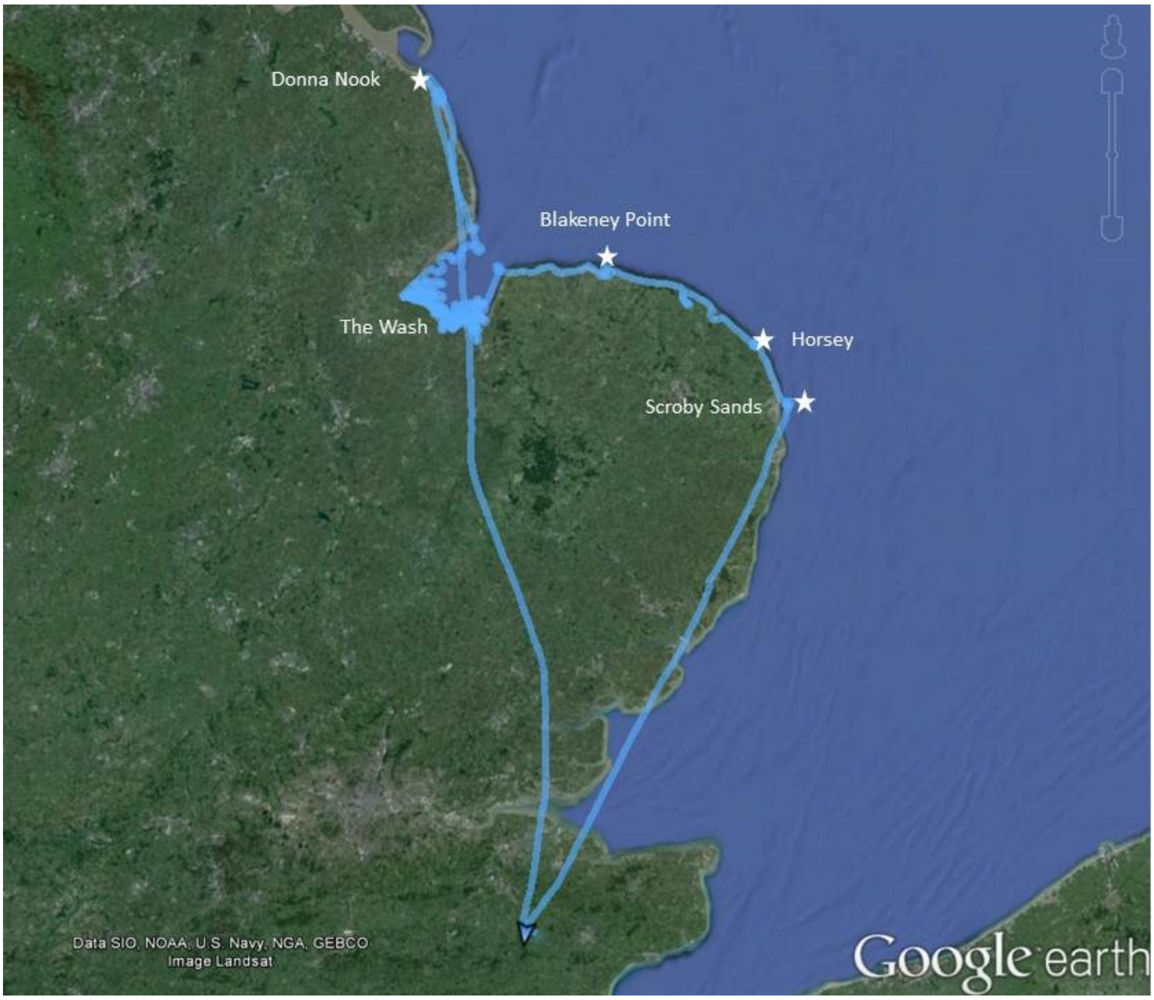

Figure 5. Survey flight path from aircraft base in Kent to Donna Nook, The Wash, Blakeney Point and Scroby Sands.

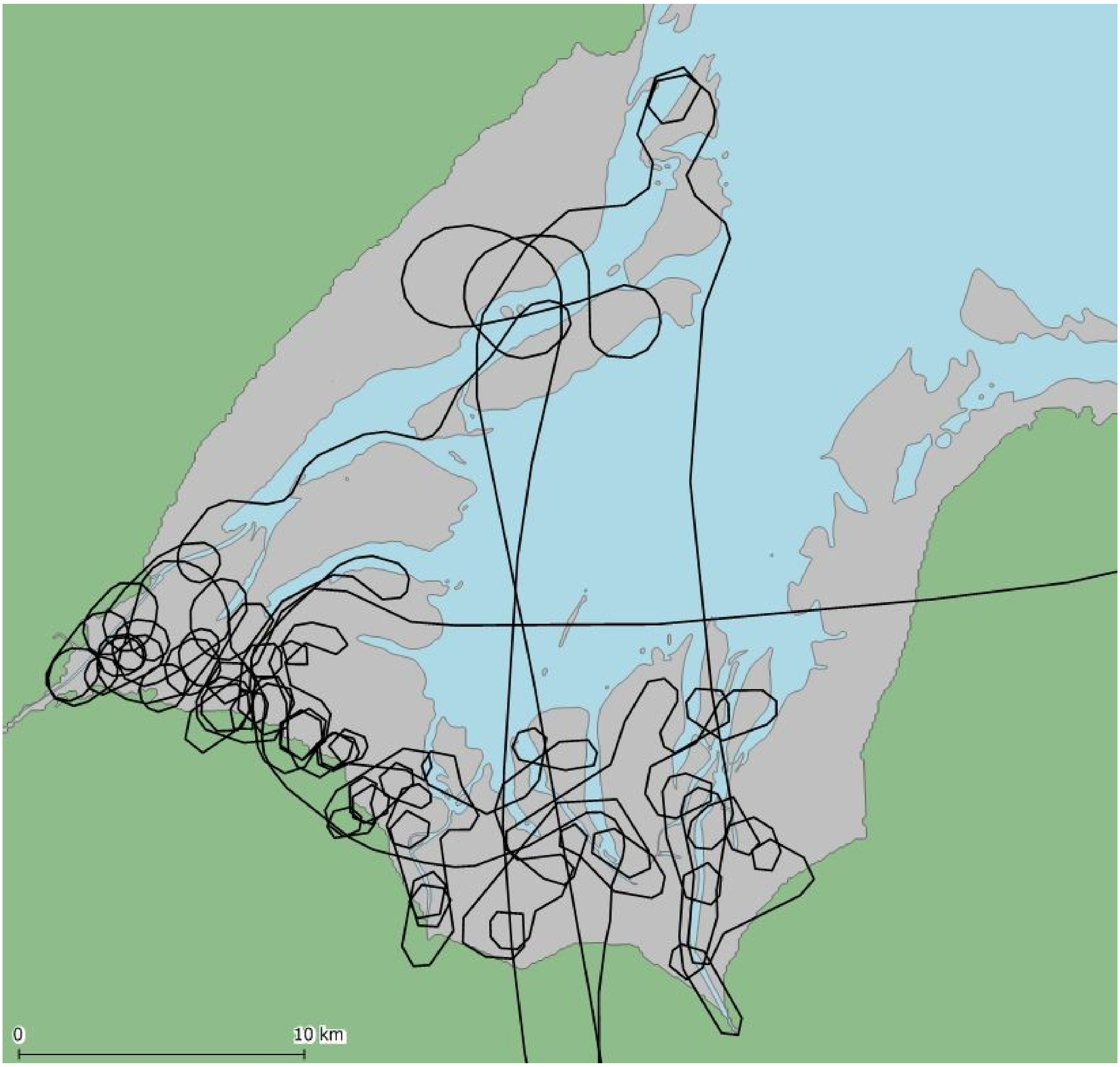

Figure 6. Survey flight paths over the Wash during the breeding season survey (29/6/2018 & 2/7/2018). The approximate locations of the groups are derived from a combination of the positions of the tight turns and our observations of the location of seals within the turn.

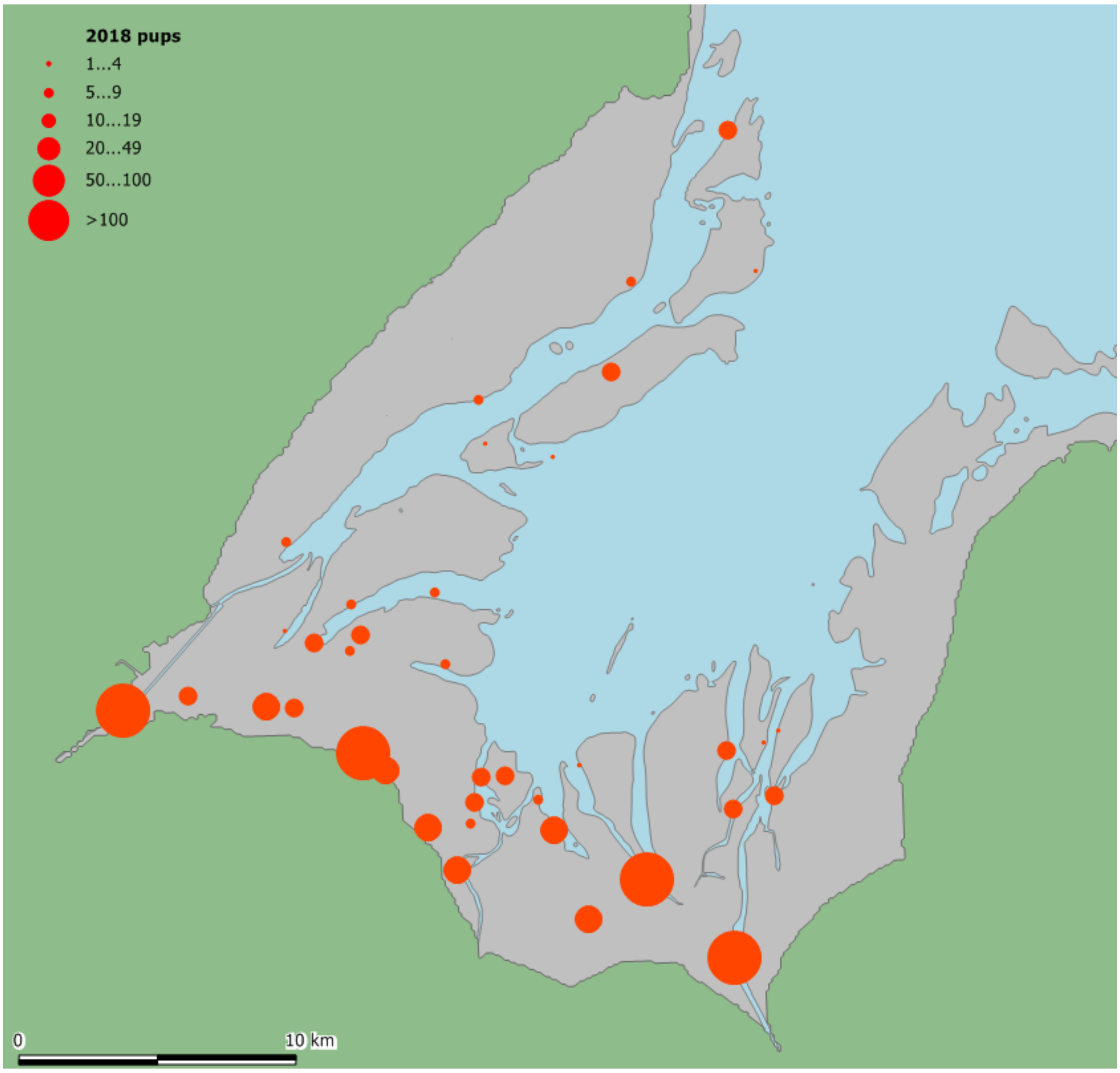

Figure 7. Distribution of pups in the Wash on 29/6/2018 & 2/7/2018. Numbers of pups are represented by the areas of the circles on each site. Locations given to nearest 50m. Names of haulout sites together with latitudes and longitudes and numbers of seals at each site are given in Table 1 and Figure 3.

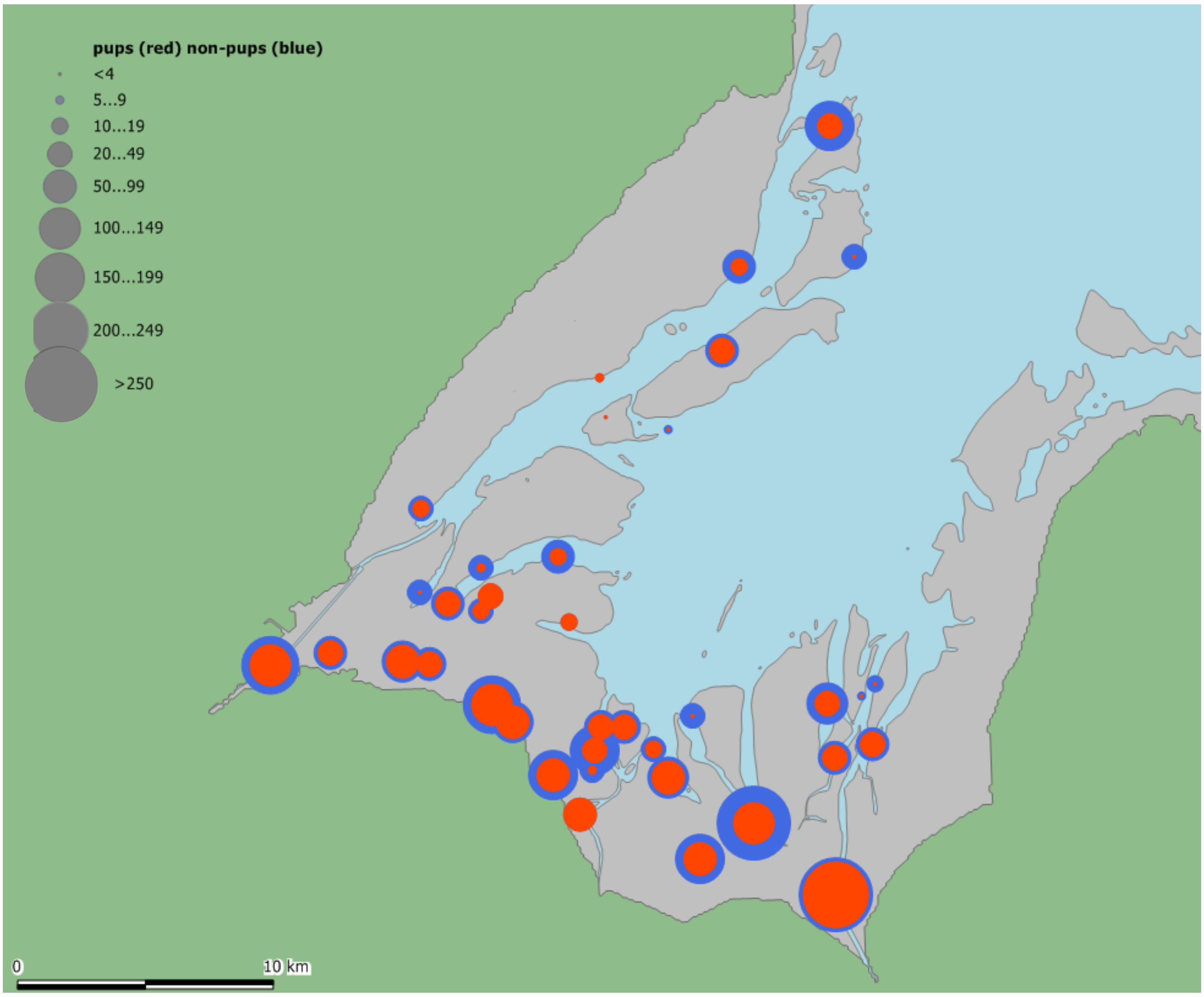

Figure 8. Distribution of harbour seal pups (RED) and older seals (1+ age classes BLUE) in the Wash on 2/7/2018. Numbers of seals are represented by the areas of the circles on each site. At four sites, shown as simple red dots, the number of pups equalled or slightly exceeded the number of older seals.

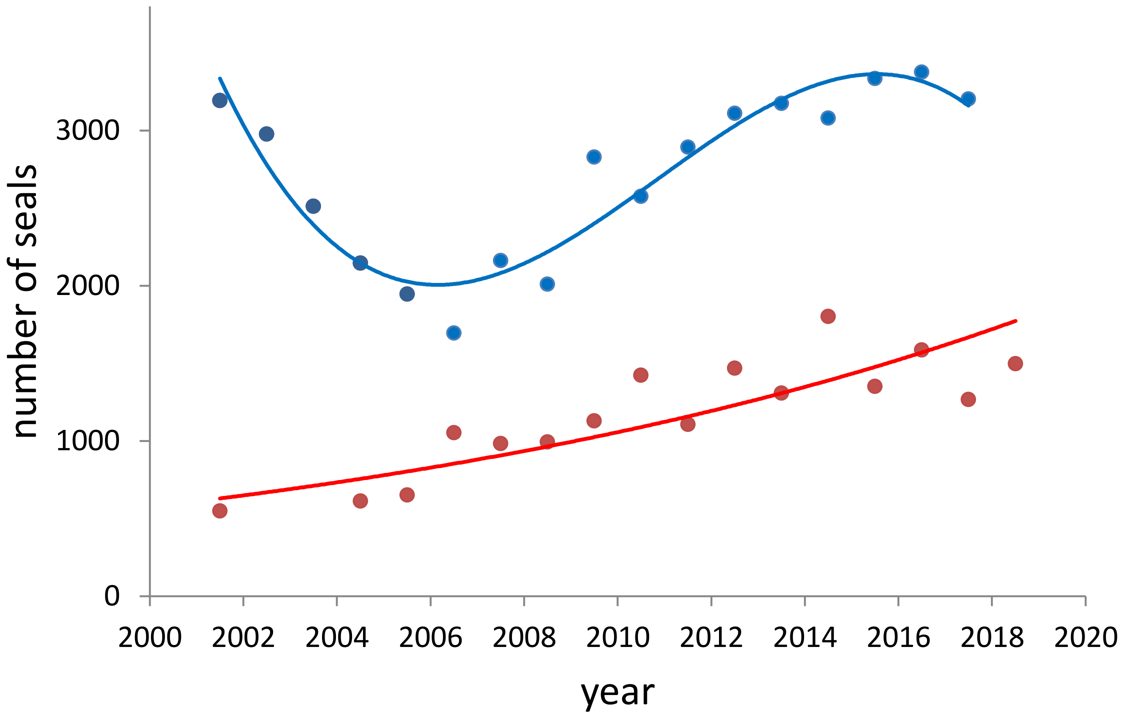

Figure 9. Maximum counts of pups in The Wash between 2001 and 2018 alongside the annual moult count over the same period.

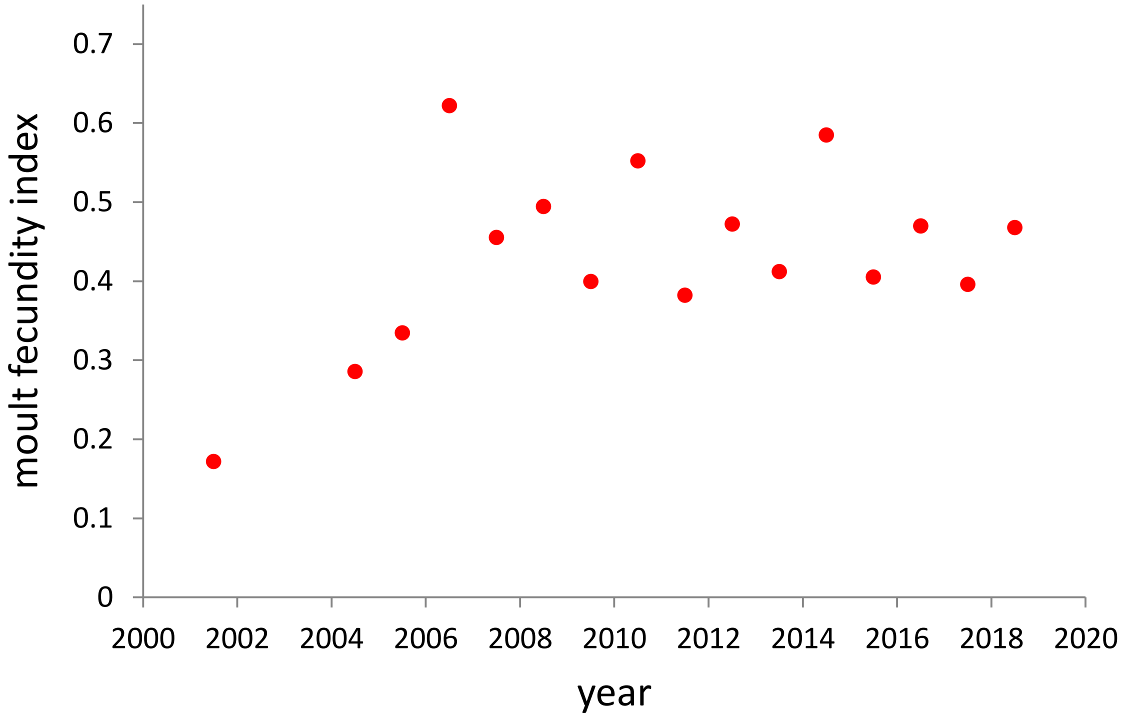

Figure 10. An index of fecundity, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size) increased between 2001 and around 2007 after which it appears stable.

Provisional Regional PBR values for Scottish seals in 2020

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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 only substantive change for harbour seals is the 40% increase in the count for the Southwest Scotland SMU leading to a commensurate increase in PBR, from 50 to 71.
The grey seal count for the West Scotland was 20% lower than the previous estimate, leading to a reduction in PBR from 1219 to 966. The Moray Firth grey seal count was 36% lower leading to a reduction in PBR from 275 to 175. The count in the Southwest Scotland SMU was almost 40% higher than previous counts leading to an increase in PBR from 86 to 119.
Recovery factors have been held constant for both species in all management regions.

Introduction

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

Materials and Methods

The PBR calculation:

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

where:

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

N_{min} is a minimum population estimate (usually the 20th percentile of a distribution.

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.

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.

3) 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 2018 in the Moray Firth were similar to the previous 5 years, confirming 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.

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

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

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Results

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

Table 1. Potential Biological Removal (PBR) values for harbour seals in Scotland by Seal Management Unit for the year 2019

	2015-2018		PBRs based on recovery factors F_R ranging from 0.1 to 1.0										selected	
Seal Management Area	count	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	1,709	1,709	10	20	30	41	51	61	71	82	92	102	0.7	71
2 West Scotland	15,600	15,600	93	187	280	374	468	561	655	748	842	936	1.0	936
3 Western Isles	3,533	3,533	21	42	63	84	105	127	148	169	190	211	0.5	105
4 North Coast & Orkney	1,349	1,349	8	16	24	32	40	48	56	64	72	80	0.1	8
5 Shetland	3,369	3,369	20	40	60	80	101	121	141	161	181	202	0.1	20
6 Moray Firth	962	962	5	11	17	23	28	34	40	46	51	57	0.1	5
7 East Scotland	342	342	2	4	6	8	10	12	14	16	18	20	0.1	2
SCOTLAND TOTAL	26,864	26,864	159	320	480	642	803	964	1,125	1,286	1,446	1,608		1,147

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

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

Seal Management Area	2015-2018 count	N_{min}	PBRs based on recovery factors F_R ranging from 0.1 to 1.0: 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	selected F_R	selected PBR
1 Southwest Scotland	517	1,996	11	23	35	47	59	71	83	95	107	119	1.0	119
2 West Scotland	4,174	16,112	96	193	290	386	483	580	676	773	870	966	1.0	966
3 Western Isles	5,772	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	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	6,014	36	72	108	144	180	216	252	288	324	360	1.0	360
6 Moray Firth	769	2,968	17	35	53	71	89	106	124	142	160	178	1.0	178
7 East Scotland	3,762	14,521	87	174	261	348	435	522	609	697	784	871	1.0	871
SCOTLAND TOTAL	26,266	101,387	604	1,213	1,822	2,429	3,038	3,646	4,253	4,863	5,472	6,079		6,079

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

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

$\mathbf{N_{min}}$ 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.

$\mathbf{R_{max}}$ 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.

$\mathbf{F_R}$ 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

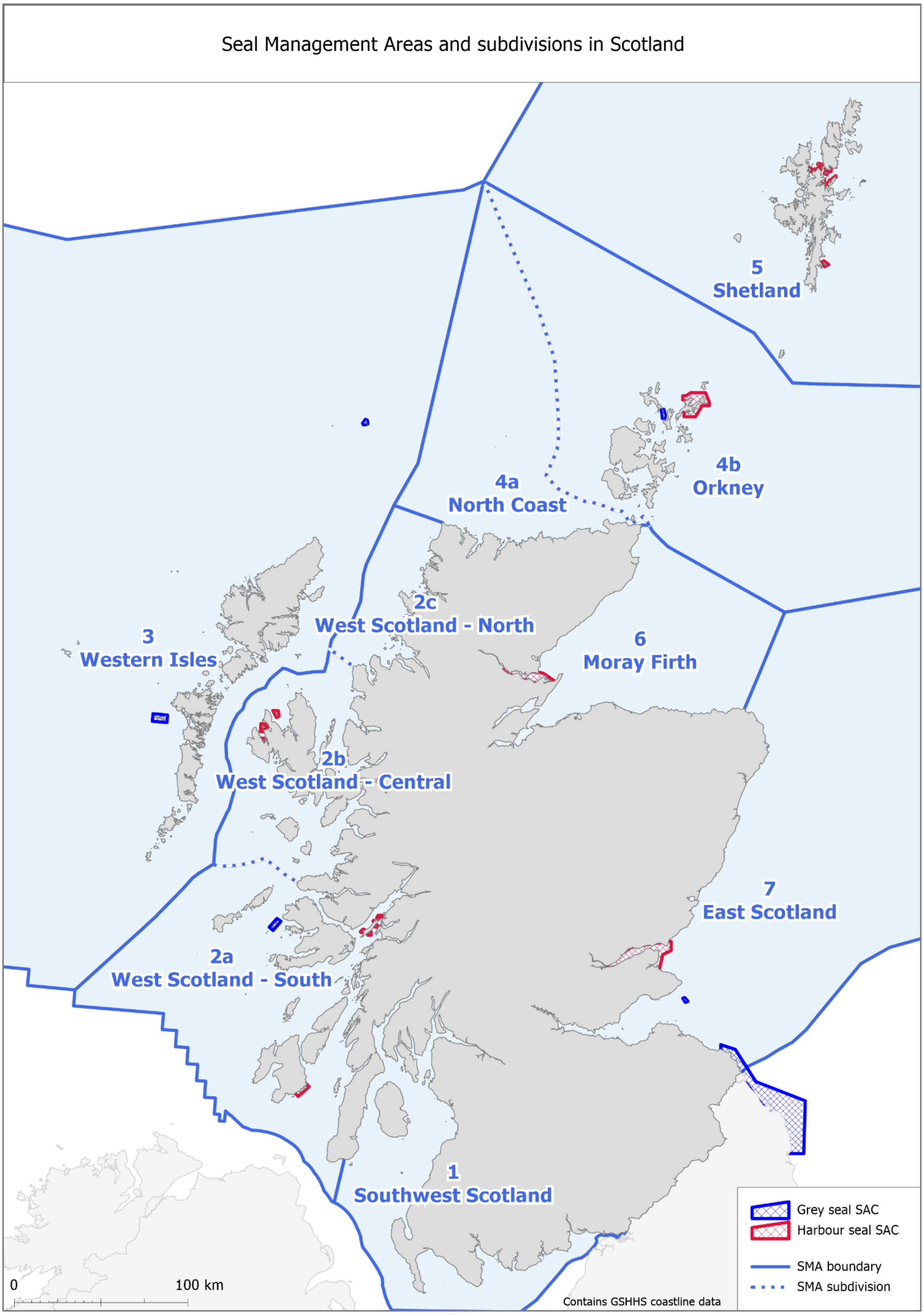

Figure 1.Seal management areas in Scotland. For purposes of PBR calculations West Scotland is