Scientific Advice on Matters Related to the Management of Seal Populations: 2022

Natural Environment Research Council Special Committee on Seals

Executive summary

Under the Conservation of Seals Act 1970 and the Marine (Scotland) Act 2010, the Natural Environment Research Council (NERC) has a duty to provide scientific advice to government on matters related to the management of UK seal populations. NERC appointed a Special Committee on Seals (SCOS) to formulate this advice. In 2022, twenty-four questions covering a wide range of management and conservation issues were received from Scottish Government, Defra and Natural Resources Wales. SCOS's answers to these questions are provided in detail in the main Advice below, and the main points and recommendations are summarised here.

- The total UK grey seal population at the start of the 2022 breeding season (before pups are born) is estimated at **162,000** (approximate 95% CI 146,700-178,500). This represents an increase of approximately **1.6%** over the previous year.

Table S1. *Estimated UK grey seal pup production by country (based on 2019 pup surveys), and total adult population at the start of the 2022 breeding season.*

Location	Pup Production (2019)	2022 Population Estimate
England	**11,300**	**27,000**
Wales	**2,250**	**5,400**
Scotland	**54,050**	**129,100**
Northern Ireland	**250**	**500**
Total UK	**67,850**	**162,000**

- UK grey seal pup production (number of pups born each year) has increased continually since regular surveys began in the 1960s, but the rate of increase has fallen over the past twenty years and was <1.4% p.a. over the last survey interval. Pup production in the west of Scotland and Orkney is stable and likely at the limit of the number of pups that can be supported by the surrounding seas. Pup production for the North Sea colonies is increasing at a rate of around 7% per year.
- Comparisons of grey seal pup production estimates and associated counts between ground and aerial based methods for east England (traditionally ground surveyed) highlight the difficulties in ground-based estimation of pup production in large colonies which can result in significant underestimation of production.
- Based on surveys between 2016 and 2021, the total UK harbour seal population is estimated at **42,900** (approximate 95% CI: 35,100-57,100). This represents a decrease of approximately 1% compared to the previous survey round (2011-2015) although numbers have increased since the late 2000s.
- There are significant differences in harbour seal population trends between regions. The west of Scotland regions are increasing slightly. All other regions are either a) stable at a depleted level after recent declines (Moray Firth, Shetland), b) are depleted and still declining (North Coast and Orkney, East Scotland) or c) have recently declined after periods of increase (Southeast England).

Table S2. *UK harbour seal population estimates based on counts during the moult; rounded to the nearest 100, except for Wales where estimates are rounded to the nearest 5.*

Location	Most Recent Count (2016-2021)	Total Population Estimate
England	**3,600**	**5,100**
Wales	**<10**	**<15**
Scotland	**26,400**	**36,600**
Northern Ireland	**800**	**1,100**
Total UK	**30,800**	**42,900**

- Concerningly, counts of harbour seals in all areas surveyed in 2021 (Northern Ireland, East Scotland, Moray Firth, and Southeast England) were all substantially lower than counts in recent years.
- For both species, trends for Special Areas of Conservation (SACs) are generally less favourable than trends for the associated wider regions which encompass them.
- The most recent estimate of bycatch of seals in UK fisheries was 356 animals in 2020 (95% CI 269-671). The estimated bycatch was 27% lower than previous year (488), but the confidence intervals are wide and overlap with previous estimates, and fishing effort was reduced in 2020. 81% of the bycatch estimate occurs in the south-west of the UK and most bycaught seals are young grey seals. These estimates exclude bycatch by non UK vessels.
- The origins of the grey seals caught in the southwest of the UK are still unclear. However, recent tracking data suggests that a substantial proportion of pups born in the Western Isles of Scotland move south to Ireland and southwest UK after leaving their natal colony.
- There are concerns about future disease outbreaks in UK seal populations. The majority of UK harbour seals are susceptible to Phocine Distemper Virus (PDV), so an epizootic may be expected soon and there are also concerns about the potential for an outbreak of Highly Pathogenic Avian Influenza (HPAI) in UK seals, given occurrences of HPAI in seals on the east coast of the US and Canada and the ongoing outbreaks in UK seabird populations.

Summary of recommendations of SCOS 2022

- Grey seal pupping colonies on the east coast of England comprise an increasing proportion of UK pup production. Historically these colonies have been ground counted. Aerial surveys conducted in east England in 2018 indicate that pup production is currently being underestimated. Continued monitoring by aerial survey is required and further work is needed to effectively combine the time series of pup production estimates from ground and aerial surveys.
- The conversion factor used to estimate population size from survey counts for harbour seals is based on a sample of 22 seals from a single year that only represents adult seal behaviour. SCOS recommend this conversion factor should be re-investigated when resources and methodology allow examination of sex and age differences as well as potential extension to surveys outside the moult.
- Recent studies suggest that fecundity or reproductive performance is influenced by prevailing environmental conditions. 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.

- Research is required to identify and investigate the causal factors of the harbour seal decline in southeast England. The rapid declines in southeast England must be due to a decline in adult survival and/or emigration to continental Europe. The possible drivers of the decline include interactions with grey seals, anthropogenic activities, and increased disease or biotoxin level. SCOS recommend that SMRU should seek funding to establish an appropriate programme of research.
- In relation to seal bycatch, SCOS recommend that effort should be directed towards identifying the species and if possible, the sex and age class of bycaught seals, and genetic samples should be collected and analysed to identify the source populations.
- SCOS recommends that as long as Potential Biological Removal (PBR) is the accepted method for estimating safe takes from UK seal populations, management should where possible be based on PBR estimates for individual Seal Monitoring Units, combined where necessary to produce sensitive PBR estimates appropriate to the scale of the management issue under consideration. Alternative methods would require additional work to develop a better understanding of the metapopulation structure and degree of movement between regions.
- In relation to seal licensing in Scotland, SCOS recommends that the animal welfare implications of any licence application to take or kill seals during the breeding season should be given careful consideration.
- There is still a lack of information about the fine scale behaviour of seals around tidal turbine renewable energy devices and as such, SCOS does not consider that there is a firm scientific basis on which to move away from the current recommendation to 'present a range of potential avoidance rates' for collision risk modelling. There is ongoing research in this area that should provide information on behaviour of seals at the range of spatial scales required to effectively derive empirical avoidance rates to operating turbines.
- SCOS recommends the coordinated development and adoption of PDV and Avian Influenza response plans for seals, across all UK nations. Scottish Government, in collaboration with SMRU, have developed a PDV contingency plan that could form the basis of this. Routine disease surveillance of stranded animals and rescues would ensure the early detection and monitoring of these diseases in the UK.
- If suitable enhancement measures need to be identified for UK seals, SCOS recommends a stepwise approach as follows: Step 1 – assessment of key impacts on populations on a regional basis where possible. Step 2 – identification of specific measures in relation to these impacts with an assessment of feasibility/risk/uncertainty to implement and monitor. Step 3 – implementation of measures, including pilot programmes.
- Natural Capital approaches are becoming an increasingly important part of valuing biodiversity to aid incorporation into decision making. In order to incorporate seal populations into UK Natural Capital accounts, a detailed review and quantification of seal ecosystem services would be required.

Contents

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. 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 2022. It begins with some general information on British seals, gives information on their current status, and addresses specific questions raised by Scottish Government (SG) 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 coasts of Canada and the United States of America and in north-west Europe.

Harbour seals have a circumpolar distribution in the Northern Hemisphere and are divided into three subspecies (Berta & Churchill, 2012). The population in European waters are all members of the Atlantic subspecies (*Phoca vitulina vitulina*).

Other seal species that occasionally occur in UK coastal waters, include ringed seals (*Pusa hispida*), harp seals (*Pagophilus groenlandicus*), bearded seals (*Erignathus barbatus*), hooded seals (*Cystophora crystata*) and walrus (*Odobenus rosmarus*), all of which are Arctic species.

Grey seal

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 seabed at depths of up to 100m, although they are 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 for 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 grey 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 foraging 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 35% of the world’s grey seals breed in the UK and 80% of them breed at colonies in Scotland with the main concentrations in the Outer Hebrides and in Orkney. There are large and rapidly growing breeding colonies on the east coast of Scotland and England with fastest growth in the central and southern North Sea. There are also breeding colonies in Shetland, on the north and northeast coasts of mainland Britain and smaller populations in Wales and southwest England.

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, Donna Nook in Lincolnshire, seals became habituated to human disturbance in the 1990s and that tolerance of human activity has spread as the population has grown in the southern North Sea colonies. Several mainland colonies now receive tens of thousands of visitors each 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 October, in north and west Scotland pupping occurs mainly between September and late November and eastern England pupping occurs mainly between early November and mid-December.

Female grey seals give birth to a single white coated pup, which they suckle for 17 to 23 days. Pups moult from their white natal coat (also called “lanugo”) to their adult pelage 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 seal

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 are generally considered to be more sedentary than grey seals, with few long range movements between distant haulout sites. Foraging ranges vary substantially both regionally and within sites. Some harbour seals forage >100km from their nearest haulout sites while others remain very close inshore within only a few kilometres of haulout 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, typically 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. Three subspecies of harbour seal are recognized. The European populations of the Atlantic subspecies, *Phoca vitulina vitulina*, range 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 32% of European harbour seals are found in the UK; this proportion has decreased 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, the Firths of Forth and Tay, and the Moray Firth. Scotland holds approximately 85% of the UK harbour seal population, with 12% in England and 3% 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) epizootic. A second epizootic in 2002 resulted in a decline of 22% in The Wash but had limited impact elsewhere in Britain. Counts of harbour seals in the Wash and eastern England did not demonstrate any immediate recovery from the 2002 epizootic and continued to decline until 2006. The counts increased rapidly from 2006 to 2012 but appeared to have remained relatively constant since then, until a decline began in 2019. In contrast, the adjacent European colonies in the Wadden Sea experienced continuous rapid growth after the epizootic, but as in SE England, the counts over the last 5 years suggest that the rate of increase has slowed dramatically.

Major declines have been documented in several harbour seal populations around Scotland, with declines since the late 1990s of 85% in Orkney, 47% in Shetland and 95% in the Firth of Tay. However, the pattern of declines is not universal. The Moray Firth count apparently declined by 50% before 2005 and has fluctuated since, showing no significant trend since 2003. The Outer Hebrides population apparently declined by 35% between 1996 and 2008 but has shown no significant trend over the entire time series. The West Scotland population is the largest population in the UK and in 2018 was approximately twice the size it was in the mid-1990s. The recorded declines are not thought to have been linked to the 2002 PDV epizootic as there was very little recorded mortality of harbour seals in Scotland in 2002.

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 seals were routinely harvested for meat, skins, and oil until the early 1900s. 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. In the 1960s and 1970s, large scale culls of grey seals were carried out in the North Sea, Orkney and Hebrides as population control measures. Monitoring of grey seal pup production started in the late 1950s and early 1960s and this has shown that numbers have increased consistently since. However, in recent years, there has been a significant reduction in the rate of increase.

Numbers of harbour seals in Scotland in the 1970s, monitored by boat surveys, were considerably lower than those in the late 1980s when aerial surveys commenced, 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 epizootics 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.

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 killing or taking of seals except under licence. In the original version of the Act, licences could be granted for ten specific reasons, including to conserve natural habitats, for scientific research or educational purposes, to protect the health and welfare of farmed fish and to prevent serious damage to fisheries or fish farms' aquaculture activities. Recent legislative changes in Scotland, via the Animals and Wildlife (Penalties, Protections and Powers) (Scotland) Act 2020, have amended the Marine (Scotland) Act 2010 to remove the provision to grant licences authorising the killing or taking of seals to protect the health and welfare of farmed fish, or to prevent serious damage to fisheries or fish farms.

Similar legislative changes in England and Wales, and Northern Ireland via Schedule 9 of the Fisheries Act 2020, have amended the Conservation of Seals Act 1970 and the Wildlife (Northern Ireland) Order 1985, now prohibiting the intentional or reckless killing, injuring or taking of seals, and removing the provision to grant licences for the purposes of protection, promotion or development of commercial fisheries or aquaculture activities. These changes were enacted to ensure compliance with the US Marine Mammal Protection Act Import Provision Rule.

In Scotland it also is now an offence to 'intentionally or recklessly harass' seals at designated haulout sites. NERC (through SMRU) provides advice on all licence applications and haulout designations.

In Northern Ireland it is an offence to intentionally, or recklessly disturb seals at any haulout site under Article 10 of Wildlife and Natural Environment Act (Northern Ireland) 2011.

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

Seal population status and trends

1. What are the latest estimates and trends in the number of seals in UK waters?	SG Q1 Defra Q1a NRW Q1

Current status of British grey seals

The total UK grey seal population of at the start of the 2022 breeding season (before pups are born) is estimated at 162,000 (approximate 95% CI 146,700-178,500). The estimate is derived from a population model which incorporates a time series of regional pup production estimates and three estimates of population size from summer haul out counts. The most recent pup production estimates are for 2019. Details are provided in SCOS-BP 21/01 and below, and estimates by country are presented in *Table 1* and by region within the British Isles in *Table 2*.

Grey seal pup productions by country (based on 2019 pup production estimates) were approximately 54,050 in Scotland, 11,300 in England, 2,250 in Wales and 250 in Northern Ireland. These equate to total population estimates of 129,100, 27,000, 5,400 and 500 respectively.

At the regional level, grey seal population trends are based on the distribution of pups during the autumn breeding season, when females congregate on land to give birth. It should be noted that outside the breeding season animals may re-distribute themselves, thus, regional population estimates do not necessarily reflect the abundance of animals in each region at other times of the year.

The most recent synoptic census of the principal grey seal breeding sites, located in Orkney, the Inner and Outer Hebrides, the Firth of Forth and along the coast of eastern England, was carried out in 2019. This census (following a correction for less frequently monitored sites, not surveyed in 2019) resulted in an estimate of 67,850 (approximate 95% CI 60,500-75,200) pups born throughout the UK in 2019 (*Table 1* & *Table 2*). A complete survey programme covering the North Sea colonies was carried in 2021 and a programme of surveys of the colonies in Orkney, the Inner and Outer Hebrides was underway in 2022. Results of these surveys will be presented at future SCOS meetings.

In order to estimate the total British grey seal population size (1+ aged population, referred to as 'adult population') at the start of a given breeding season, recent trends in pup production estimates are 'scaled up' to total population size, using a mathematical model of British grey seal population dynamics. The model uses pup production estimates by region (Inner Hebrides, Outer Hebrides, Orkney, North Sea), for the period 1984 to 2019. These regional population estimates are summed and then scaled up to include less frequently monitored colonies, to generate a UK level population estimate. The stages in the process, the fitting of the pup production model and the observed trends are described below and have been presented previously in SCOS-BPs 21/05, 19/01, 18/02 and 20/02, Russell *et al.,* (2019) and Thomas *et al.,* (2019). This model was used to project forward and produce population estimates for the start of the 2022 breeding season.

There has been a continual increase in the total UK grey seal pup production (number of pups born each year) since regular surveys began in the 1960s. That increase has continued over the last survey interval, but the overall increase is small (<1.4% p.a.). Pup production in the west coast of Scotland and Orkney is stable and likely at the limit of the number of pups that can be supported by the surrounding at-sea environment. Pup production for the North Sea colonies is increasing at a rate of around 7% per year.

Comparisons of grey seal pup production estimates and associated counts between ground and aerial based methods for east England (traditionally ground surveyed) highlight the difficulties in

ground-based estimation of pup production in large colonies which can result in significant underestimation of production (described in SCOS-BP 22/03)

Pup production

Major grey seal colonies in Scotland and on the east coast of England (***Figure 1***) are currently scheduled to be surveyed biennially (see SCOS-BP 14/01, 21/01). The most recent available pup counts are from surveys carried out in 2019. These data were provided in SCOS 2021 but are repeated here as they represent the most recent estimate. In 2021, a series of surveys of UK North Sea colonies (i.e. Isle of May, Firth of Forth Islands, Fast Castle, Farne Islands, Donna Nook, Blakeney and Horsey) were carried out, and in 2022 all other major Scottish colonies (Orkney, Moray Firth, North coast, Inner & Outer Hebrides) have been surveyed. The extensive data collected in these surveys are currently being analysed, and updated figures based on these surveys will be provided in the next SCOS report.

Pup production estimates from the 2019 aerial survey programme and 2019 ground count data, combined with estimates from less frequently surveyed colonies that were not surveyed in that year, indicated that the total number of pups born in 2019 across all UK colonies was approximately 67,850 (approximate 95% CI 50,250-85,400).

Table 1. *UK grey seal pup production by country (based on 2019 pup production estimates), and total adult population estimates at the start of the 2022 breeding season.*

Location	Pup production in 2019	2022 Population estimate**
England	**11,300**	**27,000**
Wales*	**2,250**	**5,400**
Scotland*	**54,050**	**129,100**
Northern Ireland*	**250**	**500**
Total UK	**67,850**	**162,000**

**Includes estimated production for less frequently monitored colonies, see SCOS-BP 21/01 and 20/04 for details. Populations associated with these estimates were based on the average ratio of pups to total population for the regularly monitored sites.*

*** Population estimates derived from the 2019 pup production estimates, representing the total population alive on the first day of 2022 breeding season. Confidence intervals are not provided as the national populations have been derived from regional population estimates scaled by proportions of that region's pup production in each country.*

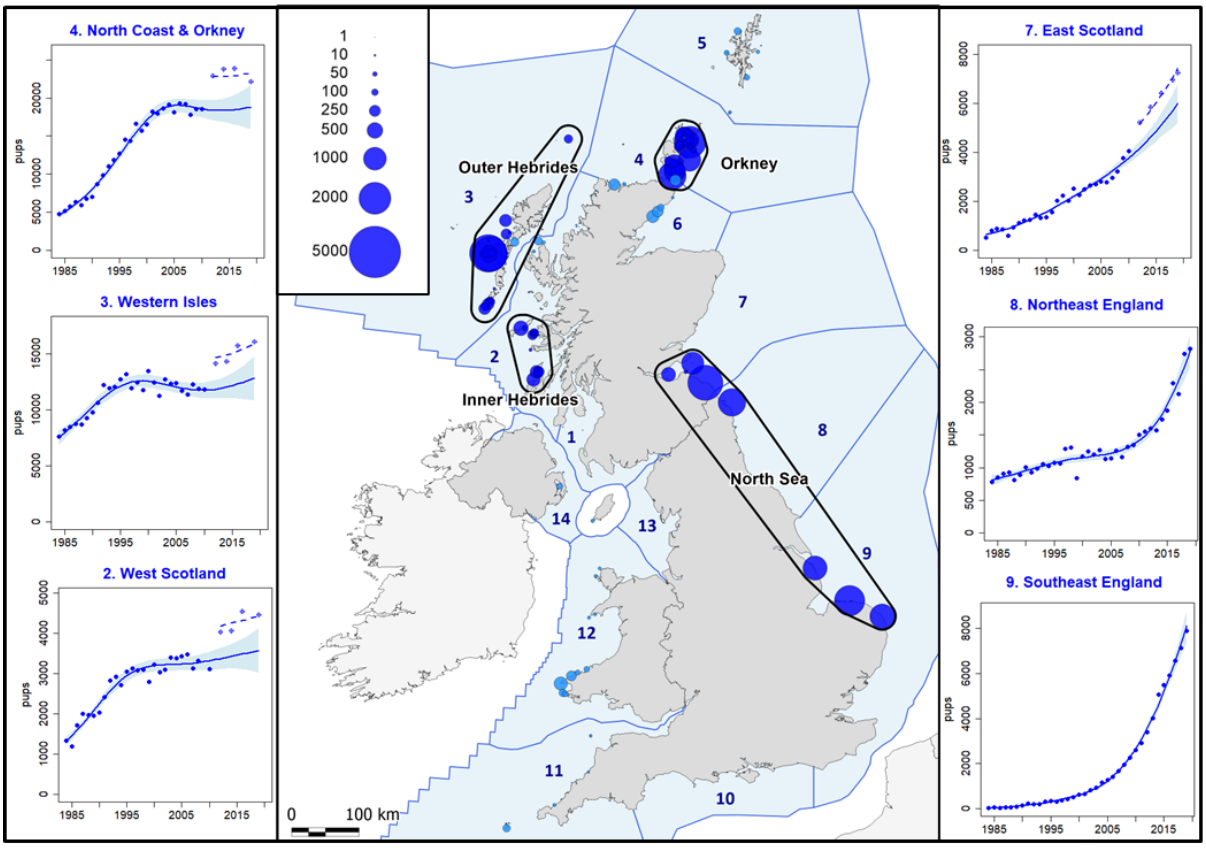

Figure 1*. Distribution and estimated pup production of the main grey seal breeding colonies around the UK(dark blue circles-regularly monitored & light blue-sporadically monitored). Black polygons indicate regional groups of regularly monitored colonies and SMU boundaries are shown in blue. For regularly monitored colonies, on a SMU-scale, the pup production estimates by year, and predicted trend and associated 95% confidence intervals, are shown. For aerially surveyed SMUs (2-7), the dashed line shows the same trend as the solid line but at the level of pup production predicted from digital surveys.*

Regional pup production estimates in 2019 at surveyed colonies were: 4,450 (approximate[1] 95% CI 3,300-5,600) in the Inner Hebrides, 16,100 (95% CI 12,000-20,300) in the Outer Hebrides, 22,150 (95% CI 16,400-27,900) in Orkney and 18,000 (95% CI 13,300-22,600) at the North Sea colonies (including Isle of May, Fast Castle, Farne Islands, Donna Nook, Blakeney Point and Horsey/Winterton) (SCOS-BP 21/01)(***Table 2***). Estimates were based on aerial surveys for all Scottish colonies and ground counts for the English North Sea colonies (Farne Islands, Donna Nook, Blakeney Point and Horsey/Winterton).

An additional 7,150 pups were estimated to have been born in Wales and at less frequently surveyed colonies in Shetland and at scattered locations throughout Scotland, Northern Ireland, and South-west England (SCOS-BP 20/04; 21/01).

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

Changes in pup production

Note that trends of grey seal pup production in Scottish Special Areas of Conservation (SACs) and the Seal Monitoring Units (SMUs) that contain them are presented in answer to Q 3 below.

There has been a continual increase in the total UK pup production since regular surveys began in the 1960s (***Figure 2***) (see SCOS-BP 18/01 & Russell *et al.,* (2019) for details). That has continued over the last survey interval (2016 to 2019), but the overall increase is small, <1.4% p.a. and is entirely limited to the North Sea colonies along the east coast of Scotland and England. The combined 2019 pup production estimate for the Inner and Outer Hebrides and Orkney was 3.3% lower than the 2016 estimate; by contrast, estimated pup production for the North Sea colonies increased by 23% over the same period (***Table 2***).

Interpretation of the trends in pup production is complicated due to a change in survey methodology after 2010. Improved camera technology (changing from film to digital) and reduced survey height changed both the efficiency of counting and the classification of moult stages in pup images. In all three regions where the pup production is estimated entirely from aerial survey counts, an apparent step change (increase) in observed numbers was noted coincident with the transition to the 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, statistical power to estimate the magnitude and nature of these changes will increase.

To facilitate comparisons between population estimates derived from the August surveys and the pup production counts it was suggested that the previous naming convention for grey seal population model regions should be altered to match the Seal Monitoring Units (SMUs) in which seals are found. For the rest of this section, 'Inner Hebrides' is equivalent to the West Scotland SMU, 'Outer Hebrides' is equivalent to the Western Isles SMU, 'Orkney' is equivalent to the North Coast and Orkney SMU, and 'Firth of Forth' colonies are equivalent to East Scotland SMU.

Russell *et al.,* (SCOS-BP 22/02) fitted a series of models to the pup production estimates for each SMU. For Scottish SMUs where the pup production estimates were derived from SMRU aerial surveys (all except Shetland and Moray Firth), a step increase in pup abundance was offered between 2010 (the last film survey) and 2012 (the first digital survey) to account for any artificial increase in pups associated with the change in aerial survey method. To maximise the data available to fit this jump, all applicable SMUs were modelled within a single generalised additive model (GAM; limited to k=5), allowing a different temporal trend for each SMU but a single adjustment for the change in survey methods. Once fitted, the single adjustment allows the trends in each SMU to be examined excluding this jump. The final model estimating trends in grey seal pup production for aerially surveyed SMUs included an estimated 21 % jump (95% CI: 13 – 30) in pup production associated with the change from film to digital (delta AIC of -24 compared to a model without the jump). This analysis allowed an examination of the trends in pup production, between 1984 and 2019, that was robust to the change in methods. Trends of grey seal pup production in Scottish SACs and the SMUs that contain them are presented in answer to Q 3 below. A map of the SMU boundaries and the distribution of seals within them is presented in ***Figure 1***.

A full description of the model selection process and the resulting trends can be found in SCOS-BP 22/02.

Pup production had levelled off in West Scotland (early to mid - 1990s; Fig 2c in SCOS-BP 22/02) and Western Isles (mid 1990s; Fig 3c in SCOS-BP 22/02) (Russell et al., 2019) but the 2016 and 2019 estimates were higher than the first two digital survey estimates (2012 and 2014). For the Western Isles this resulted in a slight recent increase in the mean predicted trend. This apparent increase is reflected in the Monach Islands SAC which accounts for > 75% of the SMU pup production. In contrast, pup production in North Rona is continuing to decline.

In the North Coast & Orkney SMU (Fig 4c in SCOS-BP 22/02), pup production has remained stable since around 2000. The Faray & Holm of Faray SACs indicate that the colony may be in decline. A declining trend was fitted for Shetland (Fig 5c in SCOS-BP 22/02); however, the time-series comprised a subset of colonies and was based on peak counts (which are sensitive to effort, i.e., number and timing of counts) and thus there are doubts as to how robustly these trends represent Shetland as a whole.

The Moray Firth SMU (Fig 6c in SCOS-BP 22/02) shows that pup production is increasing though it should be noted that there is a limited temporal extent to the data and pup production within this SMU is difficult to accurately estimate.

The East Scotland SMU (Fig 7c in SCOS-BP 22/02) is continuing to increase rapidly (5.38% per annum; 95% Cis: 3.56, 7.17) , but the two Special Areas of Conservation (SACs) which represent the vast majority of production in the SMU show differing patterns in abundance. Of these, the Isle of May SAC, which previously held all of the SMU's pup production until the mid-1990s, looks to be stable or potentially declining. In contrast the Fast Castle colony, in Berwickshire & North Northumberland Coast SAC, is showing rapidly increasing pup production.

Estimates of pup production in the rapidly increasing breeding populations on the east coast of England have until now been based on ground count data. These suggest that pup production in Northeast England, which is entirely encompassed by the Farne Islands component of the Berwickshire & North Northumberland Coast SAC, is also increasing rapidly (9.27% per annum; 95% Cis: 7.11, 11.43).

Pup production within the Southeast England SMU is continuing to increase exponentially (11.31% per annum; 95% Cis: 9.14, 13.46) but this is in large part due to increases in Blakeney Point and Horsey, while the increase at Donna Nook (Humber Estuary SAC) which, up until c. 2000 accounted for the SMUs entire pup production is now slowing. Aerial surveys of these eastern England colonies were carried out in 2018 and 2021. A comparative analysis of the ground counts and co-incident aerial survey counts and resulting pup production estimates is ongoing, but progress to date is presented in SCOS-BP 22/03. Results based on the 2018 surveys show significant differences. Peak counts and pup production estimates from aerial surveys, together with pup production estimates from ground counts are shown in ***Table 3***. The methods of ground counting and tallying those counts to produce pup production estimates differ between sites, making direct comparison of these counts difficult. However, the pup production estimates are directly comparable. In the Farne Islands and at Horsey (Norfolk) the aerial and ground survey estimates are similar (aerial estimates 5% and 3% higher respectively). However, compared to the aerial count derived production estimates, the ground count-based estimates were lower by 23% at Donna Nook and by 37% at Blakeney. This discrepancy is not entirely a result of differences in the methods used to derive the production estimates and is likely mainly the result of undercounting in the ground count surveys, e.g., at Donna Nook the ground count production was slightly lower than the peak aerial survey count and at Blakeney the ground count pup production estimate was 26% lower than the peak aerial count. This is likely to be due to the high numbers of pups and the spatial extent of the breeding groups at these sites.

Considering these major discrepancies, further work will be required to combine the aerial survey data into the (annual) ground count time series. The differences between the ground and aerial derived estimates of pup production prohibits the direct incorporation of aerial survey estimates into the current pup production time-series.

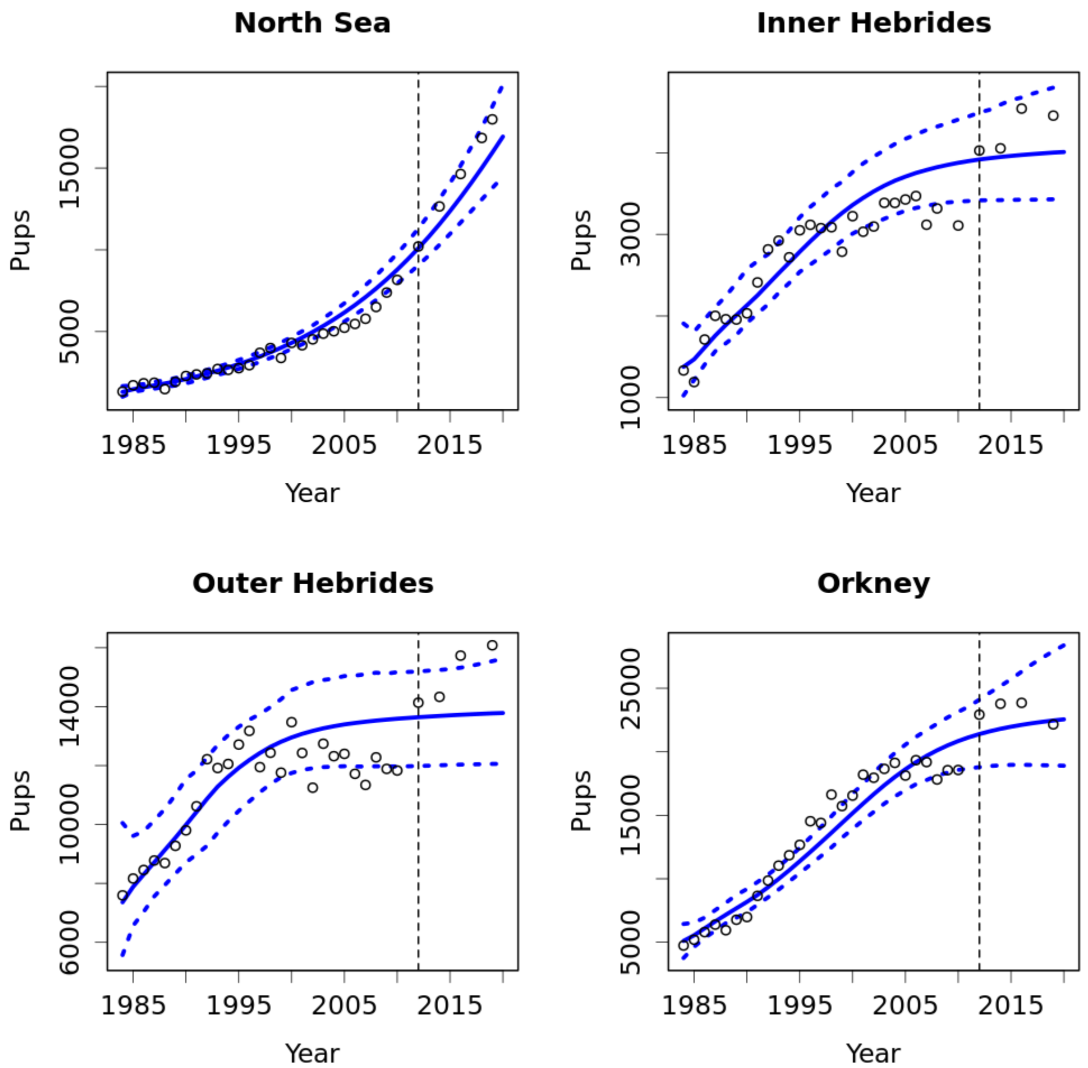

Figure 2*. Posterior mean estimates of pup production (solid lines) and 95% Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates for regularly monitored colonies (SCOS-BP 21/01 and* ***Table 2****), from 1984-2019 (circles), and three independent total population estimates (2008, 2014, and 2017;see text for details). The vertical line indicates the change to a new camera system introduced in 2012.*

Table 2. *Grey seal pup production estimates based on 2019 aerial surveys for the regularly monitored colonies in Orkney, the Inner and Outer Hebrides and Firth of Forth, and on ground counts for English North Sea colonies, combined with the most recent data from less regularly monitored colonies (see main text and SCOS-BP 21/01 and 20/04 for details). These estimates are compared with similar production estimates from 2016*

Location	**Pup Production 2019**	**Pup Production 2016**	**Average Annual Change 2016 to 2019**
Inner Hebrides	4,455	4,541	- 0.6%
Outer Hebrides	16,083	15,732	+ 0.7%
Orkney	22,153	23,849	- 2.4%
Firth of Forth	7,261	6,426	+ 4.2%
Regularly monitored Scottish colonies	**49,952**	**50,548**	- 0.4%
Other Scottish colonies [1] (incl. N & NE mainland & Shetland)	4,112	4,193	- 0.6%
Total Scotland	**54,064**	**54,741**	- 0.4%
Farne Islands	2,823	2,295	+ 7.1%
Donna Nook, Blakeney, Horsey	7,902	5,918	+10.1%
Annually monitored colonies in eastern England	**10,725**	**8,213**	+ 9.3%
SW England [1,2]	450	250	
Small sites in E and NW England [1,3]	50	50	
Total England	**11,225**	**8,513**	+ 9.7%
Wales [1,4]	2,250	1,650	
Northern Ireland [1]	250	150	
Total UK	**67,789**	**65,054**	+ 1.4%
Isle of Man	69	84	

[1] Includes estimated production for colonies that are rarely monitored from different years
[2] Includes estimates for Scilly Isles, Lundy, various sites in Devon & Cornwall
[3] Includes Coquet Island, Ravenscar, Scroby Sands, South Walney
[4] Multiplier derived from indicator colonies surveyed in 2004 and 2005 and applied to other colonies last monitored in 1994

Table 3. *Pup production from ground counts and aerial surveys, and peak aerial survey count for grey seal colonies on the east coast of England in 2018.*

Colony	Ground Count Pup Production Estimate	Aerial Survey Peak Count	Aerial Survey Pup Production Estimate
Farne Islands	2727	1966	2860
Donna Nook	2066	2083	2684
Blakeney	3012	3795	4786
Horsey	2069	1866	2140
TOTAL	**9874**	**9710**	**12470**

Monitoring of grey seals in Wales is split into two areas: North Wales (Dee Estuary – Aberystwyth) and West Wales (Aberystwyth – Caldey Island). Details of the available data, data sources and derivations of pup production estimates are given in SCOS-BP 20/04.

There are few grey seals in south Wales (Caldey Island – Bristol Channel). Intensive monitoring of pup production is primarily focussed at three sites: Bardsey Island, parts of Ramsey Island, and Skomer Marine Conservation Area (MCZ). Other areas have been monitored more sporadically, and within a season, less intensively. North Wales wide surveys have been conducted in 2001, 2002 and 2017. The latest pup production estimate for 2017 was 216. West Wales wide surveys were conducted in 1992, 1993, and 1994.

It is not possible to estimate trends in pup production on a SMU scale. Pup production at Ramsey Island indicator sites has been variable but shown little trend. There is an upward trend in pup production at Skomer MCZ, though the trend is variable. The pup production estimate for Skomer and the adjacent Marloes peninsula increased slightly from 408 in 2019 to 422 in 2020 (Wilkie & Zbijewska, 2020).

A scalar based on the ratio between pup production in West Wales and indicator sites (in mainland north Pembrokeshire sites, Ramsey Island, and Skomer MCZ), in 1993 and 1994, was used to generate a total pup production estimate for West Wales (SCOS-BP 20/04). It should be noted, this was generated using the most recent available estimates for indicator sites, rather than predictions from fitted trends at these sites. Combined with the most recent estimate of North Wales, and rounding up to the nearest 50, this results in a pup production estimate of c. 2,250. Almost half of the SMU estimate of pup production is from sites not surveyed since the early 1990s.

To produce a robust estimate of pup production, scalars between indicator sites and irregularly monitored colonies need to be updated. This is particularly important when there are multiple habitat types (e.g., caves, open beaches) in an area. Cryptic sites (such as caves, small coves) can often support much smaller colonies and thus their trends, especially in the longer term, may differ from more open sites that are also easier to monitor. Indeed, for North Wales, Robinson *et al.,* (In Press) found that a much lower proportion of pup production was at cryptic sites than found previously (Stringell et al*.,* 2014).

Total adult population size

In order to estimate the total British grey seal population size (1+ aged population, referred to as ‘adult population’) at the start of the 2019 breeding season, recent trends in pup production estimates are ‘scaled up’ to total population size, using a mathematical model of British grey seal population dynamics. This model also includes three estimates of population size derived from summer counts of grey seals (SCOS-BP 21/02). The model uses pup production estimates by region (Inner Hebrides, Outer Hebrides, Orkney, North Sea), for the period 1984 to 2019, derived from aerial surveys and ground counts. It also includes a correction to account for pup production at less frequently monitored colonies. The different steps taken for converting pup counts from aerial surveys into a total population size requires a number of steps as shown in ***Figure 3***.

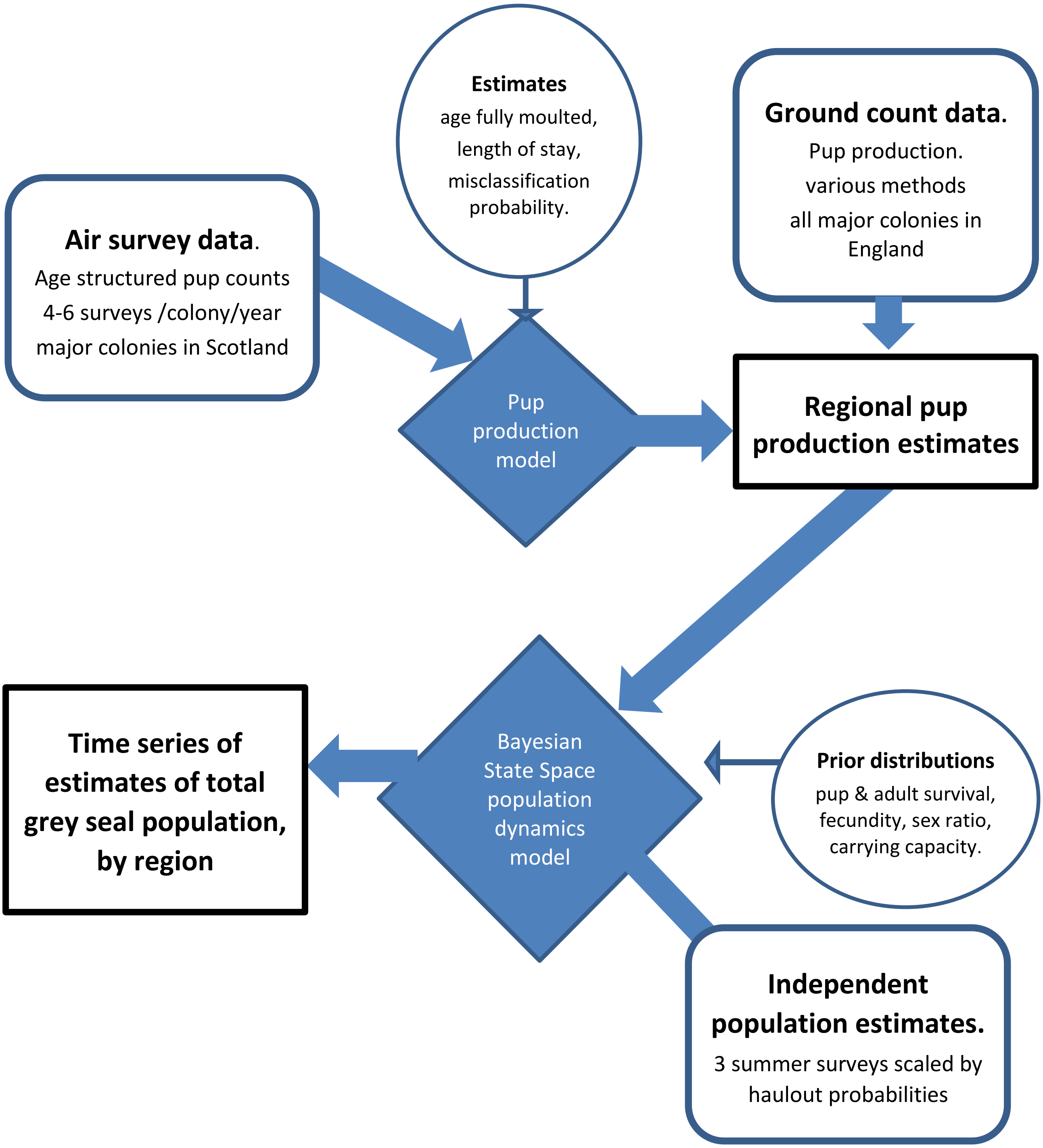

Figure 3. *Schematic diagram of steps involved in estimating total grey seal population size from pup counts.*

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 this period. Thus, estimates of the demographic parameters were available from a simple population model fitted to the entire pup production time series. Since then, 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) – i.e., density-dependent processes acting on either fecundity or pup survival – has resulted in reduced population growth rates in the Northern and Western Isles.

To estimate the population size, a Bayesian state-space model of British grey seal population dynamics was fitted to the pup production data. 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 order to help resolve this issue, in 2010 and 2011 we incorporated additional information in the form of an independent estimate of population size. This was based on counts of the numbers of grey seals hauled out during the summer and information on the seals' haulout behaviour derived from telemetry data. The latter 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). Based on telemetry data, it was estimated that 31% (95% CIs: 15 - 50%) of the population was hauled out during the specific survey window and thus available to be counted (Lonergan et al*., 20*11). Further assuming 4% of the population were in southwest UK, this led to a total UK independent population estimate in 2008 of 91,800 (95% CI: 78,400 - 109,900).

Inclusion of this initial independent estimate in 2008 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.

Additional independent population estimates (derived from summer haulout surveys) were obtained in 2014 (SCOS-BP 16/04) and 2017 (SCOS-BP 21/02). A new analysis of haulout patterns including data from an additional 60 new deployments of GPS/GSM tags on grey seals was presented in SCOS-BP 21/02 and SCOS-BP 21/03. These tags largely overcame several problems identified in haulout designation in previous deployments. The revised analyses resulted in an estimate of the proportion of the population hauled out during the survey window of 25.15% (95% CI: 21.45-29.07%) compared to 23.9% (95% CI: 19.2 - 28.6%) used previously. As per the previous analyses there was no detectable effect of region, length of individual (regarded as a proxy for age), sex or time of day on the conversion factor/scalar.

The updated scalar resulted in slightly reduced total UK grey seal population estimates for 2008 (96,028 compared to 101,196 based on the previous scalar of 23.9%) and 2014 (138,437 compared to 145,889; Russell *et al.,* 2016).

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 and an annual update is presented in SCOS-BP 22/01. A re-analysis of all the combined data available from pup tagging studies (hat tags, phone tags and GPS/GSM tags) suggested that there were no significant sex-specific differences in first year pup survival. SCOS-BP 22/01 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). The upper bound of the adult survival prior was increased slightly to 0.98 in line with revised survival estimates from long term brand mark recapture studies on Sable Island, Canada (see den Heyer & Bowen, 2017; Rossi et al., 2021). Available information on pup and adult survival rates, fecundity, sex ratio and carrying capacity are presented in answer to question 2 below and in SCOS-BP 22/01.

As there are currently no new pup production estimates available since the 2019 surveys, the model was run to produce projected regional population estimates for 2021 and 2022. Model and fitting methods are the same as those employed in recent years and are described in detail in Thomas *et al.,* (2019) and SCOS-BP 21/05; the prior distributions on model parameters are the same as those used for the last two years (see SCOS-BP 22/01 & 21/05 for details). The data are a time series of regional pup production estimates for the regularly monitored colonies in the Inner and Outer Hebrides, Orkney, and the North Sea, for the years 1984-2019, and three independent estimates of total population size (2008, 2014 and 2017).

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 revised prior on North Sea pup 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 carrying capacity.

Grey seal population estimate

From the standard model run, the estimated adult population size (here taken to mean the total 1+ age population) in the regularly monitored colonies at the start of the 2020 breeding season was 140,900 (95% CI 130,600-151,600). When projected forward the model produced total population estimates of 143,100 (95% CI 130,200-157,500) at the start of the 2021 breeding season and 145,400 (95%CI 131,400-160,600) for the start of the 2022 breeding season. The population at the regularly monitored colonies was estimated to have increased 1.6% between 2021 and 2022. This estimate is produced by a model incorporating density dependence in pup survival (but not in adult female fecundity), using the revised priors, and including the independent estimates for 2008, 2014 and 2017 (details of this analysis and posterior estimates of the demographic parameters are given in SCOS-BP 21/05).

A comprehensive survey of data available from the less frequently monitored colonies was presented in SCOS-BP 18/01 and revised estimates for Southwest England, Wales, Northwest England, and Northern Ireland are presented in SCOS-BP 20/04 and presented in ***Table 2***. Total pup production at these sites was estimated to be approximately 7,150. The total population associated with these sites was then estimated using the average ratio of pup production to population size estimate for all annually monitored sites in 2019. Approximate 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 16,600 (approximate 95% CI 15,300 to 17,900). This will undoubtedly under-estimate the uncertainty in the estimate, but it represents a relatively small proportion (12%) of the total.

Combining the annually monitored sites with the estimate for the less regularly monitored sites gives an estimated **2021 UK grey seal population of 159,700 (approximate 95% CI 146,000-173,000).** Projecting forward one more year produces a **2022 UK grey seal population of 162,000 (approximate 95% CI 146,700-178,500).**

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-recapture-based estimates of adult female survival at Sable Island in Canada were higher than this upper bound (0.976, SE 0.001) (den Heyer & Bowen, 2017). Hence, the prior for adult female survival was increased to 0.98 for last and 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. 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). Fitting to the three independent population estimates confirms that the density dependent pup survival model is a better fit than a model incorporating density dependent fecundity. A corollary of this density dependent pup survival is that the overall population should closely track the pup production estimates when experiencing density dependent control, as well as during exponential growth. This is borne out by the similarities in the fitted population model trends (***Figure 2***) and the pup production trends (SCOS-BP 21/05)

The factors influencing the dynamics of the different populations are not well known. The population dynamics model currently assumes that demographic rates are either fixed or respond to density dependent factors related simply to population size. However, it is likely that demographic parameters will be subject to environmental factors. For example, female fecundity is likely to be influenced by environmental factors regulating prey availability and seals' ability to gain fat reserves before breeding. A preliminary investigation was carried out into the possible relationship between fluctuations in pup production around the modelled trend, and the North Atlantic Oscillation (NAO) index from the previous winter, and also lagged by a further year (SCOS-BP 20/01). No association was found between the NAO winter index and variation in pup production the following year. However, NAO changes may not be a sensitive indicator of changes in seal prey and hence seal fecundity. Further investigations of this and other potential indices of environmental conditions, such as sea temperature, should be pursued once revised estimates of pup production are available.

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 4***).

Table 4 *Relative sizes and status of grey seal populations using pup production as an index of population size.*

Region	Pup Production	Year	Population trend
UK	**67,800**	2019	Increasing
Ireland	2,100	2012[1]	Increasing
Wadden Sea	1,950	2021[2]	Increasing
France	100	2021[4]	increasing
Norway	700	2015-21[3,4]	Possibly declining
Russia	800	1994	Unknown
Iceland	1,450	2017[8]	Declining
Baltic	8,900	2020[4,5]	Increasing
Europe excluding UK	**16,000**		unknown
Canada - Scotian shelf & Nova Scotia	92,300	2016[6]	Increasing
Canada - Gulf of St Lawrence	9,800	2016[6]	Increasing
USA	6,250	2019[7]	Increasing
WORLD TOTAL	**192,150**		Increasing

[1]Ó Cadhla, O., *et al.,* 2013. Monitoring of the breeding population of grey seals in Ireland, 2009 - 2012. Irish Wildlife Manuals, No. 74. National Parks and Wildlife Service, Dublin, Ireland. [2] Galatius A., *et al.,* (2022) EG-Seals - grey seal surveys in the Wadden Sea and Helgoland in 2019-2020. Common Wadden Sea Secretariat, Wilhelmshaven, Germany. [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. Document to the Norwegian Marine Mammal Scientific Advisory Board, October 2017. 9 pp. [4] ICES. 2022. Working Group on Marine Mammal Ecology (WGMME). ICES Scientific Reports. 3:19. 155 pp. http://doi.org/10.17895/ices.pub.8141. [5]Baltic pup production estimate based on mark recapture estimate of total population size (38,000) and an assumed multiplier of 4.7 HELCOM fact sheets (www.HELCOM.fi) & http://www.rktl.fi/english/news/baltic_grey_seal.html [6] den Heyer, C.E., Bowen, W.D., Dale, J., Gosselin, J-F., Hammill, M.O., Johnston, D.W., Lang, S.L., Murray, K.T., Stenson, G.B. & Wood, S.A. (2020) Contrasting trends in gray seal (*Halichoerus grypus*) pup production throughout the increasing northwest Atlantic metapopulation. Marine Mammal Science, DOI: 10.1111/mms.12773. [7] Wood *et al.,* 2020 Journal of Mammalogy, 101(1):121–128, 2020DOI:10.1093/ jmammal/gyz184 [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.

Table 4 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 used in different countries 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 countries. To avoid confusion, only the pup production values are presented here.

Current status of British harbour seals

Based on all surveys up to and including 2021, the current best estimate of the UK harbour seal population in 2021 was 42,900 (approximate 95% CI: 35,100-57,100). This is derived from the most recent composite count of 30,900 (based on surveys between 2016 and 2021) (*Table 6*), divided by the estimated proportion hauled out during the surveys (0.72 (95% CI: 0.54-0.88)). Overall, the UK population is similar to the estimate from the previous survey round, approximately 1% lower. It has increased since the late 2000s and is now only 10% lower than the late 1990s level prior to the 2002 PDV epizootic. However, there are significant differences in the population dynamics between regions. As reported in SCOS 2008 to 2020, 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.

During summer 2021 complete surveys of the harbour seal populations in the East Scotland, Moray Firth and Northern Ireland Seal Monitoring Units (SMUs) were carried out, as well as one survey of the Firth of Tay and Eden SAC (within East Scotland SMU). Within Southeast England SMU, a series of three surveys of the coast from Donna Nook to Scroby sands (by SMRU) and a single survey of the Greater Thames estuary (by Zoological Society of London, ZSL) were carried out in 2021 in response to observed declines in 2019 and 2020. In addition, three surveys of the coast from Donna Nook to Scroby sands, and single surveys of the Greater Thames estuary, the Moray Firth, and the east coast from Fraserburgh to Donna Nook were carried out in August 2022. Results from the 2022 surveys will be presented in the next SCOS report.

Recent trends, i.e., those that incorporate the last 10 years showed significant growth in both SMUs on the east coast of England up to 2018. However, the 2019 count in the large SE England SMU was approximately 25% lower than the mean of the previous 5 years. Counts for 2020, 2021 and 2022 confirm that this decline has continued.

Populations in Orkney & North Coast SMU and in the East Coast SMU 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. Northern Ireland counts are continuing to decline slowly.

It is worth noting that harbour seal counts in all areas surveyed in 2021 (Northern Ireland, East Scotland, Moray Firth & Southeast England SMUs) were substantially lower than during the preceding survey round, in 2016-2019. Apart from the confirmed decrease in the Southeast England SMU, it is not yet possible to say if the reduced counts represent real population decrease in those other SMUs.

Except for a 1-year interruption due to the Covid pandemic, SMRU have carried out surveys of harbour seals during the moult period in August each year. Recent survey counts and overall estimates were summarised in SCOS-BP 22/04. Given the length of the mainly rocky coastline around north and west Scotland it is impractical to survey the whole coastline every year, but SMRU aims to survey this entire coast every five years. Where there are indications of significant changes, the survey effort has been increased and some regions, e.g., Orkney and the Moray Firth have been surveyed more frequently. The English population and Scottish east coast populations in the Moray Firth, and the Tay and Eden estuaries are surveyed annually. Covid travel restrictions meant that the Moray Firth population was not surveyed in 2020.

Harbour seals spend a higher proportion of their time on land during the August moult than at other times of the year 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 combined thermographic, video, and high resolution (HR) still aerial imagery to identify seals along the coastline. However, the sandy habitat means that conventional photography is used to survey populations in the estuaries of the English and Scottish east coasts.

The estimated number of seals in a population based on these methods contains considerable levels of uncertainty. A large contribution to uncertainty is the proportion of seals not counted during the survey because they were in the water. Efforts are made to reduce the effect of environmental factors influencing the proportion hauled out, by systematically conducting surveys within 2 hours either side of low tides that occur between 10:00 and 20:00 during the first three weeks of August, and only in good weather conditions. The diurnal timing restriction is occasionally relaxed for sites in military live firing ranges where access is only permitted at weekends or in the evening. A conversion factor of 0.72 (95% CI: 0.54-0.88) is used to scale moult counts to total population size, and this was derived from haulout patterns of harbour seals fitted with flipper-mounted ARGOS tags (n=22) in Scotland (Lonergan et al., 2013).

The conversion factor used here was close to the middle of the range (0.6–0.8) of values estimated for other populations in Europe and North America (e.g., Harvey & Goley, 2011; Huber, Jeffries, Brown, DeLong & Van Blaricom, 2001; Ries, Hiby, & Reijnders, 1998; Simpkins, Withrow, Cesarone & Boveng, 2003). The conversion factor used is based on a sample of only 22 seals from a single year that only represented adult seal behaviour. SCOS has recommended that this conversion factor should be re-investigated when resources allow, to examine sex and age differences as well as potential extension to surveys outside the moult.

The most recent counts of harbour seals by region are given in ***Table 6*** and fitted trends by SMU are presented in ***Figure 4***. Results of surveys conducted in 2021 are described in more detail in SCOS-BP 22/04. Given that it is not possible, with current resources, to conduct a synoptic survey of the entire UK coast in any one year, data from multiple years are grouped into recent, previous and earlier counts in ***Table 6***, in order to illustrate and allow comparisons of the general trends across regions.

Table 5*. UK harbour seal population estimates based on counts during the moult; rounded to the nearest 100, except for Wales where estimates are rounded to the nearest 5.*

Location	Most recent count (2016-2021)	Total Population estimates	with 95% CIs
Scotland[1]	**26,400**	***36,600***	***(95% CI 30,000-48,800)***
England[2]	**3,600**	***5,100***	***(95% CI 4,100-6,700)***
Wales[3]	**<10**	**<15**	
Northern Ireland	**800**	**1,100**	**(95% CI 930-1,520)**
Total UK	**30,800**	**42,900**	**(95% CI 35,100-57,100)**

[1] *Compiled from most recent surveys (2016-2021), see* ***Table 6*** *for dates and details*

[2] *A complete survey of Southeast England_SMU was completed in 2021*

[3] *There are currently no systematic surveys for harbour seals in Wales*

Combining the most recent counts (2016-2021) at all sites in Scotland and Northern Ireland and 2021 counts in Southeast England, a total of approximately 30,900 harbour seals were counted across the UK: 85.4% of these in Scotland; 11.9% in England; and 2.6% in Northern Ireland (***Table 5*** & ***Table 6***). Including 4,000 seals counted in the Republic of Ireland, produces a total count of ~34,900 harbour seals for the British Isles (i.e. the UK and Ireland). Trends for individual SMUs are described in detail in SCOS-BP 22/02 and briefly in the following section and in answer to Q3. Total population estimates derived from the combined counts scaled by the proportion hauled out (0.72; 95% CI: 0.54-0.88) are given in ***Table 7.***

Table 6. *The most recent August counts of harbour seals at haulout sites in the British Isles by Seal Monitoring Unit, compared with four previous periods. The grey values given for SMUs 10-13 are rough estimates. Details of sources and dates of surveys are given in SCOS-BP 22/04. For ease of comparison, counts are grouped into survey rounds (periods). Counts for SMUs surveyed in 2021 are presented in the final column.*

		Harbour seal counts					
Seal Monitoring Unit / Country		1996-1997	2000-2006	2007-2009	2011-2015	2016-2019	2021
1	Southwest Scotland	929	623	923	1,200	1,709	
2	West Scotland	8,811	11,666	10,626	15,184	15,600	
3	Western Isles	2,820	1,920	1,804	2,739	3,532	
4	North Coast & Orkney	8,787	4,388	2,979	1,938	1,405	
5	Shetland	5,994	3,038	3,039	3,369	3,180	
6	Moray Firth	1,409	1,028	776	745	1,077	690
7	East Scotland	764	667	283	224	343	262
SCOTLAND total		29,514	23,330	20,430	25,399	26,846	*26,378*
8	Northeast England	54	62	58	91	79	89
9	Southeast England	3,222	2,964	3,952	4,740	3,752	3,505
10	South England	10	15	15	25	40	50
11	Southwest England	0	0	0	0	0	0
12	Wales	2	5	5	10	10	10
13	Northwest England	2	5	5	5	5	5
ENGLAND & WALES total		3,290	3,051	4,035	4,871	3,886	3,659
BRITAIN total		32,804	26,381	24,465	30,270	30,732	*30,037*
NORTHERN IRELAND total		-	1,176	1,101	948	1,062	818
UK total		-	27,557	25,566	31,218	31,794	*30,855*
REPUBLIC OF IRELAND total		-	2,955		3,489	4,007	
BRITAIN & IRELAND total		-	30,512		34,707	35,801	*34,862*

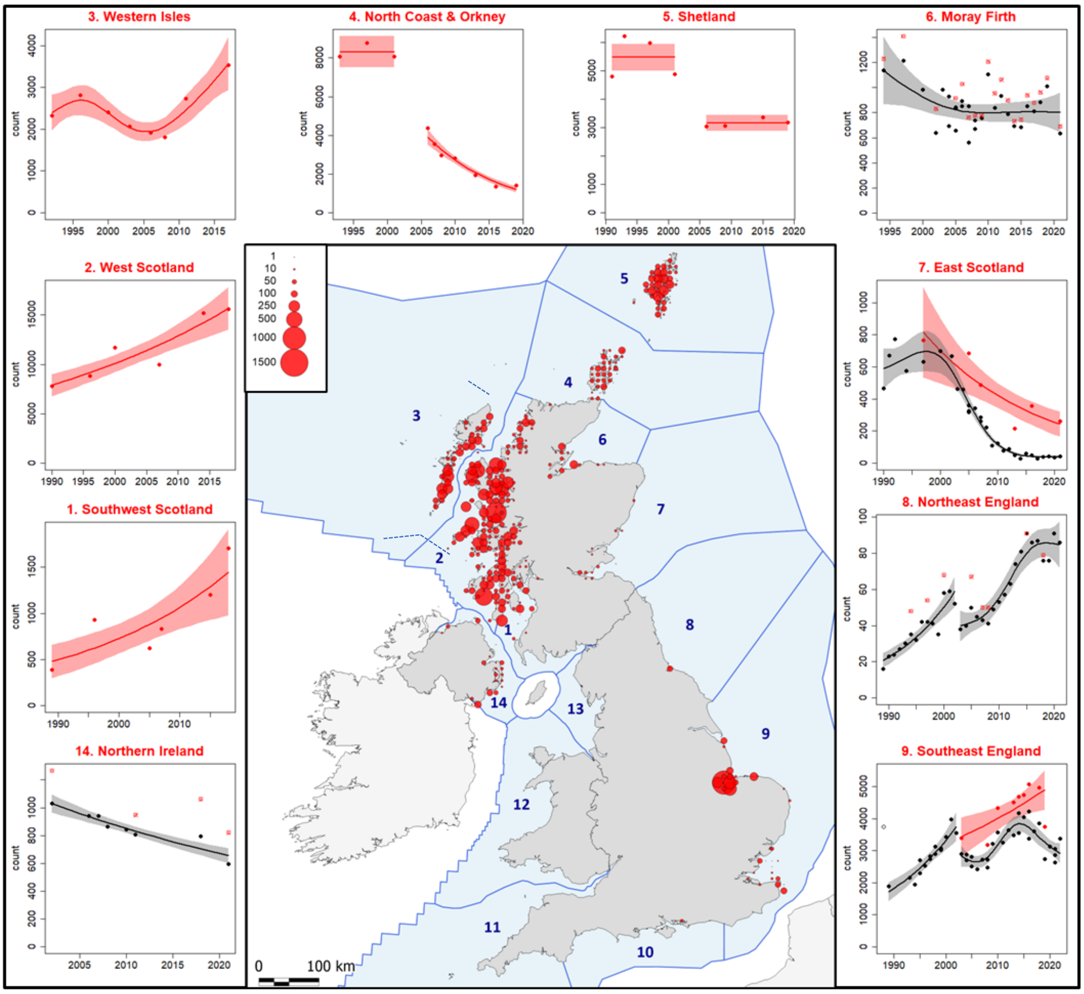

Figure 4*. August distribution of harbour seals around the UK by 10km squares based on the most recent available haul-out count data collected up until 2022 (coastline from GSHHS). Limited data available for SMUs 10-13. On a SMU-scale, the counts by year, and predicted trend and associated 95% confidence intervals are shown in red. The black lines indicate the use of a subset of the SMU. For more details see SCOS-BP 22/02.*

Population trends

The overall UK harbour seal population has increased over the last decade. Counts increased from 25,600 (rounded to the nearest 100) in the 2007-2009 period to 30,900 during the 2016-2021 period. As no count was available in Northern Ireland in the 1990s, a UK wide comparison is not possible, but the 2016-2021 count of 30,000 harbour seals in Great Britain (i.e., UK minus Northern Ireland) was similar to the 1996-1997 count of 32,800 (***Table 6***). However, as reported in SCOS 2008 to 2019, patterns of changes in abundance have not been universal; while declines have been observed in several regions around Scotland, other populations appear to be either stable or increasing. Details of fitted trends by SMU are shown in ***Figure 4***, and trends for SACs are given in answer to Q3 below, and in SCOS-BP 22/02.

Table 7. *Estimates of harbour seal populations in the British Isles by Seal Monitoring Unit. Estimates, with associated 95% confidence intervals in parentheses, are based on the most recent August counts of harbour seals at haul-out sites, scaled by the proportion of the population estimated to be hauled out during the survey window (0.72; 95% CI=0.54 – 0.88). The grey values for SMUs 10-13 are rough estimates. Details of surveys used in each compiled regional totals are given in SCOS-BP 22/04.*

	Seal Monitoring Unit or Country	2007-2009	(95% CI)	2011-2015	(95% CI)	2016-2021	(95% CI)
1	Southwest Scotland	**1281**	(1048 - 1709)	**1666**	(1363 - 2222)	**2373**	(1942 - 3164)
2	West Scotland	**14758**	(12075 - 19677)	**21088**	(17254 - 28118)	**21666**	(17727 - 28888)
3	Western Isles	**2505**	(2050 - 3340)	**3804**	(3112 - 5072)	**4905**	(4013 - 6540)
4	North Coast & Orkney	**4137**	(3385 - 5516)	**2691**	(2202 - 3588)	**1951**	(1596 - 2601)
5	Shetland	**4220**	(3453 - 5627)	**4679**	(3828 - 6238)	**4416**	(3613 - 5888)
6	Moray Firth	**1077**	(881 - 1437)	**1034**	(846 - 1379)	**958**	(784 - 1277)
7	East Scotland	**393**	(321 - 524)	**311**	(254 - 414)	**364**	(298 - 485)
SCOTLAND total [a]		**28375**	(23215 - 37833)	**35276**	(28862 - 47035)	**36636**	(29975 - 48848)
8	Northeast England [b]	**80**	(65 - 107)	**126**	(103 - 168)	**123**	(101 - 165)
9	Southeast England [c]	**5488**	(4490 - 7318)	**6583**	(5386 - 8777)	**4868**	(3980 - 6490)
10	South England [d]	20	(17 - 27)	34	(28 - 46)	69	(57 - 92)
11	Southwest England [d]		(0 - 0)		(0 - 0)		(0 - 0)
12	Wales [d]	6	(5 - 9)	13	(11 - 18)	13	(11 - 18)
13	Northwest England [d]	6	(5 - 9)	6	(5 - 9)	7	(5 - 9)
ENGLAND & WALES total		**5604**	(4585 - 7472)	**6765**	(5535 - 9020)	**5082**	(4158 - 6775)
NORTHERN IRELAND total [e]		**1529**	(1251 - 2038)	**1316**	(1077 - 1755)	**1136**	(929 - 1515)
UK total		**25566**	(29052 - 47344)	**43358**	(35475 - 57811)	**42854**	(35062 - 57139)
REPUBLIC OF IRELAND total [f]				**4845**	(3964 - 6461)	**5565**	(4553 - 7420)
BRITAIN & IRELAND total				**48204**	(39439 - 64272)	**48419**	(39616 - 64559)

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] Marine Scotland contributed funding towards Scotland surveys in 2009 and 2019.

[b] The Tees data collected and provided by the Industry Nature Conservation Association (Bond, 2019). Northumberland coast south of Farne Islands not surveyed pre-2008; no harbour seal sites known here. The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

[c] Thames data 2015&2019 collected and provided by Zoological Society London (Cox et al., 2020).

[d] Estimates compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Cumbria Wildlife Trust) or found in reports & on websites (Boyle, 2012; Hilbrebirdobs blogspot; Sayer, 2010, 2011; Sayer et al., 2012; Westcott, 2002). Increases may partly be due to increased reporting and improved species identification.

[e] Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002, 2011 & 2018 (Morris & Duck, 2019a) and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

[f] Surveys carried out by SMRU and funded by the National Parks & Wildlife Service (Morris & Duck, 2019b).

Trends by Seal Monitoring Unit (SMU)

Details of regional and local trend analyses, and model selection for each have been updated and are detailed in SCOS-BP 22/02 and are shown in ***Figure 4***. Results presented here and in answer to Q3 below are from an extension of previous analysis (Thompson *et al.,* 2019) incorporating extra data and with a change in model selection criteria from AICc to AIC, which is less conservative. At least three models were fitted for each SMU: a stable trend i.e., an intercept-only Generalised Linear Model (GLM), an exponential year effect within a GLM, and a nonlinear smooth year effect within a GAM.

Details of the analysis and figures showing fitted trends for Scottish SACs and the SMUs that contains them are presented in SCOS-BP 22/02 and described in answer to Q3 below.

Northeast and Southeast England SMU populations have generally shown increasing trends, but Phocine Distemper Virus (PDV) caused sudden, drastic declines in 1988 and 2002. To account for these sudden declines, additional models with a step change in abundance and/or trends associated with 1988 and 2002 were fitted in these SMUs. Although the declines in north and east Scotland SMUs were not thought to be due to PDV, there were sudden drops or declines in Shetland and North Coast & Orkney SMUs during multi-year gaps in surveys that spanned 2002, and a sudden change in trend around 2002 in East Scotland SMU. Because of the unknown nature of these declines, additional models were also fitted for SMUs 4 – 9 that allowed any combination of stable/exponential trends prior to and following 2002 (including the same trend across the time-series) and with/without a step change associated with 2002. For details of model fitting and model selection see SCOS-BP 22/02.

Southwest Scotland SMU: 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 6***). This was the highest count of harbour seals for the Southwest Scotland SMU, approximately three times higher than the 1990's count. The trend analysis selected a continuous increase since 1990. The rate of increase over the past five years was approximately 3.9% p.a.

West Scotland SMU: 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 6***).

The 2017-2018 West Scotland harbour seal count was 46% higher than the 2009 count. The best model, selected in the trend analysis showed a continuous increase from 1990 to 2017 at approximately 2.5% p.a. (***Figure 4***).

Although the West Scotland region is defined as a single monitoring unit, it is very large geographically in terms of total coastline and contains a large proportion of the UK harbour seal population; 50% of the most recent UK total count. The trajectories of counts within north, central and south sub-divisions of this large region differ:

- In the northern sub-region (north of Loch Ewe), the selected model for data up to 2017 indicates that counts have increased since the early 1990s, by approximately 4.9% p.a.
- In the central sub-region (Loch Ewe to Ardnamurchan) the selected model indicates that counts have increased since the early 1990s. The average rate of increase has been approximately 4.3% p.a.
- In the south sub-region (Ardnamurchan to Scarba) 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.

Western Isles SMU: A complete survey of the Western Isles SMU carried out in 2017 produced the highest recorded count for the Western Isles (3,533) which was 29% higher than the previous (2011) count of 2,739 and approximately 40% higher than the average between 1993 and 2011. Relaxing the model selection criteria resulted in the best model being a GAM that shows a decline from the mid-1990s to around 2005 followed by a steep increase to 2017. The revised trends analysis was the basis for SCOS's suggested relaxation of the Seal Conservation Area designated for the Western Isles SMU (Answer to Q19 SCOS 2021).

North Coast and Orkney SMU: Orkney was surveyed twice during the last round-Scotland census period. In 2016, 1,240 harbour seals were counted, and 1,296 in 2019 (***Table 6***). These are the two lowest counts to date, around 85% lower than the highest count in 1997 (8,522). The 2016 and 2019 counts were similar. Although this could indicate that the decline has slowed this cannot be confirmed without additional counts. Trend analysis (Thompson et al., 2019) indicates that counts were stable until 2001, that the next count in 2006 showed a decline of 46% and that from 2006 onwards, the counts have declined continuously. The average rate of decrease is currently estimated to be approximately 8.6% p.a. The North Coast section of the SMU was not surveyed in 2019 but few harbour seals are counted on the north coast section of the SMU.

Shetland SMU: A complete survey was carried out in 2019 when 3,180 harbour seals were counted compared with 3,369 in 2015 (***Table 6***). The 2019 count was close to the mean of the 2009 and 2013 counts but was 47% 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 2006-2019) do not show any obvious trend, though in both cases the sample size was limited (n=4 in both cases).

Moray Firth SMU: The total harbour seal count for the entire Moray Firth SMU in 2021 was 690. This was 32% lower than the 2019 count (***Table 6***). Approximately 30% of the harbour seals were observed between Culbin and Findhorn, significantly lower than the 60% seen in that area in 2021.

The majority of the counts in the Moray Firth were from haul outs between Loch Fleet and Findhorn, an area that held approximately 98% of the SMU total in 2016. The selected model for this area suggests that counts were decreasing between 1994 and 2000, the rate of decline slowed to around 2010 and the population now appears to be stable, although the 2021 count is 32% lower than the previous count in 2019.

East Scotland SMU: A complete survey of the East Scotland SMU was carried out in 2021. A total of 261 harbour seals were counted, indicating that the SMU population is still declining. This was 24% lower than the previous survey in 2016 (***Table 6***). Within 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 but the fitted trend suggests a decline from the late 1990s to 2016.

The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2021 was 41, equal to the mean of the previous 5 years' counts for this SAC. This represents a 94% decrease from the mean counts recorded between 1990 and 2002 (641).

Northern Ireland SMU: A complete survey of Northern Ireland was carried out in August 2021 (***Table 6***). A total of 821 harbour seals were counted, which was 23% lower than the previous count in 2018. Only four 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 2021. This area contained 80-85% of the total in the two years with complete coverage. This subset of the population declined slowly over the period 2002 to 2011 at an average rate of 2.7% p.a. The recent count suggests that this decline has continued.

Southeast England SMU: A detailed description of recent survey results from 2020, 2021 and 2022 is given in SCOS-BP 22/05. Briefly, the combined counts for the Southeast England SMU (***Figure 5***) reached a maximum around 2015-2018, but the 2019 count (3,081) was 27.6% lower than the 2012 to 2018 mean count. Additional surveys in 2020 and 2021 confirmed the decrease.

In August 2022 a further three surveys were carried out of harbour seals at sites in the Southeast England SMU from Donna Nook to Scroby Sands during August 2022. Unfortunately, two of these surveys coincided with periods of hot weather that brought large numbers of tourists to the coast. As a consequence, the haulout sites at Blakeney Point were severely disturbed during two of the surveys, meaning that only one complete count of the entire SAC was obtained.

The total count for the sites between Donna Nook and Scroby Sands has declined by approximately 30% compared to the mean of the previous five years (2019–2022 mean = 3132; 2014-2018 mean = 4296). The count for The Wash and North Norfolk SAC has decreased by approximately 19% (2019 – 2022 mean = 2758: 2015-2018 mean = 3399) over the same time periods, while Donna Nook showed a 57% decrease and Scroby Sands showed a 70% decrease. The harbour seal decline is evident at all sites and appears to have affected all sub-sections of The Wash & North Norfolk SAC.

In terms of the rest of the Southeast England SMU, a complete survey of the coast from Orford Ness (Suffolk) to Goodwin Sands (Kent) was carried out on 6 August 2022. Counts are not yet completed but are expected to be available for the 2023 SCOS meeting. The Thames population, here taken to include all haulout sites between Hamford Water in Essex and Goodwin Sands off the Kent coast, has been surveyed sporadically since 2002 and annually since 2008. In August 2019, a total of 671 harbour seals were counted compared with an average of 742 for three surveys in 2016-2018, and an average of 474 for three surveys in 2013-2015. A GLM for the series of counts from 2002 to 2019 demonstrated an increase at an average of 9.0% p.a. (bootstrap 95% CI 6.8-11.2) (Cox et al., 2020). No survey was carried out in 2020, but a survey in 2021 showed that the population has not grown over the past 4-5 years and may be starting to decline (SCOS-BP 21/07).

The fitted trend for the Wash and North Norfolk SAC (***Figure 5***) shows that the population recovered after the 2002 PDV epizootic, reached a maximum around 2014 to 2015 but has since declined rapidly.

The scale of the decline since 2015, in the absence of any clear anthropogenic effects is dramatic.The 2018 count was the second highest ever recorded in the Wash and was consistent with the pattern of relatively stable population since 2010. Given that the survey area represents the majority of harbour seals in the Southeast England Seal Monitoring Unit (SEE-SMU), including the population in the Wash & N Norfolk SAC, this likely drop in abundance is of immediate and serious concern. The SEE-SMU was the only one in the UK that was showing a sustained increase in abundance at a time when the majority of SMUs on the eastern and northern coasts had depleted or declining populations (Thompson et al., 2019; SCOS-BP 21/06). SCOS recommend that research is required to determine the time course and potential causes of this reduction and recommend that SMRU should seek funding to establish an appropriate programme of research. The proposed research programme is discussed in answer to Q5 below.

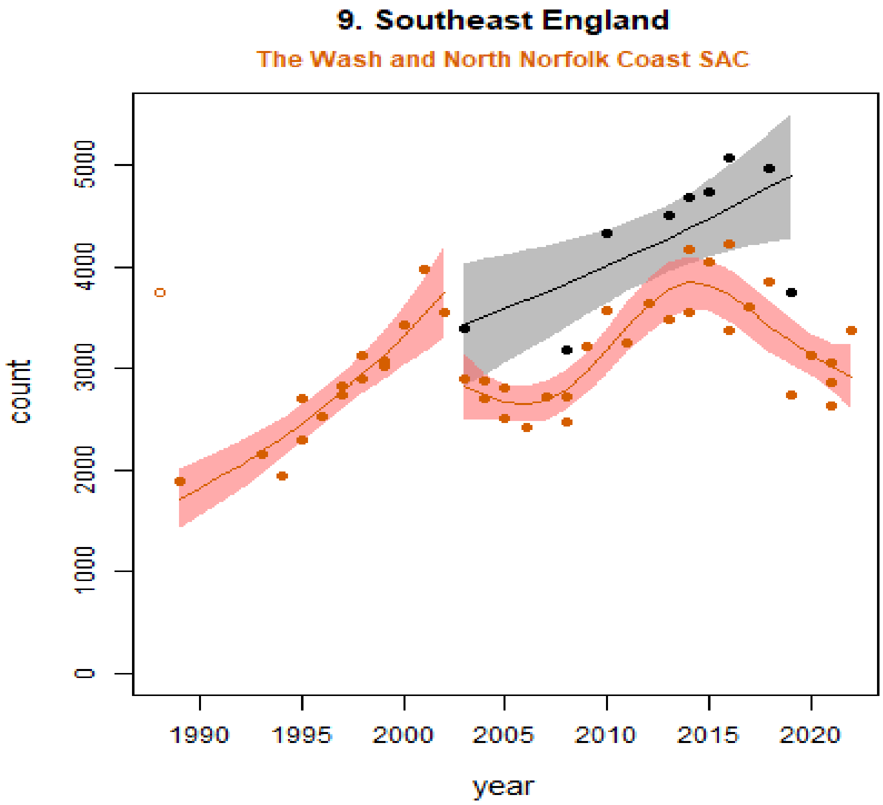

Figure 5. *Counts of harbour seals during the harbour seal moult in August, for the Wash and North Norfolk Coast SAC (the Wash and Blakeney Point, between 1988 and 2022), and for the entire Southeast England SMU (Donna Nook to Goodwin Sands) between 2002 and 2019. The plot shows the population changes after the 1988 and 2002 PDV epidemics. Separate trend lines are fitted to the post 1988 and post 2002 time series to show recoveries from the two PDV epidemics. Red lines, shading and points indicate harbour seal population trends, confidence intervals and counts within the Wash and North Norfolk SAC and the grey represents harbour seals for the entire Southeast England SMU.*

Southeast England pup production: Breeding season aerial surveys of the harbour seal population along the East Anglian coast are attempted annually, in addition to the 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. A complete survey of the Wash and the coast from Donna Nook to Blakeney was carried out in July 2022. The total pup count was 1,140. Due to a combination of aircraft availability, poor weather conditions and Covid19 travel and working restrictions no breeding season surveys were flown in 2019, 2020 and 2021. Therefore, the most recent survey for comparison was flown in July 2018 when 1498 pups were counted. The 2022 count was 24% lower than the 2018 count and 24% lower than the average for the preceding five years. This is similar to the observed decrease in the moult survey counts where the 2022 count of 3569 is also approximately 15% lower than the 2018 count of 4224. Details of the survey are presented in SCOS-BP 22/06. This apparent decrease follows an extended period of increase of around 5.6% p.a. since surveys began in 2001, although the rate of increase may have slowed prior to 2018 and may have been approaching an asymptote (SCOS-BP 19/04). The absence of pup survey data for the three years 2019-2021 in the Wash & North Norfolk SAC population was unfortunate given the scale of the declines observed in the moult survey counts, but the 2022 count suggests that the pup production likely fell in line with the moult counts.

The ratio of pup count to moult counts remained high in 2022, approximately 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 the ratio is now at a similar level to the Wash population (Galatius et al., 2020). Previous attempts to explain the apparently high fecundity/productivity in the Wash as being due to 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 the extent to which either of these metrics has changed. SCOS recommends further investigation to identify the underlying changes.

UK harbour seal populations in European context

The UK harbour seal population represents approximately 32% of the total population of the eastern Atlantic harbour seals (***Table 8***). Since 2000, the declines in some SMUs in Scotland and coincident dramatic increases in the Wadden Sea meant that the relative importance of the UK harbour seal population has decreased. Even though the Wadden Sea population has stopped increasing recently, the declines since 2018 in the Southeast England-SMU mean that the relative importance of the UK population has continued to decrease.

Although the Southeast England population increased after the 2002 PDV epizootic and has apparently levelled off at a similar size to its pre-2002 epizootic 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 epizootic has stopped (Galatius et al., 2021). Although there was an influenza-A epizootic that killed at least 1,600 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 Southeast England is notable.

Table 8. *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]	Most recent survey years
Scotland	**26,400**	2016-2021
England	**3,600**	2019-2021[2]
Northern Ireland	**800**	2021
UK	**30,800**	
Ireland	4,000	2017-18
France	1,300	2021
Wadden Sea - Germany	17,250	2021
Wadden Sea - Denmark	1,350	2021
Wadden Sea - Netherlands	8,250	2021
Delta – Netherlands	1,250	2019-20
Limfjorden	1,050	2021
Kattegat	8,400	2021
Skagerrak	2,900	2021
Baltic – Kalmarsund	2,050	2021
Baltic – Southwestern	1,200	2021
Norway	6,950	2017-21
Svalbard	1,900	2010
Iceland	10,300	2020
Europe excluding UK	**68,150**	
Europe – total	**98,950**	

[1] Counts rounded to the nearest 50. 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

Data sources

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https://doi.org/10.1371/journal.pone.0067576

Seal population structure

2. What is the latest information about the population structure, including mortality, age and sex structure, and carrying capacity of grey and common/harbour seals in English waters? What is the latest understanding about the population structure, including survival, reproduction and age structure, of grey and harbour seals in European and Scottish waters?	Defra Q2 SG Q2

Preliminary estimates of adult female survival from the Scottish Government funded Marine Mammal Scientific Support Research Program (MMSS) mark recapture scheme are presented for harbour seals in the Orkney and Skye study populations. Apart from these, SCOS are not aware of any new information on population structure, mortality, age or sex structure, or carrying capacity for European populations of harbour seals since the 2021 SCOS report. Other than a modelling study of survival and two published studies of breeding phenology there do not appear to be any new studies of population structure, mortality, age or sex structure, or carrying capacity for grey seals. For information the 2021 answer to these questions is included with minor additions.

Grey seals

There is evidence for regional differences in grey seal demographics (Smout et al., 2019) but detailed information on vital rates is 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.

Grey seal populations in the Inner and Outer Hebrides and Orkney appear to be close to their carrying capacities, but the population in the North Sea is continuing to increase rapidly and shows no sign of density dependent constraint.

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.

Earlier studies indicated a degree of reproductive isolation between grey seals that breed in the south-west (Devon, Cornwall, and Wales) and those breeding around Scotland, and within Scotland, there were significant differences between the Isle of May and North Rona. There is therefore some indication of sub-structure within the UK grey seal population, but it is not strong.

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 21/01). As currently structured the model fits single global estimates for fecundity, maximum pup survival (i.e., for an unconstrained population), and adult female survival, and fits individual carrying capacity estimates separately for each region to account for differing dynamics through density dependent pup survival. Recently Bull et al., (2021) suggested that changes in timing of births on Skomer Island were being driven by changes in population age structure that was itself responding to changes in an index of sea surface temperature. It is not clear if this represented permanent changes in age structure or temporary immigration/emigration of breeding females of different ages, nor whether this was a purely local effect. Bowen *et al.,* (2020) studied phenology in the Sable Island grey seal population in Canada over a 30-year period and showed much smaller magnitude changes that they ascribed to demographic changes and showed that females of all ages responded to environmental forcing. They also concluded from their 2768 pups that birth date had no impact on pup weaning mass.

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 22/01).

Adult female survival: Estimates of annual adult female 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-BP 20/02 - Table 2; SCOS-BP 22/01). 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 20/01). 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+).

Rossi et al, (2021) used the branded animal data set for Sable Island to show that survival rates were higher for females compared to males for all age classes, though differences were small for ages 1–19. Females' annual survival rates were very high (>97%) until age 25, after which survival declines by 8% between ages 25–29 and by another 9% for ages 30. Males similarly maintained high survival rates (>95%) until age 25, though declines in male survival rates in older age classes were much steeper than in female rates. The estimated survival rates imply maximum ages of about 35 years for males and 45 years for females.

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), which is consistent with Rossi *et al.,* findings.

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., 2006). 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 0.90 (SE 0.06) (SCOS-BP 20/01 & 21/05).

Four separate, recent studies have investigated the potential effects of environmental conditions on fecundity of grey seals:

- Kauhala *et al.,* (2019) used samples from seals shot in Finland to show that pregnancy rate can fluctuate significantly (between c.0.6 and c.0.95) and is significantly related to the quality (weight) of herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), which, in turn, were influenced by sprat and cod (*Gadus morhua*) abundance and zooplankton biomass. Their results suggest strong trophic coupling over three trophic levels in the Baltic and suggest that this is likely to influence fecundity rates.
- 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.
- Badger *et al.,* (2020) investigated the effects of increasing population density on the reproductive performance of female grey seals classed as high- and low-quality breeders. They showed that high quality females maintained their reproductive output as population density increased, while reproductive performance of poor-quality females declined.

All four studies suggest that fecundity or reproductive performance is influenced by prevailing environmental conditions. The consequences in terms of population level fecundity estimates are not clear, but 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 seals.

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 SCOS-BP 22/01 (Table 2). Mean estimates of pup survival were between 0.54 – 0.76.

The fitted value for maximum unconstrained pup survival was 0.46 (SE 0.07) from the standard model run on the 1984-2016 dataset and data from the North Sea population in 2018 (SCOS-BP 20/01 & 21/05). This value increased slightly to 0.49 when the later pup production estimates were altered by changing the probability of misclassification (SCOS-BP 20/01).

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. This is close to what Thomas *et al.,* (2019) estimated that pup survival for a population at carrying capacity will be, i.e., around 0.1-0.14.

Sex ratio: The sex ratio effectively scales the female population estimate (derived from the model fitted to the pup production trajectories) up to the total population size. With the inclusion of three independent estimates of total grey seal population size (based on separate, summer haulout surveys), 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.

In Canada, den Heyer and Bowen (2017) estimated survival rates of male and female branded seals at Sable Island. The differential survival of males and females would produce a 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 for grey seals in UK waters.

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; Thomas et al., 2019). 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 likewise at Sable Island, Canada, fecundity did not change as the island's grey seal population reached density dependent limits (den Heyer et al., 2017; Smout et al., 2019). Variation in fecundity may become increasingly important in areas where populations have reached carrying capacity, e.g., age at first reproduction appears to increase as populations reach carrying capacity (Bowen et al., 2006) and the reproductive success of individuals becomes more variable (Badger et al., 2020).

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 2019 recommended 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 genetic differences between grey seals breeding on the Isle of May and on North Rona (Allen et al., 1995). There is therefore some indication of sub-structure within the UK grey seal population, but it is not strong.

Recent genetic data from 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 mtDNA 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.

Carrying capacity.

There is clear evidence that grey seal populations in the Inner and Outer Hebrides have reached their carrying capacities (Figure 2), with little or no increase in pup production since the mid-1990s. The Orkney population also appears to be close to its carrying capacity, although recent counts suggest a continuing slow increase. However, the estimated population trend is confounded by the step change in pup production coincident with the switch to digital camera systems in 2010, which may exaggerate recent increases. In any-case, the Orkney population is clearly close to carrying capacity. Pup production at North Sea colonies is continuing to increase rapidly and does not show any indications of density dependent restraint on growth.

There is no independent information available on carrying capacity, but region-specific carrying capacities in terms of pup production are estimated by the population dynamics model used to estimate grey seal populations (Thomas et al., 2019; SCOS_BP 21/05). The model fitted to pup production time series up to 2019 produced pup carrying capacity estimates of 23,700 for Orkney (CV=18%), 14,000 for the Outer Hebrides (CV= 8%), 4,100 for the Inner Hebrides (CV=11.1%) and 33,200 for the North Sea (CV=29%). Because the North Sea pup production shows no sign of approaching carrying capacity, we have little confidence in the estimate.

Harbour seals

Knowledge of UK harbour seal vital rates is limited and inferences about 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.

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 epizootics 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.

Preliminary estimates of survival of harbour seals in Orkney and Skye are available from the ongoing harbour seal decline project. Both Orkney and Isle of Skye showed high recapture probabilities of individuals (0.93 95%CI 0.87-0.96 for all adults in Orkney and ranging 0.82-0.86 for all adults in Isle of Skye). The estimates of apparent adult survival obtained for Orkney were lower (0.821, 95%CI 0.765-0.866) than those for Isle of Skye (0.902, 95%CI 0.840-0.941). Available estimates of survival for harbour seals are scarce, especially those based on photo-ID data from live individuals. The estimate from Isle of Skye is similar to the adult (3+ years) estimate for harbour seals in Tugidak Island, Alaska (0.905 95%CI 0.829-0.950; Hastings, Small, & Pendleton, 2012), but lower than that reported from early studies in the Moray Firth (0.98 95%CI 0.94-1.00; Mackey et al., 2008). Sex-specific estimated survival rates were lower (both from Isle of Skye and from Orkney) compared to those published from the Moray Firth (Females = 0.97 95%CI 0.95-0.99; Males = 0.94 95%CI 0.90-0.97; Graham et al., 2017) or Alaska (Females = 0.929 95%CI 0.858-0.966; Males = 0.879 95%CI 0.784-0.936; Hastings et al., 2012). The survival estimates reported here should be treated as preliminary results given the short period of data available (4 years). These will be updated when further photo-ID data are available covering 2021 and 2022. Fecundity estimates will also be generated from this dataset.

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 twice that of earlier estimates and until recently was much higher than in the larger population in the Wadden Sea (SCOS-BP 22/06). 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. Data from the 2021 Wadden Sea pup and moult surveys suggest that the pup production has continued to increase while moult counts have stabilised, indicating that the index has continued to increase. In the 2022 Wash survey data the pup count has decreased in line with the moult counts indicating that the apparent fecundity has remained constant despite the significant decrease in population size (SCOS-BP 22/06).

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 spanning 30 years, 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). 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.

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 epizootics 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.

Nikolic *et al.,* (2020) reported an analysis of the genetic structure of the Moray Firth harbour seal population. Their analysis revealed that the Moray Firth cluster is a single genetic group, with similar levels of genetic diversity across each of the localities sampled. Their estimates of current genetic diversity and effective population size were low, but they conclude that the Moray Firth population has remained at broadly similar levels following the population bottleneck that occurred after post-glacial recolonization of the area.

Carroll et al., (2020) used a combination of population trends, telemetry tracking data and UK-wide, multi-generational population genetic data to investigate the dynamics of the UK harbour seal metapopulation. Their results indicate that the northern and southern groups previously identified by Olsen et al., (2017) represent two distinct metapopulations. They also examined the dynamics of the northern metapopulation before and after the declines in the early 2000s. They identified two putative source populations (Moray Firth North Coast and Orkney, and Northwest Scotland) supporting three likely sink populations (East Coast, Shetland and Northern Ireland), and a recent metapopulation-wide disruption of migration coincident with the start of the declines and conclude that the northern metapopulation appears to be in decay.

A recent study used mitochondrial control region sequences and between 9 - 11 microsatellite loci to investigate the genetic population structure of harbour seals from Ireland and Northern Ireland (up to n = 123) and adjacent UK/European waters (up to n = 289) (Steinmetz *et al.,* 2023). Results indicate three genetically distinct local populations within the island of Ireland: East Ireland (EI), North-west & Northern Ireland (NWNI), and South-west Ireland (SWI).NWNI area could not be distinguished from the Northern UK (Scotland) metapopulation. Migration rate estimates showed that NWNI receives migrants from North-west Scotland, with NWNI acting as a genetic source for both SWI and EI. Steinmetz *et al*. (2023) suggested that harbour seals in Ireland should be monitored and managed according to these three genetically distinct local populations.

Carrying Capacity

There is no available independent estimate of carrying capacity for any of the UK SMU harbour seal populations. At present, only Shetland and Moray Firth SMUs have been relatively stable over the past decade, and in both cases the counts are stable at levels substantially lower than counts in the 1990s (***Figure 4***, SCOS-BP 22/02). In both cases this could represent stabilisation at a new carrying capacity but could also indicate that unidentified density independent factors are driving populations. In all other SMUs the counts are either increasing (Southwest and West Scotland, and Western Isles SMUs), decreasing (N Coast & Orkney, East Scotland and Northern Ireland SMUs) or showing recent decreases after a protracted increase (east England SMUs) (***Figure 4***). In all cases the observed trajectories preclude estimation of robust carrying capacities.

SAC estimates and trends

3. What are the latest SAC relevant count/pup production estimates for the harbour and grey seal SACs, together with an assessment of trends within the SAC relative to trends in the wider seal monitoring unit/pup production area?	SG Q3

Trends in August counts for both harbour and grey seals and for grey seal pup production, have been estimated for all Special Areas of Conservation (SACs), in Scotland and eastern England, as well as on an Seal Monitoring Unit (SMU) scale (SCOS-BP 22/02). For Scotland, the latest counts/pup production estimates, and associated rates of change, are summarised in *Tables 9 & 10*.

For grey seals, the August counts are inherently variable, so for SACs and even SMUs with relatively low numbers and/or low survey frequency, the power to detect trends will be low. Indeed, many grey seal SACs were designated on the basis of their breeding colonies, and do not host large summer haulout numbers. For trends in grey seal pup production, the artificial increase in production estimates associated with a change from film to digital methods is taken into account, and thus the estimated rates of change are robust to this. However, as a result, the uncertainty surrounding trends in pup production within SACs that are aerially surveyed are likely underestimated (see SCOS-BP 22/02 for more details). In general, the trends in pup production within SACs are less favourable than for the SMUs which encompass them. Pup production in all SMUs is stable or increasing with the exception of Shetland. In contrast, four of six of the SACs are exhibiting significant declines or/and depletion from historic highs.

For harbour seals, all SACs and their associated SMUs on the north and east coasts of Scotland are declining and/or at historically depleted levels of abundance; the SACs are exhibiting similar or more marked declines/levels of depletion compared with the SMU in which they are encompassed. In contrast, SACs and their associated SMUs on the west coast of Scotland are stable or increasing; the Sound of Barra SAC is significantly depleted but no longer in decline. A more detailed examination of harbour seal counts within both Scottish SACs and SMUs is given in Morris *et al.,* (2021). Comparisons of the time series (generally starting in early 1990s) of harbour seals counted within SACs compared with those within a 50km range of the SACs showed that SACs are not reliable indicators of trends in the wider area.

Trends in harbour seal August counts, and grey seal August counts and pup production, have been estimated for all Special Areas of Conservation (SACs) in Scotland and eastern England, as well as on a Seal Monitoring Unit (SMU) scale (SCOS-BP 22/02). For Scotland, the latest counts/pup production estimates, and associated rates of change, are summarised in ***Tables 9 & 10***. Data for English sites are presented in SCOS-BP 22/04 & 22/05.

Where the overall mean trend(s) indicated that the estimated value for the latest survey year was not the highest in the time-series, a depletion metric was calculated as the predicted percentage reduction from the historic high (***Tables 9 & 10***).

Grey seal SACs

Six grey seal breeding colonies are designated as SACs in Scotland. Below, for each SAC, the trends relative to the associated SMU are described. Note that SMUs which do not contain SACs are not covered.

West Scotland SMU: Treshnish Isles SAC

Pup production for West Scotland as a whole appears stable. Although production at the Treshnish Isles SAC also appears stable and still makes up around 25% of the SMU's production, it is significantly depleted compared to historical highs in the late 1990s (when the SMU trend levelled off). The Treshnish Isles is not a key haulout in the SMU accounting for less than 5% of the SMU count.

Western Isles SMU: Monach Isles SAC and North Rona SAC

The mean predicted trend in the SMU pup production shows a slight increase, but this is not significant. Overall pup production appeared to have levelled off around year 2000. The Monach Isles SAC accounts for almost 80% of the SMU's production and thus trends mirror that of the SMU. In contrast, the North Rona SAC which historically was the biggest colony in the SMU, is severely depleted and is continuing to decline; it now accounts for less than 2% of the SMU's production compared to over 20% at the beginning on the time-series considered here (1984), and likely an even higher proportion in the 1960s and 1970s (Russell et al., 2019). August counts in the SMU are variable with no overall trend for the Monach Isles SAC (50% of the SMU count) or the SMU as a whole. The North Rona SAC is a small haul out.

North Coast and Orkney SMU: Faray & Holm of Faray SAC

Pup production in the SMU levelled off around year 2000**.** Since then, pup production in the SAC has been declining. It is now significantly depleted to around half historic levels, now accounting for c.10% of the SMU production. Haul out counts in August are stable in the SMU. The SAC only encompasses c. 3% of that count and is in decline.

East Scotland SMU: Isle of May SAC, and Berwickshire and North Northumberland Coast SAC

Pup production in East Scotland is continuing to increase but production on the Isle of May SAC appears to be in decline. The Isle of May SAC, which until the mid-1990s represented almost 100% of the SMU's pup production, only represents c. 25%. This is to a large extent due to the rapid increase in pup production at Fast Castle, part of the Berwickshire and North Northumberland Coast SAC which now accounts for over half the SMU's pup production and is still increasing. In reality, the SAC boundary transects the Fast Castle colony but for the purposes of this SCOS report, the entire Fast Castle pup production is assigned to the SAC. Neither SACs represent key haul out areas for grey seals during the August survey.

Harbour seal SACs

There are nine harbour seal SACs in Scotland; harbour seals are the primary reason for designation in all except Sound of Barra. Below, for each SAC, the trends relative to the associated SMU are described. Note that SMUs which do not encompass SACs are not considered here.

West Scotland SMU: Eileanan agus Sgeiran Lios SAC, Southeast Islay Skerries SAC, and Ascrib, Isay and Dunvegan SAC

Abundance in West Scotland SMU is increasing slightly as result of increases in the central and northern parts of the SMU while there is no significant trend in the southern part. The SACs in the southern part show differing trends; estimated abundance in the Eileanan agus Sgeiran Lios mor SAC is currently stable whereas abundance is increasing in the Southeast Islay Skerries SAC. Estimated abundance in Ascrib, Isay and Dunvegan SAC in the central part is currently stable though abundance is currently higher than at the start of the time series (1990).

Western Isles SMU: Sound of Barra SAC

Abundance in the Western Isles is showing significant increases after a period of decline. In contrast, there is currently no significant trend in abundance in the SAC and abundance is significantly depleted compared to historic highs. The last count (2017) represents around 4% of the SMU total compared to around 38% in 1992 (start of the time series).

North Coast & Orkney SMU: Sanday SAC

Both the SMU and the SAC therein are drastically depleted compared to historic counts and are still in decline. The current rate of decline and level of depletion are significantly more severe in the SAC than the SMU. In the last count in 2019, the SAC represented around 5% of the SMU total compared to around 19% in 1993 (start of the time series)

Shetland SMU: Mousa SAC and Yell Sound SAC

Although depleted, estimated abundance in Shetland is currently stable. This is also the case for the Yell Sound SAC. In contrast the Mousa SAC is almost completely depleted and is still in decline.

Moray Firth SMU: Dornoch Firth and Morrich More SAC

Although significantly depleted, the estimated trend in abundance in the Moray Firth is currently stable. In contrast, the SAC is more severely depleted and still in decline representing 10% of the SMU count in 2021 compared to around 50% in the early 1990s.

East Scotland SMU: Firth of Tay and Eden Estuary SAC

The East Scotland SMU is depleted and still in decline. The SAC is no longer significantly declining, appearing to have levelled off at a severely depleted level. In the last count (2021), the SAC represented around 16% of the SMU total compared to around 83% in the first SMU-wide survey (1997).

Table 9. *Trends in grey seal August counts and pup production estimates for all SMUs and SACs in Scotland. The latest counts/pup production estimates (values) are given, as well as the estimated current rate of change (for the year leading up to the latest count) and level of depletion. If the overall mean trend(s) indicated that the latest survey year was not the highest in the time-series, the predicted depletion from the historic high, and the latest year for which that high was predicted, are given. The grey seal pup production time-series began in 1984 encompassing between 30 and 32 data points (Shetland, Moray Firth and Fast Castle began in 2004 (N=10), 2006 (N=8) and 1997 (N=19), respectively). For August counts, the start year of the time series and number of data points (N) is given. Bold indicates where there was a significant change, and red indicates where there was a significant rate of decline (upper 95% confidence intervals (CIs) < 0) or a significant depletion. Trend values of 0 indicate a constant trend (see SCOS-BP 22/02 for model selection) or that the latest estimate was the highest in the time series (depletion only). NAs indicate a lack of data.*

SMU		SAC	Pup Production			August Counts				
Number	Name		Latest Estimate (2019)	Trend (% pa; 95% CI)	Depletion (%; 95% CI)	First Survey Year	N	Latest Count (Year)	Trend (% pa; 95% CI)	Depletion (%; 95% CI) since year
1	Southwest Scotland		0	NA	NA	1989	6	517 (2018)	**5.92 (3.44, 8.47)**	0
2	West Scotland		4455	0.77 (-1.58, 3.14)	0	1990	5	4174 (2018)	**2.84 (0.66, 5.08)**	0
2a	West Scotland - south		NA	NA	NA	1990	6	2922 (2018)	**3.26 (1.50, 5.06)**	0
		Treshnish Isles	1131	0.82 (-1.69, 3.48)	**-17 (-28, -5) vs 1998**	1988	6	160 (2018)	0	0
2b	West Scotland - central		NA	NA	NA	1990	6	773 (2017)	0	0
2c	West Scotland - north		NA	NA	NA	1991	6	479 (2017)	0	0
3	Western Isles[1]		16083	1.42 (-0.78, 3.65)	0	1992	8	5478 (2017)	0	0
		Monach Islands	12511	1.61	0	1992	8	2701 (2017)	0	0

				(-0.73, 4.00)						
		North Rona	286	**-9.23 (-11.55, -6.81)**	**-84 (-86, -81) vs 1984**			175 (2014)	NA	NA
4	North Coast & Orkney		22153	0.65 (-1.60, 2.95)	-1 (-16, 17) vs 2006	1989	10	8599 (2019)	-0.41 (-6.07, 5.60)	-13 (-32, 11) vs 2000
		Faray & Holm of Faray	2186	**-4.94 (-7.23, -2.50)**	**-48 (-54, -40) vs 1998**	1989	13	228 (2019)	-7.92 (-15.55, 0.55)	**-52 (-69, -26) vs 2007**
5	Shetland[2]		433	**-2.75 (-3.98, -1.49)**	**-32 (-43, -19) vs 2004**	1991	8	1009 (2019)	0	0
6	Moray Firth[3]		1865	**3.12 (0.65, 5.77)**	0	1994	28	1082 (2021)	**3.39 (0.25, 6.61)**	0
7	East Scotland		7261	**5.38 (3.56, 7.17)**	0	1997	6	2707 (2021)	0	0
		Isle of May	1885	-1.93 (-3.99, 0.16)	**-20 (-30, -10) vs 2004**	1997	6	97 (2021)	0	0
		Fast Castle, BNNC[4]	4499	**8.31 (5.81, 10.92)**	0			0 (2021)	NA	NA

[1]August grey seal counts are for a subset (excludes offshore islands); [2]No estimates for pup production available, peak counts from a limited subset of colonies used; [3] Moray Firth values for August are for a more frequently monitored subset (Loch Fleet to Findhorn); [4]All Fast Castle pup production included in total for Scotland.

Table 10. *Trends in harbour seal August counts for all SMUs and SACs in Scotland. The latest counts are given, as well as the estimated current rate of change (for the year leading up to the latest count). If the overall mean trend(s) indicated that the latest survey year was not the highest in the time-series, the predicted depletion from the historic high, and the latest year for which that high was predicted, are given. The start year of the time series and number of data points (N) is given. Bold indicates where there was a significant change, and red indicates where there was a significant rate of decline or a significant depletion. Trend values of 0 indicate a constant trend or that the latest estimate was the highest in the time series (depletion only). NAs indicate a lack of data.*

SMU		SAC	1st Survey Year	N	Latest August Count (Year)	Latest Trend (% p.a.; 95% CI)	Depletion (%; 95%CI; vs year)
1	Southwest Scotland		1989	6	1709 (2018)	**3.89 (1.86, 5.99)**	0
2	West Scotland		1990	6	15600 (2018)	**2.48 (1.64, 3.33)**	0
2a	West Scotland - south		1990	6	7069 (2018)	0	0
		South-East Islay Skerries	1990	7	706 (2018)	**1.88 (0.50, 3.25)**	0
		Eileanan agus Sgeiran Lios mor	1990	10	238 (2018)	0	0
2b	West Scotland - central		1989	7	7447 (2017)	**4.27 (3.51, 5.03)**	0
		Ascrib, Isay and Dunvegan	1990	11	712 (2017)	0.83 (-9.73, 12.61)	-22 (-54, 33) vs 2002
2c	West Scotland - north		1991	6	1084 (2018)	**4.86 (4.01, 5.71)**	0
3	Western Isles		1992	8	3532 (2017)	**6.27 (1.22, 11.64)**	0
		Sound of Barra	1992	9	132 (2017)	2.66 (-4.50, 9.94)	***-86 (-91, -79) vs 1992***
4	North Coast & Orkney		1993	10	1405 (2019)	**-8.63 (-9.98, -7.28)**	***-85 (-88, -83) vs 2002***
		Sanday	1993	12	77 (2019)	**-14.24 (-17.87, -10.28)**	***-96 (-98, -93) vs 2002***
5	Shetland		1991	8	3180 (2019)	0	***-42 (-49, -34) vs 2002***
		Mousa	1991	8	7 (2019)	**-21.62 (-30.80, -11.19)**	***-98 (-99, -96) vs 1991***
		Yell Sound Coast	1991	8	209 (2019)	0	***-39 (-57, -14) vs 2002***
6	Moray Firth[1]		1994	28	633 (2021)	-0.19 (-3.84, 3.48)	***-29 (-49, -4) vs 1994***
		Dornoch Firth and Morrich More	1992	29	69 (2021)	**-7.68 (-9.09, -6.28)**	***-90 (-94, -85) vs 1992***
7	East Scotland		1997	6	261 (2021)	**-4.93 (-7.09, -2.62)**	***-70 (-83, -47) vs 1997***
		Firth of Tay and Eden Estuary	1990	29	41 (2021	1.15 (-5.58, 8.36)	***-94 (-96, -92) vs 1998***

[1] Moray Firth values for August are for a more frequently monitored subset (Loch Fleet to Findhorn)

Regional harbour seal declines

Scottish waters

4. Please could SCOS provide an update on the Scottish regional harbour seal declines, including current and projected trends.	SG Q4

There have been significant population declines in some regions that have been offset by similar increases in others.

August 2021 surveys were carried out of the harbour and grey seal populations in the Moray Firth and the East Scotland SMUs. Counts of harbour seals were 35% and 24% lower respectively than in previous surveys.

Trends in Scottish SACs and SMUs (with the exception of Southwest Scotland SMU which does not contain an SAC) are given in answer 3 above. Trends in SMUs around Scotland and on the east coast of England are described in more detail in SCOS-BP 22/02.

The current UK harbour seal population is at a similar size to the estimates from the late 1990s (***Tables 6 & 7***). As reported in previous SCOS reports since 2008, 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.

Briefly, West Scotland and Southwest Scotland SMUs show an increasing trend since the start of the time series around 1990. The Western Isles counts declined in the late 1990s but has been increasing since lows in the mid-2000s. Shetland is apparently stable after a c. 40% decline in the early 2000s. North Coast and Orkney SMU is still declining with abundance of around 15% of 2002 levels. In August 2021 surveys were carried out of the harbour and grey seal populations in the Moray Firth and the East Scotland SMUs. In the East Scotland SMU, the count of harbour seals was 24% lower respectively than in previous surveys in 2016, so the decline is continuing. In the Moray Firth, recent surveys indicated relatively stable, but depleted, abundance but the August 2021 survey was 32% lower than the previous count (2019).

The composite count for all of Scotland, based on recent (2016-2019) surveys was 6% higher than for the previous round of surveys (2011-2015) and 31% higher than the 2007-2009 composite counts, representing approximately 3% p.a. increase, and is similar to counts in the mid-1990s. Details of trends are presented in answer 3 above and in SCOS-BP 22/02.

Predicting future trends in harbour seal populations is problematic. The current monitoring programme does not provide a reliable method of projecting trends. Simply projecting recent trends forward would provide little insight in the absence of clearly identified drivers and some information on the likely future status of those drivers. Potential drivers are being investigated under the Scottish Government funded MMS project and an integrated harbour seal population model is being developed as part of that programme.

English waters

5. Is there any update in evidence to explain trends in common/harbour seal abundance, which are considered to be declining in English waters and if so, what are the potential influencing factors and where is further research needed?	Defra Q1b

Harbour seal populations in the Wash and adjacent sites have declined rapidly since 2018. Counts in the rest of the Southeast England Seal Monitoring Unit (SEE-SMU) are also showing signs of the start of a decline. The decline is widespread throughout The Wash and adjacent sites. Counts in 2021 and 2022 confirm the scale of the decline, but do not yet confirm that it is continuing. The observed rate of decrease in counts is too great to be accounted for by increased pup mortality or reduced fecundity alone and must therefore incorporate a reduction in the number of adult seals through mortality and/or emigration.

Potential factors that could be driving the population changes in both Scotland and England were discussed in previous SCOS reports and a prioritised list was presented in Table 9 of SCOS 2021.

Potential causal factors include grey seal competition for prey, grey seal predation, disease, and some aspect of anthropogenic activity. It is likely that more than one factor is contributing to the decrease.

The information requirements for identifying which factors may be responsible for the decline are discussed below, and an outline of the research programme to address important information gaps is presented below.

The southeast England Seal Monitoring Unit (SEE-SMU) incorporates The Wash and North Norfolk SAC, and hosts > 95% of the English harbour seal population (15% of UK harbour seals; Thompson et al., 2019). This region has shown sustained increases in harbour seal numbers since the 1970s, punctuated by sudden reductions of 50% (1988) and 30% (2002) due to outbreaks of Phocine Distemper Virus (PDV). Such sustained increases contrasted with regional trends elsewhere in the UK; specifically, SMUs on the eastern and northern UK coasts, which show depleted or declining abundance. Over recent years (2014-2018), harbour seal counts in most of the SEE-SMU had levelled off (at c. 4,250 which equates to a population of c. 6,000), suggesting that carrying capacity had been reached (Thompson et al., 2019; Cox et al., 2020).

However, the counts in 2019-2022 were much lower, indicating a decline of 20 – 30 % (Figure 5). The counts are conducted during the harbour seal moult when the highest, and most consistent, proportion of the population are hauled out. Although there is inherent variability in the time series of counts, the scale of the decrease means that without a major shift in haulout behaviour of seals during the moult, these lower values indicate a real decrease in abundance. Similar counts across multiple August surveys in 2022, and the reduction in pup numbers in 2022, precludes such a change in haulout behaviour as an explanation of the reduced counts. As such these counts likely represent a real decrease in abundance which is of serious conservation concern.

Changes in haulout patterns

Harbour seal population estimates are based on the numbers of seals hauled out within a defined survey window during the annual moult (see Q1 above and SCOS-BP 22/04 for details). Using this index requires an implicit assumption that the proportion of the population hauling out remains constant over the survey period and between years. Several factors could potentially breach this assumption.

Potential changes in timing of moult are discussed in answer to question 7. It is well established that younger seals moult earlier than adults, and that adult females moult earlier than adult males

(Cronin et al., 2014). The effect of changes in population age or sex structure, on moult timing have been suggested as a possible source of error in harbour seal population estimates (Härkönen et al., 2001).

Changes in haulout behaviour have been noted in pacific harbour seals, with a switch to night-time haulouts during the summer months (Allen et al., 1984; London et al., 2012). Such a switch would reduce the proportion of the population available to be counted during the survey window. We are unaware of any major or widespread changes in human activity, or environmental factors that would have caused a significant shift from day to night-time haulout behaviour around the coasts of the SEE-SMU. To account for the decline any such change would have to have been sudden and coincident with the onset of the decline. Lonergan *et al.,* (2012) reported a higher probability of haulout during the week than at weekends in a study of haulout patterns in adult harbour seals during the annual moult in Orkney and the Inner Hebrides. Throughout the survey programme in the SEE-SMU, flights have generally been restricted to weekends because of military flying restrictions and there have been no recent change in flying schedules. Details of the survey results and trends are presented in SCOS-BP 22/05 and in answer to Q1 above.

Recent surveys of the Greater Thames estuary by ZSL have already detected the first indications of a possible decline in the remainder of the SMU population (SCOS-BP 21/7).

Grey seal numbers have increased dramatically over the past 20 years, but the large grey seal haulout group at Donna Nook, accounting for around 65% of the SEE-SMU total shows a similar levelling off and possible decline, coincident with the harbour seal decline. Conversely, grey seal numbers in the summer surveys have been increasing at The Wash, Blakeney Point, Horsey and most dramatically at Scroby Sands. Over the past five years grey seals have been expanding their haulout range within The Wash and small groups are now appearing in the sheltered tidal creeks at the southern edge of the estuary, which are important pupping sites for harbour seals.

Potential drivers of declines

The underlying drivers of the decline in the SEE-SMU are currently unknown, but its sudden onset and magnitude suggests that, like in the Orkney decline, it cannot be fully explained by decreased fecundity and/or juvenile survival. Instead, there must have been an associated decline in adult numbers. Such a decline in adult numbers could have occurred through increased emigration and/or adult mortality. The most likely main drivers of such changes are increased competition with grey seals, anthropogenic activities, disease or toxins, or interactions therein.

Although not usually considered a major factor in harbour seal population changes, emigration cannot be ruled out as a proximate driver of the decline. Adult harbour seals are generally regarded as being faithful to haulout regions, and there are no records of large-scale movements of adults between remote breeding areas, but there are limited data available to test for such movement.

The decline in the number of seals counted equates to the loss of c.1,500 individuals, which cannot be explained by local redistribution. If mass emigration has occurred, the only plausible destination would be the Wadden Sea. The growth rate in the Wadden Sea has slowed in recent years (1.2% p.a between 2012 and 2020 compared to c. 8.1% p.a. between 2002 and 2012; Galatius et al., 2020). Wadden Sea counts in 2019 and 2020 were slightly higher than predicted by the 1.2% rate. However, the Wadden Sea hosts a much larger population than the SEE-SMU (2020 moult count of c. 28,250) and thus higher variability around counts. Although genetic analyses indicate that there are connections between the SEE-SMU and the Wadden Sea harbour seals (Carroll et al., 2020), there is no evidence (from tagging data) of regular movements of adults. In any case, if mass emigration were to account for the observed declines, it would be indicative of relatively poor conditions for the SEE-SMU population.

The schematic diagram below (***Figure 6***) shows potential contributing factors in the observed decline along with the data that are required to evaluate the relative importance of these factors.

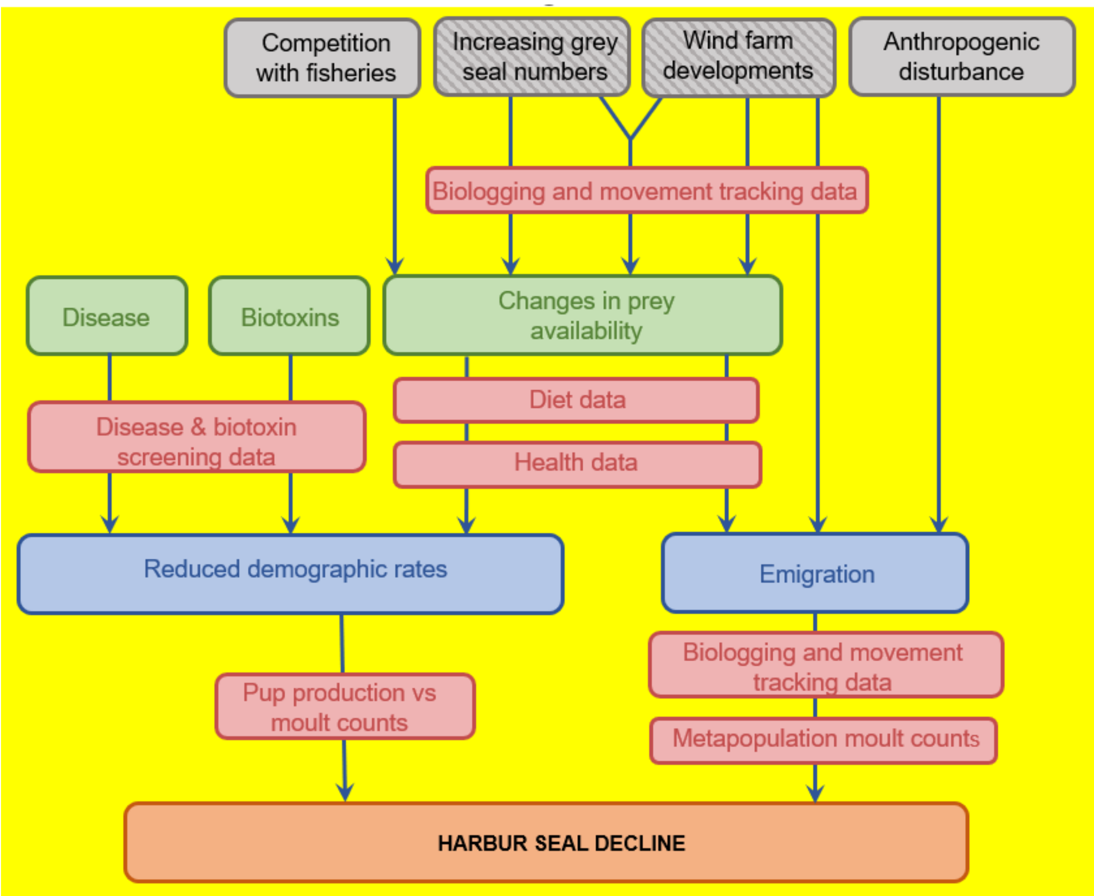

Figure 6. *Schematic representation of potential factors underlying the decline in harbour seals in the SEE-SMU and data required to identify causal factors. Green and blue boxes indicate potential primary and secondary proximate causes. Grey boxes indicate potential ultimate causes (hashed grey boxes represent ultimate causes that have increased coincident with the observed decline). Arrows show potential pathways of impact, and red boxes indicate the data which could be used to evaluate the relative importance of these processes and pathways. It should be noted that this is a simplification and any impacts of disease, biotoxins and diet are unlikely to be independent from each other.*

Grey seals

Grey seal abundance in the SEE-SMU has been increasing rapidly over the last two decades; in 1988 harbour seals outnumbered grey seals by ten to one. By 2020, however, grey seals outnumbered harbour seals by ten to one. SEE-SMU grey seal abundance is now estimated to be >40,000 compared to <2,000 individuals in 2002. The rate of increase suggests that it is, in part, fuelled by immigration of grey seals from further north where populations appear to have levelled off.

Given the contrasting trajectories of the two seal species, which exploit similar prey, it seems unlikely that there has been a sudden reduction in overall prey abundance or quality. However, dietary overlap between the two species gives rise to the potential for competition.

Wilson and Hammond (2019) used 1,976 harbour seal, and 2,205 grey seal scat samples collected between 2010 and 2012 around Scotland and eastern England, to compare the diets of the two species. Results showed considerable seasonal and regional variability, but overall, sandeel and large gadids were the two main prey types for both. Using patterns in diet, trends in seal population size and prey stock size they showed that harbour seals have declined in regions around the UK where they appear to be reliant on sandeel and where sandeel stocks have declined. Declines were not apparent in areas where sandeel had never been an important component of the diet. Sandeel continued to be an important (although reduced) prey in the diet of grey seals in regions where harbour seals have declined. They concluded that in areas where sandeel are a limiting resource, it is possible that grey seals may reduce prey availability to harbour seals and contribute to their decline through competition. Grey seals could cause nutritional stress, via exclusion from prey (interference competition) and/or depletion of prey in the area accessible to harbour seals (exploitative competition).

Grey seals are larger and can out-compete harbour seals, and also have more flexibility in their foraging range by switching haulout areas. It is expected that density dependent effects due to the increasing grey seal numbers would be evident in the harbour seal population trajectory before having any apparent effects on the grey seal population. Indeed, the harbour seal population in the SEE-SMU had recently levelled off after a sustained increase, indicating that the population was at or close to carrying capacity due to a limited resource. This would likely be related to prey availability, given that the other key resource – haulout site availability – does not appear to be limited.

The continued increase in the grey seal population likely puts additional pressure on the harbour seal population, potentially reducing carrying capacity. If that is the case, we would expect the harbour seal carrying capacity to continue to decline as grey seal numbers increase further.

Some grey seal individuals (specialists) also prey on harbour seals (Brownlow et al., 2016) and such events have occurred in the SEE-SMU. It seems unlikely that grey seal predation is a major factor in the sudden decline in the SEE-SMU harbour seal population. The grey seal population is increasing, but there would need to have been a step increase in predation to account for the declines. Such a step change would need to have resulted from a step increase in the proportion of the grey seal exhibiting the behaviour, which is considered unlikely. Large numbers of harbour seal carcasses were recorded along the Norfolk coast in 2010-2012, but since then, although grey seal predation on grey seal pups has continued to be reported from the SEE-SMU, few harbour seal carcasses have been recorded and no increase/spike in observations occurred over the period of the decline. Although unlikely to be the only cause of a decline of this magnitude, such predation may be a contributing factor. Grey and harbour seals also coexist in the Wadden Sea, and harbour seals are again apparently approaching their carrying capacity. Grey seals are increasing rapidly there but their population is still relatively small compared to the harbour seal population, and thus unlikely to be exerting as much pressure on the harbour seal population as in the SEE-SMU. If grey seal numbers continue to increase and competition is a major factor, we could expect to see similar declines in the Wadden Sea harbour seal population in the near future.

Anthropogenic Activity

***Windfarm construction and operation*.**

The second major conspicuous change in the SEE-SMU region since the last PDV epizootic, that may have influenced the harbour seal population is the increase in the number of offshore wind farm developments, with further new developments planned. The magnitude of wind farm development (in term of both numbers and footprints of individual farms) means that changes to the environment are much more marked than historic changes from oil and gas infrastructure. If wind farm construction is linked to changes in seal populations, it would indicate a disproportionate impact on harbour seals compared to grey seals. Pile driving during wind farm construction has clear, short-term impacts on seal distribution at sea, causing significant avoidance by harbour seals at ranges up to 25km from the source (Russell et al., 2016) and potential impacts on hearing threshold (Hastie et al., 2015; Whyte et al., 2020). It is unknown whether or not construction for multiple wind farms over a prolonged period of time may result in emigration or declines in demographic rates, but there are potential mechanisms by which impacts could be realised in the harbour seal populations more so than in grey seal populations.

The foraging range of the harbour seal SAC population overlaps with multiple windfarms including in the vicinity of the entrance to the haulouts in the SAC. Grey seals have larger foraging extents from haulouts and are much less faithful to these haulouts, often using multiple areas (e.g., Donna Nook, The Wash, Blakeney, Scroby Sands) over a period of months. Evidence from tracking data suggests that when harbour seals do move haulout areas, they do not usually return to the original haulout over the timescale of the tracking period (months).

The impacts of structure presence once the turbines are installed are likely to be complex. Such development is unprecedented both in terms of the multi-structure nature of windfarms and the spatial scale. There are likely impacts on fish availability on both local and wider scales through hydrodynamic changes (van Berkel et al., 2020), anthropogenic reef effects (Degraer et al., 2020), and displacement of most fishing and shipping activity (Reubens et al., 2014). Ultimately, the fact that the SAC harbour seal population appeared to have reached carrying capacity prior to the decline, combined with a high level of overlap between the SAC harbour seal foraging locations and wind farms, means that any significant changes in prey availability due to wind farms will likely have an impact on the harbour seal population. Some individual grey and harbour seals focus their foraging efforts at artificial reefs provided by underwater structures (Russell et al., 2014).

Thus, windfarms may provide enhanced foraging opportunities for some predators at the expense of less competitive predators, which are only able to forage in the surrounding environment (McLean *et al.,* 2022). For example, if grey seals out-compete harbour seals through direct interference competition, they may exclude them from foraging hot spots. The contemporaneous increases in both grey seal abundance and wind farm construction in an area could have synergistic negative impacts on harbour seal populations. With current information it is not possible to disentangle any impact of grey seal populations and wind farm developments on harbour seals. However, for conservation and management into the future it is essential that their relative importance is assessed.

Direct human disturbance

Direct disturbance of seals at haulout sites due to either terrestrial or boat based human activity is considered unlikely to be a major driver of harbour seal population dynamics in the SEE-SMU. Although disturbance can cause short term impacts on counts; for the reasons described above, the change in counts likely represents a real decrease in population size. Furthermore, most haulout sites in The Wash and at Scroby Sands are remote and difficult to access and therefore experience little or no direct human disturbance, and thus even if disturbance did cause local redistribution, it could not explain the observed decline. The haulout site at Horsey attracts large numbers of tourists, but seals at that site appear to be habituated to human presence and the numbers of both harbour and grey seals using the site in summer are apparently increasing. The sites at Blakeney Point are accessible to boat-based tourists, and although seals are habituated to seal watching vessels, the groups are often disturbed by private boaters going ashore on the haulout sites. Harbour seal numbers at Blakeney have declined slowly since 2002, but grey seal numbers have increased dramatically over the same period.

Shellfish fisheries in The Wash have the potential to disturb seals, but they operate under specific controls designed to minimise direct disturbance of seal haulout sites. Incidental observations of shellfish harvesting during aerial surveys indicate that no significant disturbance has occurred as a result of these activities (SMRU unpublished data). Again, based on incidental observations during the aerial surveys, recreational boat activity in The Wash is mainly limited to banks close to Skegness and along the northwest coast. Boats often stop near haulout sites, and in rare instances have likely caused disturbance of individual haulout groups. There is no indication that the scale, intensity, or frequency of any of these potential, incidental disturbance factors have changed coincident with the changes in the SSE-SMU harbour seal population.

Seal health and disease

Another factor that could explain a reduction in adult numbers may be changes in seal health, which can be impacted by low prey availability, disease, biotoxin levels, and interactions therein. Data from rehabilitation centres suggest that, in recent years, rescued harbour seals in the SEE-SMU appear to have particularly compromised immune systems (Himmelreich, 2019). A combination of multiple acute and chronic stressors (e.g., nutritional stress) could be contributing to poor immune system function in these animals. Recent evidence shows that many important prey species, such as sandeels, flatfish and pelagic species including herring and mackerel, are contaminated with biotoxins year-round (Kershaw et al., 2021), potentially leading to chronic exposure in seals and reduction of demographic rates. Concentrations vary between prey species, and thus seal species-specific variation in seal diet (potentially mediated through changes in prey availability) will thus influence the extent of their exposure and potential health impacts. Additionally, harbour seals appear to be more vulnerable to infectious disease outbreaks than grey seals (Hammond et al., 2005; Härkönen *et al.,* 2006; Bowedes et al., 2016; Puryear et al., 2016). Thus, the potential impacts of multiple stressors which can compromise overall health are particularly pertinent given a predicted PDV event is imminent.

Although we have not witnessed any rapid increase in reports of dead seals, as seen during previous PDV epidemics, other diseases cannot be ruled out as potential factors at this stage. In other areas of the southern North Sea, there have been mortalities associated with Influenza A (Krog *et al.,* 2015). Although there was no concurrent increase in UK dead seal reports, there have been cases reported in the UK (e.g., Venkatesh et al., 2020). Additionally, phocid herpesvirus infections in seals are associated with disease and sometimes high mortality, primarily in young or otherwise compromised animals, and have been shown to circulate in harbour seal populations in Europe (Roth *et al.,* 2013; Bodewes *et al.,* 2015) and North America (Goldstein *et al.,* 2003). From a disease transmission perspective, the considerable interchange of grey seals between the SEE-SMU and the SMUs further north (Russell 2016) is of concern. As potential carriers of PDV, and other pathogens of importance, grey seals could act as vectors to already compromised harbour seal populations with potential impacts on the UK harbour seal population as a whole.

Proposed research programme

To determine the extent, cause, and implications of the decline in harbour seal numbers in the SEE-SMU, a programme of work is required to meet the following objectives:

a. Quantify the trends in harbour seal abundance and, where possible, breeding success (number of pups produced per year), at multiple spatial scales within the SEE-SMU and neighbouring SMUs in the context of trends in grey seal abundance.
b. Evaluate the extent to which the decline could be explained by emigration.
c. Quantify the degree to which the population is under nutritional stress.
d. Quantify the current prevalence of disease and level of prior exposure in both seal species and its implications.
e. Quantify the level of biotoxins in both seal species and its implications
f. Identify the mechanisms, and potential scale and intensity of any impact of grey seals on harbour seals through competition and predation.
g. Assess to what extent wind farm construction and operation may impact harbour seals and how this may change in the future.
h. Based on a-g, provide plausible scenarios for the future of harbour seal populations in the SEE-SMU.

6. SCOS has previously provided advice on interactions between grey and harbour seals in Scottish waters in terms of direct predation and interspecific competition (e.g., for space and resources). Please can SCOS provide an update on these interactions, specifically whether direct predation is still occurring in Scottish (and global) waters and to what extent and, any scientific evidence for inter-specific competition (space and resources between the species. Furthermore, could these interactions (competition and predation) have caused the regional decline observed in harbour seals around Scotland?	SG 10

Direct predation of pinnipeds by grey seals is still occurring in the Atlantic including Scottish waters. Although the prevalence is unknown, it appears to be geographically widespread and the strandings data from Scotland indicates that it occurs at levels which may contribute to the decline of harbour seals in some areas.

Impacts of inter-specific competition on harbour seals may be realised through exploitative (limited resource) and/or interference (exclusion from resource) competition. There is no evidence that resources on land are limited (haul out or breeding sites). Thus, any competition would likely be due to processes at sea where grey and harbour seals have similar wide-ranging diets.

Grey seal populations appear to have reached carrying capacity in most of Scotland (with the exception of the east coast), most likely due to density-dependent processes acting on pup survival. This is likely largely driven by processes at-sea but the degree to which this is through intra- or inter specific competition and whether it is through interference or exploitative competition is unclear.

The degree of spatial overlap in foraging ranges and the overlap in diets (discussed in Q5 above) means that there is scope for competition between grey and harbour seals around Scotland and along the east coast of England. Although grey seals demonstrate lower haul out site fidelity than harbour seals and are thus potentially more adaptable to changes in prey availability, harbour seals do exhibit considerable flexibility in foraging ranges, and as they are smaller, they have lower absolute energy requirements and require less prey than grey seals. Therefore, prey depletion would not necessarily disproportionately impact harbour compared to grey seals. However, depletion (exploitative competition) could potentially impact the ability for the inexperienced harbour seal pups to find enough food.

There is potential for direct interference competition whereby larger grey seals could potentially exclude harbour seals from foraging patches. Such interference competition could impact all size classes of harbour seals but would likely be more severe for smaller animals.

The potential role of grey seal predation and competition in the harbour seal decline is the focus of a current PhD project based at SMRU in collaboration with SMASS and University of Aberdeen.

Grey seal males have been observed predating on grey and harbour seals, as well as harbour porpoise. The prevalence of this behaviour in terms of how many harbour and grey seals are killed each year is unknown. The behaviour is not restricted to one or two abnormal individuals, but rather is likely an example of a specialist behaviour exhibited by an unknown, and likely varying, proportion of the population across the range of the grey seal. Indeed, within the Firth of Forth, Scotland, four different male grey seals (identified through photo ID) have been observed predating on seals (harbour and grey), with a further six observations for which the individual grey seal could not be identified (due to image quality). At least another seven individual grey seals have been identified and observed predating marine mammals in Scotland, England, Wales, Ireland, and Germany. There is video evidence of a what is likely a female grey seal feeding on a young porpoise in Ireland.

Although the predation event itself was observed, it was not videoed, and it cannot be confirmed that the female seal killed the porpoise as there were other grey seals present, which in itself is unusual.

For individuals exhibiting this behaviour, the rate of predation is also unknown though at least for some individuals it represents a repeated behaviour. A single adult male was observed predating five grey seal pups (Bishop et al., 2016), and presumed to be responsible for a further nine pup carcasses, over a ten day period (Brownlow et al., 2016) - this high rate would be unlikely to be sustained when not on the breeding colony. That rate was higher than would be required to fulfil energy requirements with only a relatively small proportion of the blubber eaten. Evidence from observations and carcasses suggests that such limited eating of the carcass is typical and may be due to the force required to tear carcasses apart increasing as they cool to ambient temperature (D Thompson pers comms). Thus, it is difficult to predict an upper number of seals that a predating individual would kill per week.

It appears that predation is focussed on grey seal pups when these are available. Given that grey seal pup mortality is high (Thomas et al*.,* 2019), impacts on the grey seal population may not be expected. However, predation on female harbour seals has been observed mainly during the summer (Bexton *et al*., 2012). Given that high and consistent adult female survival is required to maintain a harbour seal population, any impact on that rate could cause declines. As part of an ongoing PhD project at SMRU, the prevalence of seal carcasses around Scotland is being examined with regard to species, sex, age and likely cause of death. The level of adult female mortality required to cause declines will be examined in this context.

It seems likely that there is some inter-specific competition given the level of overlap in the diets of the two species (Wilson and Hammond 2019; Planque *et al*., 2020), and that prey intake, mediated through density-dependent processes, appears to be limiting grey seal pup survival. However, the relative importance of exploitative (e.g., where grey seal prey consumption decreases the amount available for harbour seals) and interference competition (e.g., where grey seals reduce harbour seal foraging success by directly affecting their behaviour) both within and between species is difficult to disentangle.

There is evidence of intra-specific competition in grey seals resulting in density dependent pup survival (pup survival to age 1) which for the most part is realised at sea (rather than on the colony). In the Western Isles and Orkney, density dependence is estimated to have reduced first year survival (from 48% to around 14%; Thomas et al., 2019). It seems likely that density dependence effects will impact on pups soon after they leave the colony and could be due to interference and/or exploitative competition. For example, at the Monach Isles, around 10,000 weaned pups enter the surrounding waters over a short period so that competition is both temporally and spatially concentrated. In such a situation, intense density dependence acting on grey seal pup survival would not necessarily result in inter-specific competition with harbour seals. Indeed, these grey seal pups are naïve and take a few months to develop their foraging strategy (Carter et al., 2020) and could be at a competitive disadvantage to surviving harbour seal pups (born in June and July) that have already developed effective foraging strategies by winter.

Interference competition has been postulated as the cause of spatially segregated foraging areas for adult and juvenile grey seals in Canada (Breed et al., 2013). Adult grey seals would be expected to outcompete harbour seals in interference competition. There is considerable overlap in their at-sea distribution particularly on the east and northern coasts of the UK (Carter et al., 2022). The degree to which grey seals are locally abundant enough to exclude harbour seals from productive foraging patches is likely to depend on the degree to which resources are concentrated in limited areas. For example, in the North Sea, the sand banks are key hotspots for prey and thus predators. In the west coast of Scotland, there are less distinct foraging patches and a complex coastline, which may mean that interference competition is less likely to be an issue. The case with exploitative competition is not as straight forward. Harbour seals are smaller and therefore have a lower absolute average daily energy requirement. Grey seals appear to be more adaptable in terms of foraging range and movements between haul outs. However, at least in Scotland, harbour seals forage well within their maximum foraging range suggesting that they may have scope to forage further offshore.

Critically, species must exhibit a degree of niche partitioning to co-exist. The degree to which these species co-existed in the past in unclear. Arguably the biggest difference between grey and harbour seals is in their mating strategies: capital vs income breeders, autumn/winter vs summer breeding, low vs high pup precocity. Harbour seals can thus breed on tidal sandbanks (e.g., Moray Firth, Wash) whereas grey seals cannot. Historically, land predators, including humans, would have prevented grey seals from breeding on mainland or tidally accessible islands, and would have restricted grey seal breeding to offshore islands. Harbour seals can swim from birth and are adapted to breed in areas with only transient tidal skerries and sand banks. Thus historically, grey seals may have been dominant in the west and north coasts of the UK and harbour seals dominant along much of the east coast. Indeed, until the beginning of the 20th century breeding grey seals were absent from the UK's North Sea coastline except for a small number breeding on the Farne islands, where they had been traditionally protected since early medieval times.

The current situation with very large grey seal breeding colonies on openly accessible coast lines along the east coast of England and southeast Scotland is unlikely to represent re-colonisation. Historically, these mainland sites, which have been available since sea levels rose after the last ice age, were unsuitable due to land predators and/or humans. As noted previously (SCOS 2021) harbour seals in the southern North Sea are now likely facing competition from very large numbers of grey seals in an area where such competition did not occur in the recent past and may never have occurred. In 1988 harbour seals outnumbered grey seals by approximately 10:1 in the Southern North Sea. Now grey seals outnumber harbour seals by 10:1. The implications of such a shift warrant further investigation and monitoring (see Answer 5 above).

7. Are breeding and moulting cycles for grey and harbour seals changing and if so, how, and what is the likely cause?	Defra 1c

SCOS are not aware of any publicly available information to indicate a change in the timing of moult or breeding in UK populations of either grey or harbour seals although this reflects absence of information rather than confirmed absence of effect.

Evidence from the Wadden Sea shows that timing of the onset of the grey seal moult was highly variable over a seven year period and that variability was not explained by the environmental factors that were investigated.

Timing of pupping in the Wadden Sea harbour seal population moved forwards by three weeks between 1974 and 2010. As timing of moult is likely associated with timing of breeding it is possible that the Wadden Sea harbour seal moult has also changed over that period. Conversely, in The Wash population the dates of peak pup counts from the early 1970s were similar to the peak dates in the 2010s.

Grey seal pupping dates at Skomer varied widely over a 20 year study period but showed no overall trend. A similar but much larger study of the Sable Island grey seal population showed a progression of mean pupping date of 16 days over a 30 year study. The drift in pupping dates was ascribed to demographic changes, but pupping dates were influenced by environmental factors.

Timing of moulting

SCOS are not aware of any publicly available information to indicate a change in the timing of moult in UK populations of either grey or harbour seals. However, there are no large-scale monitoring programs capable of providing such information. Grey seals are not surveyed during their annual moult in the UK, and although harbour seals are surveyed during their moult, the monitoring programme is based on either one or two surveys each year for the large estuarine haulout groups on the east coast, or single surveys at approximately five yearly intervals for the rest of the population around Scotland.

Schop *et al.,* (2017) examined the onset of moult in wild grey seals using aerial photographs of the Wadden Sea population over seven years between 2004 and 2007. They found that onset of moult was highly variable and was not explained by the environmental factors they investigated.

While changes in timing of grey seal moult would be of academic interest, changes in timing of moult in harbour seals would have potentially significant implications for the harbour seal population monitoring programme. Harbour seal surveys are carried out during the annual moult as this is the period when we expect the highest proportion of the population to be hauled out, and because of the physiological requirements of the moult, we expect low variability in the probability that individual seals haulout. However, using the count as an index of population size relies on the assumption that the same proportion of the population is hauled out each time they are surveyed.

Although Reijnders *et al.,* (2010) only investigated harbour seal pupping phenology (see below), the association between pupping and the moult suggests that there was likely a commensurate change in the timing of the moult between 1974 and 2010. To date this is the only study to have demonstrated a significant change in harbour seal phenology. As part of preliminary investigations of the declines in some Scottish SMU populations 25adult harbour seals were fitted with satellite transmitters attached to flipper tags to look for differences in timing of moult in rapidly declining and stable populations in Orkney and the West Scotland SMUs (Lonergan *et al*., 2013). No difference in timing of moult was detected. Although these data do not contain information on trends in timing of moult, they do indicate that the drivers of major population changes were not apparently affecting timing of moult.

Cronin *et al.,* (2014) investigated the phenology of the harbour seal moult in south-west Ireland and showed that timing of the moult differed among all cohorts; yearlings began moulting first followed by adult females and finally adult males. Although the study did not examine trends in the timing of the moult it showed that timing of moult in Ireland was different to other parts of the species' range.

Timing of pupping.

There are anecdotal reports of earlier pupping in grey seals from several locations, usually in the form of reports of first births. Without substantially more information on the timing of births within and between seasons it is difficult to assess the significance of such reports.

In grey seals there are two long term monitoring programmes that allow examination of long-term trends in timing of pupping. Bull *et al.,* (2021) used timing of first birth and estimates of mean pupping dates to investigate long term trends in timing of births on Skomer Island. No long-term trend was detected, with median pupping dates apparently oscillating between mid-September and early October over the past 20 years. Bull *et al.,* suggest that this oscillation resulted from changes in population age structure that was itself responding to changes in an index of sea surface temperature. It is not clear how such putative bi-directional changes in age structure could occur in a long lived, slowly reproducing species, nor if the changes represented permanent changes in age structure or temporary immigration/emigration of breeding females of different ages. It is also unclear how the proposed changes in age structure would differ from purely local effects involving movements or changes in recruitment to Skomer and nearby breeding sites on the adjacent mainland coast. Bowen *et al.,* (2020) studied phenology over a 30-year period at Sable Island, Canada, and showed that mean birth dates moved forwards by approximately 16 days. The rates of change were lower than reported from Skomer. Bowen *et al.,* also suggest that the drift in pupping season was likely due to demographic changes, and they showed that females of all ages responded to environmental forcing. They also concluded from data on 2,768 pups that birth date had no impact on pup weaning mass and by implication would have no detectable impact on post weaning survival.

Reijnders *et al.,* (2010) reported that mean birth dates of harbour seals in the Wadden Sea moved forward by 21 days between 1974 and 2009, and by up to 25 days in the Dutch sector of Wadden Sea. They examined the effects of changes in population demography, changes in maternal life-history traits and variations in environmental conditions to investigate the drivers of the change in phenology and concluded that the most likely mechanism was a shortening of embryonic diapause and postulated that this could have been due to increased prey availability.

A time series of harbour seal pup counts in The Wash includes multiple surveys in 2008,2009, 2015, 2016. No clear change in timing of the peak number of pups ashore was detected over the eight year period. Another season with multiple surveys is planned for the near future and will provide an opportunity to investigate changes in timing of pupping.

Seal Management and Conservation

Seal Licensing and PBRs

8. Can SCOS provide updated Potential Biological Removals (PBRs) figures for 2022?	SG Q5

In the UK, safe level of anthropogenic takes from defined populations (SMUs) is based on the Potential Biological Removals method (Wade, 1998) which uses information on intrinsic rates of increase for the species in question, recent conservative population estimates (N_{min}), and a recovery factor F_R set between 0 and 1 based on the current population trajectory of the SMU. The method and criteria for selecting F_R values and the population data used in the calculations are described in SCOS-BP 22/07.

PBR values have been updated for Moray Firth and East Scotland. In August 2021 surveys were carried out of the harbour and grey seal populations in the Moray Firth and the East Scotland SMUs. Counts of harbour seals in the Moray Firth were 32% lower than in 2019 and in east Scotland were 24% lower than the previous survey in 2016-2018. As a consequence, the PBR for harbour seals is reduced from 6 to 4 in Moray Firth and from 2 to 1 in East Scotland. Counts of grey seals were 12% higher and 24% lower respectively than previous surveys, so PBR for grey seals is increased from 370 to 414 in Moray Firth and reduced from 823 to 605 in East Scotland.

PBR estimates for both harbour and grey seals for each SMU in Scotland, together with a description of the calculations and the rationale for selection of SMU specific Recovery Factors (F_R), and N_{min} values are presented in SCOS-BP 22/07. PBR values for the grey and harbour seal "populations" that haul out in each of the seven SMUs in Scotland are presented here (*Table 11 & Table 12*), based on suggested values for the recovery factor and the latest confirmed counts in each monitoring area. Recovery factors are unchanged from 2021.

Table 11. *Potential Biological Removal (PBR) values for harbour seals in Scotland by SMU for 2023. The most recent population data, estimates of N_{min} and the recommended FR values are shown.*

	2016-2021		**selected**	
Seal Monitoring Unit	**count**	**N_{min}**	**FR**	**PBR**
1 Southwest Scotland	1709	1709	0.7	**71**
2 West Scotland	15600	15600	1.0	**936**
3 Western Isles	3532	3532	0.5	**105**
4 North Coast & Orkney	1405	1405	0.1	**8**
5 Shetland	3180	3180	0.1	**19**
6 Moray Firth	690	690	0.1	**4**
7 East Scotland	262	262	0.1	**1**
SCOTLAND TOTAL	26378	26378		**1144**

Table 12. *Potential Biological Removal (PBR) values for grey seals in Scotland by SMU for 2023. The most recent population data, estimates of N_{min} and the recommended FR values are shown.*

	2016-2021		**selected**	
Seal Monitoring Unit	**count**	**N_{min}**	**FR**	**PBR**
1 Southwest Scotland	517	1927	1.0	**115**
2 West Scotland	4174	15554	1.0	**933**
3 Western Isles	5773	21512	1.0	**1290**
4 North Coast & Orkney	8599	32043	1.0	**1922**
5 Shetland	1009	3760	1.0	**225**
6 Moray Firth	1856	6916	1.0	**414**
7 East Scotland	2712	10106	1.0	**605**
SCOTLAND TOTAL	**24640**	**91818**		**5504**

9. Can SCOS advise on whether there should be a closed pupping season during which seals should not be killed or taken to conserve seals or other wild animals (including wild birds) or wild plants (section 110 (1) (c))?	SG Q6

The primary reasons for imposing a closed season would be animal welfare concerns. Killing a lactating female seal will, in most cases, lead to death by starvation for her dependent pup. This will undoubtedly lead to prolonged, severe suffering for that pup.

In terms of impact on a population, killing a female seal removes that individual and her potential, future reproductive output. Therefore, in terms of direct effects on the numbers of seals, and the effects on future population trends, there is little difference between killing lactating adult female seals or killing pregnant seals at any other time of year.

Killing seals at a breeding site, during the breeding season could involve significant disturbance which could lead to death by starvation for some additional pups.

The killing or taking of seals can only be carried out under licence. Given the high degree of control that such a management system allows, a de-facto closed season could be imposed by requiring due consideration of the welfare implications in any application to kill or take seals or by the application of specific conditions.

Taking seals in such a way that lactating adult females are permanently removed would have the same consequences as killing an adult female in terms of the welfare of dependent pups. However, "take" covers a wide range of activities including temporary disturbance during seal capture for research. Experience shows that such activities have no detrimental effect on individual seals or their dependent offspring. A nuanced approach to licecnsing that takes such factors into consideration would remove the requirement for establishing closed seasons.

The primary reasons for imposing a closed season would be animal welfare concerns. Killing a lactating female seal will, in most cases, lead to death by starvation for her dependent pup. This will undoubtedly lead to prolonged, severe suffering for that pup.

Killing seals at a breeding colony during the breeding season could involve significant disturbance of the breeding groups. For grey seals there is anecdotal evidence to suggest that culling activities caused severe disturbance, increased pup mortality, and possibly caused re-distribution of breeding seals to other sites. Such effects could lead to death by starvation for some pups. For harbour seals any attempts to kill seals at breeding haulouts will inevitably lead to short term disruption of haulout and suckling. It is less clear that there would be longer lasting or widespread disruption to other seals. Breeding female harbour seals forage during lactation and could therefore be targeted at sites remote from breeding sites. In such a case there would be no disturbance of non-target mother pup pairs.

In terms of impact on a population, killing a female seal removes that individual and her potential, future reproductive output. Killing an adult female seal during the breeding season is likely to result in the death of her pup. However, because fecundity rates are high, any adult female shot outside the breeding season is likely to be pregnant and killing the female will kill the foetus. Therefore, in terms of direct effects on the numbers of seals, and the effects on future population trends, there is little difference between killing adult female seals at any time of year.

The population consequences of killing a juvenile seal will depend on the time of year. First year mortality is thought to be extremely high (c. 85%) in grey seal populations that are close to carrying capacity. Killing a pup during the breeding season will therefore have little or no effect on the number of animals surviving to age 1. Killing pups outside the breeding season, particularly late in the year, after natural mortality has removed a large proportion of juveniles, will have a greater impact on the number of seals surviving to age 1.

The killing or taking of seals can only be carried out under licence. A de-facto closed season could be imposed by taking due consideration of the welfare implications of any application to kill or take seals. It is not clear if current licensing guidelines in the UK allow such considerations or specific time or location conditions to be applied when granting licences to kill seals.

Taking seals in such a way that adult females are removed, and mother pup bonds are broken would have the same consequences as killing an adult female in terms of the welfare of dependent pups. However, "take" covers a wide range of activities including temporary disturbance during seal capture for research. Experience shows that such activities have no detrimental effect on individual seals or their dependent offspring.

A nuanced approach to licecnsing as already practiced in Scotland should remove the requirement for establishing blanket closed seasons. SCOS recommends that the animal welfare implications of any licence application to shoot seals during the breeding season should be given careful consideration.

If a closed season is to be set, it should cover the period from the start of pupping to the end of lactation for the last pups born. For grey seals there is a clockwise cline in pupping dates around the UK coastline, with significant numbers of pups being born in late summer/early autumn in SW Britain and in January in SE England where suckling pups will still be observed in late January. Therefore, any closed season should be tailored to account for local timing of pupping. In Scotland, the onset of pupping in the Inner Hebrides is in early September but in the Firth of Forth it is usually around the middle of October, so applying a single closed season for all regions may not be the most efficient method. Suggested dates for closed seasons for grey seals around Scotland are presented in ***Table 13***.

For harbour seals there are no reliable data on first pupping dates except for the study sites in Orkney and Skye and the long term study site in Loch Fleet. Pup counts from multiple aerial surveys within individual breeding seasons are available from four years in The Wash and several years in the Moray Firth. These data could be used to fit birth curves for harbour seals and in combination with information on birth dates and lactation durations could be used to define appropriate closed seasons for harbour seals.

Table 13*. Suggested dates for closed seasons in the main grey seal breeding areas around Scotland, based on estimates of start and end of pupping from aerial survey data and observations on the Isle of May and North Rona, and a conservative estimate 20 days lactation.*

Pupping region.	start of pupping	end of pupping	Suggested closed season
Inner Hebrides	early September	late October	September-November
Outer Hebrides	early September	late November	September-December
Northern Isles	early October	Mid December	October- December
Firth of Forth	mid October	late December	mid October-mid January

10. Following on from last year's question on Potential Biological Removal values (Q21), and the differences outlined between the use of the PBR for Scottish seal monitoring units and that for UK populations to inform the USA Marine Mammal Protection Act (MMPA); can SCOS advise which is the preferred method for use or whether other population viability models would be more suitable to best understand population level impacts that may occur from anthropogenic activities.	SG Q7

The two alternative PBR calculations (individual SMU-based and UK-wide) were made to satisfy different requirements and it is likely that the preferred method will differ depending on the spatial scale associated with the management issue being addressed.

SCOS recommends that management of UK seals should where appropriate be based on the PBR estimates (derived using summer survey counts) for individual SMUs, combined across multiple SMUs where ecologically relevant or necessary, to produce sensitive PBR estimates appropriate to the management issue under consideration. SCOS Noted that the uncertainty in population estimates increases with time since the last survey and this increased uncertainty should be accounted for in PBR estimates.

Two types of alternative approach to the PBR are available; rule-based methods and predictive modelling methods. Both require a population dynamics model. The essential difference between the two approaches is that the rule based approaches incorporate explicit rules for decisions about the level of acceptable removals.

Rule-based methods, including the International Whaling Commission Revised Management Procedure (IWC RMP) and the Canadian Precautionary Approach to Marine Mammal Harvests, use population size and trend estimates to set thresholds on the number of individuals that can be removed without a significant detrimental effect on the population.

A widely used predictive modelling method is population viability analysis (PVA), which estimates the probability that a population would go extinct within a given time frame. The model structure usually involves a matrix population model or an individual based model (IBM).

Off-the-shelf software packages have been developed to carry out predictive modelling as part of a PVA and have been widely used to predict impacts of human activity on marine mammal populations. Data requirements, model structure and assumptions are presented below together with examples of their application for marine mammal management issues.

Both rule based and predictive modelling will use similar estimates or ranges of demographic parameters, and similar assumptions about population structure. It is therefore likely that they will predict similar population responses to removal of set numbers of individuals.

The two alternative calculations were made to satisfy different requirements and it is likely that the preferred method will differ depending on the management issue being addressed.

In 2021, JNCC entered population data and PBR estimates into the NOAA bycatch portal to comply with requirements under the USA Marine Mammal Protection Act. The values posted differ from the PBR values calculated for individual SMUs presented in the preceding SCOS report. SCOS do not consider that there is a specific preferred option. The two alternative calculations were made to satisfy different requirements and it is likely that the preferred method will differ depending on the management issue being addressed.

Given that there are now two different sets of PBR calculations in the public domain it is important that the differences and the justifications for the two sets are clearly understood. A detailed description of the two sets of calculations was provided in SCOS 2021. The two sets of calculations are described below.

UK-wide PBRs.

A UK wide PBR estimate was calculated to satisfy the requirements of a specific transnational trade issue, where the foreign partner had a legislative requirement for information to be entered in a standardised format. That entailed calculation of a single UK-wide PBR, which was based on different metrics for grey and harbour seals:

- For grey seals the UK population estimate and N_{min} values were based on the output of the population dynamics model that converts pup production estimates to total population size (SCOS-BP 21/05).
- For harbour seals the UK population estimate and N_{min} values were based on the pooled counts of seals hauled out during the annual moult, scaled by an estimate of the proportion of seals hauled out and an estimate of the variability of that scaling factor (SCOS-BP 22/04).

SMU PBRs

The PBRs in the SCOS reports are estimated for each individual Scottish SMU and are based on the most recent summer counts of grey and harbour seals hauled out in each SMU. As most interactions with human activities and management actions are likely to occur while seals are dispersed outside the breeding season, there is a need to allocate management targets (in this case PBR estimates) appropriately across all SMUs. This is particularly important for grey seals that disperse widely from their breeding sites with the consequence that several SMUs hold substantial populations during the summer foraging season but do not have large grey seal breeding sites.

The best estimate of the number of seals in an SMU is the number counted there, corrected for the proportion that are not hauled out and are unavailable to be counted. The methods used for grey and harbour seals differ slightly.

- Grey seal counts from the August surveys are multiplied by a factor derived from telemetry data which showed that around 25.15% (95% CI: 21.45-29.07%) were hauled out during the survey windows (Russell et al., 2021). These data suggest that the N_{min} (the 20th percentile of the estimated population size) should be 3.73 x count.

- Harbour seal PBR estimates are based on the most recent summer counts of harbour seals hauled out in each SMU. A highly precautionary approach is employed, using the moult count as a proxy for N_{min} rather than estimating the lower 20th percentile of the population estimate. This means that the PBRs presented in the SCOS report are approximately 28% lower than estimates based on the 20th percentile. Given the continued declines in Orkney and North coast SMU and the Tay and Eden SAC as well as the absence of any recovery in Shetland or the Moray Firth SMUs, this policy has remained in place.

The PBR method was developed to manage anthropogenic impacts on discrete functional population units. The individual SMU approach violates the assumption that the populations are discrete/closed, particularly for grey seals. This is taken into account when deciding on the appropriate F_R for harbour seals. It is not a concern for grey seals where the F_R is set to 1 in all SMUs so that the sum of the individual SMU PBR estimates is the same as the PBR for all the SMUs combined. As widely discussed in SCOS 2020 there can be difficulties in managing wide-scale issues using the individual SMU approach. However, pooling groups of SMUs to address specific wide-scale issues should address such problems. On the other hand, using a single UK-wide PBR approach implicitly assumes a fully mixed population and thus precludes fine scale management of localised issues or at least requires that the national PBR be subdivided in some appropriate way.

SCOS recommends that as long as PBR is the accepted method for estimating safe takes from UK seal populations, management of UK seals should, where possible, be based on the PBR estimates for individual SMUs, based on summer counts of hauled out seals, combined where appropriate to produce sensitive PBR estimates appropriate to the management issue under consideration. Of paramount importance in the application of PBR is the uncertainty in population estimates. N_{min} is set to the 20th percentile of the population estimate, to provide an appropriate degree of precaution. However, in a dynamic population the uncertainty in the population estimate will increase with time since the last survey. At present no account is taken of this in UK PBR estimates. However, the method used to select the recovery factor does take some account of the confidence in the population estimate and the degree to which the population can be considered closed.

Alternatives to PBR

SCOS 2020 (Q10) provided information on a range of alternative population modelling approaches for assessing anthropogenic impacts, with specific reference to grey seals in SW British Isles. Several such models were reviewed by Sparling *et al.,* (2017) to provide an accessible summary reference guide to marine mammal population modelling for statutory nature conservation bodies (SNCB) for assessing potential impacts on marine mammal populations.

There are essentially two types of approach, rule-based methods and predictive modelling methods, although this distinction is somewhat artificial as plausible/accepted population models are required to underpin the rule-based methods.

Rule-based methods that originated from the management of exploited populations use information on the current size and health of populations to set thresholds on the number of individuals that can be removed without having a significant detrimental effect on the population. In addition to the PBR, two other methods have been developed specifically for managing marine mammal populations under exploitation: the International Whaling Commission Revised Management Procedure (IWC RMP) which was developed to set safe limits for sustainable harvesting of whale populations (Cooke 1999, https://iwc.int/rmpbw) and the Canadian Precautionary Approach to Marine Mammal Harvests (Stenson *et al.,* 2017).

One widely used predictive modelling method is population viability analysis, a process of quantitative risk assessment developed in the field of conservation biology to estimate the probability that a population would go extinct within a given time frame. PVA has been extended for a wide range of uses – including the prediction of the potential consequences of impacts of developments on marine mammal and bird populations (e.g., Maclean et al., 2007; Thompson et al., 2013). The exact approach and model structure will vary depending on the question being addressed, but usually involve either a matrix population model or and individual based model.

A number of off-the-shelf software packages have been developed to carry out predictive modelling as part of a PVA e.g., VORTEX (Lacy, 2000) and ULM (Unified Life Models; Legendre & Clobert, 1995). VORTEX has been used as a predictive modelling tool in the assessment of the impact of offshore wind farm construction on bottlenose dolphin populations in the Moray Firth and the outer Firth of Tay (De Silva et al., 2014) and for cumulative assessments on the east coast of Scotland by Marine Scotland Science. Similar methods were used in the 'Moray Firth Seal Assessment Framework' (MFSAF; Thompson et al., 2013), where an existing stage-based matrix model of the harbour seal population in the Moray Firth was used to simulate the trajectory of impacted and baseline populations.

For matrix based predictive methods, estimates of population size, and of age-or stage-specific birth and death rates are required. Information on density dependence effects and an estimate of carrying capacity are usually required but are seldom available. For IBMs the survival and reproductive rates of individuals are determined by their actions during simulation and therefore population vital rates and the carrying capacity of the environment (and therefore resultant DD) are emergent properties of the models, but the outputs are critically dependent on the assumed link functions in the models.

Both rule based and predictive modelling will use similar estimates or ranges of demographic parameters, and all involve similar assumptions about population structure. It is therefore likely that they will predict similar population responses to removal of set numbers of individuals. The scale of allowable removals will likely be influenced heavily by the degree of precaution applied by the user and the way in which density dependence is implemented in the models.

For harbour seals, an integrated population model is currently under development as part of the Scottish Government funded MMSS programme. Such a model could be used to evaluate the evidence for the potential proximate and ultimate causes of the local declines. However, while a flexible population dynamics model has been developed for the Moray Firth where there are long time series of data on both population size and pup production, the capacity to extend such models to harbour seal populations around the rest of Scotland will be limited by lack of data. Long time series of population and pup production estimates also exist for The Wash harbour seal population where the population has undergone a recent decline. Notwithstanding the fact that The Wash population represents only a proportion of the SEE-SMU, the available data and additional information being collected to investigate causes of the recent declines in that population may provide an opportunity to compare PBR with predictions of PVA based on more complicated/flexible population dynamics models.

For grey seals, the impact of “takes” could, in principle, be incorporated into the population-model currently used to estimate population size for the regularly monitored colonies. Such a model has already been implemented to account for the impact of the Canadian grey seal harvest (Stenson et al., 2012). It would allow age-specific “takes” to be modelled and thus impacts considered, given age-specific survival and density dependence. For example, a “take” of 20% of pups in the first few months of life would not have a significant impact on the population trajectory in an area where density dependent pup survival means only a small number can survive the first years (e.g., at carrying capacity estimated survival to age 1 is c. 14%).

However, there are additional considerations that need to be addressed before such a method could be applied to practical management issues. The current population model is based on regional pup production estimates and is therefore representative of the breeding distribution rather than the summer distribution. Most of the putative “takes” of grey seals occur outside the breeding season when grey seals are more widely distributed, and after pup dispersal.

Other considerations would be the restricted spatial extent of the population model, and how the regions of the population model relate to the SMUs. The southwest UK, where most of the bycatch occurs, is not incorporated in the UK population models. The paucity of information on either the pup production or the summer distribution and abundance of grey seals in Wales and SW England precludes their inclusion in the population model. Indeed, recent attempts to extend the model to incorporate SW British seals led to a dramatic widening of the confidence intervals. The SW British grey seal population is the only case where takes are thought to be close to current PBR estimates, but it is clear that with currently available data on both pup production and summer population distribution, using a population model would be unlikely to generate increased allowable takes for the southwest.

Both rule based and predictive modelling will use similar estimates or ranges of demographic parameters, and all involve similar assumptions about population structure. It is therefore likely that they will predict similar population responses to removal of set numbers of individuals. The scale of allowable removals will likely be influenced heavily by the degree of precaution applied by the user and the way in which density dependence is implemented in the models.

Bycatch and depredation

11. What are the latest estimates of seal (grey and harbour) bycatch across fisheries in Scotland and the wider UK?	SG Q9
What are the latest bycatch estimates for grey seals in the UK, especially Southwestern British Isles, including Ireland?	NRW Q2

The most recent estimated bycatch of seals in UK fisheries was in 2020. The total estimate was 356 animals (95% CI 269-671). Most bycatch in UK waters occurs in large mesh gill net/tangle net fisheries; rare and sporadic captures in trawl fisheries are discussed below. The estimated bycatch was 27% lower than for the previous year (488), but the confidence intervals are wide and overlap with previous estimates and fishing effort was reduced in 2020. Bycatch estimates for ICES Divisions are presented in *Table 14*.

Sampling under the UK Bycatch Monitoring Programme in 2020 was severely disrupted by Covid 19 restrictions. Approximately 81% of the 2020 bycatch estimate occurs in the south-west, in ICES area 7, where the UK gillnet/trammel/tangle net fishery is concentrated. The remainder occurs in area 4 which covers the North Sea and waters around Shetland and Orkney with less than 3% occurring in area 6 around the Hebrides and Northwest Scotland. Estimated bycatch in area 6 and area 4a was 46 seals.

Most seals that have been examined were young grey seals. Although species I.D. is uncertain where seals cannot be brought on deck this is unlikely to be a major issue as all the seal bycatch in gillnets occurs in the southwest where harbour seals are rare. SCOS recommends that effort should be directed towards identifying the species, sex and age structure of bycaught seals. Of particular importance is the collection and analysis of skin samples for genetic profiling to identify the source populations of the bycaught seals in south-west UK fisheries, and identification to species for the North Sea bycaught seals.

There is now a mandatory requirement for fishers to report any bycatch of marine mammals to the MMO, within 48 hours of the end of the fishing trip. Information from these reports should be available for the next SCOS meeting.

In order to continue to export fisheries products to the United States, and to assist conservation efforts in mitigating marine mammal bycatch, there is now a mandatory requirement for fishers to report any bycatch of marine mammals to the MMO, within 48 hours of the end of the fishing trip. The reporting template requires information on vessel i.d., location, gear type, target species, presence/absence of an observer, marine mammal species and number. The information supplied by fishers will be used to report on incidental injury, mortality, or bycatch of marine mammal species at an aggregated level to the National Oceanic and Atmospheric Administration (NOAA) in order to comply with their reporting requirements. Data from this scheme should be available for the next SCOS meeting.

Seal bycatch estimates

It should be noted that the following discussion refers to the bycatch in UK registered vessels. Bycatch in non-UK vessels in UK waters has been estimated by ICES Working Group on Bycatch (WGBYC) but the published results do not allow calculation of overall bycatch estimates (ICES, 2022). Those results are discussed below. The following discussion is therefore based primarily on the UK Bycatch Monitoring Programme (UKBMP).

Sampling in the UKBMP during 2020 was severely impacted by the onset of the Covid-19 pandemic in early 2020 which led to a series of national lockdowns. The restrictions on movement and social mixing meant that for significant parts of the year no at-sea data collection was undertaken. Covid-19 protocols also meant that initially only smaller day boats were sampled on which observers could remain outside on deck for the duration of the trip. This, and the understandable reluctance of some skippers to carry observers due to infection risk, meant that sampling levels were significantly below normal levels. The static net sampling in 2020 focussed on smaller vessels in Subarea 7 which coincides with the highest concentrations of netting effort in UK waters.

Seal bycatch estimates for the UK are made for both species of seal (grey and harbour) combined (Kingston *et al*., 2021). Most seals that have been examined were young grey seals, and all seals taken in gillnets were taken in the southwest where harbour seals are rare. Although it is reasonable to assume that almost all of these bycaught animals are grey seals, for bycatch in the North Sea at least, a proportion of the bycatch were harbour seals. The numbers of harbour seals recorded are too low to generate a useful bycatch estimate, so a single combined seal bycatch total is calculated.

The total seal bycatch estimate by UK vessels in UK waters in 2020 is 356 animals (95% confidence limits 269-671). The mean estimate is 27% lower than for the previous year (488), but the confidence intervals are wide and overlap. Estimates of seal bycatch have fluctuated year to year since records began in 2013 but have generally been in the region of 400-600 seals per year, with no clear trend (***Table 14***). The lower 2020 estimate will to some extent be due to the effects of Covid-19 which directly reduced fishing effort across most gear categories in 2020; demersal trawls and seines, pelagic trawls, and static net fisheries showed 15%, 3%, and 19% reductions in effort respectively compared to the mean effort from 2018 and 2019.

In 2020 no seal bycatch was recorded on any of the vessels with observers onboard. This clearly represents a significant reduction in the number of observations compared to previous years but is almost certainly related to the significant drop in observation effort stemming from the impacts of the Covid-19 pandemic rather than an indication of reduced bycatch rates and mortality during 2020.

The calculation of bycatch rates uses sampling data over multiple years. For species such as seals that do not exhibit large, short-term fluctuations in population abundance or bycatch rates this allows robust mortality estimates to be calculated across metiers when sampling levels might be considered low, or when particular metiers or fisheries have not been sampled in a year, or where no bycatch was recorded in a particular year.

No specific sub-regional small scale hot spots in bycatch levels have been identified in UK fisheries. Recent analysis of data from the Irish EEZ (Luck *et al.,* 2020) shows that bycatch rates are related to proximity to areas of high seal density, around haulout sites and in inshore waters in particular. That analysis suggests that bycatch estimates can be significantly biased by the distribution of sampling effort. Increased marine mammal bycatch monitoring on French, Irish and other EU registered vessels fishing in this region would be helpful. UK sampling has covered all vessel categories (inshore and offshore) in this region, though sampling from Welsh ports and in the Bristol Channel has been limited and could be increased. The potentially large takes in these fisheries mean that the bycatch rates presented above may significantly under-estimate the scale of the problem.

Table 14. *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
2019	488	375-872
2020	356	269-671

Distribution of bycatch

The published data are not presented at sufficiently high resolution to ascertain whether there are any particular local hotspots of bycatch within particular ICES areas, but we are not aware of any such persistent hotspots.

Table 15 shows the estimates for UK registered vessels by ICES Division and general area. Approximately 74% of the bycatch (262 seals) was estimated to have occurred in ICES area 7, around the south and south-west of the UK and Ireland. The majority of this occurred in the Western Channel and Celtic Sea (around 191 seals per year), largely due to the concentration of gillnet/tangle net fishing effort. Seals are present in the Western Channel and Celtic Sea, but densities are likely to be lower than around Scotland or in the North Sea. Bycatch rates in the Eastern Channel are estimated at around 62 seals per year.

Estimated total bycatch by UK boats in Scottish waters is not directly available from the current monitoring programme, due to the mismatch between national boundaries and ICES statistical divisions. ICES subarea 6 comprises mainly Scottish waters off the west coast but includes some Northern Irish and Irish waters; ICES division 4a comprises Scottish waters off the north and east coasts. The combined bycatch estimate for ICES subarea 6 and division 4a in 2020 was 46 (95% confidence limits 38-55), representing around 13% of the UK total.

It is likely that the above estimate of UK registered vessel bycatch is a gross underestimate of the total bycatch, particularly in the Southwest. Bycatches (of unknown extent) by Irish, French, and Spanish vessels working the same areas will add to the total. Luck *et al.,* (2020) estimated total bycatches of between 202 and 349 seals per year between 2011 and 2016 by all vessels within the Irish EEZ. Unfortunately, these cannot be simply added to the UK vessel bycatches as the Irish EEZ figures will include some of the UK registered vessel bycatch. Although bycatch was not broken down by country of registration, the fishing effort by French vessels (43%) was similar to the combined effort by Irish (21%) and UK (23%) registered vessels in the Irish EEZ. In addition, some French and Irish vessels fish in UK waters and will also likely take seals as bycatch but are not included in either Kingston *et al.,* (2021) or Luck *et al*.'s (2020) estimates.

***Table* 15.** *Estimated number of seals bycaught in UK net fisheries in 2020, by ICES Division. Estimates rounded to nearest integer*

Region	ICES Division	Estimated total bycatch	Two-Sided 95% LCL	Two-Sided 95% UCL	One-sided 90% UCL
North Sea	4a	36	30	43	41
	4b	2	1	3	2
	4c	43	35	64	58
West Scotland offshore	6b	10	8	12	12
Irish Sea	7a	1	1	5	4
	7c	8	6	9	9
Eastern Channel	7d	62	45	125	103
Western Channel and Celtic Sea	7e	104	83	152	138
	7f	74	61	99	91
	7g	7	6	15	12
	7h	4	3	7	6
	7j	2	1	2	2
Biscay	8	3	2	3	3

The UK vessel estimates therefore represent an unknown proportion of the overall bycatch off the southwest British Isles. Estimated bycatch of seals by non-UK registered vessels in UK waters as well as total bycatch estimates for Irish waters have recently been compiled by the ICES WGBYC. The data are reported as number of bycaught seals, by metier and ICES fisheries area (ICES, 2022). A total of 17 grey seals (2 from the Greater North Sea and 15 from the Celtic Seas), 52 harbour seals (6 from the Greater North Sea and 51 from the Celtic Seas) and 3 unidentified seals (2 from the Greater North Sea and 1 from the Celtic Seas) were reported under the WGBYC data call.

Bycatch totals for a five year period (2017-2021) were calculated only for trammel and trawl nets (metiers GTR and OTM) for the Celtic Seas, producing an estimated bycatch of 1323 grey seals over the five years. Totals were not calculated for grey seals from set gill nets (metier GNS) or drift nets (metier GND) due to potential biases in the monitoring programme. However, GNS accounted for approximately 90% of the observed bycatch. Obtaining a realistic total bycatch including this metier is clearly required for any assessment of the scale of bycatch. No totals were presented for harbour seals in the Celtic Seas or for either species in the North Sea. There are therefore limits to the conclusions that can be drawn from the data, and the large number of harbour seals reported from the observer programme in area 7j is a potential cause for concern.

Gear type

Most of the seal bycatch recorded in 2020 was in large mesh tangle nets and trammel nets, which accounted for 90% of the estimated bycatch. Effort in these fisheries is highly focused in areas 7d, e & f (61% of UK tangle net effort). Reflecting this, sampling has been focused mainly in 7d-g. Areas that are under-sampled and where there is either a large amount of fishing 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).

No seal bycatch was reported from trawl fisheries in 2019 or 2020. In 2018, six grey seals were reported caught in sandeel trawls. Seal bycatch records in trawl fisheries are clumped, often involving several individuals in one location, but the overall recorded mean bycatch rate is very small and will have extremely wide confidence intervals, so no estimate of trawl fishery bycatch is included in the annual bycatch estimates.

Sampling is not strictly apportioned according to effort or to gear type, and it is possible that there may be additional sources of bycatch mortality that remain unknown. Sampling under the Protected Species Bycatch Monitoring Programme is focused on static gear in those areas where effort is generally highest, notably in the SW of Britain. No formal assessment of potential biases in the sampling programme has yet been made.

Of the seals reported under the 2021 WGBYC data call (ICES, 2022) all 17 grey seals were taken in static nets and 51 out of 52 harbour seals were reported from static nets with one from a pelagic trawl. One of the unidentified seals was taken in a bottom trawl. Although not scaled for observer or reporting effort, this suggests that static tangle nets are the main cause of bycatch throughout UK and Irish waters (ICES, 2022).

12. Is there evidence that the bycatch of grey seals in the SW of England are young animals from Scottish colonies?	SG Q9
Has there been any further information about the Origin of bycaught seals in SW British Isles?	NRW Q3

To date there is no direct evidence that that the bycatch of grey seals in SW British Isles includes young seals from Scottish colonies. The fact that grey seal populations in SW UK and Ireland are apparently increasing despite estimated levels of bycatch suggests there is significant immigration. Western Scotland, where the grey seal population appears to have reached carrying capacity driven by density dependence acting on pups, is the most likely source of immigrants. Preliminary results from an ongoing study (Russell *et al.,* 2023) tracking moulted grey seal pups from the Monach Isles, (Western Isles SMU) showed that c. 60% of the 50 seals tagged moved south to Northern Ireland, Ireland, and/or Cornwall. If this is representative of the movements of pups from the west of Scotland area, this equates to immigration of between 6,000 and 10,000 pups

into the southwest area; the lower estimate of immigration is similar to the pup production in the southwest area.

These results suggest that a substantial proportion of bycaught seals may have originated from Scotland. However, the implications in terms of adjusting the PBR (or similar) threshold are not clear. A genetic study on the structure of the European metapopulation is nearing conclusion (Steinmetz *et al.,* In Prep). That study will provide the necessary context to additional work that is required to compare genetic samples from bycaught seals with those from the Monach Isles.

Evidence from southwest UK (Wales, Southwest England, Northern Ireland SMUs) indicates that the population is increasing (reviewed in Russell and Morris 2020). This is despite an estimated level of bycatch (of young individuals) that exceeds the PBR. Similarly, estimated bycatch levels in Ireland exceed the precautionary PBR threshold there (Luck et al*.,* 2020). Thus, grey seal subpopulations in Ireland and southwest UK (here termed southwest area) are likely to be receiving significant immigration. Any substantial net movement into southwest UK and Ireland is most likely to be through pup dispersal. The main potential source of pups is the Western Isles SMU, in which over 15,000 pups are estimated to be born each year (ten times the combined estimate for Wales and Southwest England; Russell et al*.,* 2019). The pup production in the Western Isles SMU has been relatively constant for >20 years, with the population appearing to reach carrying capacity in the mid-1990s most likely driven by density-dependence acting on pups at sea (Thomas *et al.,* 2019).

A recent study of movements of moulted pups from Scotland provides information on the level of immigration into the southwest area from western Scotland (see Russell *et al.,* 2023 for details). In 2021 the UK Department of Business, Energy and Industrial Strategy funded the deployment of 50 ARGOS tracking devices (tags) on moulted pups on breeding sites in the Monach Isles, Western Isles. The Monach Isles the largest breeding colony in Europe with approximately 12,500 pups being born on these islands each year.

The tags provided locational data at haul out sites. Of the 49 pups that left the colony, 31 moved south with their final locations recorded in Ireland (n=29) or Cornwall (n=2). Although it is possible that some of those pups may return to Scotland, it seems likely that the net movement during the first year would remain at least as high as the 31 individuals suggest. Indeed, once in Ireland, only one tagged individual subsequently hauled out in Scotland (Inner Hebrides) before returning to Ireland. There was an indication of continued southern movements in many pups with the first haul out in north or Northern Ireland before moving south down the west coast of Ireland. For a conservative estimate of 80% of the pups on the Monach Isles surviving to leave for sea, these findings suggest around 6,000 pups from the Monach Isles moved south to Ireland/southwest UK.

Grey seal pups often show extensive movements in their first few months before exhibiting more adult-like foraging trips (Carter *et al.,* 2017). However, given the evidence for density dependence acting on pup survival in western Scotland, it seems likely that such a high proportion moving south is in part due to the seals encountering relatively poor foraging conditions around their natal colonies. This may mean that the pups arriving in Ireland were in relatively poor condition, and thus may have higher mortality than pups born in the area. Tags transmitted for between one and seven months (Russell et al., 2023) and for the most part it is not possible to attribute the cause of the cessation of transmission: battery running out, tag detachment or pup death. However, two of the tagged pups were found dead on the west coast of Ireland – one on a beach (cause of death unknown) and the other bycaught in a crayfish net.

If the movements are representative of grey seals born at other sites in the Western Isles and West Scotland (which has also appeared to reach carrying capacity), the number of pups from Scotland moving into Irish and SW area waters would be nearer 10,000. The latest combined pup production estimates for Ireland, Wales and southwest England are around 5,350. Pup production in Ireland was increasing and these estimates are from 2012, thus this value may be an underestimate. However even if 5,350 was the number surviving to leave the colony, it would still result in in Scottish pups matching (if representative of the Monach Isles) the number of pups born in the area or outnumbering them by 2:1 (if representative of wider West Scotland). The 5350 local pup production estimate includes pup production estimates from Wales and eastern Ireland, but it should be noted that no tagged pups from the Monach Isles hauled out in either.

The implications of these preliminary findings for the PBR estimates for the Ireland and southwest UK are unclear although they demonstrate that the assumption of a closed population that underpins PBR is violated. Thus, in theory, number of individuals that can be safely taken, estimated via PBR or other means, could potentially be increased to take into account the immigration. However, as well as uncertainty surrounding the number of immigrants (see above) there are multiple, potentially interacting, factors that complicate any such revision, including: the proportion of immigrants that would return to Scotland to breed; to what degree the population estimate used in the PBR already includes immigrants; the age at which individuals are most likely to be bycaught; the background survival rate of immigrants; the extent to which pup survival is mediated by density dependence; how the allowable take should be allocated between the SMUs/countries in the southwest area. The potential complications are briefly outlined below to facilitate discussion.

Grey seals demonstrate a degree of natal philopatry, returning to the colony or area in which they are born to breed (Pomeroy, Twiss and Redman 2000). The impact of pup emigration on natal philopatry is unknown though the rapid increases in pup production in southeast England indicates that, to a degree, pups recruit into populations in which they forage. The population trajectory for the west of Scotland (SMUs 2 and 3) is stable suggesting a first-year survival of around 14%. If the emigrating pups do not recruit in Scotland, then they are, in the population model, assumed to have died.

PBR relies on a population estimate and the intrinsic growth rate of the species. In most SMUs, the August counts (scaled to 20th percentile of population estimates) are used to set the PBR – these counts would, to a degree, include the surviving pups born the previous year and juveniles. Indeed, they are essentially an indicator of the number of seals foraging in the area; some individuals breed and forage in different regions presumably driven by breeding site fidelity and foraging conditions (Russell *et al.,* 2013).

In SMUs for which there are no reliable August counts, a scalar from estimated pup production is used – this would not explicitly include non-recruited immigrants – the scalar is derived from other SMUs and thus implicitly their age-structure. If bycatch is primarily of young individuals (< 1 year old), then potentially a large proportion of these bycaught individuals could be immigrants which would not have featured in either method of estimating abundance for PBR.

The level of immigration also calls into question the background survival rate of pups – Thomas *et al.,* (2019) estimated pup survival to be c. 48% for an unconstrained population. The increasing abundance in the southwest area, especially given the level of bycatch, suggested that the population was not yet at carrying capacity and is likely to subject to limited, if any, density dependent constraints. However, the number of pups immigrating may result in intra-specific competition, and the indication that they continued to the move south once in the area, may mean prey availability was limiting. If this was the case, there may be a degree of density dependence acting on pup survival resulting in a smaller net increase in abundance as a result of immigration than the estimated numbers of immigrants from western Scotland would suggest.

No tagged individuals hauled out in Wales or the east coast of Ireland. It is unknown the degree to which tagged pups would have continued to move and the proportion that may have eventually go there. However, if the levels of immigration were resulting in increased levels of density dependence, then pups born in the area may also be more likely to move to find favourable foraging patches and thus may have moved into the areas tagged animal did not.

It is important to note that most of these issues are not restricted to PBR and thus for alternative, potentially more appropriate methods, these uncertainties would need to be resolved or incorporated. Deployment of a further 25 tags that will provide locational data at sea is planned for autumn 2023. As well as increasing our understanding of movements at sea and adding to the sample size from 2021, the resulting data will be used to estimate relative survival rates of resident pups versus those that emigrate. However, other questions such as the relative survival of immigrating pups versus those born in the southwest area will remain.

13. Can SCOS advise on what type of fisheries are associated with higher (a) seal bycatch and (b) depredation?	Defra Q4

a) Seal bycatch is concentrated in tangle, trammel, and gill net fisheries in UK waters, with sporadic reports of bycatch from trawl fisheries.

b) SCOS is not aware of any reliable, quantitative information on the incidence or scale of seal depredation in UK waters. MMO report that anecdotal reports of fish damage and losses are increasing, but there is no formal recording or investigation of individual reports.

Depredation has been reported from a wide range of fisheries in UK & Irish waters, including:
- **Salmonid fixed net and sweep net fisheries in Scotland and drift and fixed gill net fisheries in northeast coast of England.**
- **cod trammel net fisheries in east Scotland.**
- **mackerel line-fisheries in Scotland;**
- **small boat inshore fisheries in southeast and southwest England;**
- **bottom set gillnets and tangle nets, trawls and line fisheries for pollack, cod, flatfish and angler fish in Irish waters.**

a) ***Seal Bycatch***: Most of the seal bycatch recorded in the UK Bycatch Monitoring Program was caught in large mesh tangle nets and trammel nets. This metier has accounted for approximately 90% of the estimated bycatch since records began in 2013 (Kingston et al., 2021) and is also responsible for the majority of bycatch in Irish fisheries (Cosgrove et al., 2016; Luck et al., 2020). Bycatch was closely related to distance from known haulout sites. A large bycatch of seals was reported during experimental tangle net fishing off west coast of Scotland in the mid-1980s (Northridge, 1988), there is little detail on the circumstances, but it was thought to be a consequence of setting nets close to seal haulout sites.

The only other metier in which seal bycatch has been recorded during observer programmes around the British Isles was trawl nets, e.g., six grey seals were reported caught in sandeel trawls in 2018 (Kingston et al., 2021), and four grey seals were recorded in herring trawls off southern Ireland (Morizur et al., 1999). Seal bycatch records in trawl fisheries are scarce and clumped, often involving several individuals in one location, but the overall recorded mean bycatch rate is very small (Northridge et al, 2020).

Historically, bycatch in salmon bag nets (fixed, coastal trap-nets) around the coasts of Scotland and Northumberland, was a regular occurrence (Thompson & Hiby, 1983; Harris, 2012) but that fishery has been closed since an indefinite moratorium was introduced in 2019.

Sampling under the Protected Species Bycatch Monitoring Programme is focused on static gear in those areas where effort is generally highest, notably in the SW of Britain. No formal assessment of potential biases in the sampling programme has yet been made and it is possible that there may be additional sources of bycatch mortality that remain unknown. However, if present, such bycatch would be small in comparison to that of the static tangle/trammel net fisheries

Estimated bycatch of seals by non UK registered vessels in UK waters as well as total bycatch estimates for Irish waters have recently been compiled by ICES Working Group on Bycatch (ICES, 2022). The 2020-21 observations showed that the majority of seals were caught in set nets as reported for UK registered vessels.

As reported above, it is now a mandatory requirement for fishers to report any bycatch of marine mammals to the MMO, within 48 hours of the end of the fishing trip. Data from this scheme should be available for the next SCOS meeting.

b) ***Seal depredation***: SCOS is not aware of any reliable, quantitative information on the incidence or scale of seal depredation in UK waters. MMO report that anecdotal reports of fish damage and losses are increasing, but there is no formal recording or investigation of individual reports.

Depredation has been reported from a wide range of fisheries in UK & Irish waters, including:

- Seal damage to salmonids in fixed net and sweep net fisheries in Scotland and in the drift and fixed gill net fisheries on the northeast coast of England (Thompson & Hiby, 1983; Harris, 2012).
- Damage to cod in trammel net fisheries in east Scotland.
- Damage and loss of fish in mackerel line-fisheries in Scotland (Whyte et al., 2020).
- Damage and loss of fish in small boat inshore fisheries in southeast and southwest England (MMO 2018, Bosetti & Pearce, 2003)
- Depredation on bottom set gillnets and tangle nets, trawls and line fisheries for pollack, cod, flatfish and angler fish in Irish waters (Cronin et al., 2014).
- There may be seal interactions with other fisheries that have not been publicised.

There have been attempts to quantify losses (e.g., NESFC (2008) reported in MMO 2018) based mainly on anecdotal information, but there are no large scale, wide area comparative data for UK fisheries. There is therefore insufficient information to allow an assessment of the scale or intensity of depredation in any UK fishery and consequently no way to assess which fisheries are associated with higher depredation.

Cosgrove *et al.,* (2013) carried out a targeted study of depredation by seals in Irish fisheries, based on 91 observer days in gill net fisheries for hake and pollack and trammel/tangle net fisheries for turbot and crawfish. They estimated that 18% of pollack, 10% of hake and 59% of monkfish landings were depredated by seals. Correcting for estimated fish removals they estimated that over 50% of hake and pollack landings could have been lost. This study indicates that depredation may have significant economic impacts and highlights the requirement for robust quantitative information from UK fisheries.

As reported previously (SCOS 2021), comparison of the at sea distribution of grey and harbour seals from SMRU's seal density maps and a map of netting activity, has been suggested as a way of identifying areas of "potentially significant overlaps between seals and netting activity" around the UK coast (MMO, 2020a). No details of the method of comparison were provided, and it does not appear that evidence of interaction was included in the assessment, but areas of significant overlap were identified for both UK seal species:

- For grey seals the areas identified were the north-east (specifically around Alnmouth), the east coast (around Great Yarmouth/Lowestoft and Southwold) and the southwest (particularly the Isles of Scilly, Land's End and north Cornwall coast).

- For harbour seals the areas of potential overlap were identified as the north-east (specifically off Tynemouth), the east coast (around Great Yarmouth/Lowestoft) and the south-east (around Felixstowe and Sheerness, the Greater Thames Estuary, to Dover).

14. Can SCOS provide advice on international best practice/success stories on mitigating (a) depredation and (b) seal bycatch .	Defra Q5

a. There has been limited progress in the development or demonstration of any measures to mitigate seal depredation in commercial fisheries since SCOS 2021. There are limited options for reducing interactions by changes in fishing practices. Where they have been tried, none has been reported successful in the long-term.

Modifications to salmon trap nets have been developed in the Baltic salmon fishery, but there is no longer a salmon trap net fishery in UK waters. Alternative gears, such as seal-safe cod pots are being tested in UK and Sweden and active small scale seine netting to replace vulnerable static tangle and gill nets have been trialed in Sweden and Denmark.

Active seal deterrence is often proposed as an option and several active methods involving use of pyrotechnics and underwater impulsive sounds are potentially available. Such methods have not yet been shown to be effective in the long term. Recent trials with acoustic startle devices on bottom-set nets in SW England, and on mackerel line fishing boats in NE Scotland have shown increased catches but there are doubts about cost effectiveness.

b. There is increasing realisation that reducing seal bycatch is beneficial to both seal conservation – in population dynamics as well as animal welfare context – and to fisheries – where bycatch events could lead to significant downtime, economic losses and risks to health and safety onboard. This raised awareness has strengthened policy ambitions to reduce, and where possible eliminate bycatch of seals and other marine mammals in UK waters, and to support initiatives where scientists, regulators and industry seek to co-develop solutions to mitigate marine mammal bycatch.

SCOS is not aware of any published information on modifications to gear that have been shown to reduce bycatch in the type of gear causing almost all the seal bycatch in the UK.

Changes to fishing practice similar to those being trialled for reducing depredation would also reduce risk of bycatch, e.g., changing timing or location and duration of sets, avoiding setting nets close to haulout sites or switching to seal-safe pot/trap fishing could reduce bycatch, but would not be suitable for all target species or locations.

Seal safe trawl nets incorporating rigid grids that prevent seals entering the inner chambers of trawls and guide the seals through an escape hatch have been shown to dramatically reduce bycatch in several fisheries. However, the bycatch of seals in trawl fisheries in UK waters comprises infrequent/sporadic events that may not warrant imposition of fleet wide mitigation measures.

a) Depredation mitigation.

There are two approaches to reducing conflicts between sea fisheries and seals. The first involves changing fishing activities to minimise the number and duration of interactions and thereby reduce the opportunities for seals to inflict damage. The second involves deploying some form of deterrent to disrupt seals' foraging activities or drive them away from the fishery.

Most of the reports of damage and detailed records of fish damage come from either static tangle nets or fixed nets for salmon. As far as SCOS are aware there have been no suggested physical alterations to tangle nets that can reduce depredation and there are limited options available for reducing opportunities for interactions with static tangle nets. Salmon fixed nets are not currently in use in Scotland since a temporary ban on killing salmon by netting, until salmon stocks recover, was introduced in 2019.

Cosgrove *et al.,* (2013) showed that several aspects of fishing activity affected depredation and bycatch rates in bottom set tangle nets for pollack and hake. Soak time, depth, haul speeds and haul sequence, noise from fishing activity, season, day/night deployment and net type all affected depredation as well as location, particularly in terms of distance to nearest concentration of seal haulout sites. Theoretically it should be possible to reduce depredation by modifying some aspects of fishing practice. However, fishers who responded to an MMO (2020) survey reported taking actions to reduce impacts, including reducing soak times, moving to different sites, attending gear, reducing noises that may attract seals and adjusting rigging (for pots), but also reported that these methods were not effective long-term solutions because seals rapidly adapted to them.

In the UK and the USA there have been anecdotal reports of a range of methods being attempted to protect fisheries by driving seals away from fishing activities, using various pyrotechnics (MMO 2020, Thompson et al., 2021), but few have been part of formal studies to assess effectiveness, and to date none of these methods has proven successful as long-term solutions (Thompson et al., 2021) although they are still widely used in US freshwater and inshore fisheries.

Alternative fishing methods may reduce depredation in some circumstances. Pot fisheries for cod are less likely to suffer depredation by seals than are static tangle net fisheries. An experimental trap fishery for whitefish is being trialled in Scottish waters (ICES WGBYC, 2021) with trap designs incorporating seal barriers to prevent seals gaining access to the trap, thus avoiding both depredation and bycatch risk. A project to develop “seal-safe fishing gear” is underway in Denmark and includes trials of a small-scale seine net fishery as an alternative to static gears. Similar studies of small-scale seine netting and seal proof cod pots have been carried out in Sweden as alternatives to bottom set gillnet fisheries (ICES WGBYC, 2021).

One possible solution is the use of acoustic deterrent devices. A series of trials with one device, the Genuswave TAST have been conducted on bottom set gill nets off Devon and in a hook and line fishery for mackerel in the outer Moray Firth (MMO, 2020b; Whyte et al., 2021). Results showed an increase in catch in both studies. However, the cost effectiveness of such a system for small inshore fisheries that suffer much of the reported damage is unclear.

b) Bycatch mitigation

Little attention has been paid to bycatch mitigation methods for UK pinnipeds. For example, ICES WGBYC (2021) recently reviewed the literature on bycatch mitigation. Only two of the 28 cited publications addressed pinnipeds and, in both cases, referred to measure to mitigate otariid mortality in trawl fisheries. SCOS is not aware of any published information on modifications to gear that have been shown to reduce bycatch in the type of gear causing almost all of the seal bycatch in the UK. Large mesh tangle nets (>10cm knot to knot) have been widely used for catching seals both for harvest and for live capture for research. Smaller mesh nets are less effective, but loose, bottom-mounted small mesh nets will still entangle seals, particularly juveniles, and Trammel nets that are a combination of both types of netting are likely to pose a higher-level threat to seals. All seals caught in bottom set nets will drown within minutes of entanglement.

Unfortunately, there do not appear to be any available methods for directly preventing entanglement. Changes to fishing practice similar to those being trialled for reducing depredation would also reduce risk of bycatch in most cases. For example, changing timing or location and duration of sets could help reduce bycatch, e.g., avoiding setting nets close to haulout sites. Switching to seal-safe pot/trap fishing rather than tangle netting could avoid bycatch problems, changing to short soak duration or active seine netting could significantly reduce the risk of bycatch, but again would not be suitable for all species or locations.

Use of acoustic deterrents is another possible mitigation method, but its widespread use on large numbers of tangle nets would raise concerns about effects on non-target species. Use of startle devices such as the TAST would go some way to alleviate that problem, but again the cost effectiveness of such devices would need careful consideration.

Methods to prevent bycatch of pinnipeds in trawl nets have been developed and are routinely deployed in fisheries that are subject to large scale interactions with otariid seals (e.g., CCAMLR 2017; Hamilton and Baker 2015; Lyle *et al.,* 2016; Tilzey *et al.,* 2006). Rigid grids prevent seals entering the inner chambers of trawls and guide the seals through an escape hatch. These have dramatically reduced bycatch in several fisheries. SMARTTRAWL, a system using automatic species i.d. and controllable fish diversion grids to reduce non-target species bycatch in trawls (https://fiscot.org/fis-projects/in-water-improvements-in-selectivity-fis024/) could potentially be adapted to prevent seal bycatch. However, the bycatch of seals in trawl fisheries in UK waters comprises infrequent/sporadic events that may not warrant imposition of fleet wide mitigation measures.

In contrast to the small-scale efforts to develop mitigation methods for seals, there has been a major effort to mitigate bycatch in other taxonomic groups, in particular cetaceans. ICES (2021) reviewed recent mitigation effort publications between 2019 and 2021. Two literature reviews and a workshop report and 10 papers on use of various small cetacean bycatch reduction devices including pingers, acoustic deterrents, net modifications and changes in fishing practice are cited. There is also an extensive literature on turtle, bird and fish bycatch reduction methods published since 2019 (ICES, 2021).

15. Since the removal of the netsman's defence in March 2020, have there been any changes in the number of seal mortalities or causes of seal mortalities around the UK?	Defra Q6

The removal of seal shooting licences for protection of fisheries in Scotland and Northern Ireland and the removal of the netsman's defence in England and Wales has almost certainly reduced the number of seals deliberately killed in UK waters.

However, there is a lack of historical data in England and Wales to determine whether any changes in the number or causes of seal mortalities have occurred since the removal of the netsman's defence.

The provisions of the Conservation of Seals Act, including the netsman's defence, have never applied in Northern Ireland, and have not applied in Scotland since the Marine (Scotland) Act 2010 took effect. All seal shooting in Scotland has required a licence since 2010. Further restrictions to remove shooting of seals for protection of fisheries were enacted in 2021 in both Northern Ireland and Scotland.

Data from the Scottish Marine Animal Strandings Scheme (SMASS) indicates that since equivalent legislative changes in Scotland, at least one case of unlicensed shooting has been recorded. Ongoing reporting and investigation of causes of seal mortality will allow the presence of unlicensed seal shooting to be detected, however given the complexity of the factors involved in strandings and reporting rates, it is unlikely that confidently quantifying changes in the incidence of unlicensed shooting will be possible.

In 2020, Schedule 9 of the Fisheries Act 2020, amended the Conservation of Seals Act 1970 and the Wildlife (Northern Ireland) Order 1985, prohibiting the intentional or reckless killing, injuring, or taking of seals and removing the provision to grant licences for the purposes of protection, promotion or development of commercial fisheries or aquaculture activities.

Historically, seals have not been consistently included in the national strandings programme in England and Wales (CSIP). There have been regional and or short duration attempts to monitor causes of stranded seal mortality from around England in 2015-2016 (Deaville *et al*., 2018) and in Cornwall between 1998 and 2011 (BDMLR, 2020), but there are no comprehensive data in England and Wales on the number and causes of seal mortality. Although there have been sporadic reports of stranded seals with evidence of shooting, e.g., two harbour seals at Walton on the Naze in 2019, the lack of systematic nationwide recording makes it extremely challenging to ascertain whether there have been any changes in the number or causes of seal mortalities since the removal of the netsman's defence. Recording of seal strandings and a limited number of post-mortem investigations have now been incorporated into the CSIP for the next 10 years, and although strandings rates and causes of mortality can be monitored going forward, there is a lack of historical baseline against which to make comparisons.

In Scotland, the Animals and Wildlife (Penalties, Protections and Powers) (Scotland) Act 2020 was passed in June 2020. Similar in purpose to the amendments to the Conservation of Seals Act 1970 by Schedule 9 of the Fisheries Act (2020), this Act contained provisions to remove two grounds for which Scottish Ministers could grant licences authorising the taking or killing of seals. Therefore, from the commencement date of these provisions (February 2021), Scottish Ministers no longer issue licences to take or kill seals under sections 110 (1)(f) (for the purposes of protecting the health and welfare of farmed fish) and 110 (1)(g) (for purposes of protecting and preventing serious damage to fisheries or fish farms) of the Marine (Scotland) Act 2010). Licences can still be issued for the purpose of "conserving seals or other wild animals (including wild birds) or wild plants" (section 110 (1) (c). In 2021 no licences were issued and in 2022 only a single licence was issued under section 110 (1) (c).

In Scotland, seals are included in the Scottish Marine Animal Stranding Scheme (SMASS) and all reported seal strandings are recorded and necropsies carried out where possible. Examination of the records indicate that unlicensed shooting has likely occurred on occasion, but changes are difficult to quantify. A single shot seal was recorded in the year after the legislation changed, given that this was over a period where no licences were issued this was clearly an unlicensed shooting. Therefore, while strandings data can potentially identify unlicensed seal shooting, data are a combination of the biological, physical, and social processes that influence stranding and reporting rates (ten Doeschate *et al.,* 2018), so although it may be possible to detect the presence of unlicensed shooting, strandings data are unlikely to reliably indicate any quantifiable changes in the incidence of unlicensed shooting.

Seal population enhancement

16. Can SCOS advise on any proven and monitorable enhancement measures to increase the overall size of grey and/or harbour seal populations? What monitoring would be needed to establish whether enhancement of populations is occurring as a result of the measure?	Defra Q8

It is challenging to identify proven and monitorable enhancement measures which will increase the size of grey and harbour seal populations in the UK. Most recovery plans/strategies for depleted marine mammal species globally have focused on the amelioration of identified threats such as hunting or fisheries bycatch. Identification of suitable measures for UK seals would require identification of specific drivers/threats/limits to population growth and focus measures on

reducing these. There are unlikely to be simple single factors limiting most UK seal populations and therefore it is challenging to identify suitable specific measures. Given the highly mobile nature of seals, it will also be challenging to implement monitoring at a temporal and spatial scale that allows cause and effect of measures to be directly established.

There are a number of management measures that are likely to be beneficial for seal populations in general, including bycatch reduction, reduction in levels of disturbance (both on land at haul out/breeding sites as well as at sea as a result of underwater noise), reduction in pollution (including plastic pollution/marine debris), maintenance or enhancement of fish stocks through reduction of fishing pressure and restoration of degraded marine habitats (which will enhance prey populations).

To date, such enhancement measures have only been applied as remedial measures once populations have been depleted or are seen to be declining.

It is likely that the cumulative benefits of a range of protections and interventions would be the most appropriate approach for UK populations where no single factor can be identified as a driver of decline or as a limit to population growth.

Specific legislative and policy requirements of drivers such as compensatory measures under "Imperative reasons of over-riding public interest" (IROPI) or Marine Net Gain may be hard to meet with the range of enhancement measures available and the temporal and spatial complexities involved.

Monitoring the effectiveness of measures will be challenging but continued UK-scale monitoring of seal population trends at a spatial and temporal resolution that allows regional specific trends to be reliably tracked provides the best chance of detecting changes in trajectories. Consideration should also be given to the identification of metrics that could be used as early indicators of changes in population status.

Approaches for population enhancement measures for mobile and wide ranging species such as seals are probably best developed at a strategic level rather than piecemeal on a project by project basis regardless of the driver. A stepwise approach to implementing such a programme is recommended.

The UK Government, devolved administrations and the UK's Statutory Nature Conservation Agencies are placing increasing emphasis on nature recovery. There are a number of policy drivers for this work including:

- Recovering designated features to favourable condition
- Compensation to offset impacts from development
- Species Recovery programmes
- Marine Net Gain

There is therefore growing interest in measures that could work to increase populations at both local (e.g., protected site populations) and wider national population scales.

SCOS noted that the drive for measures to increase and expand populations will be highest for depleted populations and noted that grey seal populations are at historically high levels throughout the UK, and notwithstanding the recent declines in some SMUs, the UK harbour seal population is close to the maximum recorded level. SCOS also noted that care will be needed to ensure that population enhancement measures designed for one species do not adversely affect other species, for example by increasing competition between grey and harbour seals in the Southern North Sea.

It is challenging to identify specific measures that have been proven to increase the size of grey and/or harbour seal populations. It is equally challenging to further identify any measures that are directly monitorable in such a way that the link between the measure and the response can be firmly established.

There are several global examples of species recovery programs focussed on specific measures designed to ameliorate focal drivers of a documented decline, including the setting of harvest limits and measures targeted on bycatch reduction. One global example of successful measures being taken to enhance populations of seals is the case of Hawaiian monk seals (*Monachus schauinslandi*). A number of measures have been undertaken to arrest and reverse the decline, with these being as varied as the many threats confronting the species (Harting *et al*., 2014). Here, it appears that the cumulative benefits of multiple interventions taken to reduce or eliminate mortality risks were important in the recovery of the monk seal population. Harting *et al.,* (2014) liken this application of multiple interventions to “a fusillade of many silver BBs” rather than a metaphorical single silver bullet. The species recovery plan targeted a range of interventions including controlling impacts of military facilities in the North-western Hawaiian Islands; managing fisheries to reduce their impacts; removing marine debris; and responding to other issues, including die-offs, inadequate nutrition, aggression by male seals, and shark predation (Lowry et al., 2011).

To identify potential candidate enhancement measures for UK seals, it may be useful to review examples of where UK seal populations have increased and explore the reasons for these. In many cases populations have increased from historical lows as a result of hunting or disease outbreaks. For example, the harbour seal population in The Wash increased rapidly following the Phocine Distemper Virus outbreaks in 1988 and 2002 and the North Sea grey seal population is thought to have rapidly increased over the last few decades as a result of the banning of commercial seal exploitation when the Conservation of Seals Act (1970) became law in the UK. Neither of these provide an obvious measure for use in future enhancement measures.

Conversely, where clear drivers of decline in seal populations have been identified, management measures can be applied to target those specific drivers to halt declines and allow populations to increase in recovery. For example, the introduction of the Moray Firth Seal Management Plan which reduced the shooting of harbour seals appeared to successfully halt the decline of harbour seals in the Moray Firth that had occurred between 1994 and 2003 (Butler *et al*., 2015). However, this approach relies on the clear identification of a specific driver and effective mechanisms for prevention of the process. Current identified regional declines (e.g., Northern Isles and Scottish east coast harbour seals) are not associated with single clear drivers and in most cases it is likely that a combination of factors that are responsible. In some cases, potential contributory factors include inter-specific interactions which would be very challenging to mitigate.

Similarly, if the factors that are limiting population growth in specific populations can be identified, that would provide potential opportunities for targeted measures. However, factors limiting population growth in seals are likely to be a result of a combination of density dependent processes acting at sea at a regional level on pup survival (Thomas *et al.,* 2019) and colony specific processes likely mediated by differential recruitment (Russell *et al*., 2019). Although these processes are not likely to be independent of each other, this complicates the ability to assign cause and effect to specific drivers and to identify candidate enhancement measures. The highly mobile nature of seals and the spatial separation between breeding regions and foraging regions (for grey seals at least) means that there is often a mismatch between the areas where seals are spending much of their time while foraging, and the areas where trends in abundance are monitored (Carter *et al.,* 2022). This further complicates the ability to apply specific monitorable management measures to enhance seal populations. The highly mobile nature of seals and the lack of discrete, closed, regional populations also make it challenging to implement monitoring at a temporal and spatial scale that would allow cause and effect of measures to be directly established.

Options to enhance populations could include more general measures to reduce or remove pressures that have been identified as impacts or concerns. For example, where fisheries have an impact, the reduction of fisheries bycatch is a tangible measure that would likely directly benefit seal populations. However, proven options for mitigation of seal bycatch are generally lacking, as discussed in Answer 15 above (Defra Q5). Other potential pressures that could be candidates for measures include the reduction of underwater noise (e.g., the application of noise abatement during activities such as pile-driving) or the protection from human disturbance at haul outs or breeding sites (e.g., by the use of physical barriers and/or wardening). However, although underwater noise and human disturbance have been demonstrated to have an impact on seals (e.g., Russell, *et al.,* 2016b; Paterson *et al.,* 2019) there is no evidence that these impacts are currently having a limiting effect on the size of seal populations.

Measures to ensure healthy fish stocks, for example by limiting fishing pressure is of paramount importance. The recent Defra consultation on the future management of sandeel and Norway pout fisheries considered the potential ecological effects of implementing further management measures for sandeel and Norway pout stocks[2]. Wilson and Hammond (2019) demonstrated that harbour seal declines have occurred in regions where they appear to be reliant on sandeels, indicating that reduction in the availability of sandeels may have been a contributory factor in the observed declines.

Another potential option for enhancement is the designation of additional protected areas, although as detailed in the discussion in Q17 in SCOS 2021, in most of the areas where declining or depleted seal populations are found the terrestrial sites are already designated so further opportunities are limited. All these potential measures have challenges associated with their implementation so work would be required to identify and address these challenges to fully understand the feasibility of each option.

Other than perhaps the direct protection of haul out and breeding seals from disturbance, which may be effective at a local scale if disturbance is thought to be limiting local population growth, such general enhancement measures may not meet the needs of the key drivers for the development of enhancement and compensatory measures. For example, where compensation is required to offset the adverse effects of developments under “Imperative Reasons for Overriding Public Interest” (IROPI), compensation should be focussed on the same type of ecological features as those affected by the identified impact and enhancement of equivalent ecological ‘functionality’ sought. In short there is a requirement to ensure that compensatory measures directly target the impact mechanism and area of impact. This will be challenging to demonstrate for many specific impacts and marine mammal receptors and there may be sufficient justification for moving away from this approach. It is also a requirement that the effectiveness of such measures is monitored, which, as discussed above, is challenging for wide ranging mobile marine mammals. SCOS is aware that approaches to ‘strategic compensation’ in relation to offshore renewable energy development are under discussion.

The principles of requirements for offshore developers to achieve ‘marine net gain’ are not currently well-defined although it is recognised that marine habitats and species are highly dynamic and interconnected and therefore any marine net gain assessments should include species as well as habitats and should extend beyond the footprints of developments. How metrics relating to seal populations can be incorporated into marine net gain accounting warrants further investigation. Defra’s recent consultation proposed to discount ‘incidental net gain whose benefits are subject to significant uncertainty’ so unless robust evidence emerges that habitat changes, changes in prey availability and resulting changes in seal utilisation have a measurable effect on predator populations, it is unclear how net gain may be associated with benefits for seal populations.

[2] https://www.gov.uk/government/consultations/future-management-of-sandeel-and-norway-pout-in-uk-waters-call-for-evidence/outcome/summary-of-responses

SCOS is not aware of the specific legislative requirements of other drivers for enhancement measures such as species recovery plans and the recovery of designated features to favourable condition, it may be that these goals are more amendable to the application of more general measures.

The effectiveness of site-based protections are easily monitored by regular counts of seals using the site. However, given the challenges of reliably linking cause and effect with monitoring changes in seal populations, clearly documenting evidence for the benefits of more general measures or those applied at sea will be very challenging. The UK's existing seal population monitoring programme already provides information at temporal and spatial resolutions that allow detection of large-scale changes in population trajectories. Maintaining and potentially intensifying the current UK-scale monitoring of seal population trends at a spatial and temporal resolution that allows regional specific trends to be reliably tracked will provide the best chance of detecting changes in trajectories. Consideration should also be given to the identification of metrics that could be used as early indicators of population health or change (National Academies 2017, Booth *et al*., 2020), in particular metrics that are sensitive to changes in fecundity and pup/juvenile survival and that can be monitored in the field (e.g., the proportion of immature animals in the population based on size distributions). Monitoring body condition from photogrammetry is also a promising avenue for the measurement of the condition and energetic status of large numbers of animals (e.g., Shero et al., 2021).

Regardless of the driver, approaches for population enhancement measures for mobile and wide-ranging species such as seals are probably best developed at a strategic level rather than on a project by project basis. A stepwise approach to implementing such a programme would be recommended: step 1 – assessment of key impacts on populations on a regional basis where possible (including potential future impacts due to e.g., offshore wind). SCOS (2021) provided an overview of the current principal threats to seal populations, but further work would be required to determine relative importance of each threat and to apply this on a regional basis. Step 2 – identification of specific measures in relation to these impacts with an assessment of feasibility/risk/uncertainty to implement and monitor. Step 3 – implementation of measures, including pilot programmes.

Ecosystem services

17. Can SCOS provide advice on the key 'ecosystem services' provided by seals, for example economic/social/wellbeing?	Defra Q9

Although there have been several recent studies exploring ecosystem services provided by cetaceans, the definition and quantification of the ecosystem services provided by seals have not gained much specific attention to date. Here we provide an overview of the potential ecosystem services that seals, and seal populations provide globally. These include regulating services such as roles in ecosystem functioning, carbon sequestration, nutrient recycling, as well as cultural services such as tourism, wellbeing, and education. A more detailed investigation would be required to quantify and evaluate the relative importance of these for UK seals. Such an exercise would provide useful information for nationwide efforts to quantify 'natural capital' and demonstrate the intrinsic value of a healthy marine ecosystem.

Natural capital and the definition and quantification of ecosystem services has become a standard analytical approach to valuing nature. The Dasgupta review in 2021 (Dasgupta, 2021), highlighted the need for a unifying system of nature valuation to become a central pillar of global economic decision making and stem the rapid decline of biodiversity. Defra have established a Natural Capital and Ecosystem Services assessment programme. As part of that programme there is a need to identify and assess the importance of ecosystem services provided by seals, to inform and justify their inclusion as specific components within the wider more holistic marine natural capital ecosystem assessment work.

Ecosystem services are the direct and indirect benefits that are provided to humans by the natural environment. The concept was created to recognise and quantify all the beneficial services provided by ecosystems and their components. The Millennium Ecosystem Assessment (2005) defined four types of ecosystem services. These are: 1) provisioning services or goods (e.g., food, building materials, fuel), 2) supporting services (e.g., element and nutrient recycling), 3) regulating services (e.g., carbon sequestration and storage, erosion prevention), and 4) cultural services (e.g., tourism, recreation, health, and wellbeing). Although there have been a number of recent studies exploring ecosystem services provided by cetaceans and marine mammals as a general grouping (e.g., Roman et al., 2014, Riisager-Simonsen et al., 2020, Malinauskaite *et al.*, 2021, Cook *et al.*, 2022., Durfort *et al.*, 2022), the definition and quantification of the ecosystem services provided by seals as a single functional group have not gained much specific attention to date. Here we present an overview of the potential ecosystem services that seals, and seal populations provide globally (***Table* 16**). A more detailed investigation would be required to quantify and evaluate the relative importance of these for UK seals. Such an exercise would provide useful information for nationwide efforts to quantify 'natural capital' (e.g., allowing extension of NatureScot's Natural Capital Asset Index into the marine environment) and demonstrate the intrinsic value of a healthy marine ecosystem.

***Table* 16.** *Ecosystem services provided by seals. Much of this information is generalised from the review of global marine mammal ecosystem services by Riisager-Simonsen et al. (2020).*

Ecosystem service	**Description**
Provisioning – raw materials and food	Although seals are no longer hunted in the UK, they are in several parts of the world including US, Canada, Greenland, Iceland, Russia, Norway, Namibia where products include meat, oil and fur for a range of uses.
Regulating – climate regulation	Marine vertebrates play an integral role in the ocean carbon cycle and therefore have a role in climate change mitigation (Martin *et al.*, 2021). The role of baleen whales in global carbon sequestration has gained some attention (e.g., Durfort *et al.*, 2022) but few studies have looked specifically at seals. Given the large numbers of many seal populations globally, equalling significant biomass, they likely represent a large amount of carbon sequestration in biomass which is then returned to the seafloor in carcass form after natural death.
Supporting – nutrient recycling	Due to the need to return to the surface to breathe, marine mammals can enhance primary productivity in feeding areas by the release of nitrogen at the surface from urine and faeces (Roman and McCarthy, 2010). There is also likely to be the transfer of nutrients from offshore environments where most foraging occurs, to coastal environments where seals return to haul out and breed. E.g., the predictable deposition of >200 T of carrion on and around breeding haulout sites and the deposition of >1000 T of carrion in inshore waters around the UK will support significant local scavenger populations (Quaggiotta *et al*., 2018).
Regulation – trophic effects	As predators, seals are likely to exert significant effects on prey populations and trophic relationships and are likely to be an important component of the functioning of marine ecosystems (Estes, 1996). For example, Aarts *et al.,*

	(2019) suggested that predation by seals on demersal fish may be potentially alleviating density dependent competition between fish, resulting in increased fish growth, partly compensating for the reduction in numbers. Seals may also form an important component of the diet of some predators in some areas, for example, killer whale and grey seal predation.
Cultural services - tourism	Seal tours operate in several areas around the UK with boat operators taking tourists to see local haul out sites (e.g., see Strong and Morris 2010) and large numbers of tourist trips to observe grey seal breeding sites in eastern England. This activity also provides an economic benefit to tour operators and other businesses in the locality. Seals were considered to be the third most influential draw for tourists wanting to see wildlife in Scotland and 74% of tour operators considered seal-watching tours to be an important part of the local economy in rural West Scotland (Parsons, 2003).
Cultural services - education	Seals are present in several zoos and aquaria in the UK and globally. Body parts are often used in museum exhibitions and science outreach activities. Seal watching tourism operators often engage in educational activities about seals with their customers.
Cultural services – cultural identity and folklore	Seals are important in traditional cultures, in the UK, seals are important components of Celtic and Norse traditions and folklore. For example, the seal people, known as selkies or selkie folk are mythological beings who are half human, half seal, changing from seal to human by shedding their skin. These folk tales are particularly prevalent in the Northern Isles. Seals are also important component of the cultural traditions of Pacific Northwest coastal tribes in America, and in Norse, Greek, Sami and Inuit mythologies.
Cultural services – wellbeing and mental health	The value of nature experience for mental health is becoming increasingly recognised (Bratman *et al.*, 2019) and although there is a lack of data on the link between seals and mental health, there is likely to be a significant ‘experiential’ value to encounters with seals in nature.
Cultural services – scientific use	Seals have been used as ‘oceanographic samplers’ to provide valuable data from remote and inaccessible areas, unreachable by humans (McMahon *et al.*, 2021). Marine mammals, including seals, are often termed ‘sentinels of ocean health’ given their top predator status and long-life spans and as such, provide information about the state of the marine environment (e.g., Hendrix *et al.*, 2021).

Renewable energy

18. Is there any further information (since last SCOS) on seal interactions with tidal energy devices?	NRW Q4

There is currently no information available on grey seal interactions with tidal energy devices. Grey seals range widely from, and frequently switch between distant haulout sites, whereas harbour seals usually return to, and forage relatively close to haulout sites within a small area. Individual harbour seals tagged in the vicinity of tidal energy devices are therefore more likely to

remain close to them than would grey seals tagged at the same location. Harbour seals have been regarded as a better study species for investigating fine scale interactions with tidal energy devices.

Existing studies represent good progress in our understanding how harbour seals behave in response to operating turbine at scales of 100's to 1,000's of metres; however, information on the fine scale underwater movements (at a scale of metres) of individual seals around operating turbines remains the critical research gap with respect to deriving avoidance/evasion rates.

SCOS does not consider that there is a scientific basis on which to move away from the present 'range of potential avoidance rates' currently recommended (Scottish Natural Heritage 2016). There is clear evidence of avoidance, with 27-68% reductions in seal activity in the vicinity of tidal turbines, or in response to playback of turbine noise at ranges between 200 and 2000m. SCOS therefore recommends that collision risk estimates based on 0% avoidance should be given little weight.

There is currently no information available on grey seal interactions with tidal energy devices; this is a key data gap for assessing the impacts of tidal turbines on grey seals. Grey seals are wide ranging, and usually forage at some distance from their haulout sites and often move large distances between haulout sites. There is therefore a low probability that any randomly selected grey seal at a haulout site, even a site close to a tidal turbine, will forage in the vicinity of the turbine. Harbour seals are relatively sedentary, generally foraging relatively close to and return to haulout sites within a small distance from their initial capture site. Therefore, tagged harbour seals caught close to tidal turbines are likely to forage, or to travel through areas, close to the turbine. To some extent, harbour seals have been regarded as a better study species for investigating fine scale interactions with tidal energy devices, and to date, the locations of tidal turbine developments have been at sites where harbour seals have been the main species of concern.

As reported previously to SCOS, there are a number of studies that report changes in harbour seal distributions in response to operational tidal turbines, including to the Strangford Lough turbine (Joy *et al.*, 2018), to playbacks of tidal turbine sounds (Hastie *et al.*, 2017; Robertson *et al.*, 2018), and to the MeyGen turbine array (Onoufriou *et al.*, 2021). The mean changes in abundance (%), the tidal turbine and location of the study, and the scale that a response was measured at, were presented in SCOS, 2021 and are shown in ***Table 17***. Based on the results presented in these studies, there does not appear to be a scientific basis on which to define a specific avoidance rate to allow a move away from the 'present a range of potential avoidance rates' currently recommended (Scottish Natural Heritage 2016). However, there is clear evidence of avoidance, with 27-68% reductions in seal activity in response to the presence of operating tidal turbines, or in response to playback of turbine noise. These reductions were estimated at ranges between 200 and 2000m and do not give a realistic measure of fine scale avoidance or evasion, but SCOS recommends that collision risk estimates based on 0% avoidance should be given little weight in impact assessments.

Although these studies represent good progress in our understanding how harbour seals behave in response to operating turbine at scales of 100's to 1,000's of metres, information on the fine scale underwater movements (at a scale of metres) of individual seals around operating turbines remains the critical research gap with respect to deriving avoidance/evasion rates and understanding the potential impacts of tidal devices. However, a NERC and Scottish Government funded research project recently (May 2022) deployed a combined active sonar and passive acoustic tracking system alongside an operating tidal turbine at the MeyGen turbine array off the north of Scotland. This system tracks individual seals in high resolution (metres) within ~30 m of the turbine and aims to quantify movements around the turbine. Importantly, it will not be possible to differentiate seal species using this approach so consideration as to how to apply any avoidance rates derived from these data to each species will be required. Initial results confirm that seals can be detected and tracked within several tens of metres of the operational turbine, and the combination of this and the results of the previous studies (Hastie *et al.*, 2017; Joy *et al.*, 2018; Robertson *et al.*, 2018; ***Table 17***) should provide information on behaviour of seals at the range of spatial scales required to effectively derive empirical avoidance rates to operating turbines.

***Table 17**. Summary of the previous studies to measure the avoidance of operating turbines, or their sounds, by harbour seals. The table shows the mean change in abundance (%), the tidal turbine and location of the study, the scale that a response was measured at, and the reference for the study.*

Mean % change in abundance	Source	Scale	Reference
-68% (95% CIs: -37%, -83%)	SeaGen turbine (Strangford Lough)	Within 200m	Joy *et al.,* (2018)
-27% (95% CIs: -11%, -41%)	Acoustic playback of turbine sounds (Kyle Rhea, Skye)	Within 500m	Hastie *et al.,* (2018)
No significant change	Acoustic playback of turbine sounds (Puget Sound, U.S.)	Within 1000m	Robertson *et al.,* (2018)
-28% (95% CIs: -11%, - 49%)	MeyGen turbine array (Pentland Firth)	Within 2000m	Onoufriou *et al.,* (2021)

19. Can SCOS recommend what the most appropriate avoidance rates should be for use in collision risk models or encounter rate models for grey seals and tidal turbines?	NRW Q5

As outlined in the answer to Q17 above, SCOS does not consider that there is a firm scientific basis on which to move away from the 'present a range of potential avoidance rates' currently recommended (Scottish Natural Heritage 2016).

20. Is it appropriate to use harbour seal as a proxy for grey seal in underwater noise assessments and collision risk modelling?	NRW Q6

Compared to harbour seals, there is a paucity of information on the responses of grey seals to anthropogenic sounds. There are a small number of studies with captive grey seals which show that they exhibit significant behavioural changes to a range of acoustic stimuli, and grey seals tagged with SMRU GSM tags exhibited significant changes in their behaviour as a result of exposure to pile driving.

Compared to harbour seals, there is also a paucity of information on grey seal behaviour around tidal turbines, and behavioural responses by grey seals to anthropogenic sound.

Comparison of species hearing sensitivity suggests that the detection of anthropogenic sounds by grey and harbour seals are unlikely to be significantly different.

In the absence of grey seal specific information, harbour seals are likely to be the best available proxy in terms of their hearing sensitivities and perhaps also in terms of behavioural responses. However, it is important to consider that the probability and severity of any behavioural responses may be highly species and context specific and is likely to be influenced by a range of intrinsic and extrinsic factors. Therefore, any application of harbour seal behavioural response analyses to grey seals should be made with this important caveat in mind. The use of proxies may be unavoidable with the currently available information but should not detract from the need to collect species-specific information.

During environmental assessments, the use of behavioural or physiological response data from individual species as proxies for others is relatively commonplace. For example, Southall *et al.,* (2019) derived functional hearing groups and response thresholds for marine mammals; these were based on data from a relatively limited number of species but were developed such that they could be applied to all marine mammal species. Further, Thompson *et al.,* (2013) use data on the probability of avoidance by harbour porpoises (*Phocoena phocoena*) to pile driving, and apply these to harbour seals in an assessment of the potential impacts of pile driving during the installation of an offshore wind farm.

Compared to harbour seals, there is a relative paucity of information on the behaviour of grey seals around operational tidal turbines (as described above), and behavioural responses by grey seals to anthropogenic sound. However, several recent studies have reported behavioural responses of grey seals to sound. For example, studies with captive grey seals show that they exhibit significant behavioural changes to a range of anthropogenic sounds including high frequency sonar (Hastie *et al*., 2014), and pile driving and tidal turbines (Hastie *et al.*, 2021). Further, results of analyses of responses to pile driving by grey seals tagged with SMRU GSM tags showed that seals exhibited significant changes in their behaviour due to sound exposure; these included altered surfacing or diving behaviour, and changes in swim direction including swimming away from the source, heading into shore or travelling perpendicular to the incoming sound, or coming to a halt (Aarts, Brasseur & Kirkwood 2017). To our knowledge, there are currently no formal analyses of the relationships between sound levels and the probability or severity of a behavioural response (dose response/severity functions) for grey seals exposed to anthropogenic sounds; however, it would be useful to investigate whether existing data (e.g., Aarts, Brasseur & Kirkwood 2017) would be sufficient to derive dose response functions

In terms of assessing the appropriateness of using harbour seals as a proxy for grey seals in a behavioural response context, it may be useful to compare their relative hearing sensitivities. Hearing sensitivity is measured as the lowest audible sound level in air and water, either in behavioural experiments with trained animals (e.g., Reichmuth *et al.,* 2013) or through neurophysiological measurements of auditory brainstem or cortex activity (e.g., Lucke *et al.,* 2016). Most hearing studies have focused on harbour seals (for review, see Hanke & Reichmuth 2022), which provides a reference for comparison to other species. Hanke and Reichmuth (2022) conclude that, with some notable exceptions (northern elephant seals and Hawaiian monk seals), the audiograms of other phocid seals are similar to hearing profiles of harbour seals (for review, see Erbe *et al.,* 2016). This suggests therefore that the detection of anthropogenic sounds by grey and harbour seals are unlikely to be significantly different between the species. However, it is important to highlight that, although sound detection may be similar, the probability and severity of any subsequent behavioural responses may be highly species specific, and is likely to be influenced by a range of intrinsic (e.g., sex, age class, body condition) and extrinsic (e.g., habitat, behavioural state) factors. Therefore, any application of harbour seal behavioural response analyses to grey seals should be made with this caveat in mind.

Health and disease

21. As SCOS will be aware, NOAA recently reported seal deaths linked to Avian Influenza (HPAI) in Maine. What advice can SCOS give regarding the early detection and monitoring of this disease in UK seals? Should HPAI be discovered in seals in the UK, what advice would SCOS give relating to biosecurity measures and population modelling related to any outbreak?	SG Q8

SCOS consider that active routine disease surveillance should be implemented to ensure the early detection and monitoring of the disease in the UK. This should include mechanisms for stranding scheme personnel to report any increases in strandings rates of seals and regular sampling of stranded seals for disease screening (including but not restricted to HPAI). This routine surveillance should be extended to rehabilitation centers and any live captures of healthy animals. Challenges with resource availability and laboratory capacity will need to be addressed.

A process should be in place for identifying Unusual Mortality Events and triggering the implementation of pre-planned coordinated response plans in the event of future infectious disease outbreaks. This will help to minimize the risk of further mortality and maximise the chances of collection of the information necessary to determine event cause and to determine the effect on the population(s) concerned.

In the event of an outbreak of HPAI in seals in the UK, biosecurity measures such as closure of the sites to the public should be considered on site specific basis. It is important to note that seals are highly mobile and therefore seal to seal transmission could occur and spread the virus widely with no human involvement.

Robust modelling to establish the potential population impacts of a disease outbreak on a population requires a range of information on the disease and its host populations. Modelling could be used to estimate the population impact of disease outbreaks, e.g., PDV and to predict the potential impact of future outbreaks.

NOAA Fisheries declared an Unusual Mortality Event in July 2022 when elevated numbers of grey and harbour seal strandings were reported along the southern and central coast of Maine throughout June and July. Because of the ongoing outbreak of highly pathogenic Avian Influenza A (HPAI) H5N1 in wild birds, stranded seals were sampled and tested for HPAI H5N1. Seals of both species were found to be positive. The rate of seal strandings in July was approximately three times the normal rate for the time of year. NOAA Fisheries established a multi-agency co-ordinated response to manage the event with several partners including the NOAA authorised marine mammal stranding network partner Marine Mammals of Maine (MMoME), Atlantic Marine Conservation Society, Tufts University and state and federal partners including the US Department of Agriculture's Animal and Plant Health Inspection Service's National Veterinary Services Laboratories. This response included daily exchange of information, support for resource logistics and the development of regular, detailed public communications. A dedicated website was set up with weekly updates of the numbers of seal strandings and a Frequently Asked Questions (FAQ) resource and regular press and media briefing sessions were held. Follow up research is underway including genetic sequencing of the virus strain. Strandings had returned to levels equivalent to those previous years by September.

In the UK, there is no national routine surveillance of marine mammals for any disease, including for avian flu, therefore there is a risk that early identification of any outbreak may not be possible. Strandings personnel and their volunteer networks should be on alert for any increases in reporting of stranded seals around the UK coasts and should take samples from strandings for screening for HPAI in a co-ordinated and consistent way. Standardised protocols for sampling should be developed and agreed between the different organisations (strandings, rescue and rehabilitation centres, researchers). In Scotland a number of samples have been sent by the Scottish Marine Animal Strandings Scheme (SMASS) to the UK Animal and Plant Health Agency (APHA) for testing. Samples should also be taken routinely from animals admitted into rehabilitation centres and wherever possible, during research work involving live captures of wild seals. The latter is currently already in place in the form of a collaboration between the Sea Mammal Research Unit and Dr Divya Venkatesh at the University of Oxford and samples have been taken from live healthy animals during tagging studies. However, there are currently significant challenges with laboratory capacity and resources for the testing of samples from seals, particularly as a result of concerns about domestic animal and public health as a result of the wider epidemic.

Transmission from wild birds to seals is more likely to happen at haul out sites where seals are on land and in close proximity to infected birds, or their faeces/feathers. Similarly, transmission from seal to seal is also more likely where seals are hauling out in close proximity to each other. The key risk periods for seals are therefore likely to be periods where individuals may spend protracted periods of time onshore such as during the breeding season or the moult period, particularly during the winter months where seasonal increases in avian influenza incidents are associated with incursions of infected migratory birds.

SCOS advise that the UK government and devolved administrations adopt a process and associated criteria for determining an unusual mortality event, similar to the process in the US under the Marine Mammal Protection Act[3]. This process would draw on reported information from the strandings network. Determination of an unusual mortality event (UME) should then trigger an immediate response plan and investigation, making available additional resources to respond to collect and process data, as well as to respond to further strandings should they occur. Co-ordinated response, recovery and sampling protocols should be developed in preparation for any future infectious disease outbreak in the UK. See below under question 21a for an example of such a contingency plan.

Biosecurity measures

Should an outbreak occur in the UK, the health risk to the public is deemed to be low[4], although precautions would be recommended for those regularly coming into contact with seals. There are only two documented cases globally of avian influenza transmission from seals to humans, although transmission from other species to humans have been reported. Risks are highest to those working with seals (both dead and live). Those individuals should consider the use of PPE including protective clothing, masks and gloves. Clothing and footwear should be changed before leaving any premises or sites where direct handling of seals has occurred or where HPAI has been confirmed. Should an outbreak in wild seals be identified, restricting public access to known haul out and breeding sites should be considered on the basis of site and species-specific risk assessments, taking account of the sensitivity of the site, the conservation status of the associated populations, the risk of transmission between sites from human activity and considering any specific mitigation measures that could be implemented. Such an approach would consider the likelihood and magnitude of human and domestic animal contact and the likelihood of human disturbance further impacting compromised animals.

[3] https://www.fisheries.noaa.gov/insight/understanding-marine-mammal-unusual-mortality-events#what_criteria_define_an_ume?

[4] https://www.gov.uk/government/publications/avian-influenza-in-uk-seal-populations-hairs-risk-assessment/influenza-of-avian-origin-in-uk-seal-populations-qualitative-assessment-of-the-risk-to-the-uk-human-population

However, in relation to disease transmission, it is important to note that seals are highly mobile and could potentially transmit disease over a widespread area; there are known examples of grey and harbour seal movements from and to the UK across Celtic, Irish and North Seas and long-range movements between parts of the UK are common, particularly for grey seals. A previous outbreak of avian influenza in seals in 2014 indicated rapid seal to seal transmission along the coasts of Sweden and Denmark and subsequent spread to Germany and the Netherlands (Zohari *et al.*, 2014, Bodewes *et al.*, 2015, Krog *et al.*, 2015), although there is no evidence that it reached the UK. A stranded porpoise in Sweden in June was found to have died of avian influenza indicating transmission had likely occurred between birds and cetaceans in Europe. No further cases have been reported.

Population modelling

Modelling could be used to estimate the population impact of a current (or historical) disease outbreak but also to predict the potential magnitude of impact associated with future disease outbreaks. For historical outbreaks or those that are currently occurring, observed levels of mortality and counts, can be used to estimate the direct population impact. For example, the PDV epidemics in the Wash were associated with declines in abundance of 53% in 1988 and 22% in 2002. The ability of populations to recover from such mortality events depends on their current trends and drivers therein.

To incorporate non-fatal impacts on populations (e.g., reduced fecundity) or to robustly predict impacts of future outbreaks in other areas, information on epidemiological parameters and host populations would be required. The requisite species-specific epidemiological parameters would include the disease reproduction number (R) and impacts on demographic rates, as well as appropriate population specific levels of immunity. Initially a feasible range of these parameters could be considered, with the ranges being refined as more information became available. The robustness of the results of such models would also depend on baseline knowledge of demographic rates and age and sex structure of host populations.

For grey seals, there are estimates of such demographic parameters (Thomas *et al.*, 2019), some of which are based on data from elsewhere (SCOS-BP 22/01). With the exception of pup survival, which is mediated by levels of density dependence, all parameters are assumed consistent across regions of the UK. For harbour seals, feasible ranges for demographic rates have been derived from studies both in the UK and elsewhere. However, these ranges are broad with unknown relationships between the parameters which would make robust modelling of population impacts problematic. For specific areas (e.g., Moray Firth; Caillat *et al.,* 2019; Orkney and Skye, see Q2) refined estimates are available. To be able to predict the spread of the disease, reliable estimates of the rates of movements between regions (SMUs) and between haulout sites within regions will be needed for both species. Such information can most effectively be derived from telemetry data.

22. Can SCOS advise on reports of the prevalence of (a) PDV, (b) avian flu, and (c) mouth-rot in UK and neighbouring waters, and lessons learned/best practise mitigation responses from past UK/other countries' responses (where available).	Defra Q7

There are no current estimates of prevalence for PDV, avian influenza or mouth rot in UK seals.

(a) At present there have been no reported outbreaks of PDV in Europe since 2002 and sporadic monitoring up to 2019 in the North Sea and Baltic detected no PDV outside the known epizootics. Globally, PDV has been associated with a total of four unusual mortality events (UMEs) in harbour seals, two in western Europe (1988, 2002) and two in the northwest

Atlantic (2006, 2018). Given the time since the last UME in 2002, levels of immunity in the UK harbour seal population are likely to be very low, therefore harbour seals in the UK are susceptible to a future PDV outbreak. Possible routes of introduction are from incursion of Arctic seals or from grey seals acting as carriers between Arctic seals and North Sea seal populations. A re-appearance of PDV could be catastrophic for some UK harbour seal populations that are in decline or are severely depleted relative to historical levels. It is unlikely that an outbreak could be prevented but SCOS recommends the coordinated development and adoption of a PDV response plan across all UK nations. Scottish Government, in collaboration with SMRU, have developed a PDV contingency plan that could form the basis of this.

(b) SCOS advice in relation to avian flu prevalence and best practice response is provided above in answer 21.

(c) No information on the incidence of mouth-rot and associated mortality rates have become available further to that presented in SCOS 2021.

(d) SCOS noted that the delay between application and granting of authority to conduct studies requiring capture and sampling of seals precludes any rapid response to the onset of a disease event. SCOS recommend that a mechanism to allow rapid permitting should be a priority.

a) Phocine Distemper Virus (PDV)

To date, there have been no reported outbreaks of PDV in Europe since 2002, and sporadic monitoring up to 2019 in the North Sea and Baltic detected no PDV cases outside the known epizootics (Stockholm *et al*., 2023), except for a small number of cases on the Belgian coast in 1998 (Jauniaux *et al*., 2001). Globally, PDV has been associated with a total of four unusual mortality events (UMEs) in harbour seals, two in western Europe (1988, 2002) and two in the northwest Atlantic (2006, 2018). There have also been a number of sporadic reports of PDV positive animals in North America although reports of PDV outside of UMEs are rare in European waters (Puryear *et al.*, 2021).

Phocine Distemper Virus (PDV) was first identified in European seal populations in 1988 where it caused the death of more than 23,000 harbour seals in European waters (Härkönen *et al.,* 2006). The outbreak began on the Danish island of Anholt in the Danish Kattegat and spread over several months to affect seals in the Baltic, Wadden Sea, North Sea and Irish Sea. Within the UK, the highest mortality levels were in The Wash and the Moray Firth. A second PDV outbreak began on Anholt island in the Danish Kattegat in May 2002. Following the same path as the 1988 outbreak, the virus spread through European waters, causing the death of approximately 30,000 harbour seals and 500 grey seals. In the UK, a decline of 22% occurred in the Wash, however, unlike the 1998 epidemic, the 2002 outbreak did not appear to reach epidemic proportions in Scotland or Northern Ireland, despite PDV seal deaths being found in these regions (Hall *et al.*, 2006).

The most likely source of the 1988 epidemic was contact with Arctic harp seals, a species in which the virus seems to circulate (Duignan *et al.*, 1997). In the year prior to the 1988 epidemic, large numbers of harp seals migrated from the Barents Sea to reach northern waters where they probably came into close contact with harbour and grey seals. However, such migrations were not recorded ahead of the later epidemics, and the origin of the 2002, 2006 and 2018 outbreaks remain unclear. One hypothesis is that grey seals, which roam more widely than harbour seals, came into contact with infected harp seals further north and subsequently introduced the virus to harbour seals. There is growing consensus that grey seals may be key vectors in the transmission of PDV between harbour seal colonies in European waters, especially where large geographical jumps are made. Harbour seals usually return to the same haul-out area whereas grey routinely move much greater distances between haul-out sites. Prior to the 2002 outbreak in the UK, screening of grey seals in a number of breeding colonies in 2001 indicated a large proportion of the adult females who would have been alive during the 1988 epidemic were seropositive (i.e., had indications of previous exposure to the virus), whereas younger animals were all negative indicating that seals born after 1988 were not exposed to PDV (Pomeroy *et al.*, 2005). During the 2002 epidemic, the proportion of seropositive seals at studied grey seal breeding colonies reached 83% (compared to 96% in 1988) (Pomeroy *et al.*, 2005). Despite this, during both the 1988 and 2002 epidemic, no fatal cases of PDV were found in UK grey seals (Hall *et al.*, 2006). This suggests that grey seals could have a role as a carrier and may be a link between Arctic hosts and the more southerly populations of harbour seals.

Testing of harbour seals in the Wadden Sea and adjacent waters between 1990 and 2014 indicated that following each PDV outbreak, due to seropositive individuals dying and no new exposure occurring, levels of seroprevalence decreased, with samples becoming seronegative between six and eight years after each epidemic indicating that populations are now again susceptible to a new outbreak (Ludes-Wehrmeister et al., 2016). In 2022, grey (n=10) and harbour (n=29) seals in Shetland tested negative for Canine Distemper Virus antibodies (indicative of a lack of exposure to PDV). A re-appearance of PDV would likely result in another epizootic. There is also concern that Arctic sea-ice reduction could increase contact between Arctic and sub-Arctic marine mammals and lead to increased levels of viral transmission (VanWormer et al., 2019). A re-appearance of PDV could be catastrophic for some UK harbour seal populations that are in decline or are severely depleted relative to historical levels.

It is highly unlikely that an outbreak could be prevented but measures can be taken to ensure a co-ordinated response. In collaboration with SMRU, Scottish Government have developed a draft PDV contingency plan drawing upon lessons learned in previous outbreaks and best practice in disease response. This plan “aims to put in place measures to deal effectively with another outbreak should it occur in Scottish waters”. Although it is acknowledged that the current plan is likely to change and develop, at present it includes the following key stages:

A PDV network will be established consisting of policy officers from across the Scottish Government involved in seal policy, nature conservation, fisheries, animal health, public health, waste disposal, tourism, emergency planning and civil contingencies, as well as the Government’s ecological advisers. In addition, representatives from the Scottish Marine Animal Stranding Scheme (SMASS), NatureScot, Sea Mammal Research Unit (SMRU), Scottish Environment Protection Agency (SEPA) Maritime and Coastguard Agency (MCA), the police, local authorities and welfare organisations would also be represented.

- **Guidance on the outbreak, its effects on seals and advice to people on dealing with sick or injured animals will be made available to the general public through a dedicated PDV website.** The guidance will include specific ‘Questions and Answers’ on the nature of the outbreak, risks to humans and actions taken by the government, research, and animal welfare organisations.
- **Public health guidance will be developed to provide sound advice to all personnel involved in the PDV response** in relation to stranded seals and protective measures which the public and occupational groups at risk should take. This will focus on occupational groups that come into contact with sick or dying seals and are at greater risk than the general public.
- **A single national hotline for stranded seals will be established, with reports of live seals being referred to animal welfare organisations and dead seals to SMASS.** This will provide a central co-ordination point to record and verify all reports of dead and sick seals with associated information on the date, time, location, species and condition of the carcass.
- **The existing Scottish marine animal strandings network would be used to collect detailed information on seal mortality.** If greater coverage is required, an urgent appeal for volunteers would be sought from key wildlife organisations and the wider public.

- **The Government will consider the need to introduce additional conservation measures to protect vulnerable seal populations.**
- **An infrastructure to sample and where possible to necropsy and dispose of seal carcasses will be established on confirmation of the PDV outbreak.** It is anticipated that all post mortem examinations in Scotland would be undertaken by SMASS. In the event of a large-scale outbreak, consideration should be given to the need for a cold store facility where seals can be stored prior to post mortem and incineration at the site. Samples taken during post mortem will be sent to a laboratory for molecular diagnostic testing.
- **Incineration or rendering of carcasses will be the preferred disposal method depending on professional advice and local circumstances.** The 2002 outbreak showed that disposal was a key component of any successful and effective response to an outbreak, and it is expected that this situation will also be true of any future outbreak.
- **The use of emergency vaccination to protect seals in rehabilitation centres will be considered, but no mass vaccination of seals will occur in the wild.**
- **In the interest of animal welfare, options for the euthanasia of infected animals will be developed.**

To our knowledge, there are no similar response contingency plans in place or in development in England, Wales and Northern Ireland. SCOS recommends that plans are developed and co-ordinated across all the of the UK nations.

b) Avian Influenza

In the UK, there have been sporadic occurrences of avian Influenza infecting seals. This includes a grey seal pup (H3N8) in a rehabilitation facility in Cornwall in 2017 (Venkatesh et al., 2020), four juvenile harbour seals and one juvenile grey seal at the RSPCA East Winch Wildlife rehabilitation centre (H5N8) on the Norfolk coast in 2020 (Floyd et al., 2021). Wild-caught seals for SMRU projects are currently sampled for presence of avian flu, and for evidence of past exposure as part of a collaboration with University of Oxford. There is some concern that current sampling methods may not be efficient at detecting avian flu virus.

SCOS recommendations for lessons learned/best practice for a response in the event of an outbreak in the UK are detailed above in the answer to Question 21.

c) Mouth Rot

Further to information provided in SCOS (2021) about observations of ‘mouth rot’ in harbour seal pups on the east coast of England throughout 2021, there have been more reports of harbour seal pups with mouth rot over summer 2022 on the east coast of England but no further information is available to SCOS at this time. SCOS understands that detailed investigations of the pathology, bacteriology and virology of the disease are still underway by researchers at Teesside University together with British Divers Marine Life Rescue and results are expected in 2023.

SCOS noted the need for increased expertise in seal disease/health issues and the need for additional resources for collection, storage, and analysis of appropriate samples for disease monitoring.

23. There is evidence globally, that pinnipeds can become trapped in aquaculture facilities, sometimes for up to several days if they cannot be removed. In most instances, these animals will have no opportunity to haul out or access required resources for survival. Can SMRU provide	SG Q10

advice on the extent to which such animals could be considered as suffering.	

In situations where seals are trapped in large aquaculture cages for short periods of time, e.g., less than 10 days, there does not appear to be a major welfare concern in terms of deprivation of haulout opportunities. In the absence of human disturbance, it is also unlikely that seals will experience a lack of food in cages containing large quantities of fish. Even if feeding opportunities are reduced or eliminated by human intervention, a healthy seal is unlikely to experience significant negative impacts from food deprivation over such short periods of time. Seals already in poor condition would be more susceptible to effects of food deprivation.

Seals are likely to experience increased stress if they are aware that they are trapped and/or they are exposed to human disturbance. At present there is insufficient information to assess the levels of such stress or its consequences in terms of elevated stress hormone levels or increased energy expenditure. However, evidence from studies involving direct capture and handling of wild phocid seals shows typical mammalian stress responses. Limited evidence suggests that repeated handling does not impair the normal hormonal response to stress. To date there are no studies describing long term impacts of such acute stress events in phocid seals.

SCOS note that the first line of defence should always be to ensure that seals cannot gain access to cages. Maintenance of seal proof cage nets, perimeter fences and potential methods such as electrified deck deterrents should be used where appropriate to minimize the likelihood of seals gaining access.

Seals do occasionally manage to enter fish cages at finfish farms and are sometimes unable then to escape. The question asks for an assessment of suffering in seals in such situations. Suffering is a subjective term with no clear legal definition in an animal welfare context. It is a condition that can only be defined in terms of a seal’s perception of the unpleasantness of its current situation. This is impossible to answer. The question has therefore been addressed in terms of the likely direct physiological and/or energetic effects of constraints on haulout behaviour, feeding and freedom of movement, or the physiological effects of stress due to entrapment. In most cases there is little or no information on the potential long-term consequences of entrapment, but that is unlikely to be an issue with a seal in a fish farm cage.

There are three aspects to this question:

1. do seals trapped in aquaculture facilities suffer as a consequence of haulout deprivation?
2. do seals trapped in aquaculture facilities suffer from restricted access to other resources?
3. do seals trapped in aquaculture facilities suffer as a result of stress induced by entrapment?

1. Haulout deprivation.

The drivers of seal haulout behaviour are not well understood, but there does appear to be a direct relationship between the duration of swimming trips and duration of subsequent haulout events (Brasseur et al., 1996). This suggests a physiological requirement to haulout, but it is not known what that requirement is. Potential drivers include the need to perfuse skin with blood for maintenance and repair, and thermo-regulation in cold water.

In the short to medium term (e.g., < 20 days) the lack of haulout opportunity is unlikely to be an issue for grey seals or for adult harbour seals. In the UK, adult harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) of all ages make foraging trips that vary in length but can last for several weeks (e.g., Carter *et al*, 2017; Sharples *et al*., 2012). Even grey seal pups on their first trip to sea, immediately after leaving the breeding beach, have been recorded making trips of over 30 days

(Bennett et al., 2010; Carter *et al*., 2017). Although the long-term effects of such behaviour on survival, growth and development are not known, there is no evidence to suggest that they are related to increased mortality in the short term.

There is anecdotal evidence that juvenile/recently weaned grey seal pups may suffer reduced surface temperatures and require periods of extended haulout time after long trips. However, experience with captive grey seal pups in SMRU shows that continuous swimming for periods of up to five days in ambient temperature seawater in early spring have no apparent negative impacts (SMRU unpublished information). There is little information on the swimming behaviour of harbour seal pups, but they swim regularly and may go on foraging trips with their mothers before weaning. As far as we are aware, juvenile harbour seal have not been seen inside aquaculture cages in the UK.

The potential impact of long term exclusion from haulout are unknown. The timing of entrapment may influence the impacts. For example, there is anecdotal evidence from seals in captivity which suggests that seals which spend protracted periods in the water during moult may take longer to complete the moulting process (SMRU unpublished observations). Both species require haulout sites to pup and to moult. Other potential long term impacts are unlikely to be relevant in cases of seal entrapment in fish farm cages.

2. Restricted access to other resources

Apart from haulout availability the only other short to medium term resource requirement for free swimming seals is available prey. A seal that enters a salmon cage voluntarily will likely have done so to gain access to a large high value food resource. If left undisturbed it is likely to eat a substantial quantity of salmon; potentially killing and injuring large numbers of fish in the process. If a seal has access to salmon and is feeding, it is unlikely to suffer any malnutrition effects.

Human activity at the site, particularly if directed towards the seal is likely to reduce the seal's ability to feed. In that case, a seal held for a long period in a fish cage will lose weight. The consequences for an individual seal will depend on its body condition and its reproductive status. A healthy seal with a typical blubber energy store will be able to withstand periods of several weeks without suffering any malnutrition effects. A seal in poor body condition, for example recently first year seals that are struggling to thrive or adult seals immediately post moult will have a much smaller energy store and will be less able to withstand an enforced fast.

3. Entrapment stress

The extent to which seals will suffer from stress as a consequence of being trapped in aquaculture cages will depend on a range of factors including the duration of the entrapment, the individual seal's reaction to perceiving that it is trapped, and the level of human activity around the site. It is likely that a seal entering a cage to prey on salmon will initially be no more stressed than during any other foraging activity. Even if entering aquaculture cages is more stressful than other activities the seal must have decided that the perceived risk is outweighed by the access to a large reward.

Once it attempts to leave the cage and discovers that it can't get out, it is likely to experience stress. It is not possible to predict the level or intensity of any stress response. Responses are likely to be highly variable. Based on observation of wild seals brought into temporary captivity, the speed of acclimation is highly variable in both harbour and grey seals, with some animals approaching humans for food within a day and others having to be released after failing to acclimatise to the captive facility and human presence after a protracted period of 3 - 4 weeks.

To date there have been no studies of the short-term stress responses of seals to being held captive in a large pool. Measures of endocrine stress indicators such as cortisol levels are highly influenced by short term surges as a result of the restraint and handling involved in obtaining the requisite blood samples, making such studies difficult.

In the absence of directly relevant information there are data from two types of stress inducing situations that may be informative:

Short term, acute capture/handling stress

The short-term/immediate vertebrate response to acute stress is an increase in circulating glucocorticoid hormones, e.g., cortisol, which increase rapidly for approximately 30 min before gradually declining back to baseline levels (Gardiner and Hall, 1997; Vleck et al., 2000; Wingfield et al., 2001). This response stimulates an increase in circulating metabolic fuel (fatty acids and glucose) to prepare the body for the physical activity that may be required to respond to an acute stressor, such as fight for survival or to flee from danger. The duration of this response is thought to be an indicator of an animal's ability to cope with stress (Harcourt & Hall, 2010).

Effects of capture and handling of seals have been documented for a range of both phocid and otariid seals. For example, adult harbour seals, grey seal pups, juvenile elephant seals (Mirounga leonine) and breeding male Weddell seals (*Leptonychotes weddellii*) have all shown clear, prolonged elevation in cortisol and other stress linked hormones in response to capture and handling (e.g., Kershaw & Hall, 2016; Bennett et al., 2012; Champagne et al., 2012; Harcourt & Hall, 2010) and adult harbour and grey seals have shown elevated heart rates in response to disturbance (Karpovich et al., 2015; Twiss et al., 2020). However, all of these responses are normal and required for the animal to deal with the stressor and are not indicative of harm or impacts on welfare if they are short lived.

Repeated exposure to severe stress may impact on animals' future abilities to respond to stress. However, Bennett et al., (2012) showed that repeated handling of grey seal pups (every three days) did not affect the cortisol, thyroid hormone response or mass loss during fasting when compared to less frequently handled seals. This indicates that repeated acute stress does not alter the normal stress response in grey seal pups. Harcourt & Hall. (2010) also noted that the male Weddell seal cortisol response was similar in successive captures.

In severe cases, capture stress can lead to cardiomyopathy. This potentially fatal condition has been reported in stranded cetaceans (e.g., Herraez et al., 2013; Cowan and Curry, 2008). South American fur seal pups have also shown fatal cardiomyopathy and skeletal muscle damage in response to handling, although parasite infection and/or chronic infectious disease may have been contributory factors (Seguel at al., 2013).

Long term chronic stress

In the natural world seals are likely to be exposed to chronic stress. For example, around much of the UK, grey and harbour seals are exposed to the threat of predation by killer whales and adult male grey seals, and to anthropogenic disturbances to a varying degree. Few studies have been carried out to assess the levels of response to chronic stressors. Fur seal responses to different levels of white shark predation risk in South Africa varied with differing levels of threat. Faecal glucocorticoid concentrations were significantly higher at "colonies exposed to high levels of unpredictable and relatively uncontrollable risk of shark attack, but not at colonies where seals were either not exposed to shark predation or could proactively mitigate their risk through anti-predatory behavior" (Hammerschlag et al., 2017). The results suggest that perceived risk induced a stress response that increased when the ability to predict or mitigate the risk was reduced.

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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

Annual review of priors for grey seal population model 2022

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Summary

No new published information is available.

Prior distributions (Table 1) for the grey seal population model (SCOS-BP 21/05) 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 (SCOS-BP 21/05). 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 (2021 SCOS-BP 21/05). 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)

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 0.87 and 0.95 (Smout, King & Pomeroy, 2019; 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.

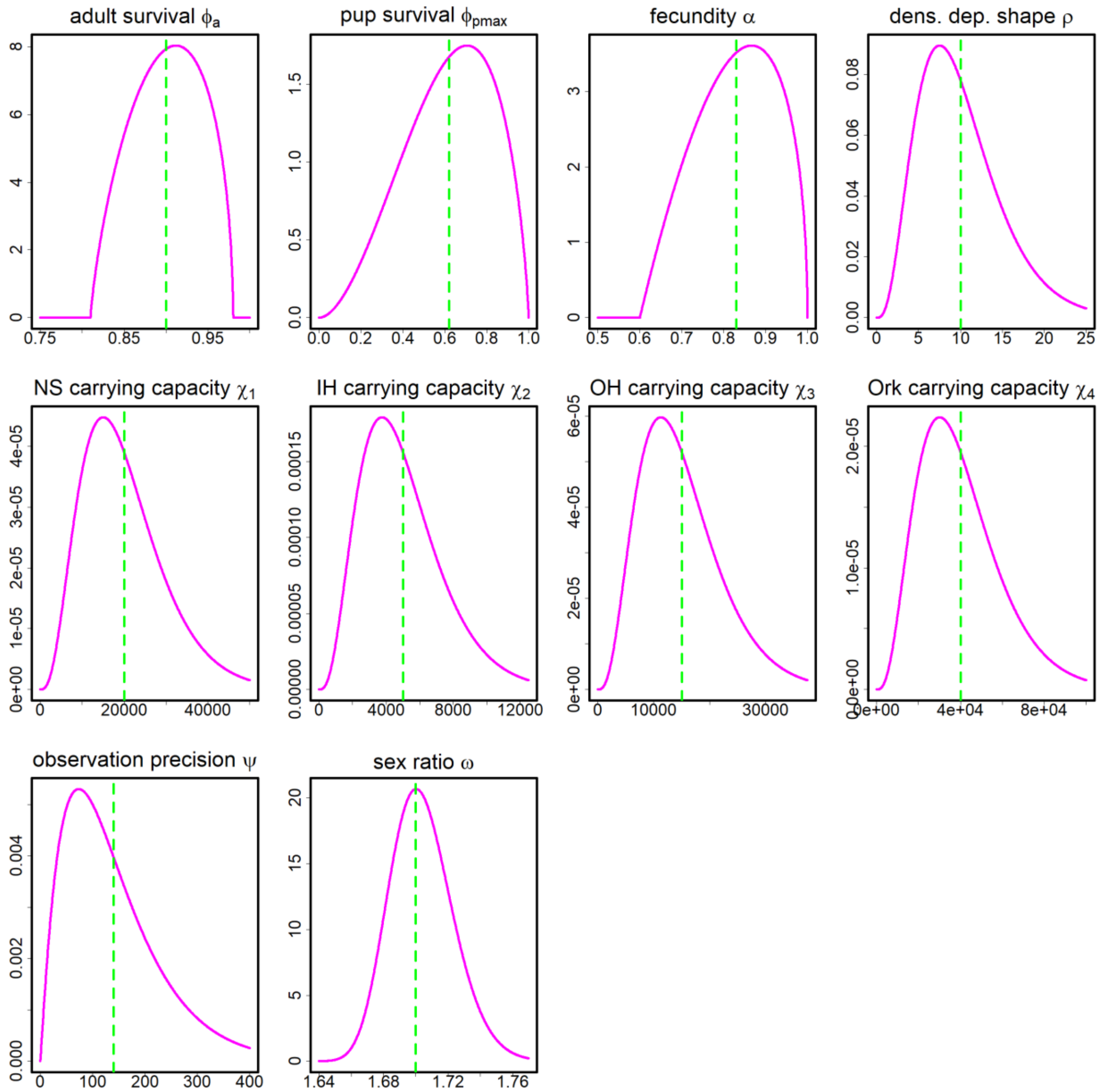

Figure 1. Prior probability density functions for each model parameter input in Thomas (2020), drawn from the distributions specified in Table 1. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions, respectively. Prior means are shown as green dashed vertical lines.

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+). Rossi et al., (2021) found that females on Sable Island maintained very high annual survival rates (>97%) until age 25, after which survival declines by 8% between ages 25–29 and by another 9% for ages 30+. Males similarly maintained high survival rates (>95%) until age 25, though declines in male survival rates in older age classes were much steeper than in female rates. Thus, as agreed by SCOS in 2018, 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 $\boldsymbol{\phi_{p}}_{max}$

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 survival 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; Kauhala and Kurkilahti 2020) based on shot animals showed pregancy rate can fluctuate significantly (between c.0.6 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). A recent study from Sable Island demonstared that fecundity varied as a function of your breeding status in the previous year: non-breeder, first-time breeder, and breeder (in order of lowest to highest). UK estimates of fecundity rates for populations of marked study animals, adjusted for estimates of unobserved pupping events were 0.79 (95% CI 0.77-0.81) and 0.82 (95% CI 0.79-0.84) for a declining (North Rona) and increasing (Isle of May) population, respectively (Smout et al., 2019). 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, Male survival post sexual maturity has been estimated to be 0.98 (SE 0.003) (Brusa et al. 2020 - based on data from Manske et al. 2002). The estimated the sex ratio on Sable was 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	Time	Data	Location	Considerations	Source
	mean	uncertainty	n	mean	uncertainty	n	n	period				
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	Harwood & Prime 1978

										representative within focal age class.	
≥ 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	0.94	95% CIs: 0.93 - 0.95	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, 2019
Adult	0.896	95% CIs: 0.87 - 0.90	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:	140	1979 - 1981	Shot samples	Farne Islands, UK		Boyd 1985

		0.89 - 0.97						
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
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: 0.77 - 0.82	584	1993 - 2013	CMR (brand, flipper tag, photo ID)	North Rona, UK	Accounted for unobserved pupping	Smout *et al.* 2019
Birth	0.82	95% CIs: 0.79 - 0.84	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	0.56		66	2001-2018	Shot/bycatch samples	Finland	Age 5-6 years old	Kauhala and Kurkilahti 2020
Birth	0.79		460	2001-2018	Shot/bycatch samples	Finland	Age 7-24 years old	Kauhala and Kurkilahti 2020

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Trends in seal abundance and grey seal pup production

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Abstract

In Scotland and eastern England (SMUs 1-9), encompass the majority of the UK holdings of harbour and grey seals. In these SMUs, both species are regularly surveyed in August, with grey seals also being monitored in the breeding season.

The key method of monitoring harbour seal trends in these areas are through aerial survey counts during their August moult (covering all areas in a 5-year cycle). For grey seals, population estimates and trends in grey seal abundance are estimated within an age-specific population dynamics model (Thomas 2021) using data from four regions: Inner & Outer Hebrides, Orkney, and North Sea; the first three regions are equivalent to the West Scotland, Western Isles and North Coast & Orkney SMUs respectively, and the North Sea region is an aggregation of East Scotland, Northeast & Southeast England SMUs. The data considered in the population model are pup production estimates from regularly monitored breeding colonies and independent estimates of population size.

The population model provides population estimates on the scale of the four regions, and is based on the distribution during the breeding season. It is critical to understand spatial variation in abundance and trends therein, on an SMU scale, during the foraging season (the majority of the year) which is when seals are most likely to be impacted at-sea processes (e.g. anthropogenic activities, prey availability), and also when they are most likely to impact harbour seals. In addition, an analyses of pup production data is required for an understanding of trends for SMUs and trends in the context of SACs while accounting for, and quantifying, the jump in pup production associated with the change in survey methods (film to digital).

In Russell *et al.* (2021), the latest trends of the above-described three metrics (harbour and grey seal August counts, and grey seal pup production) were displayed on an SMU-scale. Here we update these trends for SMUs in which more recent data are available, and also illustrate trends for the Special Areas of Conservation (SACs). In addition, we quantify the current rate of change in abundance (percentage change in the year leading up to the last survey year) and quantify the degree to which current levels of abundance are depleted compared to earlier in the time-series. Both the current rate of change and depletion levels should be considered in management decisions. In addition, for grey seals, both August and breeding trends should be considered in combination.

Introduction

Scotland and eastern England (SMUs 1-9) hold the majority of the UK populations of grey and harbour seals. The key method of monitoring harbour seal trends in these areas are through aerial survey counts during their August moult (covering all areas in a 5-year cycle). Estimates of harbour seal trends are essential for effective conservation and management. Such estimates based on data up until 2017 were provided in Thompson *et al.* (2019), and thereafter updated in a SCOS BP (Russell *et al.* 2021).

For grey seals, population estimates and trends in abundance are estimated within an age-specific population dynamics model (Thomas *et al.* 2021) using pup production data from four regions: Inner & Outer Hebrides, Orkney, and North Sea; the first three regions are equivalent to the West

Scotland, Western Isles and North Coast & Orkney SMUs respectively, and the North Sea region is an aggregation of East Scotland, and Northeast & Southeast England SMUs. The data considered in the population model are pup production estimates from regularly monitored breeding colonies and independent estimates of population size. These independent estimates are generated using grey seal count data from August surveys and a telemetry-derived scalar to account for seals not hauled out during surveys. They are termed independent because they are independent from those derived from pup production data.

The population model provides population estimates on the scale of the four regions, and is based on the distribution during the breeding season. It is also critical to understand spatial variation in abundance and trends on an SMU scale, during the foraging season (the majority of the year) which is when seals are most likely to be impacted by at-sea processes (e.g. anthropogenic activities, prey availability), and also when they are most likely to have an effect on harbour seals. In addition, an analysis of pup production data that accounts for, and quantifies, the jump in pup production associated with the change in survey methods (film to digital), is required for an understanding of trends for SMUs and SACs.

In Russell *et al.* (2021), the latest trends of the above-described three metrics (harbour and grey seal August counts, and grey seal pup production) were displayed on an SMU-scale. Here we update these trends for SMUs in which more recent data are available and also illustrate trends for the Special Areas of Conservation (SACs). In addition, we quantify the current rate of change in abundance (percentage change in the year leading up to the last survey year) and the degree to which current abundance is depleted compared to earlier in the time-series. Both the current rate of change and depletion levels should be considered to inform management decisions. In addition, for grey seals, both August and breeding trends should be considered in combination.

Methods

August surveys

All data were based on counts made during the annual harbour seal moult in August (2 hours either side of low tide). Almost all data are from aerial surveys conducted by SMRU, augmented by data from fixed wing aerial surveys of the Thames estuary, conducted by Zoological Society London (aerial survey; Cox *et al.* 2020) and ground surveys in the Tees estuary, conducted by Industry Nature Conservation Association (Bond 2020). Surveys of rocky shores were conducted by helicopter using a thermal imaging camera whereas surveys of sandbanks (much of the UK east coast) were predominantly conducted by fixed-wing. All SMUs are surveyed at least once in a five-year period. In SMUs or subsets that are more readily surveyable (fixed wing, relatively simple coastline, sand banks), and a need for higher survey effort was identified due high variation of counts or rapidly changing counts, frequency is higher. Indeed, a subset of the Moray Firth SMU, the Firth of Tay & Eden SAC, Humber Estuary SAC, and The Wash & North Norfolk SAC are usually surveyed annually, and in some cases, up to three times in one year.

Where possible, entire SMUs were surveyed synoptically (i.e. within a single August survey season). However, in some cases that was not possible and so counts had to be combined across multiple years; the resulting count was assigned to the year that encompassed the majority of the total (focal year). For more details on survey methods, refer to Thompson *et al.* (2019).

For the trend analyses, where the limited number of years with counts prohibited robust model fitting for a particular SMU, the largest subset of sites within it (i.e. the subset of haulout sites with the largest proportion of the SMU total), for which the monitoring was frequent enough to allow model fitting, was used as a proxy. For some SMUs, trends for the whole SMU and a proxy were fitted (if the proxy represented a higher sample size). The relationship between the SMU and subset counts in years when the whole area was surveyed can be used to assess how representative the subset trends are of the regional trends.

Analyses

All analyses were conducted in R (R Core Team 2021).

To calculate the current rate of change and depletion, the percentage difference between the predicted abundance in the year of the latest survey (t2) and another year (t1) was calculated. Confidence intervals around these estimates were generated via parametric bootstrapping.

$$\text{change } \frac{abundance_{t2} - abundance_{t1}}{abundance_{t1}} \; x \; 100$$

For estimating current rate of change, t1 was the year preceding the latest survey year. For estimating depletion, t1 was the latest year in the time series for which the highest abundance was estimated. Thus, t1 was the same as t2 when the current predicted abundance was the highest or equal highest in the time series – in these cases, depletion is given as 0 (Table 1).

August counts: harbour and grey seals

Counts were modelled as a function of year assuming negative binomial errors broadly following methods described in Thompson *et al.* 2019. Updated counts (compared to Russell *et al.* 2021) were available for SMUs 6 – 9). For some SMUs, the limited number of data points resulted in problems estimating the theta parameter for the negative binomial distribution. In these cases, a Poisson distribution was assumed. In contrast to Lonergan *et al.* (2013) and Thompson *et al.* (2019), AIC rather than AICc was used for model selection. For all datasets, at least three models were fitted: an intercept-only GLM (null model; i.e., a stable trend), an exponential (linear on the link scale) year effect within a GLM, and a nonlinear smooth year effect within a GAM (restricted to 5 knots). Limited flexibility for the smooths represented a pragmatic approach aimed to estimate trends on the appropriate temporal scale.

For harbour seals, Phocine Distemper Virus (PDV) caused sudden declines in the Northeast and Southeast England SMUs in 1988 and 2002. Thus, additional models were fitted with a step change in abundance and/or trends associated with 2002 (PDV epidemic; data were not available on SMU scales prior to the 1988 PDV epidemic). Although the declines in north and east Scotland SMUs were not thought to be due to PDV, there were sudden drops or declines in Shetland and North Coast & Orkney SMUs during multi-year gaps in surveys that spanned 2002, and indications of changes in trend around 2002 in Moray Firth and East Scotland SMUs. Because of the unknown nature of these declines, additional models were also fitted for these SMUs. Specifically, additional models were fitted for SMUs 4 – 9 that allowed any combination of stable/exponential trends prior to and following 2002 (including the same trend across the time-series) with/out a step change associated with 2002. If < 4 data points were available prior to 2002, only a stable trend was offered to this period. In some SMUs there was evidence of a non-linear trend in the final period (2002 onwards), thus for this final period GAMs (smooth trends) were used, if preferred by AIC.

Grey seals - pup production

Pup production estimates (Thomas 2021; SCOS-BP 21/01) used for SMUs 2-4 and 6 – 7 (see Russell *et al.* 2019) were almost entirely derived from aerial survey data; these were estimated using probabilities of correctly classifying a moulted pup (PMoult) values of 0.5 and 0.9 for film and digital surveys, respectively; all other parameters were kept constant throughout the time series and as reported in Russell *et al* (2019). Some counts of Inchkeith (East Scotland) were provided by Fife Seal Group. The values used for the remaining SMUs (5, 8 – 9) were based on ground counts: Shetland (peak counts; NatureScot), Northeast England (production; National Trust) and Southeast England (production; National Trust, Lincs Wildlife Trust, and Friends of Horsey Seals). Note there are no known established breeding colonies in the Southwest Scotland SMU. The latest pup production estimates for each SMU, any proxies and SACs are reported in Table 1.

The production estimates used here as proxies for West Scotland, Western Isles and North Coast & Orkney match those used in the population model (regularly monitored colonies in Inner Hebrides, Outer Hebrides, and Orkney, respectively), and represent c. 87, 98 and 97% of production in those SMUs. The estimates for East Scotland, Northeast England and Southeast England sum to the totals used for the North Sea region in SCOS-BP 21/05. Shetland and Moray Firth SMU data are not incorporated in the population model.

Pup production (peak count for Shetland; SCOS-BP 21/01) was modelled as a function of year assuming negative binomial errors (see Russell *et al.* 2019 for details). For Scottish SMUs surveyed by SMRU (all except Shetland), a step increase in pup production was offered between 2010 (the last film survey) and 2012 (the first digital survey) to account for any artificial increase in pups associated with the change in aerial survey method, thus allowing the trends to be examined accounting for this jump. To maximise the data available to fit this jump, all applicable SMUs were modelled within a single GAM (limited to k=5), allowing a different temporal trend for each SMU but a single adjustment for the change in survey methods. In contrast to Russell *et al.* (2021), Moray Firth was excluded because of the relatively few data points from film surveys.

The estimated jump from the model described above was incorporated when estimating trends for all the aerial-surveyed SACs and for the Moray Firth SMU. The SACs were not included in the estimation of the jump to avoid to the same data (SACs individually and as part of the SMU totals) being considered twice in the estimate of the jump. It should be noted that only the mean estimated jump (i.e. not including the associated uncertainty), was incorporated. Visually, the estimated jump appears to match the observed data for the SACs and Moray Firth (see Figures). However, the lack of incorporation of its uncertainty likely resulted in some degree of underestimate in the width of the confidence intervals around reported trends.

For SMU and SACs where the data were derived from ground surveys, three models were fitted: an intercept-only GLM (null model), an exponential (linear on the link scale) year effect within a GLM, and a nonlinear smooth year effect within a GAM (restricted to K=5).

Results & Discussion

All results are summarized in Table 1 and illustrated in Figures 1-9.

Harbour seals

The SMU-trends for SMUs 1-5 and 8 are as presented in Russell *et al.* (2021) – there were no additional data points, but trends are now presented for all SACs. In brief, SMUs 1-3 are exhibiting an increasing trend. For West Scotland (SMU 2), this is driven by increases in the central and northern parts, with no significant trend in the southern part. The SACs in the southern part show differing trends; estimated abundance in the Eileanan agus Sgeiran Lios mor SAC is currently stable whereas abundance is increasing in the Southeast Islay Skerries SAC. In contrast to the trend in the central part, the Ascrib, Isay and Dunvegan SAC in the central part is currently stable though abundance is currently higher than at the start of the time series (1990). Abundance in the Western Isles is showing significant increases after a period of decline. In contrast, there is currently no significant trend in abundance in the Sounds of Barra SAC and abundance is significantly depleted compared to historic highs. The last count (2017) in the SAC represents around 4% of the SMU total compared to around 38% in 1992 (start of the time series).

Counts in the North Coast & Orkney SMU, and its SAC (Sanday), are drastically depleted compared to historic counts and both are still in decline. The current rate of decline and level of depletion are significantly more severe in the SAC than the SMU. In the last count in 2019, the SAC represented around 5% of the SMU total compared to around 19% in 1993 (start of the time series). In contrast

Shetland, although depleted, is not exhibiting a trend. This is also the case for the Yell Sound SAC. In contrast the Mousa SAC is almost completely depleted and is still in decline.

SMUs 6-9 (additional data compared to Russell *et al.* 2021) all show stable or declining trends. Although significantly depleted, the estimated trend in abundance in the Moray Firth is currently stable, though it should be noted the 2021 count in the subset considered was 37% lower than the one in 2019, and is the lowest count in the last 10 years. The SAC is more severely depleted and still in decline, representing 10% of the SMU count in 2021 compared to around 50% in the early 1990s.The East Scotland SMU is depleted and still in decline. The SAC is no longer significantly declining, appearing to have levelled off at a severely depleted level. In the last count (2021), the SAC represented around 16% of the SMU total compared to around 83% in the first SMU-wide survey (1997). Previously the rate of decline in the SAC was much more rapid than in the SMU, suggesting that outwith the SAC, harbour seals were increasing; this no longer appears to be the case.

SMUs 8 and 9 had shown sustained increases between Phocine Distemper Virus (PDV) outbreaks but in recent years declined (Russell *et al*. 2021). The most recent counts for the Tees, which hold the majority of the small population in Northeast England, mean that abundance is estimated as stable following the increase rather than declining (as in Russell *et al.* 2021). In contrast the trend for The Wash and North Norfolk SAC (SMU 9) which holds the majority of Southeast England's harbour seals is still in decline.

Grey seal August trends

Current grey seal trends in August were estimated to be stable in five of the nine SMUs considered. The increasing trends are in Southwest Scotland, West Scotland, Moray Firth, and Northeast England.

In two of the SMUs for which a stable trend was selected, Western Isles (Fig 3b) and East Scotland (Fig 7b), the most recent count is above the mean for the time series. There were limited data to fit a robust trend in East Scotland (n=6), and for the Western Isles the counts are variable with two periods of increasing counts. The North Coast & Orkney appears to have reached carrying capacity. Shetland (Fig 5b) is the only SMU for which there is a real possibility of recent declines; an exceptionally low count at the start of the time series precludes the fitting of a robust trend to current data.

Slight increasing trends (with considerable uncertainty) were estimated for West Scotland and its component parts. There was considerable uncertainty around the trend for Northeast England (Fig 8b), indeed it is not clear whether or not the last three counts represent a step increase in abundance or a continuing trend. For Southeast England SMU, the trend was fitted to the three of the five largest haulouts (Donna Nook, The Wash and Blakeney Point; c. 74% of the grey seal abundance in the SMU; Fig 9b). These three haulouts represent the most comprehensive time-series but there are indications that Donna Nook (Humber Estuary SAC) is now in decline (Fig 9b). The more recent major haulout sites likely to show different trajectories; data is lacking for Horsey but numbers at Scroby Sands are rapidly increasing (Thompson and Russell 2021). Thus, it is likely that the true rate of increase in the SMU is higher than reported here.

Generally, grey seal SACs are designated on the basis of their breeding colonies. Some SACs have relatively low numbers in August and so patterns in the August counts are not examined: Treshnish Isles SAC (West Scotland), North Rona (Western Isles), Isle of May (East Scotland), East Scotland component of the Berwickshire & North Northumberland Coast SAC. Counts for Faray & Holm of Faray SAC (North Coast & Orkney) are generally < 500 and have been variable but appear to be in decline. The remaining SACs (Monachs SACs, the Northeast England component of the Berwickshire & North Northumberland Coast SAC, and the Humber Estuary SAC) have significant numbers during both August and breeding. There is no indication of a pattern in the counts for the Monach Islands

SAC (Fig 3b; average around 1500; range 1250 - 1991) but the last count was considerably higher (2701) than the mean. The English component of the Berwickshire and North Northumberland SAC (Fig 8b) used to be the whole count for the Northeast England, it still accounts for >90% and thus the trends will mirror those of the SMU. As mentioned above the Humber Estuary SAC (Fig 9b; Donna Nook) comprises a decreasing proportion of the Southeast England SMU.

Grey seals pups

The final model estimating trends in grey seal pup production for aerially surveyed SMUs (excluding Moray Firth) included an estimated 21 % jump (95% CI: 13 – 30) in pup production associated with the change from film to digital (delta AIC of -24 compared to a model without the jump). The difference compared to that reported in Russell *et al.* 2021 is due to the exclusion of Moray Firth here.

The plots show the pup production trends (and associated confidence intervals) for each SMU if no jump had occurred; in essence, once the jump has been taken into account, the estimates based on both the film and digital surveys are used to fit the trends. The dashed line through the digital surveys shows the same trend but at the higher level of the estimates associated with the digital surveys. For the SMUs which comprise ground-counted colonies, a GAM was selected for Northeast and Southeast England, and a GLM with a declining trend for Shetland.

Although pup production had levelled off in West Scotland (early to mid-1990s; Fig 2i c) and Western Isles (mid 1990s; Fig 3c), the 2016 and 2019 estimates were higher than the first two digital survey estimates (2012 and 2014), which for the Western Isles has resulted in a slight recent increase in the mean predicted trend. This apparent increase is reflected in the Monach Islands SAC which accounts for almost 80 % of the SMU pup production. In contrast, the North Rona SAC, which historically was the biggest colony in the SMU, is severely depleted and continuing to decline. North Rona now accounts for less than 2% of the SMU's production compared to over 20% at the beginning of the time-series considered here (1984), and likely an even higher proportion in the 1960s and 1970s (Russell *et al.* 2019). In the North Coast & Orkney SMU (Fig 4c), since 2000 pup production has remained stable in the SMU as a whole but started to decline in the SAC. Production in the SAC is now significantly depleted to around half historic levels, accounting for c.10% of the SMU production. A declining trend was fitted for Shetland (Fig 5c); however, the time-series comprised a subset of colonies and was based on peak counts (which are sensitive to effort; i.e. number and timing of counts) and thus there are doubts as to how robustly these trends represent Shetland as a whole. The Moray Firth SMU (Fig 6c) shows indication that pup production is increasing though it should be noted that there is a limited temporal extent to the data and pup production within this SMU is particularly difficult to estimate. Pup production in East Scotland is continuing to increase but production on the Isle of May SAC appears to be in decline. The Isle of May SAC which until the mid-1990s represented almost 100% of the SMU's pup production now only represents c. 25%. This is to a large extent due to the rapid increase in pup production at Fast Castle, part of the Berwickshire and North Northumberland Coast SAC, which now accounts for over half the SMU's pup production and is still increasing. In reality, the SAC boundary transects the Fast Castle colony but for the purposes of this report, the entire Fast Castle pup production is assigned to the SAC.

Pup production in Northeast England, which is almost entirely encompassed by the Farne Islands component of the Berwickshire & North Northumberland Coast SAC (<100 pups elsewhere), is also increasing rapidly. Finally, pup production within the Southeast England SMU is continuing to increase exponentially but this is largely due to increases in Blakeney Point and Horsey, while the increase at Donna Nook (Humber Estuary SAC) which, up until c. 2000 accounted for the SMUs pup production is now slowing, and thus represents a decreasing proportion of the SMU's pup production.

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Table 1. *Trends in harbour seal August counts (top), and grey seal August counts and pup production (bottom) for all SMUs (1-9) and SACs in Scotland & eastern England.* The latest counts/pup production estimates (values) are given, as well as the estimated current rate of change (for the year leading up to the latest count). If the overall mean trend(s) indicated that the estimated value for the latest survey year was not the highest in the time-series, the predicted depletion from the historic high, and the latest year for which that high was predicted, is given. The time-series considered for grey seal pup production for most colonies began in 1984 encompassing between 30 and 36 data points (Shetland, Moray Firth and Fast Castle began in 2004 (N=10), 2006 (N=8) and 1997 (N=19), respectively). For August counts, the start year of the time series and number of data points (N) is given. Bold and italics, indicate there was a significant (upper 95% confidence intervals (CIs) < 0) estimated rate of decline (bold), or depletion (italics). Rates of change are rounded to 2 decimal places and depletion to integers. Values of 0 indicate a constant trend or that the latest estimate was the highest in the time series (depletion only). NAs indicate a lack of data.

SMU		SAC	1st Survey Year	N	Latest August Count (Year)	Latest Trend (% p.a.; 95% CI)	Depletion (%; 95%CI; vs year)
1	Southwest Scotland		1989	6	1709 (2018)	3.89 (1.86, 5.99)	0
2	West Scotland		1990	6	15600 (2018)	2.48 (1.64, 3.33)	0
2a	West Scotland - south		1990	6	7069 (2018)	0	0
		South-East Islay Skerries	1990	7	706 (2018)	1.88 (0.50, 3.25)	0
		Eileanan agus Sgeiran Lios mor	1990	10	238 (2018)	0	0
2b	West Scotland - central		1989	7	7447 (2017)	4.27 (3.51, 5.03)	0
		Ascrib, Isay and Dunvegan	1990	11	712 (2017)	0.83 (-9.73, 12.61)	-22 (-54, 33) vs 2002
2c	West Scotland - north		1991	6	1084 (2018)	4.86 (4.01, 5.71)	0
3	Western Isles		1992	8	3532 (2017)	6.27 (1.22, 11.64)	0
		Sound of Barra	1992	9	132 (2017)	2.66 (-4.50, 9.94)	*-86 (-91, -79) vs 1992*
4	***North Coast & Orkney***		1993	10	1405 (2019)	**-8.63 (-9.98, -7.28)**	*-85 (-88, -83) vs 2002*
		Sanday	1993	12	77 (2019)	**-14.24 (-17.87, -10.28)**	*-96 (-98, -93) vs 2002*

5	*Shetland*		1991	8	3180 (2019)	0	*-42 (-49, -34) vs 2002*
		Mousa	1991	8	7 (2019)	**-21.62 (-30.80, -11.19)**	*-98 (-99, -96) vs 1991*
		Yell Sound Coast	1991	8	209 (2019)	0	*-39* (-57, -14*) vs 2002*
6	*Moray Firth*[1]		1994	28	633 (2021)	-0.19 (-3.84, 3.48)	*-29* (-49, -4*) vs 1994*
		Dornoch Firth and Morrich More	1992	29	69 (2021)	**-7.68 (-9.09, -6.28)**	*-90* (-94, -85*) vs 1992*
7	***East Scotland***		1997	6	261 (2021)	**-4.93 (-7.09, -2.62)**	*-70* (-83, -47*) vs 1997*
		Firth of Tay and Eden Estuary	1990	29	41 (2021)	1.15 (-5.58, 8.36)	*-94* (-96, -92*) vs 1998*
8	Northeast England[2]		1989	33	86 (2021)	-0.74 (-6.42, 5.33)	-1 (-12, 11) vs 2020
9	Southeast England		2003	9	3752 (2019)	2.23 (0.60, 3.89)	0
		The Wash & North Norfolk SAC	1988	42	3372 (2022)	-3.35 (-7.84, 1.17)	*-24* (-33, -13*) vs 2015*

[1] Moray Firth values for August (Table a and b) are for a more frequently monitored subset (Loch Fleet to Findhorn; > 90% of SMU count for harbour seals & > 75% for grey seals) [2] Harbour seal SMU 8 values are for The Tees (>95% of the SMU count in 2019).

SMU		SAC	Pup Production			August Counts				
Number	Name		Latest Estimate (2019)	Trend (% pa; 95% CI)	Depletion (%; 95% CI)	First Survey Year	N	Latest Count (Year)	Trend (% pa; 95% CI)	Depletion (%; 95% CI) since year
1	Southwest Scotland		0	NA	NA	1989	6	517 (2018)	5.92 (3.44, 8.47)	0
2	West Scotland		4455	0.77 (-1.58, 3.14)	0	1990	5	4174 (2018)	2.84 (0.66, 5.08)	0
2a	- south		NA	NA	NA	1990	6	2922 (2018)	3.26 (1.50, 5.06)	0
		Treshnish Isles	1131	0.82 (-1.69, 3.48)	*-17* (-28, -5*) vs 1998*	1988	6	160 (2018)	0	0

2b	- central		NA	NA	NA	1990	6	773 (2017)	0	0
2c	- north		NA	NA	NA	1991	6	479 (2017)	0	0
3	Western Isles[3]		16083	1.42 (-0.78, 3.65)	0	1992	8	5478 (2017)	0	0
		Monach Islands	12511	1.61 (-0.73, 4.00)	0	1992	8	2701 (2017)	0	0
		North Rona	286	***-9.23*** **(-11.55, -6.81)**	*-84 (-86, -81) vs 1984*			175 (2014)	NA	NA
4	North Coast & Orkney		22153	0.65 (-1.60, 2.95)	-1 (-16, 17) vs 2006	1989	10	8599 (2019)	-0.41 (-6.07, 5.60)	-13 (-32, 11) vs 2000
		Faray & Holm of Faray	2186	***-4.94*** **(-7.23, -2.50)**	*-48 (-54, -40) vs 1998*	1989	13	228 (2019)	-7.92 (-15.55, 0.55)	*-52 (-69, -26) vs 2007*
5	***Shetland***[4]		433	***-2.75*** **(-3.98, -1.49)**	*-32 (-43, -19) vs 2004*	1991	8	1009 (2019)	0	0
6	Moray Firth[1]		1865	3.12 (0.65, 5.77)	0	1994	28	1082 (2021)	3.39 (0.25, 6.61)	0
7	East Scotland		7261	5.38 (3.56, 7.17)	0	1997	6	2707 (2021)	0	0
		Isle of May	1885	*-1.93 (-3.99, 0.16)*	*-20 (-30, -10) vs 2004*	1997	6	97 (2021)	0	0
		Fast Castle, BNNC[5]	4499	8.31 (5.81, 10.92)	0			0 (2021)	NA	NA
8	Northeast England					1997	7	4668 (2020)	11.69 (8.61, 14.81)	0
		BNNC	2823	9.27 (7.11, 11.43)	0	1997	7	4251 (2020)	11.48 (8.31, 14.69)	0
9	Southeast England[6]		7902	11.31 (9.14, 13.46)	0	1988	43	5729 (2022)	NA	NA
		Humber Estuary	2187	3.26 (1.16, 5.36)	0	1988	49	3463 (2022)	-2.69 (-11.3, 7.12)	-7 (-34, 32) vs 2017

[3]August grey seal counts are for a subset (excludes offshore islands), [4]No estimates for pup production available, peak counts from a limited subset of colonies used. [5]All Fast Castle pup production included in Berwickshire and North Northumberland Coast (BNNC) SAC total for Scotland. [5] For August count, counts and associated trends are based on a subset (Donna Nook to Blakeney; c.75% of SMU) which excludes the two most rapidly increasing haul outs (Scroby Sands and Horsey). For this reason, the trends and depletion value is shown as NA to avoid misinterpretation.

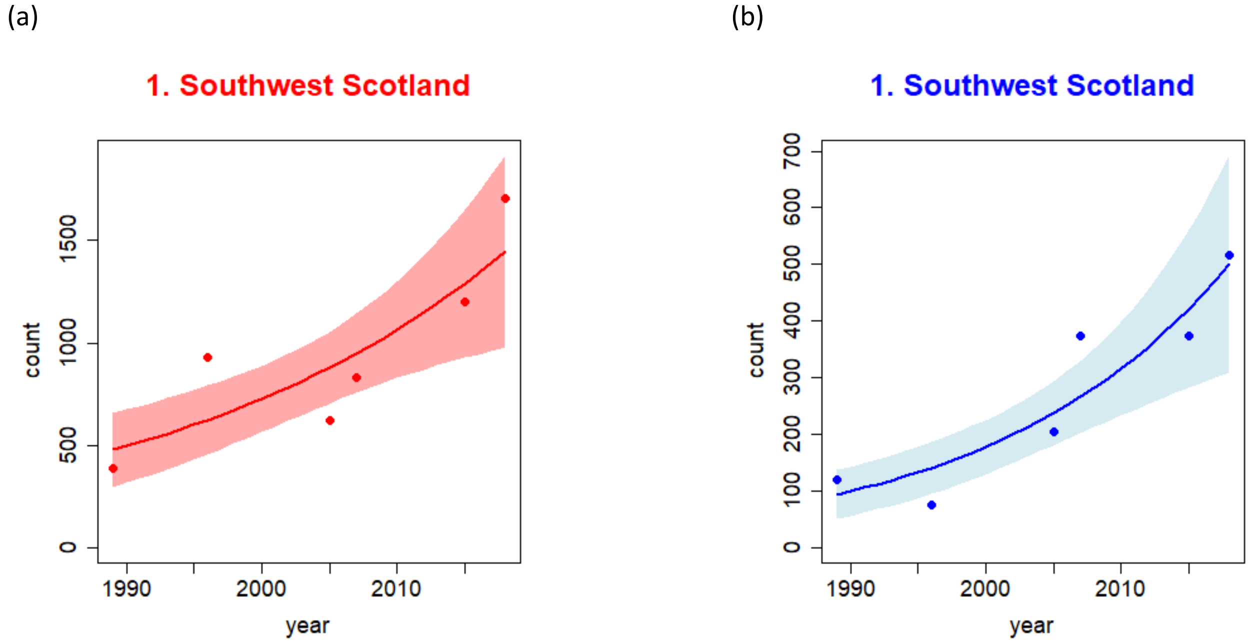


Figure 1. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the Southwest Scotland SMU. The *filled circle* points represent the values used to fit the trends.

(a) (b) (c)

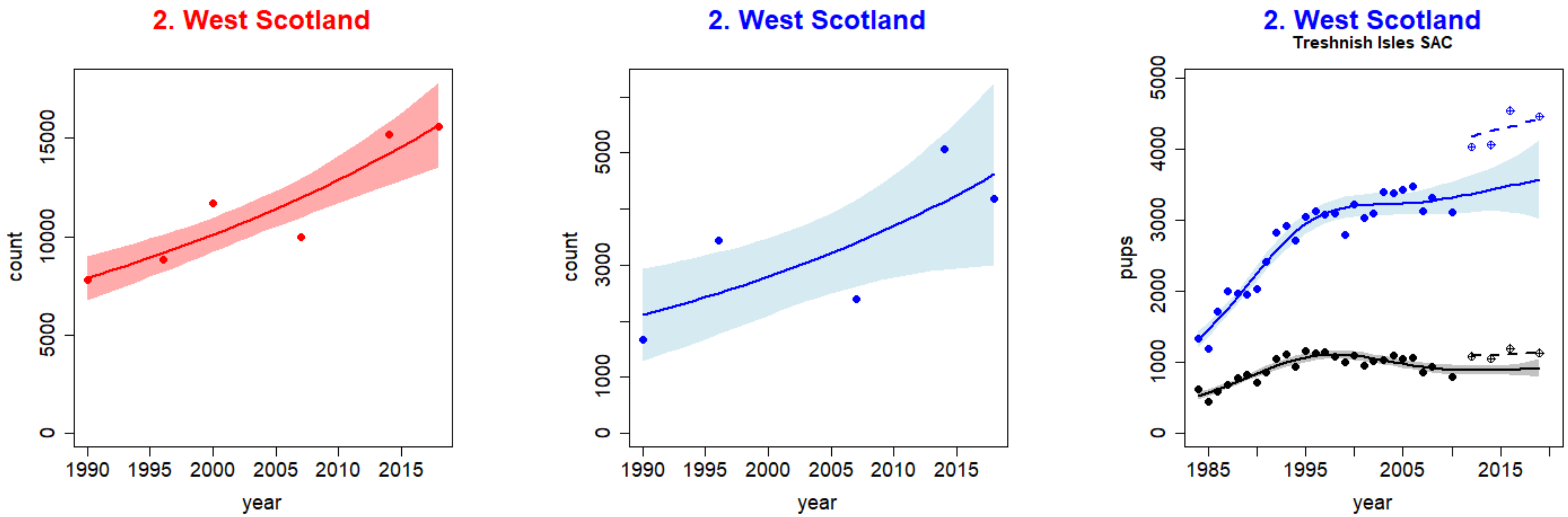


Figure 2i. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the West Scotland SMU and encompassed SACs (c only). The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for digital survey estimate (*circle plus*).

(a) (b)

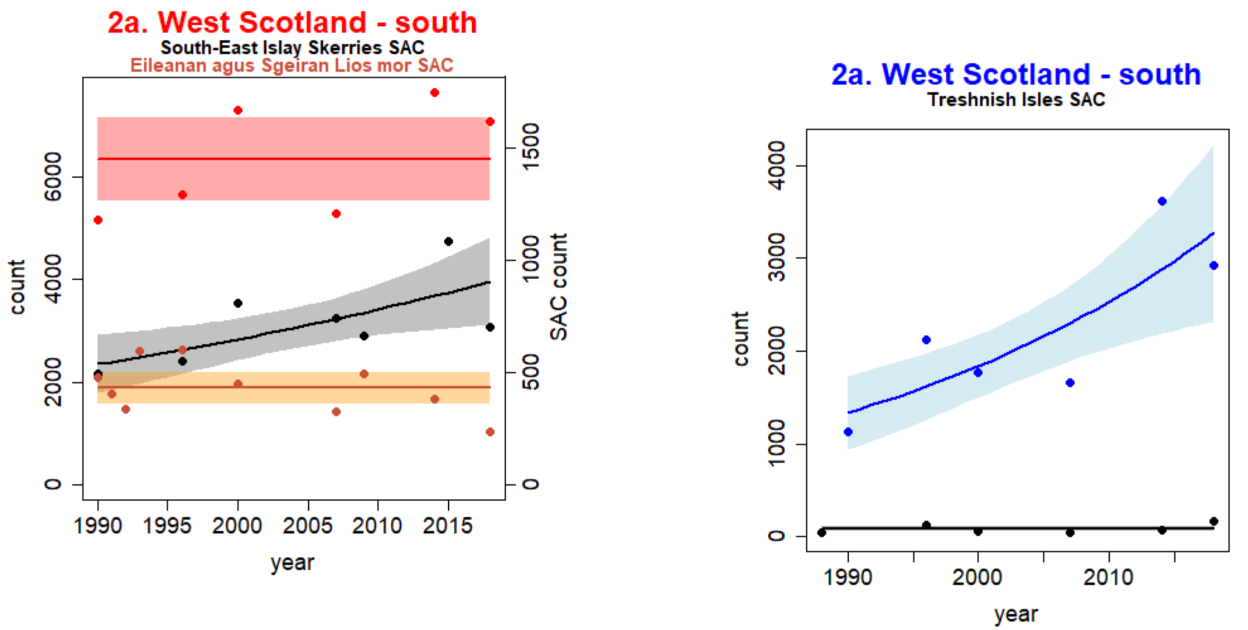
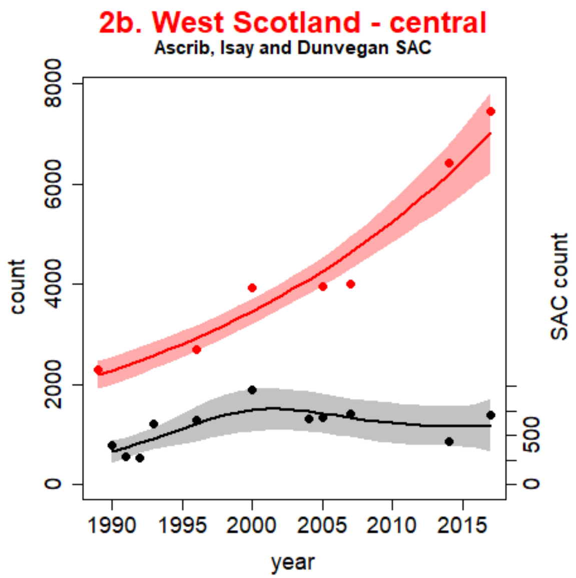


Figure 2ii. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the southern part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

(a)



(b)

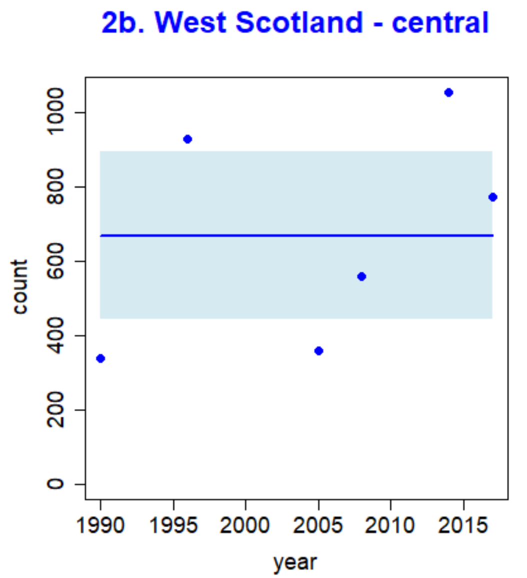


Figure 2iii. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the central part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

(a) (b)

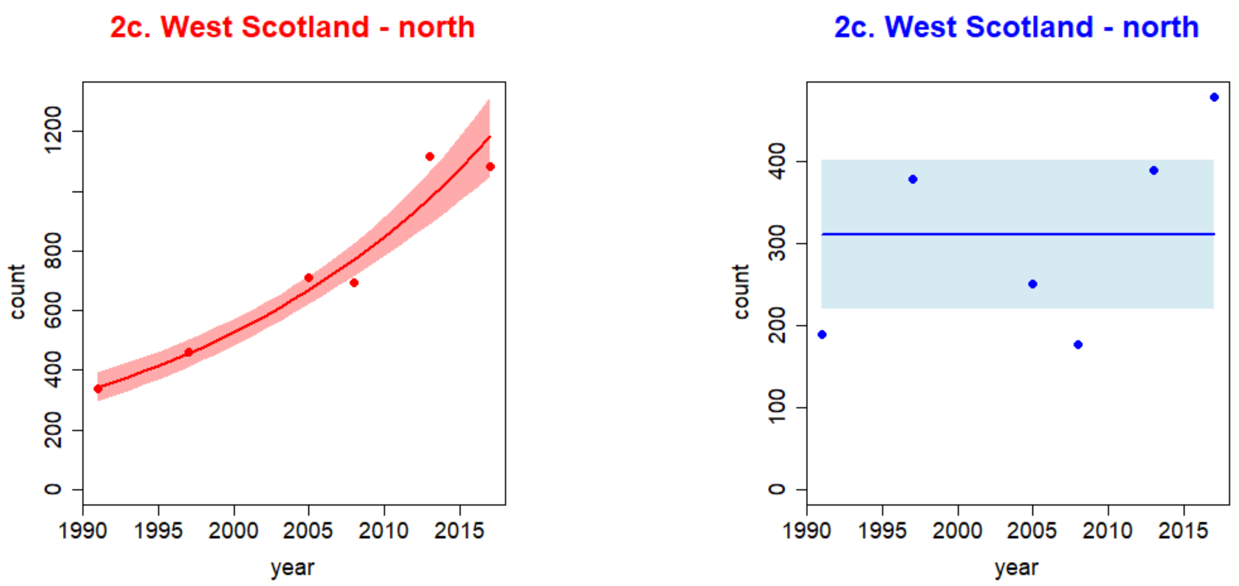


Figure2iv. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the northern part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends.

(a) (b) (c)

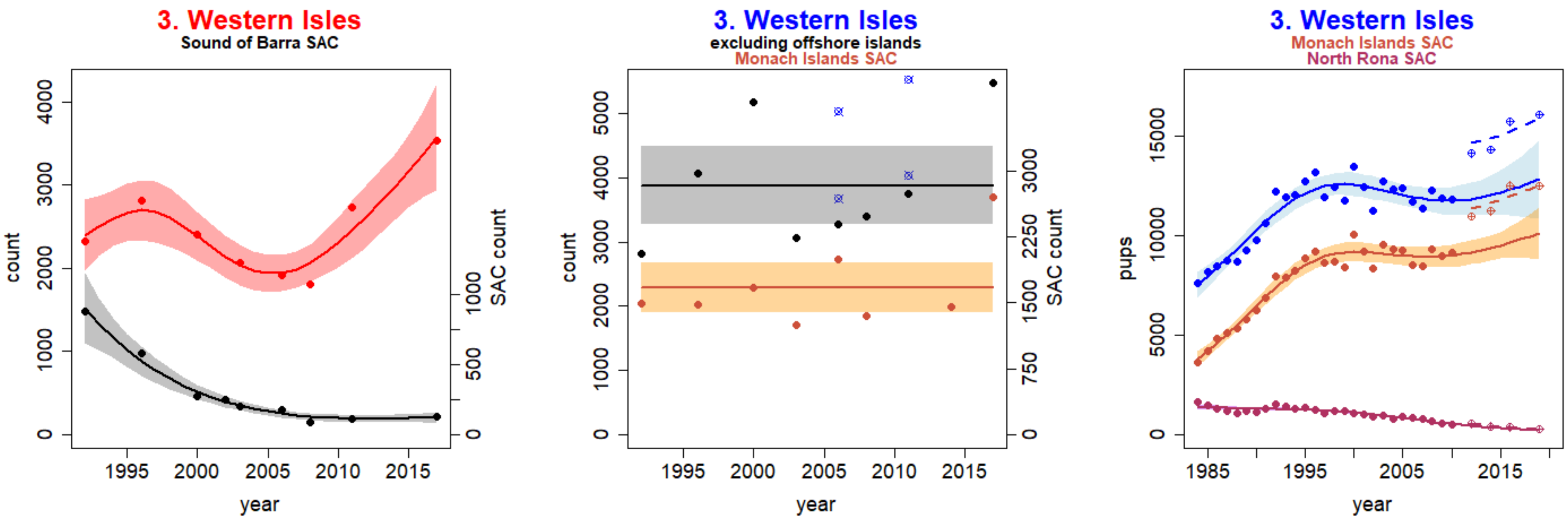


Figure 3. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the West Scotland SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The *circle cross* points (b) represent the SMU-wide total and were not used for model fitting. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for digital survey estimate (*circle plus*). Note the different axes for the SACs (a, b).

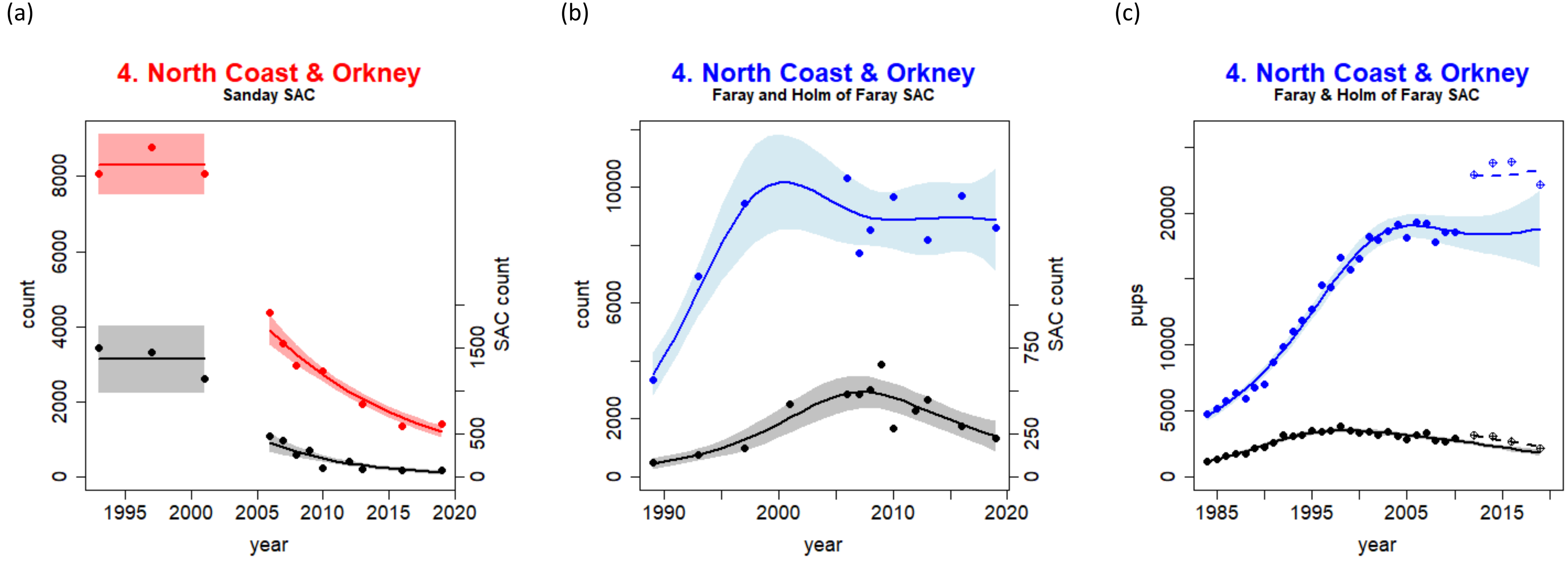


Figure 4. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the North Coast & Orkney SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for digital survey estimate (*circle plus*). Note the different axes for the SACs (a, b).

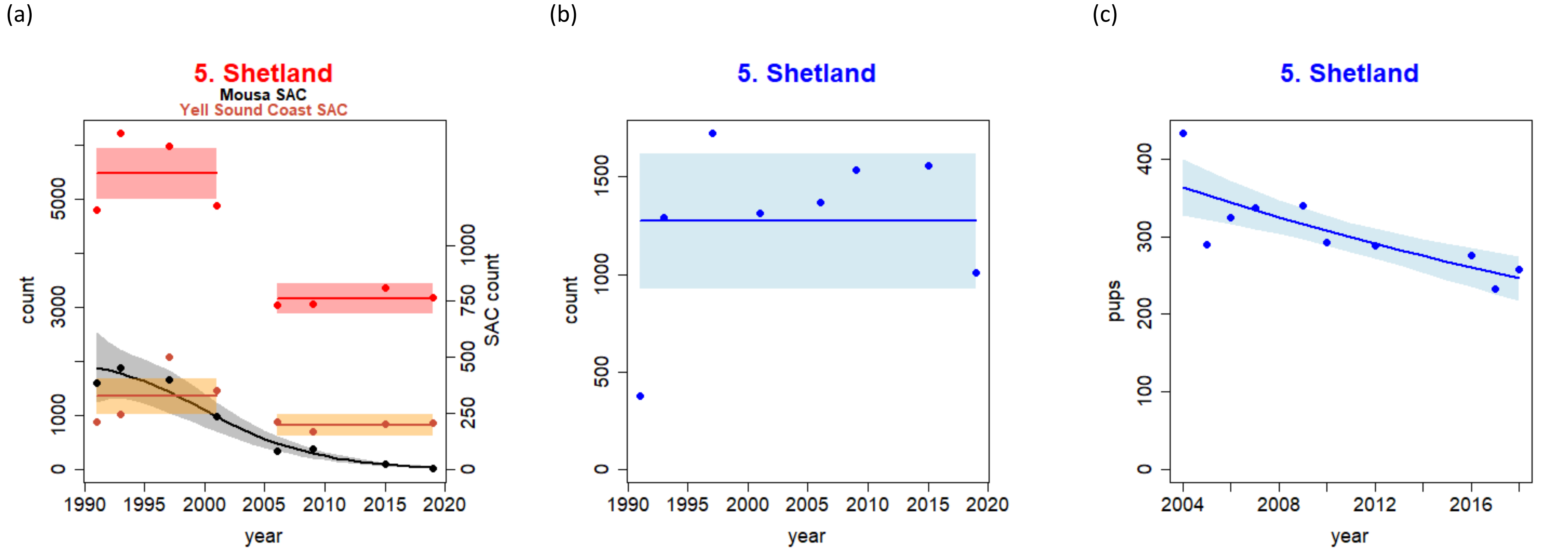


Figure 5. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal peak counts (c) in the Shetland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

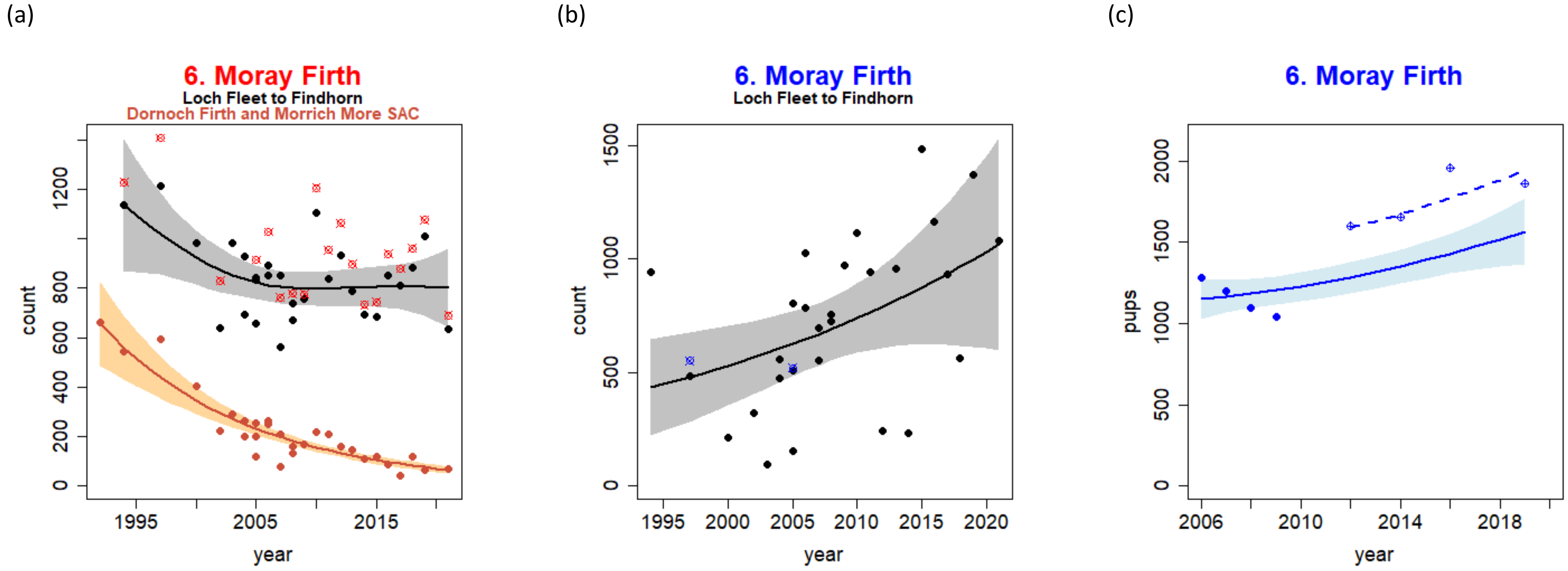


Figure 6. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Moray Firth SMU (subset for a) and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The *circle cross* points (a, b) represent the SMU-wide total and were not used for model fitting. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for digital survey estimate (*circle plus*). The black crossed circles in (a) illustrate the SMU-wide counts and were not used for model fitting.

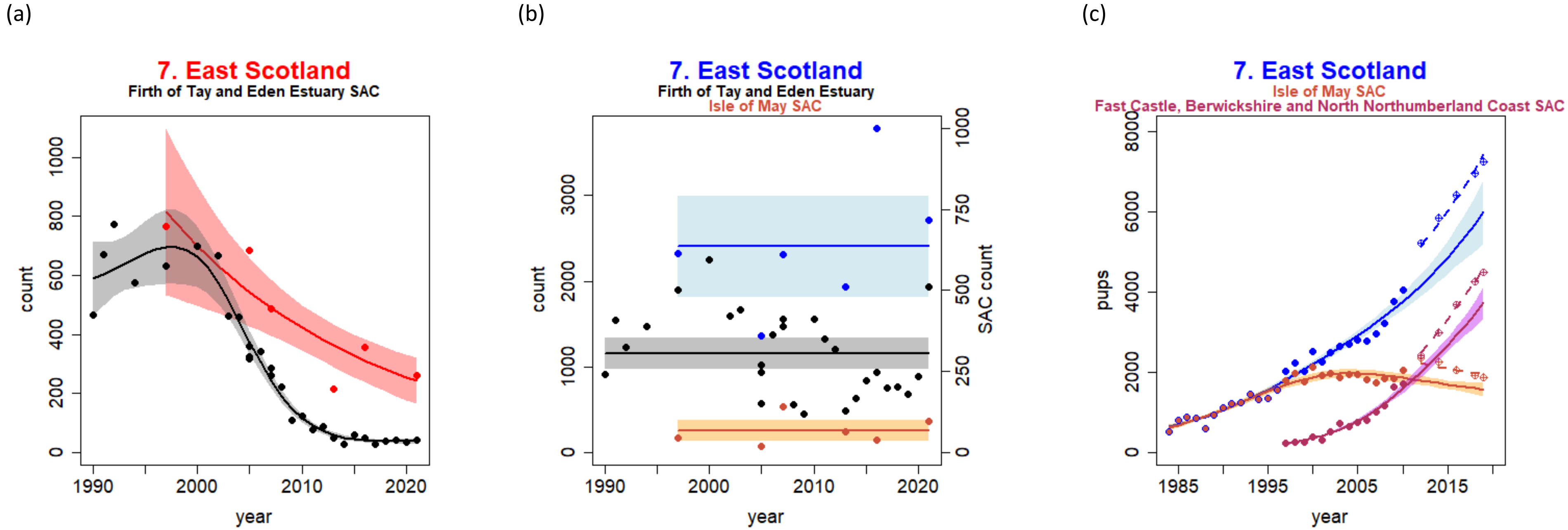


Figure 7. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the East Scotland SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for digital survey estimate (*circle plus*). Note the different axes for the SACs (b).

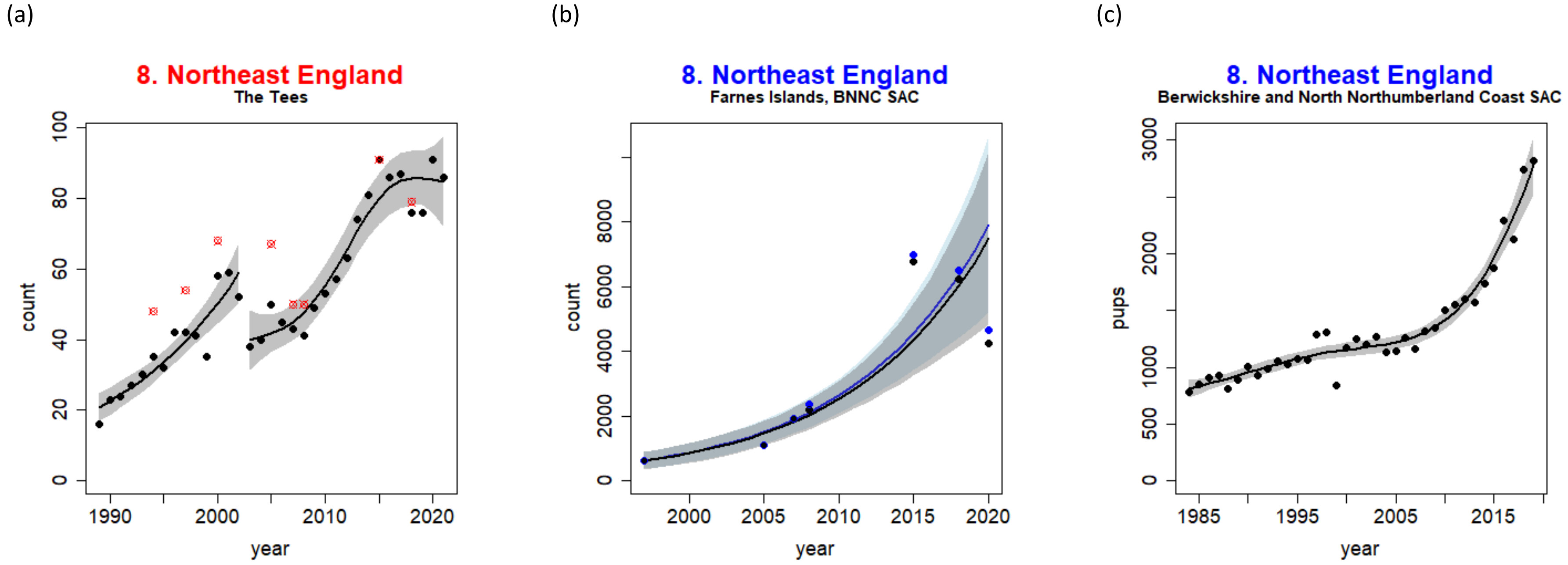


Figure 8. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Northeast England SMU and encompassed SAC(s). The *filled circle* points represent the values used to fit the trends. The *circle cross* points (a) represent the SMU-wide total and were not used for model fitting. Note that the SAC represents >99% of the SMU's production (c).

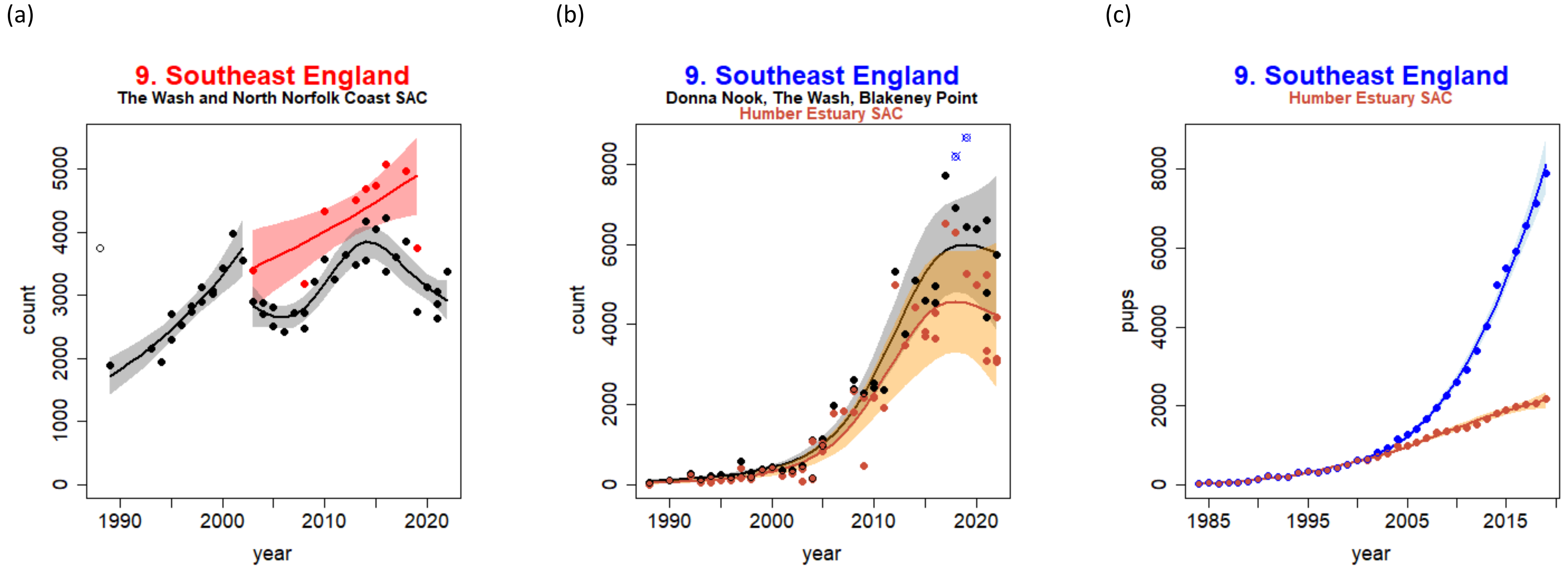


Figure 9. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Southeast SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. The *circle* point (a) was not used to fit the trend (count prior to PDV epidemic). The *circle cross* points (b) represent the SMU-wide total and were not used for model fitting.

Grey seal pup counts and estimates: east England

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Abstract

Historically, grey seal colonies in Northeast (Farne islands) and Southeast England (Donna Nook, Blakeney and Horsey) Seal Monitoring Units (SMUs) were not covered by aerial survey. These colonies have been ground counted by various organisations: National Trust (Farne Islands and Blakeney Point), Lincolnshire Wildlife Trust (Donna Nook) and Friends of Horsey Seals (Horsey). The method of pup estimation from these counts differs between colonies. Estimated pup production in these colonies has rapidly increased in the last 20 years from around 2,000 pups in the early 2000s to over 10,000 in 2019. The size of the colonies has made counting increasingly labour intensive, and in some cases, hindered by risk of disturbance and safety concerns for counters. Indeed, National Trust no longer generate estimates of pup production from ground counts on the Farne Islands or Blakeney with the last colony-wide estimate from ground counts in 2019.

SMRU conducted a full set of aerial surveys of east England in 2018 and 2021. Here we compare the counts and associated pup production estimates from ground and aerial surveys in 2018. The findings here indicate that in southeast England, the ground counts, and likely the resulting pup production estimates, are underestimates. Moreover, the findings, particularly the similarity of the aerial and ground derived estimates for the Farne Islands, suggest that the pup production estimates from the digital aerial surveys are likely closer to true pup production levels than from the film.

The cessation of ground counts and the preliminary results from the 2018 survey led to the decision to include east England in the aerial survey programme going forward. This has ramifications for the Scotland aerial surveys, but it is hoped that drone surveys can eventually replace the aerial surveys in eastern England. The differences between the ground and aerial derived estimates of pup production prohibits the direct incorporation of aerial survey estimates into the current pup production time-series. It is not possible to estimate a single scalar from ground to aerial survey estimates. This is because of the varying ground survey methods used in the colonies, and the likelihood that the accuracy of the counts is associated with colony size and density. Indeed, it is likely that counts earlier in the time series, and thus production estimates, are much more accurate than in 2018. The counts from the 2021 aerial surveys are currently being completed. These data will present another opportunity to compare ground and aerial counts, and where possible (Donna Nook and a subset of Horsey), production estimates. On the basis of the combined findings (2018 and 2021), the most appropriate way of incorporating these data into the population model will be decided.

Introduction

There are four large colonies on the east coast of England (Figure 1 in SCOS report), all of which were historically ground surveyed: Farne Islands (1956-2019), Donna Nook (since 1970), Blakeney Point (2002-2019) and Horsey (since 2002). Survey methods differed between the colonies, but have been, for the most part, consistent within colonies with small adjustments with change in personnel.

On the Farne Islands, during surveys conducted by the National Trust, all non-marked whitecoat pups were counted and marked with dye to allow the number of pups sprayed over the season to be used to directly estimate pup production. In each survey, all marked whitecoat pups as well as moulted pups are also counted. The frequency is weather dependent but for the main pupping islands, surveys were generally conducted at least every 2 weeks. This method has the potential to provide a virtually error-free estimate of pup production up until the end of the surveys; any pups born after the cessation of surveys will be missed. However, it is the ground survey method likely associated with the highest level of disturbance and associated safety concerns. These concerns led to the National Trust to start drone trials in 2017 resulting in high quality whole-island images for the 2021 season. For logistical reasons, the drone surveys were restricted to November limiting the ability to use these for direct estimation of pup production. However, concurrent ground, drone and aerial surveys conducted in 2021 will allow an extremely useful comparison of methods. Although some ground counts were conducted in 2021, these were solely for comparisons between ground and drone counts. The last ground-derived production estimate for the Farne Islands was for the 2019 season.

The pups at the other colonies on the east coast of England - Donna Nook (surveyed by Lincolnshire Wildlife Trust), Blakeney Point (surveyed by National Trust) and Horsey (surveyed by Natural England and then Friends of Horsey Seals) - were not routinely marked. However, at Blakeney, dead pups were marked to avoid repeat counting. At Donna Nook, pups are counted weekly with timing and frequency constrained by the adjacent RAF range. Pup production is estimated by combining (1) the highest (peak) pup count of live pups, (2) the number that died up to and including the peak, (3) newborn pups each week after the peak. At Blakeney Point, the method is similar, but the highest number of pups (1) used in the estimate is from mid-November (prior to the peak), and from that date in the season, surveys were conducted every 3-4 days with generally only pups thought to be born since the last survey being recorded. Thus, for both colonies, the accuracy of the estimate is dependent on the accuracy of delineating pups into those born prior to, and since, the last survey. Accuracy is also dependent on the degree to which the highest count represents all pups born up to that point. At Horsey, weekly full pup counts are conducted throughout the season, but pup production estimates are based on the cumulative total of pups estimated to be new-born each week (i.e. the peak is not used directly), and thus is the method most reliant on aging pups. At Horsey, counts are conducted over two days, but for the purposes of comparison, we have assigned the counts to the second day. At the Farne Islands, Donna Nook and Blakeney Point, all counts are led by the ranger. For the most part this has likely afforded considerable consistency in methods across years, with rangers being in place for many years. For Horsey, the length of coastline requiring two groups to count each week, and necessary reliance on volunteers, may impact consistency. However, there is training for counters which has stayed consistent through time.

SMRU conducted a set of aerial surveys of the east coast of England in both 2018 and 2021. Here, we focus on the 2018 comparison, as counts for 2021 aerial surveys are still being finalised.

Methods

For 2018, ground-based pup production estimates and associated raw count data were sourced from the relevant organisations and people (see Acknowledgements). During the 2018 season, five and four aerial surveys were carried out in Northeast England and Southeast England, respectively. Images from these surveys were stitched together to generate colony-wide images and the number of whitecoat and moulted pups counted. These counts were used to derive a birth curve and estimate pup production (see Russell *et al.* 2019 for details; Figure 1). The estimated peak number of pups on each colony and the associated date was also output to aid comparison with ground counts.

The Farne Islands consists of multiple islands. The survey frequency of ground counts was linked to the number of pups, with the main pupping islands being surveyed most frequently. Furthermore, it takes multiple days to survey the islands. Thus, for the most part, comparisons between ground and aerial surveys needed to be conducted on the individual island. Islands with pup production estimates of ≥ 100 were used in the comparison (5 islands). Thus, the pup production model was fitted to aerial survey counts by individual islands, and also for the Farne Islands as a whole. Production estimates for individual islands may not sum to the totals across multiple islands.

Pup production estimates from ground and aerial surveys were compared in terms of both number of pups and percentage difference to aerial survey values. This was conducted on a colony basis, and for the Farne Islands also at the individual island scale (see above). Peak counts were compared but such comparisons should be considered in combination with the estimated date of peak pup abundance (Table 1). Direct comparison of counts was only useful when they were on the same day. Thus, to aid comparison of methods, all available ground-based pup counts were also plotted with the aerial survey counts and output from the associated pup production models.

Results and Discussion

A comparison of counts and production estimates are given in Table 1. Comparison of peak counts between ground and aerial survey should be viewed with caution; there are rapid changes in the numbers of pups in a season and surveys are conducted at a variable frequency. To aid interpretation the estimated date of peak numbers of pups, from the pup production model fitted using the aerial survey counts, is also given.

The plots illustrate that, as highlighted previously, the overall fit of the total aerial survey pup counts is good (Figure 1). However, in general, the aerial survey counts of whitecoat and moulted pups are lower and higher than the model predictions, respectively. Although, this could be in part due to a net misclassification of white coats as moulted pups (not incorporated in the pup production model formulation), it is likely that most of the discrepancy is caused by the mean age at leaving the colony (time to leave; TTL) set in the model (31.5 days) being lower than in reality (see Russell *et al.* 2015 for a review of the pup production parameters). Increasing the age of leaving set in the model would result in a decrease in the overall pup production estimate. It is important to clarify that this does not explain the apparent jump in pup production from film to digital, as the same issues would have applied to estimates derived from film counts. A project is currently underway to replace the current pup production model, taking advantage of the developments in statistics and computing power since the construction of the original pup production model. This project has suggested that here may be an artefact in the current model which, for a given TTL, results in an underestimation of the production, though this needs further investigation. It should also be noted that the aerial-survey derived estimates assume that 5% of pups that, given the birth curve and TTL parameters, should be present on the colony are missed. This could be because they are not detected or are dead and have washed off the colony. The degree to which dead pups remain present and visible on the colony will vary with habitat and weather conditions. The higher regularity of the ground surveys mean less dead pups should be missed.

For the Farne Islands the production estimate derived from aerial surveys was slightly higher (< 5%) than for ground. However, on an individual island level (n=5), aerial survey derived estimates were between 12% higher and 9 % lower, with both extremes of the range equating to differences of around 35 pups. Counts could only be compared on an island scale. For the two key pupping islands (Brownsman and Staple), despite the peak ground count being conducted close to the estimated peak date it was almost 15% lower (114 and 71 pups, respectively) than the peak aerial survey count. Indeed, most of the ground counts of these two islands were lower than numbers estimated present from the pup production model (fitted to the aerial survey data). Because the ground counts themselves are not used to estimate pup production (rather it is the number sprayed), undercounting would not impact production estimates as long as the non-marked whitecoats were found and marked on a survey before they moulted.

Table 1. *Peak counts and pup production estimates for east England grey seal breeding colonies in 2018, by method (ground vs aerial). Comparisons are made using aerial derived counts and estimates as the baseline.*

Colony		Peak count							Production			
		Ground		Aerial		Estimated date of peak	Difference		Ground	Aerial	Difference	
		Count	Date	Count	Date		Pups	%			Pups	%
Farne Islands	Brownsman	721	24/11/2018	835	30/11/2018	26/11/2018	-114	-14	1121	1151	-30	-3
	Staple	437	17/11/2018	508	18/11/2018	25/11/2018	-71	-14	688	652	36	6
	North Wamses	133	17/11/2018	117	18/11/2018	21/11/2018	16	14	185	169	16	9
	South Wamses	222	17/11/2018	214	18/11/2018	24/11/2018	8	4	301	323	-22	-7
	West Wideopen	222	02/12/2018	214	14/12/2018	07/12/2018	8	4	271	308	-37	-12
	All								2737	2860	-123	-4
Donna Nook		1874	30/11/2018	2083	30/11/2018	01/12/2020	-209	-10	2066	2684	-618	-23
Blakeney					14/12/2018	11/12/2018			3012	4786	-1774	-37
Horsey		1518	13/12/2018	1866	14/12/2018	13/12/2018	-348	-19	2069	2140	-71	-3

There was more focus on counting whitecoats pups than moulted pups (National Trust, pers comm.) which may explain some of the discrepancy. It should also be noted that although the ground counts were classed into white and moulted, the classification of moulted differs from that used for the aerial survey counts. Thus, direct comparison of the classed counts (estimated and predicted) is not possible. The National Trust classify pups as moulted when ≤ 20% of lanugo (white fur; National Trust pers. comm) remains compared to ≤5 % for aerial survey counts. Peak ground counts for the other three islands were between 4 and 14% higher than for aerial, but in terms of number of pups the differences were small (up to 16 pups). Furthermore, overall, only two of the ground counts across these three islands (of 21) were higher than predicted by the pup production model fitted to the aerial survey counts (Figure 1a).

Aerial-survey derived pup production estimates were 23, 37%, and 3% higher than ground-derived estimates for Donna Nook, Blakeney Point and Horsey, respectively. For Donna Nook, the peak count was conducted on the same day for ground and aerial, with a mismatch of 209 pups (aerial survey count 10% higher than ground). In general, the ground counts were lower than predicted from the pup production model (Figure 1b). The higher mismatch between the pup production estimates, compared to the count estimates may, in part, be a result of difficulties in accurately aging the pups, and also that the peak count may not have represented all pups born up until that date. The peak ground count in 2018 was 8 weeks after the first count (of 2 pups). The counts did increase quite slowly in the first 4 weeks to 82, but it is likely that some pups had left by the peak count. At Blakeney point, only newborn pups are counted from mid-November. However, a full count was conducted in mid-December, around a week after the peak; that count was around 1/3 lower (c. 1200 pups) than expected (based on the pup production model; Figure 2c). Indeed, the highest aerial survey **count** was 26% (783 pups) higher than the ground-derived pup production **estimate**. In discussion with National Trust at Blakeney, they highlighted the difficulties in conducting the counts given the colony size and density, and tussock grass. Despite the similarity in Horsey pup production estimates derived from ground and aerial based methods, there were considerable differences in the counts (Figure 1d). Indeed, despite being conducted within a three-day window, the aerial peak count was almost 20% higher (348 pups). The method typically used for Horsey (cumulative newborn pup count), was to some degree impacted by an attempt to match SMRU's count classification (to aid comparisons) for one count. However, from the raw count data provided by Friends of Horsey Seals, we could not regenerate their pup production estimate with estimates generated using two methods (cumulative newborns and peak plus newborns) not being as high as the one provided.

These findings highlight the difficulties in counting such large colonies and in the aging of pups (to classify them as born since last survey). The latter will likely depend on the experience of the counters, the availability of landmarks (e.g. groynes) to aid counting, and the consistency of the inter-survey interval. It is not possible to disentangle the contributing factors for the under counting in ground surveys, presenting difficulties in combining the ground and aerial surveyed time series (Figure 2). Based on the preliminary findings of the aerial surveys of Blakeney, discussions between SMRU and Blakeney resulted in the cessation of colony-wide Blakeney ground surveys following the 2019 season (Grey seals on Blakeney Point | Norfolk | National Trust). Instead, National Trust have been focussing on collecting data which will complement SMRU's colony-wide estimates. The comparisons also highlight the importance of a consistent monitoring method and the need for comparisons when methods change going forward. The limited number of distinct colonies in eastern English colonies mean, in contrast to most Scottish colonies, they could potentially be surveyed by drone in the future. This would have advantages in terms of image quality and likely reduced carbon emissions associated with surveys. Furthermore, drones with infrared capability would facilitate estimation of mortality levels. Drone surveys have been shown to be feasible for the Farne Islands. However, deriving pup production from the associated counts would be dependent on the survey frequency and temporal extent which are both dependent on weather conditions. It would also require knowledge of observation parameters including the probability of detecting pups and misclassification between the white and moulted classes (Russell *et al.* 2015). The continuation of the drone monitoring of the Farnes is uncertain (funded by National Trust). Natural England are trialing drone surveys of Horsey but the size of the Blakeney colony currently prohibits drone operators licensed for visual line of sight operations (VLOS) as they require the operator to be within 500m (which would be within a dense area of the colony). Even an extended license of 1 km (VLOS) would likely require the operator to stand within the colony. Investigations into the use of drone surveys for these colonies will continue. However, until there is the potential for a sustainable, consistent, appropriate drone survey programme in place, continued aerial surveys of the east coast of England are fundamental for monitoring grey seal populations in England and the UK as a whole.

These comparisons between ground and aerial survey data also have ramifications for the pup production model. Although the aerially derived pup production estimates were higher than those derived from ground, it was generally not as marked as for the counts. Indeed, estimates for the Farne Islands were similar to those from ground counts. Given the method used here (marking of pups), it seems unlikely that the ground-based methods could underestimate pup production. Thus, the fact that aerial-survey derived estimates for the two main pupping islands were similar to those derived from ground counts suggests that the higher pup production associated with the digital survey methods (compared to film) may be nearer the true value than the lower levels estimated from film derived surveys. The drone images from the Farne islands in 2021 will provide further comparisons with aerial survey methods and inform the observation parameters for the pup production model currently in development.

Acknowledgements

We are indebted to National Trust, Lincolnshire Wildlife Trust and Friends of Horsey Seals. As well as their pup production estimates, they provided raw count data, description of methods, and answered endless questions. In particular, thank you to Gwen Potter, Harriet Reid, Duncan Halpin and Chris Bielby (National Trust); Matt Blissett (Lincs Wildlife Trust); and Chris Godfrey, Julie Sisson and Sally Butler (Friends of Horsey Seals). We would also like to thank Richard Bevan (Newcastle University).

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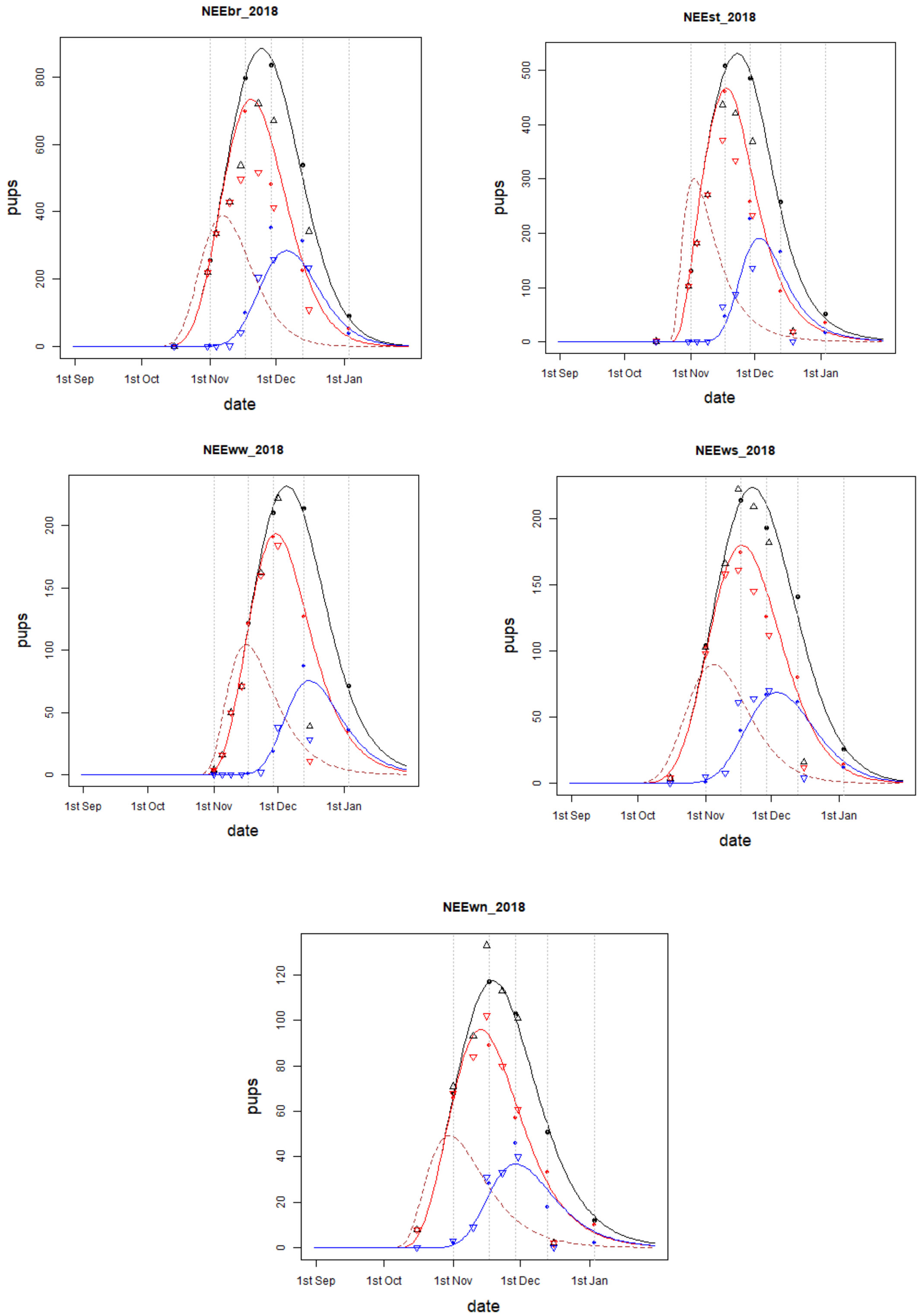
(a)


NEEbr_2018
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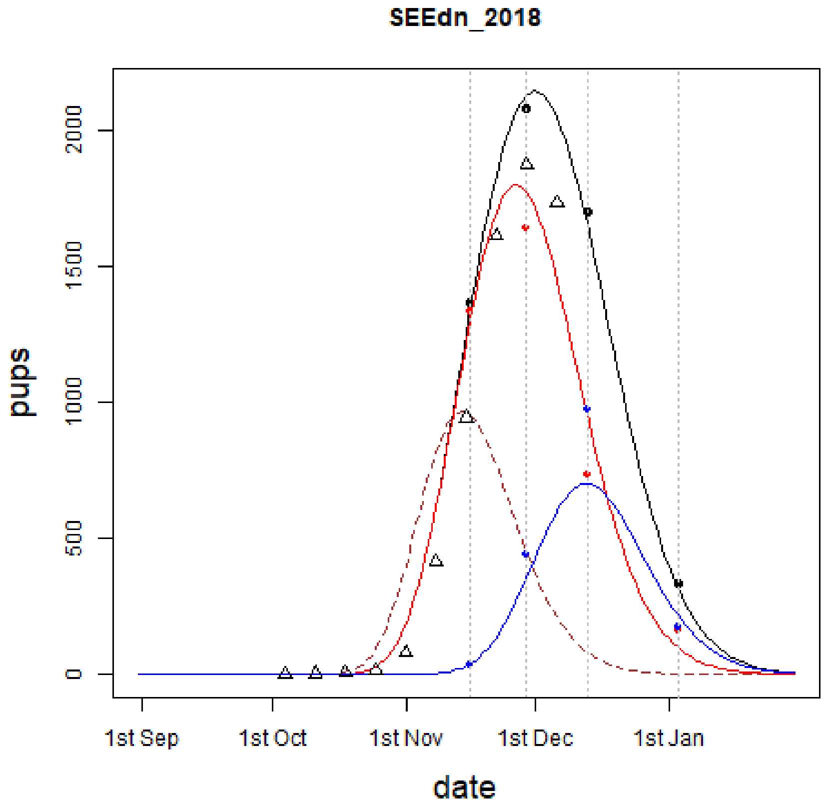
(b)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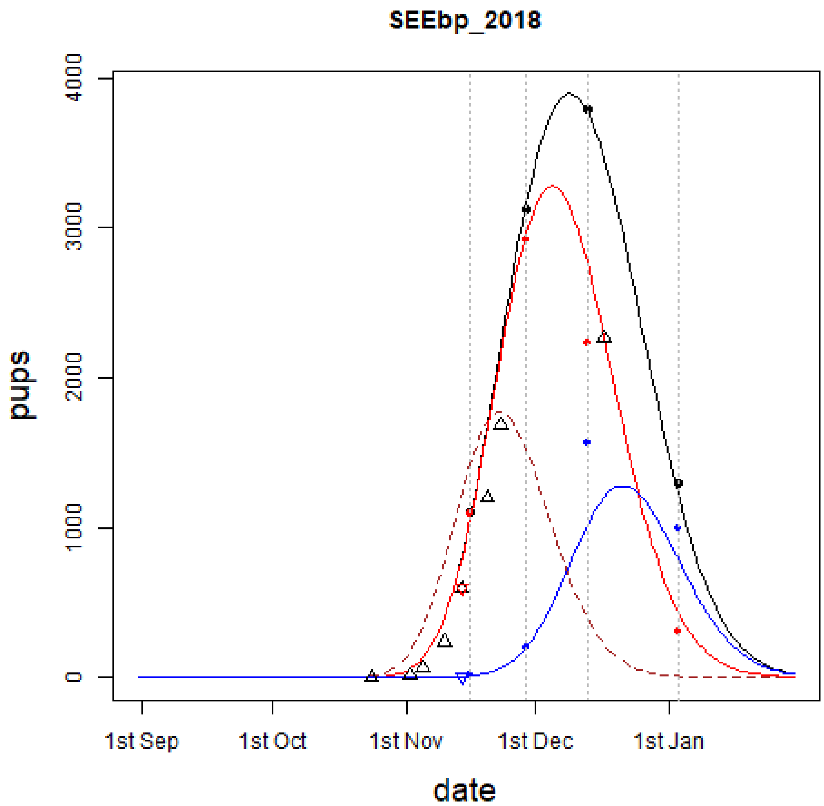
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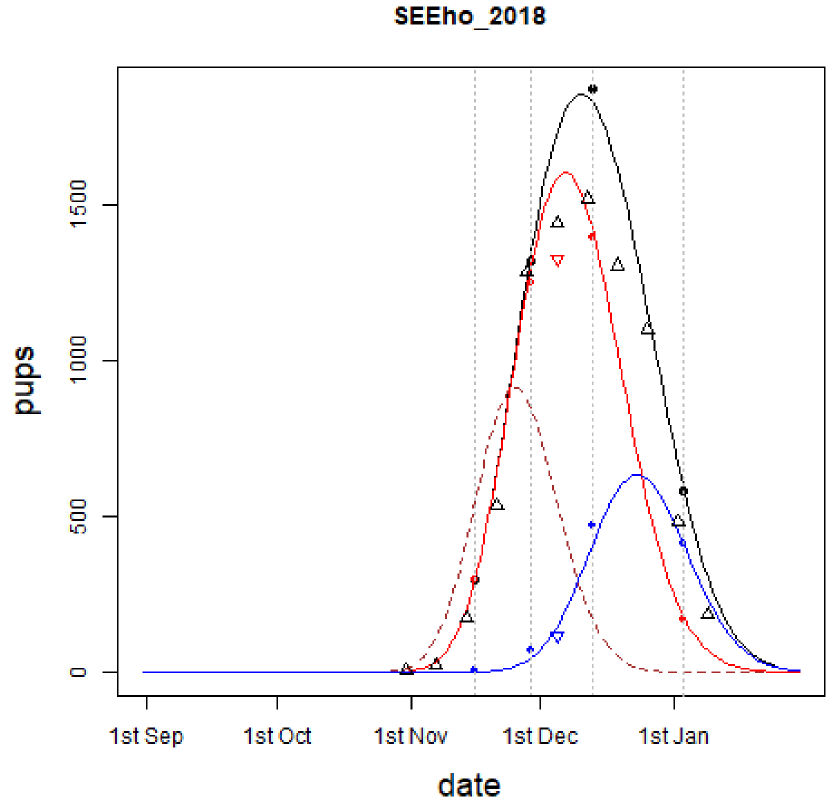
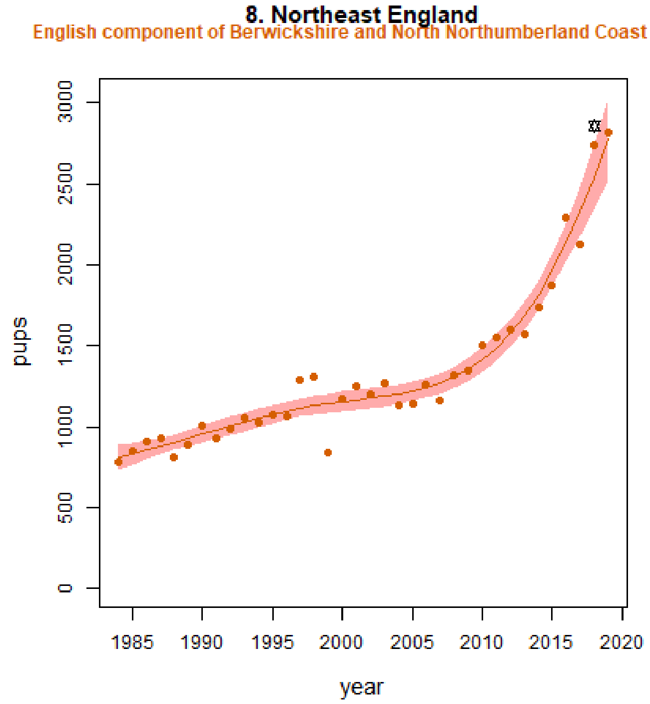


Figure 1. Grey seal pup counts and birth curve for eastern England in 2018. (a) The five main Farne islands for grey seal pupping: Brownsman (NEEbr) and Staple (NEEst; top row); North (NEEwn) and South Wamses (NEEws; second row) and West Wideopens (NEEww; bottom row), (b) Donna Nook (SEEdn), (c) Blakeney Point (SEEbp), and (d) Horsey (SEEho). Filled points represent the aerial survey counts, and the solid lines represent the estimates from the associated pup production model: whitecoats (red), moulted pups (blue) and total pups (black). The dashed brown line represents the estimated pup birth curve (multiplied by 10 for illustration purposes). The grey dotted vertical lines represent the dates of the aerial surveys. The triangles, coloured as above, represent the ground counts.

(a)



(b)

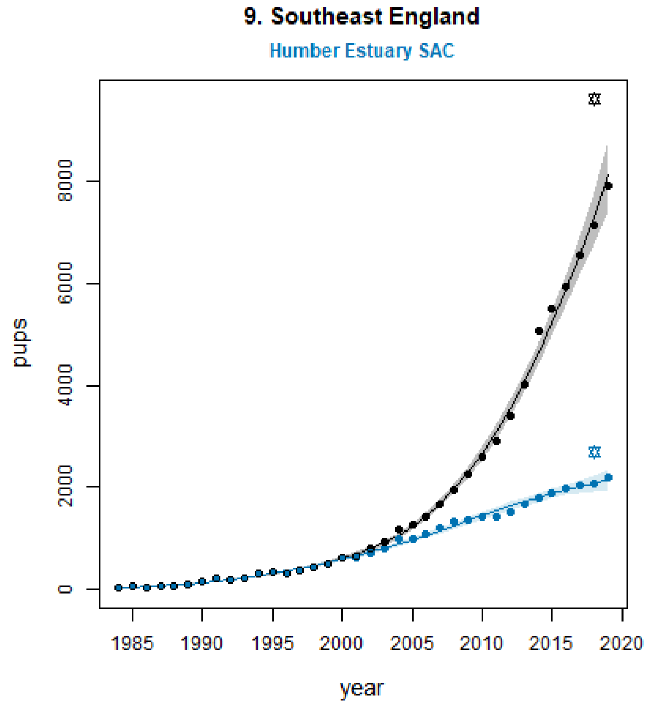


Figure 2. Trends in grey seal pup production estimates (SCOS BP 22/02) for Northeast England (a) and Southeast England (b) SMUs (and associated SAC colonies: Farne Islands (a) and Donna Nook (b)). These trends (line and 95% confidence interval shading) are generated from ground count derived estimates (filled points). The associated aerial-survey derived estimate (stars) are shown.

The status of UK harbour seal populations in 2021 including summer counts of grey seals.

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Abstract

In August 2021, during the harbour seal moult, the Sea Mammal Research Unit (SMRU) carried out helicopter surveys using a thermal imager of the east coast of Scotland from Inverness to the border and of the entire coast of Northern Ireland. Part of the Moray Firth and the Firth of Tay and Eden Estuary SAC are surveyed annually by fixed-wing.

The annual SMRU fixed-wing surveys in England cover the Lincolnshire and Norfolk coasts. In 2021 three surveys of the coast between Donna Nook (Lincolnshire) and Scroby Sands (Suffolk) were completed. The Zoological Society of London carries out annual surveys of the wider Thames area. Various different organisations around England and Wales contribute additional local counts. For areas that were not surveyed between 2016 and 2021 older data or estimates were used to create country-level totals.

From the most recent August surveys, carried out mainly between 2016 and 2021, the minimum number of harbour seals counted in Scotland was **26,378**, and in England & Wales it was **3,659**. Including **818** harbour seals counted in Northern Ireland in 2021, the UK harbour seal total count for this period was **30,855**.

Grey seals are counted during harbour seal surveys although grey seal counts can vary more than harbour seal counts during the summer months. From the most recent August surveys, carried out mainly between 2016 and 2021, the number of grey seals counted in Scotland was **24,640**, and in England & Wales it was **15,946**. Including **549** grey seals counted in Northern Ireland in 2021, the UK grey seal total count for this period was **41,135**.

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 currently found in western Scotland, the Outer Hebrides, Shetland, Orkney, 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 1996, harbour seal surveys in Scotland have been part funded by NatureScot (previously Scottish Natural Heritage) and NERC, with irregular contributions from Marine Scotland. SMRU aerial surveys in Southeast England during the harbour seal moult are funded by NERC. The harbour seal breeding season surveys in The Wash are funded by Natural England and NERC.

Since 1988, SMRU's surveys of harbour seals around the Scottish coast, where around 85% of UK harbour seals are found, have been carried out on an approximately five-yearly cycle. Since 2002, annual surveys have been carried out in parts of the Moray Firth (between Helmsdale and Findhorn) and in the Firth of Tay & Eden Estuary SAC where counts began to decline in the early 2000s. Helicopter surveys in 2006 also revealed significantly lower harbour seal numbers in Orkney and in Shetland (Lonergan *et al*. 2007). As a consequence, Orkney was surveyed more frequently to determine whether observed declines continued. Data presented here are the results of the fourth and final year of the latest round-Scotland survey that started in August 2016.

Approximately 80-90% of the English harbour seal population is found on the Lincolnshire and Norfolk coast which is surveyed once or twice annually during the August moult. Since 2004, additional breeding season surveys (in early July) of harbour seals around The Wash were undertaken for Natural England. The wider Thames area in Essex and Kent has been surveyed annually since 2013 by the Thames Harbour Seal Conservation Project, run by the Zoological Society of London.

A full survey of harbour and grey seals in Northern Ireland and the Republic of Ireland was completed in 2017 and 2018 and a further survey of Northern Ireland was completed in 2021.

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 (Russell *et al*., 2016).

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 colour video camera, a high-resolution digital still camera equipped with a 300mm telephoto lens, and a laser range finder. Video and still images are recorded onto laptops which display a moving map, highlighting areas of coast that have already been searched during the survey.

Surveys of the estuarine haul-out sites on the east coast of Scotland and England were conducted 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 12:00 and 19:00. 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.

Surveys coordinated by the Thames Harbour Seal Conservation Project were carried out mainly by air, with some sites counted from boat and from land.

Results and Discussion

1. UK totals

1.1. Harbour seals in the UK during the moult season in August

The overall distribution of harbour seals around the UK from August surveys carried out between 2016 and 2021 is shown in Figure 1. For ease of viewing at this scale, counts have been aggregated by 10km squares.

The most recent minimum harbour seal population estimates for UK Seal Monitoring Units (SMUs) in 2016-2021 are provided in Table 1 and are compared with four previous periods (1996-1997, 2000-2006, 2007-2009, and 2011-2015).

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 2016 and 2021, is **26,378** (Table 1). This is approximately 4% higher than the previous Scotland census in 2011-2015, but is still close to 11% lower than the highest Scotland total counted in 1996-1997 (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; Thompson *et al.*, 2019) while counts in the West Scotland SMU appear to have increased.

The most recent minimum estimate for England & Wales, obtained from surveys carried out mainly in 2021, is **3,659** (Table 1). This is around 25% lower than the three totals obtained for 2016, 2017, and 2018 that ranged from 5,095 to 5,202. It is the lowest total in around ten years (Table 1) (see SCOS_BP 22/05 for details of SEE_SMU surveys).

The 2021 count for Northern Ireland of **818** was 23% lower than the previous complete count from 2018 (1,062).

The sum of all the most recent counts carried out between 2016 and 2021 gives a UK total of **30,855** harbour seals (Table 1). This is close to the UK count for 2011-2015 (31,218), and is around 6% lower than the highest UK total in 1996-1997, assuming a count of approx. 1,000 harbour seal in Northern Ireland.

1.2. Grey seals in the UK in August

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 2007-2009 and 2011-2015 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 distribution of grey seals from the most recent August surveys carried out up until 2019 is shown in Figure 2. For ease of viewing at this scale, counts have been aggregated by 10km squares.

The most recent count of grey seals in Scotland, obtained from August surveys carried out mainly between 2016 and 2021 is **24,640** (Table 2). This is 9% higher than the total Scotland count obtained from August surveys between 2011 and 2015.

There were **14,211** grey seals counted in eastern England between 2016 and 2021. Combined with an estimate of **1,735** in West England & Wales and the 2021 count of **549** in Northern Ireland (Table 2), the most recent UK total count of grey seals in August is **41,135**.

2. Aerial surveys in Scotland in August 2021

In August 2021, the east coast of Scotland from Findhorn to the English border was surveyed by helicopter using a thermal imager. The annual fixed-wing surveys using hand-held photography covered the western part of the Moray Firth between Helmsdale and Findhorn.

Figure 3 shows the years when different parts of the Scottish coast were last surveyed. Harbour seal counts from the most recent surveys in 2016-2021 and from four previous survey periods (1996-1997, 2000-2006, 2007-2009, and 2011-2015) are in Table 1.

The most up-to-date August distribution of harbour seals in Scotland, from surveys between 2016 and 2021, is shown in Figure 4. The trends in counts of harbour seals in different Seal Management Areas in Scotland, from surveys carried out between 1991 and 2021 are shown in Figure 5.

The most up to date August distribution of grey seals in Scotland, from surveys between 2016 and 2021, is shown in Figure 6. Grey seal counts from the most recent surveys and from four previous periods (1996-1997, 2000-2006, 2007-2009, and 2011-2015) are in Table 2.

2.1. Moray Firth

In 2019, **5** harbour seals and **50** grey seals were counted between Duncansby Head and Helmsdale.

Between Helmsdale and Findhorn, **633** harbour seals were counted in 2021 (Table 3) . The highest count was recorded in 1997 (1,407), the first time this area was counted in a single survey. The average August count since annual coverage began in 2005 is just under 900. Although the total counts for this area have not been following a clear trend over the last 20 years, there are some obvious local trends. The Dornoch Firth SAC contributed 42% to the highest 'Helmsdale to Findhorn' total count in 1997. Since then, the number of harbour seals found in the SAC have continued to decline, contributing only 6% in 2019. In contrast, Culbin Sands has become the main haul-out area in the Moray Firth. In the late 2000s, fewer than a dozen harbour seals were generally found there. Since then, counts have continued to increase, and Culbin contributed 57% (588) to the total 'Helmsdale to Findhorn' harbour seal count in 2019.

In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn) **1,322** grey seals were counted in 2021 (Table 4). This is around 25% lower than the highest count recorded in 2010 (1,751). In the 1990s, the vast majority of grey seals were found in the Outer Dornoch. Similarly to harbour seals, the number of grey seals using haul-out sites at Culbin and at Findhorn has increased dramatically, and 55% of grey seals counted in 2019 were found here (456 and 400 respectively).

2.2. Firth of Tay and Eden Estuary SAC

The harbour seal count for the Firth of Tay and Eden Estuary SAC was **41** in 2021 (Table 5). This is close to the average count for 2013-2020 (42; range: 29-60). There is still no sign that this population is recovering following the dramatic decline observed in the 2000s. In the 1990s and early 2000s, large groups containing 100-200 harbour seals were found on the sandbanks at Tentsmuir and in the Eden estuary. More recently, harbour seals are mainly found in very small groups in the Firth of Tay . The 2021 count is around 95% lower than the highest count recorded in 1992 (773).

In the Firth of Tay and Eden Estuary SAC, **1,940** grey seals were counted in 2021 (Table 6). The grey seal total for the SAC has always been dominated by the number of animals hauled-out at Tentsmuir/Abertay. Over 2,000 individuals were counted on these sandbanks in 2000, and an average of 1,250 between 1990 and 2012. Since then, this average has dropped to <600 (range: 323-738), contributing only 80% to the total SAC count, compared to 93% for 1990-2012. The 2021 count was significantly higher than in recent years.

3. Aerial surveys in Southeast England in 2021

3.1. August surveys between Donna Nook and the Greater Thames Estuary

The great majority of English harbour seals are found in the Southeast England SMU (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. 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 (Figure 7).

Three aerial surveys of harbour seals were carried out by SMRU in Lincolnshire and Norfolk during August 2021. The mean 2021 count for the coast between Donna Nook and Scroby Sands (**3,007**) was similar to the 2019 and 2020 counts and approximately 27% lower than the 2012-2018 average (4,200, range: 4,022-4,367; Table 7; Figure 7). These counts confirm that the moult survey counts have declined substantially. These results and preliminary results of 2022 surveys are described in more detail in SCOS_BP 22/06).

The Zoological Society of London carried out a survey of the Essex and Kent coast in 2021, where **498** harbour seals were counted compared with an average of 742 for the three surveys in 2016-2018, and an average of 474 for the three surveys in 2013-2015 (Table 7; Cox *et al.*, 2020).

The combined counts for the Southeast England Seal Monitoring Unit (Flamborough Head to Newhaven) combining counts in 2021 for Lincolnshire and Norfolk, and the Thames (**3,505**) was similar to the 2019 estimate and 30% lower than the average for the three totals in 2016-2018 (approx. 5,000).

Although the Southeast England population returned to its pre-2002 epidemic levels by 2012, it lagged behind the rapid recovery of the harbour seal population in the Wadden Sea where counts increased from 10,800 in 2003 to 26,200 in 2012 (Trilateral Seal Expert Group, 2013), equivalent to an average annual growth rate of 9.5% over the ten years. Although this rate has dropped significantly since then, to <1% per year on average, the highest total was recorded in 2020 (**28,352**; Galatius *et al*., 2020), 2% higher than the 2019 count.

A total of **7,694** grey seals were counted in the Southeast England SMU between Donna Nook and Dover in August 2021 (Table 2). This is lower than the totals recorded in the previous four years. The grey seal count in this SMU has increased tenfold over the past 18 years, the biggest increase for either species in any UK SMU since August surveys began.

4. Aerial surveys in Northern Ireland in 2021

Northern Ireland was surveyed by helicopter in August 2021 and produced a total count of **818** harbour seals, approximately 23% lower than the 2018 count and 23% lower than the average of the previous four survey periods (1,071, Table 1; Morris & Duck, 2019). A total of **549** grey seals were counted during the survey in 2021.

5. Harbour seal data available for other areas

In Northeast England, harbour seals in the Tees Estuary have been monitored by the Industry Nature Conservation Association (INCA) since 1989. Following a slow increase in numbers from an average of 43, in 2003-2008, to an average of 84 in 2014-2021, with a mean count of **86** harbour seals in August 2021 . An average of **30** grey seals were counted in August 2021.

In the Solent, in South England, Langstone Harbour Board & Chichester Harbour Conservancy have been carrying out dedicated harbour seal surveys around Langstone and Chichester since 2015.

More recently, small numbers have been recorded by National Trust volunteers in the Newtown National Nature Reserve on the Isle of Wight. In August 2020, an average of **47** harbour seals and **18** grey seals were counted in the Solent.

To our knowledge, no dedicated harbour seal surveys are routinely carried out in the rest of England or in Wales, due to very low numbers.

Estimates given in Table 1 and Table 2 are derived from compiling information from the various sources listed below the tables.

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Table 1. The most recent August counts of harbour seals at haul-out sites in the British Isles by Seal Monitoring Unit compared with previous periods. The totals under 2021 that are in italics include the 2016-2019 counts for SMUs 1-5. The grey values given for SMUs 10-13 are estimates.

			Harbour seal counts					
Seal Monitoring Unit / Country			1996-1997	2000-2006	2007-2009	2011-2015	2016-2019	2021
1	Southwest Scotland		929	623	923	1,200	1,709	
2	West Scotland	a	8,811	11,666	10,626	15,184	15,600	
3	Western Isles		2,820	1,920	1,804	2,739	3,532	
4	North Coast & Orkney		8,787	4,388	2,979	1,938	1,405	
5	Shetland		5,994	3,038	3,039	3,369	3,180	
6	Moray Firth		1,409	1,028	776	745	1,077	690
7	East Scotland		764	667	283	224	343	262
SCOTLAND total			29,514	23,330	20,430	25,399	26,846	*26,378*
8	Northeast England	b	54	62	58	91	79	89
9	Southeast England	c	3,222	2,964	3,952	4,740	3,752	3,505
10	South England	d	10	15	15	25	40	50
11	Southwest England	d	0	0	0	0	0	0
12	Wales	d	2	5	5	10	10	10
13	Northwest England	d	2	5	5	5	5	5
ENGLAND total			3,288	3,046	4,030	4,861	3,876	3,659
BRITAIN total			32,807	26,381	24,465	30,270	30,732	*30,037*
NORTHERN IRELAND total		e		1,176	1,101	948	1,062	818
UK total				27,557	25,566	31,218	31,794	*30,855*
REPUBLIC OF IRELAND total		f		2,955		3,489	4,007	
BRITAIN & IRELAND total				30,512		34,707	35,801	*34,862*

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 Marine Scotland contributed funding towards Scotland surveys in 2009 and 2019.

b The Tees data collected and provided by the Industry Nature Conservation Association (Bond, 2019). Northumberland coast south of Farne Islands not surveyed pre-2008; no harbour seal sites known here. The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

c Thames data 2015,2019&2021 collected and provided by Zoological Society London (Cox et al., 2020).

d Estimates compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Cumbria Wildlife Trust) or found in reports & on websites (Boyle, 2012; Hilbrebirdobs blogspot; Sayer, 2010, 2011; Sayer et al., 2012; Westcott, 2002). Increases may partly be due to improved reporting and species id.

e Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002, 2011 & 2018 (Morris & Duck, 2019a) and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

f Surveys carried out by SMRU and funded by the National Parks & Wildlife Service (Morris & Duck, 2019b).

Table 2. The most recent August counts of grey seals at haul-out sites in the British Isles by Seal Monitoring Unit compared with four previous periods. The totals under 2021 that are in italics include the 2016-2019 counts for SMUs 1-5. The grey values given for SMUs 10-13 are estimates. Grey seal summer counts are known to be more variable than harbour seal summer counts. Caution is advised when interpreting these numbers.

			Grey seal counts					
Seal Monitoring Unit / Country			1996-1997	2000-2006	2007-2009	2011-2015	2016-2019	2021
1	Southwest Scotland		75	206	233	374	517	
2	West Scotland	a	3,435	2,383	2,524	5,064	4,174	
3	Western Isles		4,062	3,674	3,808	4,085	5,773	
4	North Coast & Orkney		9,427	10,315	8,525	8,106	8,599	
5	Shetland		1,724	1,371	1,536	1,558	1,009	
6	Moray Firth		551	1,272	1,113	1,917	1,657	1,856
7	East Scotland		2,328	1,898	1,238	2,296	3,683	2,712
SCOTLAND total			21,602	21,119	18,977	23,400	25,412	*24,640*
8	Northeast England	b	613	1,100	2,350	6,942	6,501	6,517
9	Southeast England	c	417	2,266	1,786	5,637	8,667	7,694
10	South England	d		2	2	5	30	35
11	Southwest England	d		425	425	500	500	500
12	Wales	d		750	750	850	900	900
13	Northwest England	d		30	30	50	250	300
ENGLAND total				3,823	4,593	13,134	15,948	15,946
BRITAIN total				25,692	24,320	37,384	42,260	*40,586*
NORTHERN IRELAND total		e		272	243	468	505	549
UK total				25,964	24,563	37,852	42,765	*41,135*
REPUBLIC OF IRELAND total		f		1,309		2,964	3,698	
BRITAIN & IRELAND total				27,273		40,816	46,463	*44,833*

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 Marine Scotland contributed funding towards Scotland surveys in 2009 and 2019.

b The Tees data collected and provided by the Industry Nature Conservation Association (Bond, 2019). N'umberland coast south of Farne Islands not surveyed pre-2008, so earlier counts may be incomplete. The 2008 survey from Coquet Island to Berwick funded by the Department of Energy and Climate Change (DECC, previously DTI).

c Thames data 2015, 2019, and 2021 collected and provided by Zoological Society London (Cox et al., 2020).

d Estimates compiled from counts by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Natural England, Natural Resources Wales, RSPB, Hilbre Bird Observatory, Boyle, 2012; Büche & Stubbings, 2019; Hilbrebirdobs blogspot; Leeney et al., 2010; Sayer, 2010, 2011, 2012a, 2012b; Sayer et al., 2012; Westcott, 2002, 2009; Westcott & Stringell, 2004; Woodfin Jones, 2019). Apparent increases may partly be due to increased reporting.

e SMRU surveys funded by Northern Ireland Environment Agency (2002, 2011 & 2018 (Morris & Duck, 2019a) and Marine Current Turbines Ltd (2006-2008 & 2010 (SMRU Ltd, 2010)).

f Surveys carried out by SMRU and funded by the National Parks & Wildlife Service (Morris & Duck, 2019b).

Table 3. August counts of harbour seals in the annually surveyed western Moray Firth between Helmsdale and Findhorn. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all subarea counts in the table.

Area	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2021
	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	fw	ti
Helmsdale to Brora			193		188			113	150	54	73	19	101	87	102	70	1	21	40	22	30	17	0
Loch Fleet			27	33	59	56	64	71	80	83	82	65	114	113	133	135	156	144	145	138	152	109	142
Dornoch Firth	662	542	593	405	220	290	231	191	257	144	145	166	219	208	157	143	111	120	85	39	117	62	69
Cromarty Firth	41	95	95	38	42	113	88	106	106	102	90	90	140	101	144	63	100	22	72	20	43	84	82
Beauly Firth	220	203	219	204	66	151	178	127	176	146	150	85	140	57	60	30	37	34	30	5	30	24	58
Ardersier		221	234	191	110	205	202	210	197	154	145	277	368	195	183	199	28	34	36	81	98	116	84
Culbin & Findhorn		58	46	111	144	167	49	93	58	79	92	73	123	163	254	218	260	330	484	526	444	613	198
Total			1,407		829			911	1,024	762	777	775	1,205	924	1,033	858	693	705	892	831	914	1,025	633

fw: fixed-wing survey; ti: thermal imager helicopter survey.

Table 4. August counts of grey seals in the annually surveyed western Moray Firth between Helmsdale and Findhorn. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all subarea counts in the table.

Area	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2021
	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	fw	fw
Helmsdale to Brora			3		6			111	102	52	449	72	635	156	316	81	27	161	28	201	147	191	240
Loch Fleet			0	0	0	0	0	0	1	3	1	0	7	7	20	18	7	10	31	22	15	17	35
Dornoch Firth	233	903	456	121	321	79	473	431	748	516	523	819	717	679	74	604	127	716	387	273	321	401	639
Cromarty Firth	9	0	0	0	0	0	0	0	1	0	0	0	1	2	1	3	1	0	1	0	0	0	1
Beauly Firth	8	2	3	8	0	0	0	0	3	4	0	0	2	3	1	5	2	0	2	0	1	1	14
Ardersier		36	24	85	0	3	44	55	142	74	142	94	331	74	24	109	2	14	28	87	83	98	239
Culbin & Findhorn		0	0	0	0	10	0	11	11	28	75	58	58	179	121	218	93	743	717	548	144	856	154
Total			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	1,564	1,322

fw: fixed-wing survey; ti: thermal imager helicopter survey.

Table 5. August counts of harbour seals in the annually surveyed Firth of Tay and Eden Estuary SAC. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all subarea counts in the table.

Area	1990	1991	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	1fw	2fw,1ti	1fw	1fw,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1ti	1fw	1fw	1fw	1fw	1ti
Upper Tay	27	73	148	89	113	115	51	83	134	91	91	63	49	45	41	16	40	36	21	51	41	28	32	36	31	37
Broughty Ferry	77	83	97	64	35	52	0	90	55	51	31	27	13	28	15	18	16	3	0	2	4	0	4	2	0	0
Buddon Ness	13	86	72	53	0	113	109	142	66	25	96	64	27	8	23	11	8	10	1	3	0	0	2	0	0	3
Tentsmuir	319	428	456	289	262	153	167	53	126	63	34	31	50	8	9	0	5	0	0	0	1	0	0	0	0	0
Eden Estuary	31	0	0	80	223	267	341	93	78	105	90	90	83	22	36	32	19	1	7	4	5	1	2	3	0	1
SAC total	467	670	773	575	633	700	668	461	459	335	342	275	222	111	124	77	88	50	29	60	51	29	40	41	37	41

fw: fixed-wing survey; ti: thermal imager helicopter survey.

Table 6. August counts of grey seals in the annually surveyed Firth of Tay and Eden Estuary SAC. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all Subunit counts in the table.

Area	1990	1991	1992	1994	1997	2000	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	2fw,1ti	1fw	1fw,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1ti	1fw	1fw	1fw	1fw	1ti
Upper Tay	0	0	18	20	61	64	78	50	42	22	27	26	55	98	16	39	127	62	115	132	78	52	43	74	176
Broughty Ferry	0	3	0	9	0	0	0	16	0	8	1	8	0	0	2	3	0	2	0	0	0	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	0	0	0
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	561	684	1,567
Eden Estuary	0	0	16	0	10	0	25	4	27	57	31	33	0	39	17	36	14	39	32	66	76	46	82	125	197
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	686	883	1,940

fw: fixed-wing survey; ti: thermal imager helicopter survey.

Table 7. August counts of harbour seals in the Northeast and Southeast England Seal Monitoring Units. Mean values are given for areas surveyed more than once in a single season. Italics indicate that a small proportion of the area was not surveyed.

	Northeast England			Southeast England						
Year	N'umber-land	The Tees	Other sites	Donna Nook	The Wash	Blakeney Point	Horsey	Scroby Sands	Essex Kent	SE total
1988				173	3,035	701				
1989		16		126	1,556	307				
1990		23		57	1,543					
1991		24			1,398					
1992		27		32	1,671	217				
1993		30		88	1,884	267				
1994	*13*	35		103	2,011	196		61		
1995		33		115	2,084	415		49	*130*	*2,793*
1996		42		162	2,151	372		51		
1997	*12*	42		251	2,466	311		65		
1998		41		248	2,374	637		52		
1999		36		304	2,392	659		72		
2000	*10*	59		390	2,779	895		47		
2001		59		233	3,194	772		75		
2002		52		341	2,977	489				
2003		38		231	2,513	399		38	180	3,361
2004		40		294	2,147	646		57		
2005	*17*	50		421	1,946	709		56		
2006		45		299	1,695	719		71		
2007	*7*	43		214	2,162	550				
2008	9	41		191	2,011	581		81	319	3,182
2009		49		267	2,829	372		165		
2010		53		176	2,586	391		201	379	3,733
2011		57		205	2,894	349		119		
2012		63		192	3,372	409		161		
2013		74		396	3,174	304		148	482	4,504
2014		81		353	3,086	468		285	489	4,681
2015	*0*	91		228	3,336	455		270	451	4,740
2016		86	0	369	3,377	424		198	694	5,061
2017		87		290	3,210	399		271	795	4,965
2018	3	76		146	3,632	218	17	210	738	4,961
2019		76		128	2,415	329	16	193	671	3,752
2020	0	91		157	2,866	258	1	45		
2021		86		122	2,667	181	12	25	498	3,505

SOURCES - 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 thermal imager surveys from Farne Is. to Scottish border in 1997, 2005, 2007, 2015, and 2018. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2020). Single SMRU fixed-wing count in 1994.
Other sites - St Mary's Island, Ravenscar, Filey Brigg (SMRU aerial surveys).
Essex & Kent - 2013-2017, 2019, and 2021 surveys carried out by the Zoological Society of London (Barker & Obregon, 2015; Cox *et al*., 2020).

Table 8. August counts of grey seals in the Northeast and Southeast England Seal Monitoring Units. Mean values are given for areas surveyed more than once in a single season. Italics indicate that a small proportion of the area was not surveyed.

	Northeast England			Southeast England						
Year	N'umber-land	The Tees	Other sites	Donna Nook	The Wash	Blakeney Point	Horsey	Scroby Sands	Essex Kent	SE total
1988					52	1				
1989		7								
1990		9		115	10					
1991		8			48					
1992		9		235	35	6				
1993		9		59	64	7				
1994	*100*	6		100	94	40		43		
1995		10		123	66	18		32		
1996		11		119	60	11		46		
1997	*603*	10		289	49	45		34		
1998		11		174	53	33		23		
1999		12		317	57	14		89		
2000	*568*	11		390	40	17		40		
2001		11		214	111	30		70		
2002		12		291	75	11				
2003		11		232	58	18		36	96	440
2004		13		609	30	10		93		
2005	*1,092*	12		927	49	86		106		
2006		8		1,789	52	142		187		
2007	*1,907*	8		1,834	42					
2008	2,338	12		2,068	68	375		137	160	2,807
2009		12		1,329	118	22		157		
2010		14		2,188	240	49		292	393	3,161
2011		14		1,930	142	300		323		
2012		18		4,978	258	65		126		
2013		16		3,474	219	63		219	203	4,178
2014		16		4,437	223	445		509	449	6,063
2015	*6,926*	16		3,766	369	528		520	454	5,637
2016		22	60	3,964	431	355		642	481	5,872
2017		27		6,526	688	502		425	575	8,716
2018	6,427	15		6,288	253	360	205	497	596	8,199
2019		14		5,265	540	635	119	1,333	775	8,667
2020	0	22		4,982	644	765	504	1,191		
2021		30		3,897	799	493	380	1,377	749	7,694

SOURCES - Counts from SMRU aerial surveys using 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, and 2018. Fixed-wing surveys of Holy Island only in 1994 & 2000. **The Tees** - Ground counts by Industry Nature Conservation Agency (Bond, 2020). Single SMRU fixed-wing count in 1994. 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). **Essex & Kent** - 2013-2017, 2019, and 2021 surveys carried out by the Zoological Society of London (Barker & Obregon, 2015; Cox *et al*., 2020).

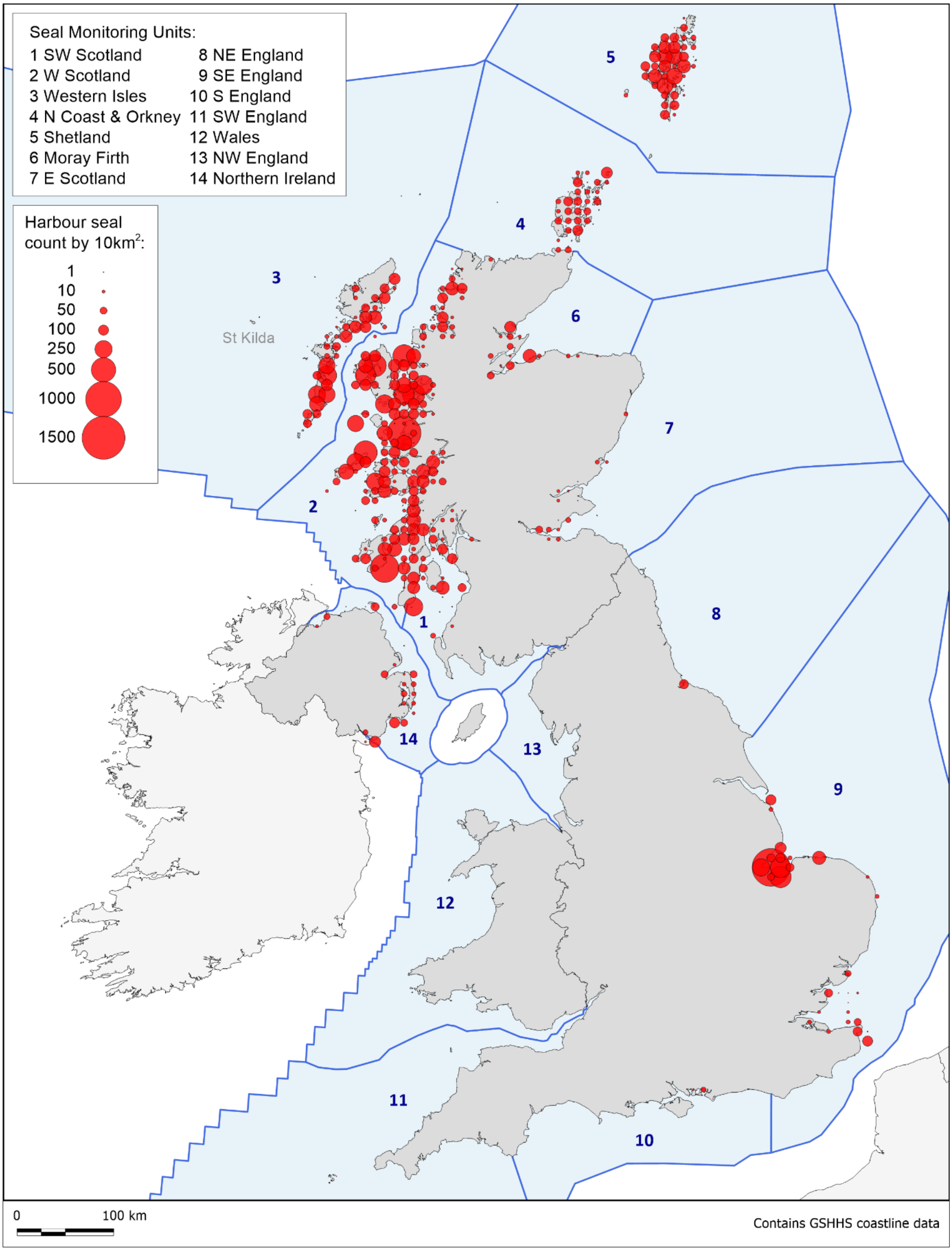

Figure 3. August distribution of harbour seals around the British Isles by 10km squares based on the most recent available haul-out count data collected up until 2021. Limited data available for SMUs 10-13; no data available for St Kilda.

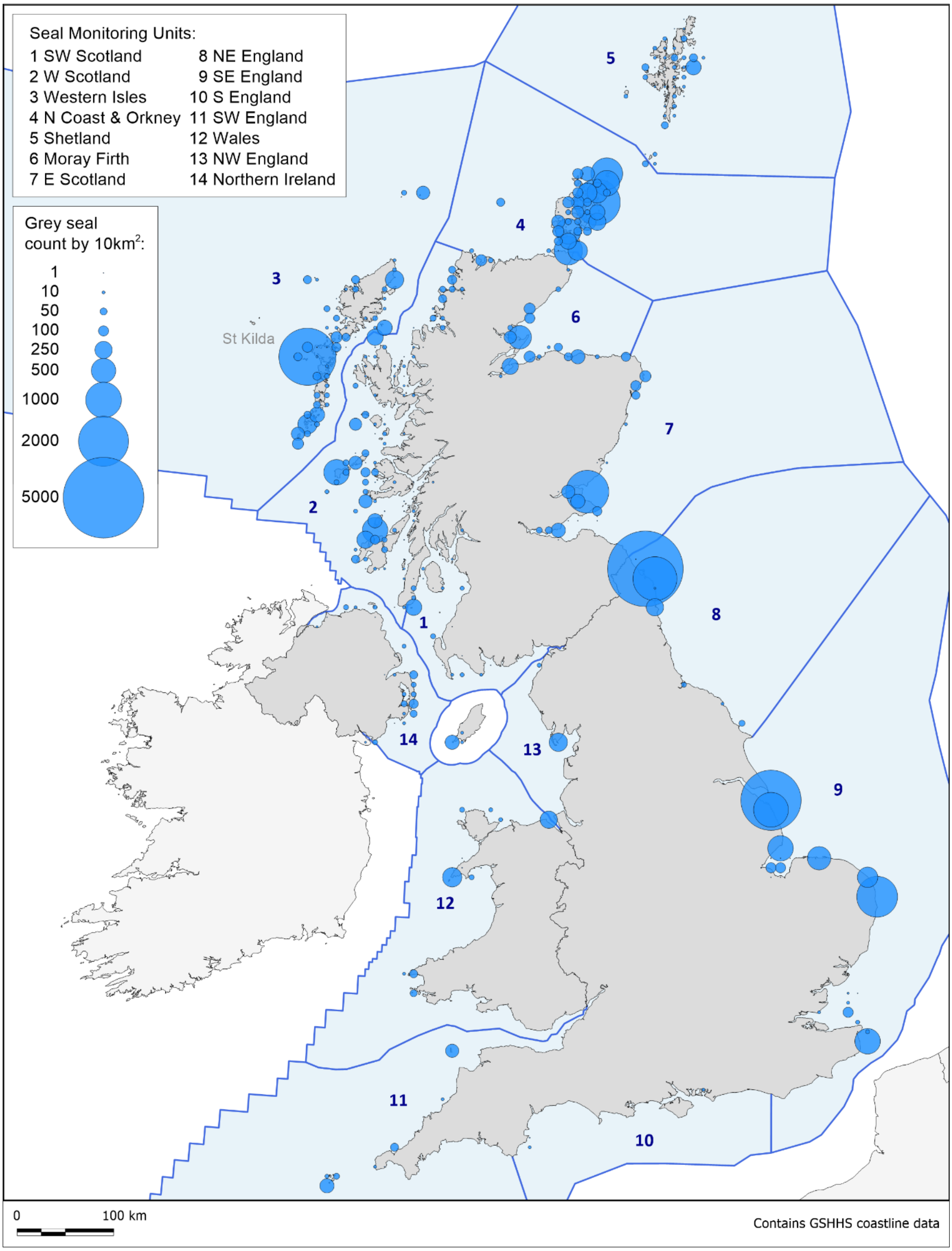

Figure 4. August distribution of grey seals around the British Isles by 10km squares based on the most recent available haul-out count data collected up until 2021. Limited data available for SMUs 10-13; no data available for St Kilda.

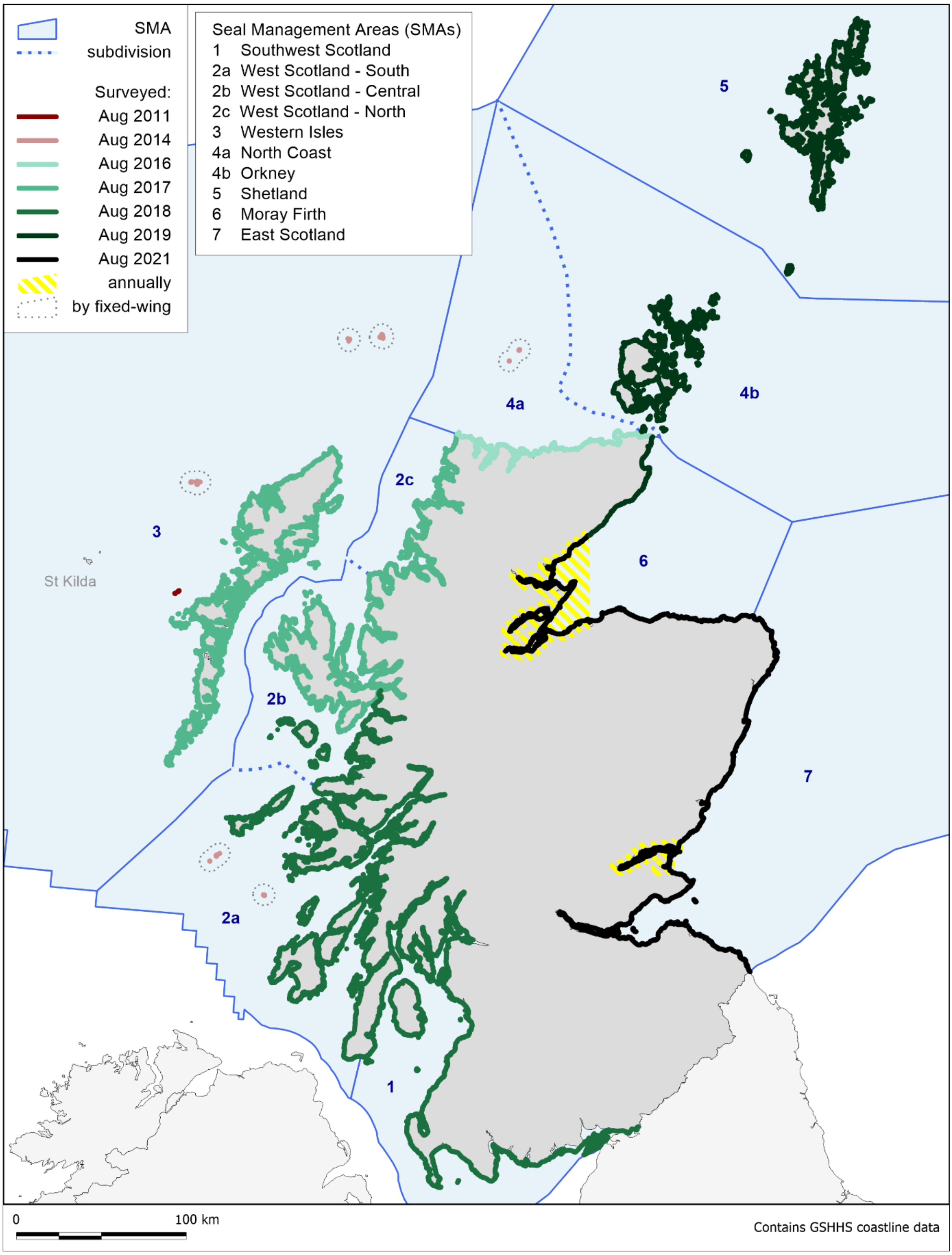

Figure 5. Map showing when the most recent aerial surveys were carried out during the harbour seal moult in August. Most areas were last surveyed between 2016 and 2021. The yellow shaded areas of the Firth of Tay and the Moray Firth (between Helmsdale and Findhorn) are surveyed every year, usually by fixed-wing aircraft. Offshore islands were last surveyed in 2014 by fixed-wing aircraft. However, only very small numbers of harbour seals are found on islands last surveyed pre-2016. St Kilda has not been covered by aerial surveys.

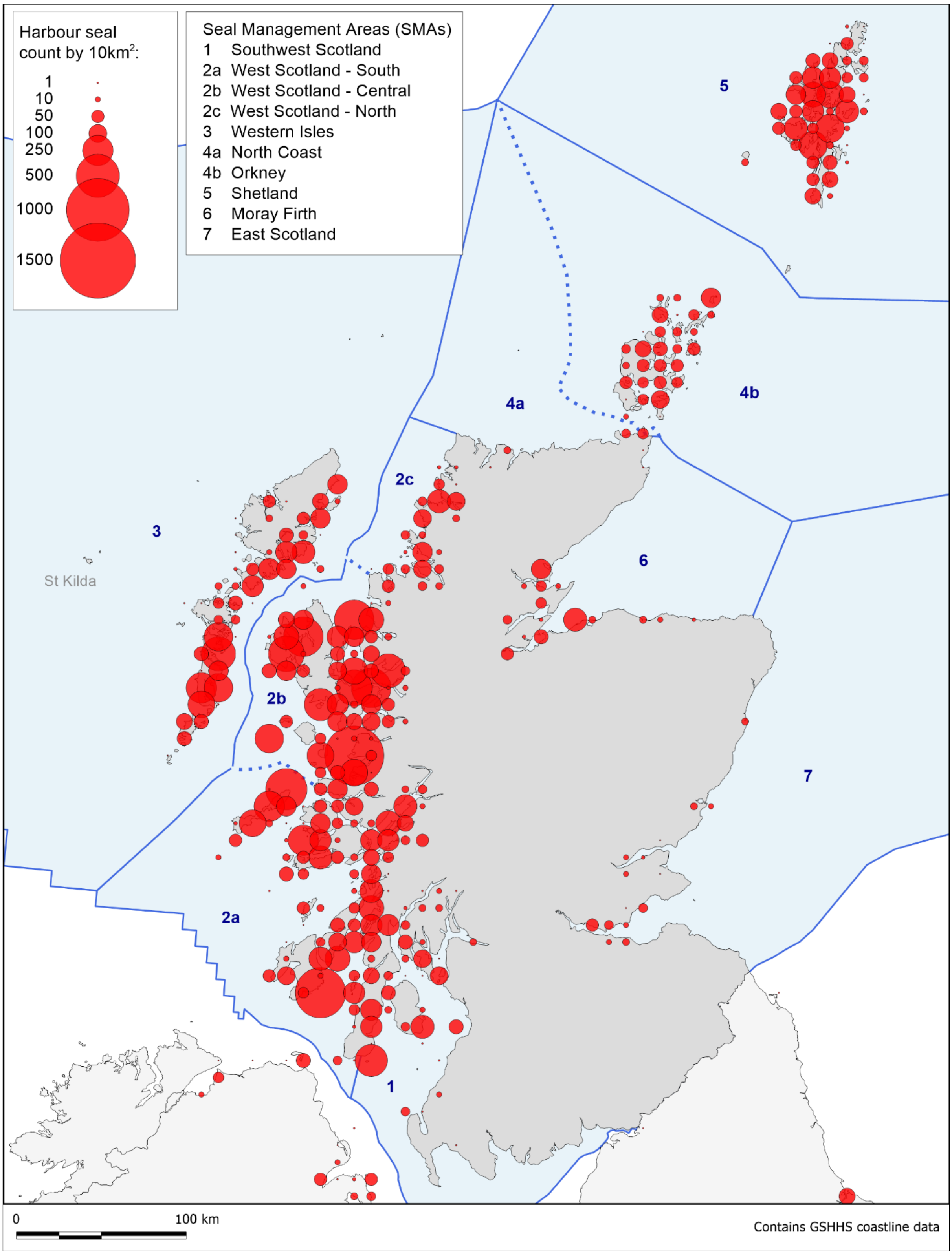

Figure 6. Map of harbour seal distribution by 10km squares based on haul-out counts obtained from the most recent aerial surveys carried out during the harbour seal moult in August 2016-2021.

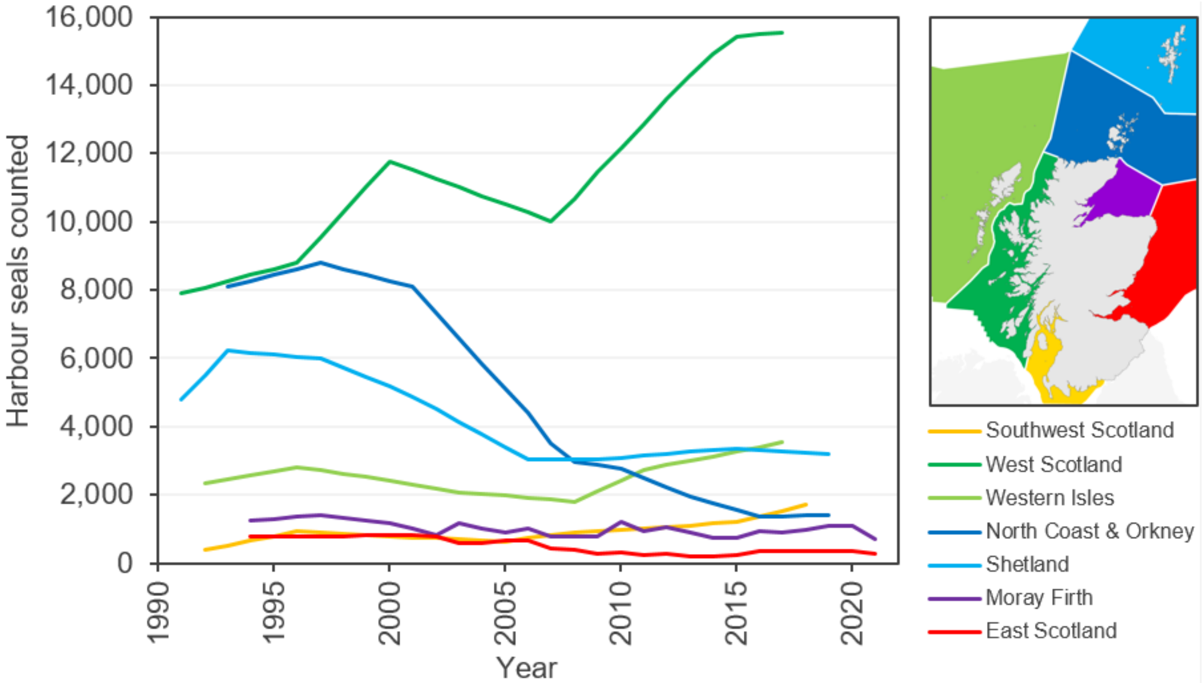

Figure 7. Comparison of August harbour seal counts in Scottish Seal Management Areas (SMAs) from 1991 to 2021. Because SMA totals represent counts of seals distributed over large areas, individual data points may contain counts made in more than one year. Interpolated values are used for years with incomplete coverage.

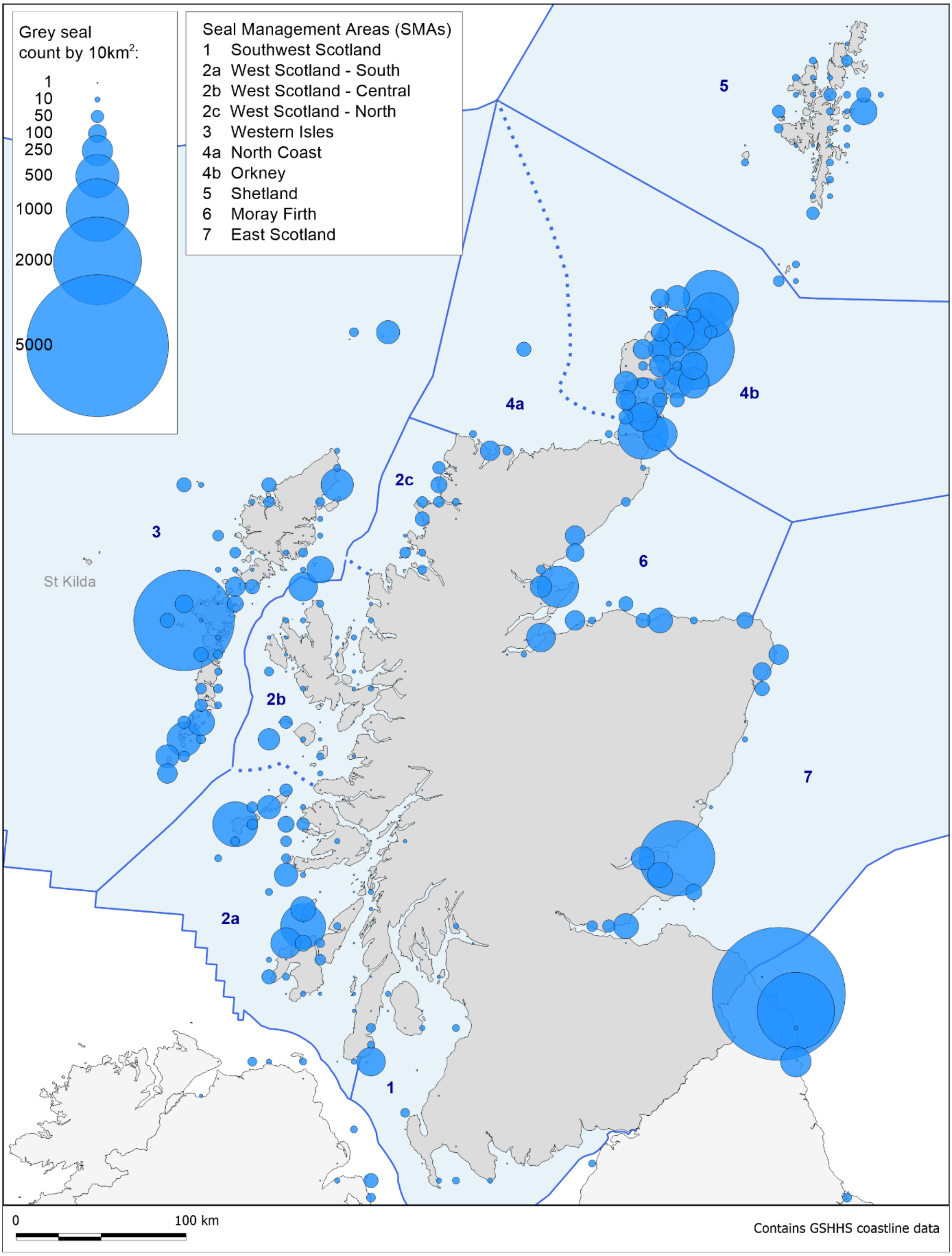

Figure 6. Map of grey seal distribution by 10km squares based on haul-out counts obtained from the most recent aerial surveys carried out during the harbour seal moult in August 2016-2021.

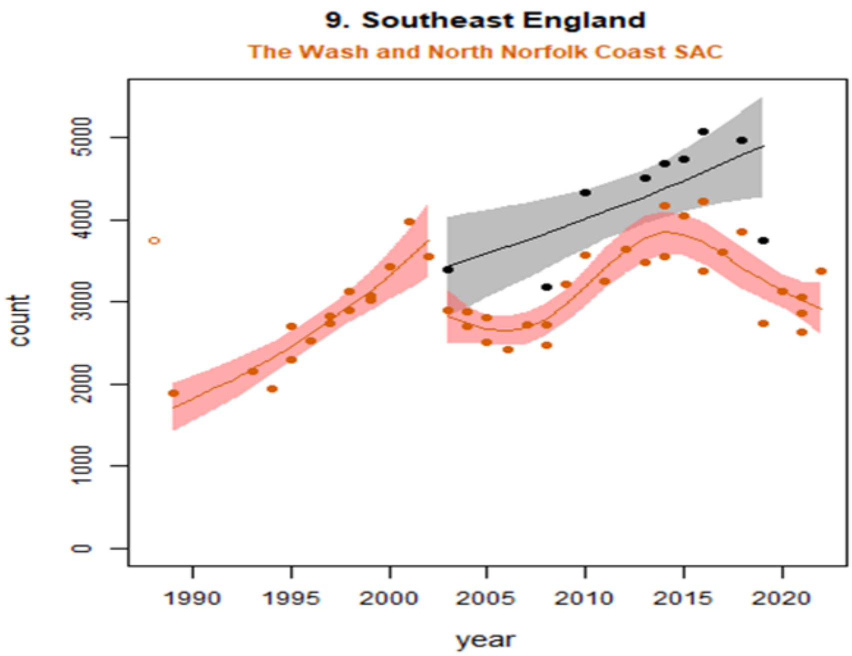

Figure 7. Trends in harbour seals counts in The Wash (red) and the combined Wash and North Norfolk SAC, between 1988 and 2022 (shaded areas indicate the 95% confidence intervals for the fitted curves). For more details see BP 22/06.

Recent changes in status of harbour seals in the Wash and North Norfolk SAC and adjacent sites.

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Abstract

The populations of harbour seals within the Southeast England Seal Monitoring Unit (SSE-SMU) are monitored using aerial survey counts obtained during the August moult. The population showed a continuous increase from 1970 until 2018, punctuated by two PDV epizootics that reduced the population by approximately 50% in 1988 and 30% in 2002. However, in 2019 the count for the regularly monitored population in The Wash and adjacent sites (Donna Nook, Blakeney and Scroby Sands) was approximately 30% lower than the mean of the previous 5 years (2014-2018). This apparent drop occurred in the absence of any indication of a recurrence of PDV or any reported increase in strandings of dead seals. This flagged up the need for additional survey data to confirm and track the changes. These sites were surveyed again in August 2020,2021 and 2022.

Overall, the counts for these sites between Donna Nook and Scroby Sands have decreased by approximately 27% compared to the mean of the previous five years (2019–2022 mean = 3132; 2014-2018 mean = 4296). The count for the Wash and North Norfolk SAC (i.e. the Wash + Blakeney) has decreased by approximately 20% (2019 – 2022 mean = 2947: 2014-2018 mean= 3658), while Donna Nook showed a 56% decrease and Scroby Sands showed a 71% decrease over the same time periods.

The harbour seal decline is evident at all sites within the SMU and appears to have affected all sub-sections of the Wash & North Norfolk SAC.

Grey seal numbers have increased within the SMU, but the summer counts for the largest grey seal haulout group at Donna Nook shows a similar levelling off and possible decline, around the same time as the harbour seal decline. However, grey seal counts are still increasing in the Wash, Blakeney and Scroby Sands.

Grey seals are expanding their haulout range within the Wash and small groups are now appearing in the sheltered tidal creeks at the southern edge of the estuary where large numbers of harbour seals haulout.

Introduction

This is a preliminary note about recent changes in the aerial survey counts of harbour and grey seals in the Wash and North Norfolk SAC (comprising The Wash and Blakeney haulouts) and adjacent sites within the Southeast England Seal Monitoring Unit (SEE-SMU). The harbour seal population in the SEE-SMU is monitored using aerial survey counts obtained during the annual moult in August. The time series of counts for the northern half of the SMU (Donna Nook to Scroby Sands) began in 1988 immediately prior to the first Phocine Distemper Virus (PDV) epizootic. Sporadic surveys of The Wash were carried out in the late 1960s and early 1970s during a period of intensive pup harvest and continued sporadically during the late 1970s and early 1980s. The time series of counts shows a continuous increase from the end of hunting until 2018, punctuated by two PDV epizootics that reduced the population by approximately 50% in 1988 and 30% in 2002 (Thompson *et al*. 2019). However, in 2019 the count for the regularly monitored population in The Wash and adjacent sites

(Donna Nook, Blakeney and Scroby Sands) was approximately 27.5% lower than the mean of the previous 5 years (2014-2018). This apparent drop occurred in the absence of any indication of a recurrence of PDV or any reported increase in strandings of dead seals. This flagged up the need for additional survey data to confirm and track the changes, to provide a baseline for studies to investigate likely causes of a decline.

The Covid-19 pandemic prevented an intensive survey round in 2020, but a single survey from Donna Nook to Scroby Sands was completed, and a more intensive series of surveys were carried out in 2021 and 2022 and expanded to include the coastline of Suffolk, Essex and Kent (referred to as the Greater Thames Estuary (GTE)) in 2022. The preliminary results of the three years' survey effort for the Donna Nook to Scroby Sands surveys are presented here. Counts of the survey images for 2022 have only recently been completed, so the descriptions of trends in the data should be regarded as preliminary estimates and treated with caution. Counts from the GTE will be combined with recent surveys conducted by Zoological Society of London (ZSL) and presented to the next SCOS meeting.

Methods

Surveys of the coastline between Donna Nook in Lincolnshire and Scroby Sands in Norfolk were conducted by fixed-wing aircraft using hand-held oblique photography (see Thompson *et al*., 2019 for detailed methods), during the harbour seal moult in August.

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) and good weather, i.e. good visibility and no rain. Dates of surveys are therefore constrained by weather conditions, times of low tides and military activity over a large part of the survey area.

Results

1. 2020 survey

The harbour seal count of The Wash and adjacent sites (Donna Nook, Blakeney and Scroby Sands) in 2019 was approximately 27.5% lower than the mean of the previous 5 years (2014-2018). Despite the restrictions due to the Covid 19 pandemic a survey of the coast between Donna Nook, Lincolnshire and Scroby Sands, Norfolk was carried in August 2020. The 2020 count was 8% higher than the 2019 count but was still 21.5% lower than the 2014-2018 mean

Notwithstanding the variability associated with the proportion of the population hauled out and thus available to count, it was thought likely that these lower counts represented a real decrease. The level of decrease and trajectory was unclear, but the data indicated a potential step change decrease of around 25% between 2018 and 2019. Given that the survey area represents the majority of harbour seals in the SEE-SMU and encompasses the population in the Wash & North Norfolk SAC, this likely drop in abundance is of immediate and serious concern. This SMU had shown a sustained increase in abundance (punctuated by sudden drops associated with the Phocine Distemper Epidemics) while most SMUs on the eastern and northern coasts had depleted or declining populations (Thompson *et al.*, 2019; SCOS, 2020).

2. 2021 surveys

In response to the perceived decline, funds were provided by Defra and Natural England to supplement the NERC funding and allow additional surveys of the coast between Donna Nook and Scroby Sands. Due to a combination of Covid related travel restrictions and the last-minute collapse of the contracted aerial survey company we were unable to carry out a planned pup census for the area. However, three surveys were carried out during the harbour seal moult, on 12th, 22nd and 23rd August 2021; two covered the entire coastline between Donna Nook and Scroby Sands and one covered the coast between Donna Nook and Blakeney. All three surveys covered the Wash and North Norfolk SAC.

3. 2022 surveys

In 2022 three surveys were carried out during the harbour seal moult, on 5th, 12th, and 13th of August. All three surveys covered the entire coast between Donna Nook and Scroby Sands. Unfortunately, the surveys on 12th and 13th August coincided with a period of very warm weather and unusually large numbers of tourists visited the Norfolk coast. On both days, groups of people were present on the haulout sites at Blakeney at the time of the surveys. Seals were excluded from the majority of the site and no counts were obtained. No problems were detected at the remaining sites. As a result, only one complete count of the Wash and North Norfolk SAC was obtained.

4. harbour seals

Counts of harbour seals from surveys between 2016 and 2022 are shown in table 1. The mean of the 2021 counts for the entire coast between Donna Nook and Scroby Sands (2995), was 7% lower than the mean of 2019 and 2020 counts (3206). The single complete count for 2022 was 17% higher than the mean of the 2019 to 2021 counts. Overall, the counts for these sites between Donna Nook and Scroby Sands have decreased by approximately 27% compared to the mean of the previous five years (2019–2022 mean = 3132; 2014-2018 mean = 4296).

The count for the Wash and North Norfolk SAC (i.e. the Wash + Blakeney) has decreased by approximately 20% (2019 – 2022 mean = 2947: 2014-2018 mean= 3658), while Donna Nook showed a 56% decrease and Scroby Sands showed a 71% decrease over the same time periods. Fitted trends (Fig. 1) indicate that the Wash & North Norfolk SAC population recovered after the 2002 PDV epidemic, reached a maximum around 2015 at a level close to the pre-epidemic maximum and has declined sharply since then. However, the nature of this decline is still uncertain in terms of whether it represents the beginning of a sustained decline or a step change (similar to those seen in response to the PDV epidemics in the SEE-SMU and for unknown reasons in the Shetland SMU.

As the Wash and Blakeney counts represent the majority of the SEE-SMU population, a similar trajectory is shown by the overall SMU counts. The absence of Blakeney counts for the 12th and 13th August 2022 surveys is unfortunate. The single complete survey count for 2022 was higher than the previous two year’s counts, but the single point had little influence on the fitted curve. For surveys between 2019 and 2021 and the one completed survey in 2022, the Wash counts made up 90.0% of the SAC total. The mean of the three counts of the Wash in 2022 was approximately 17% higher than the mean of the 2019 to 2021 counts.

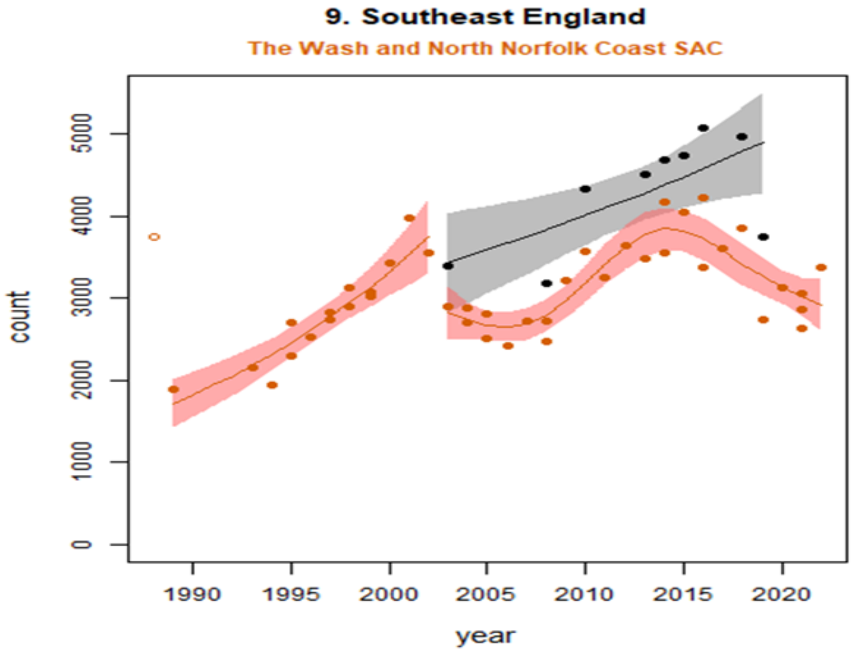

*Figure 8 Counts of harbour seals in the Wash and North Norfolk SAC (red) and the total for the Southeast England SMU (grey) during the harbour seal moult in August, between 1988 and 2022, showing the changes in counts after the 1988 and 2002 PDV epidemics. Separate trend lines are fitted (see Russell et al. 2022 SCOP BP) to the 1989-2002 counts and post 2002 counts showing recoveries from the two PDV epidemics. Red lines illustrate the mean trend in harbour seal counts (and associated 95 % confidence intervals) for The Wash and North Norfolk SAC and the grey lines show the same for the SMU as a whole (*between *Donna Nook in Lincolnshire and Goodwin Sands off the Kent coast).*

Table 18. Counts of harbour seals at Donna Nook, the Wash, Blakeney and Scroby sands during August between 2016 and 2022. N/S = not surveyed

Date	13/08 2022	12/08 2022	05/08/ 2022	23/08/ 2021	22/08/ 2021	12/08/ 2021	22/08/ 2020	11/08/ 2019	11/08/ 2018	11/08/ 2017	21/08/ 2016	05/08/ 2016
Wash	3126	2990	3095	2439	2837	2624	2866	2415	3632	3210	2992	3762
Donna Nook	144	89	140	75	116	153	157	128	146	290	275	462
Blakeney	N/S	N/S	277	187	221	135	258	329	218	271	388	460
Scroby Sands	81	103	57	24	25	N/S	45	193	228	399	184	211
Total	n/a[2]	n/a[2]	3569	2725	3199	2912[1]	3326	3065	4224	4170	3839	4895

[1]Total does not include Scroby Sands, but minor underestimate as Scroby Sands held 1% of the harbour seals in the 2021 and 2020 counts.
[2]No count obtained at Blakeney due to dog walkers and picnickers on the haulout sites.

Table 19 Counts of grey seals at Donna Nook, the Wash, Blakeney, Horsey and Scroby sands during August between 2016 and 2022. N/S = not surveyed

Date	13/08 2022	12/08 2022	05/08/ 2022	23/08/ 2021	22/08/ 2021	12/08/ 2021	22/08/ 2020	11/08/ 2019	11/08/ 2018	11/08/ 2017	21/08/ 2016	05/08/ 2016
Wash	1146	1089	918	813	583	1001	644	540	343	688	491	387
Donna Nook	3185	3058	4174	3339	3105	5248	4982	5265	6288	6526	4288	3640
Blakeney	n/s	n/s	637	635	488	356	765	635	360	425	177	533
Horsey	283	0	429	368	391	N/S	504	119	205	N/S	N/S	N/S
Scroby Sands	2112	1916	2269	1607	1146	N/S	1191	1333	497	502	668	615
Total	n/a[1]	n/a[1]	5729	4787	4176	6605	6387	6440	6901	7639	4956	4560

[1]No count obtained at Blakeney due to dog walkers and picnickers on the haulout sites.

Overall, the harbour seal population in the study area has decreased by approximately 27% since 2018, and the decline appears to be widespread across the area. Counts at the four main haulout areas, Donna Nook, The Wash, Blakeney and Scroby Sands, have all declined over the past four years. The patterns differ between sites, with the Wash, and possibly Scroby Sands, showing increases from around 2004 to 2015-18 followed by sharp declines, while at Blakeney there appears to have been a gradual decline over the entire period (2002 – 2022) and at Donna Nook the harbour seal counts were relatively stable until 2018 before declining (figure 2). Counts divided into four subsections of the Wash show that the decrease in harbour seal counts since 2018 has occurred throughout the Wash and does not appear to be localised.

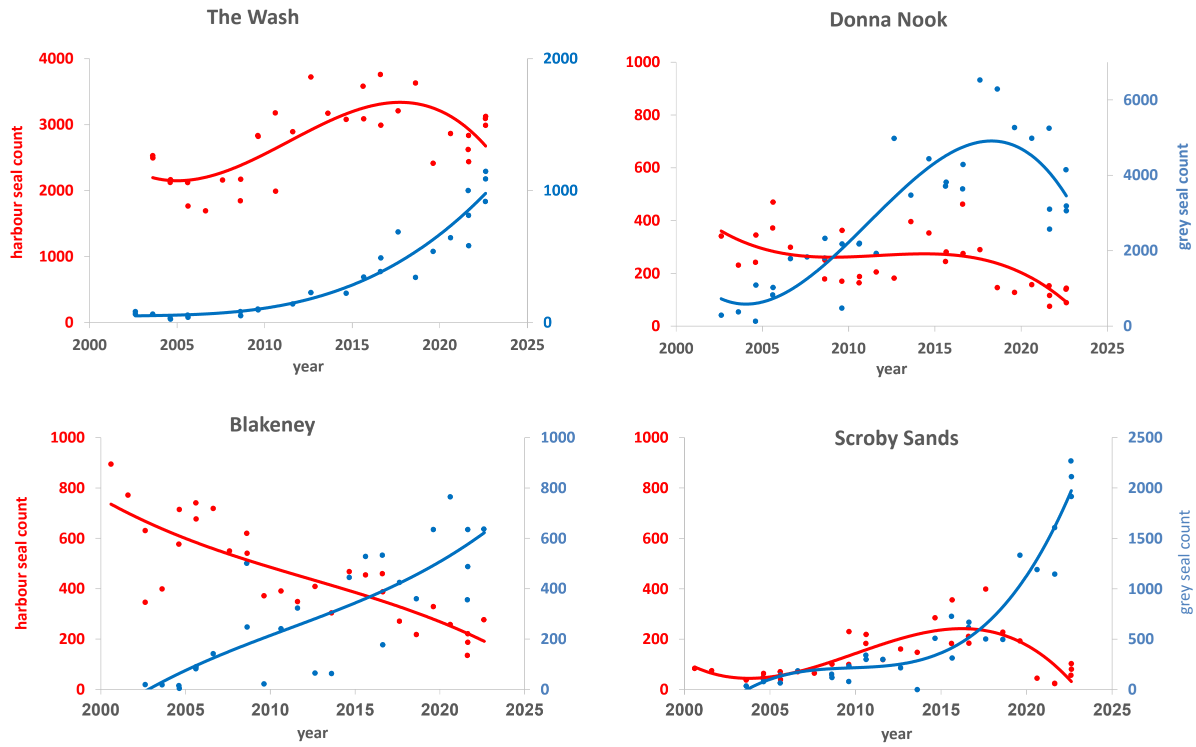

Figure 9 Counts of harbour seals (red) and grey seals (blue) for the period 2002 to 2021, in The Wash, at Donna Nook, Blakeney Point and Scroby Sands. Cubic polynomial lines have been fitted to the count data to illustrate the general patterns.

5. grey seals

Counts of grey seals from surveys between 2017 and 2022 are shown in table 2. Figure 3 shows the trends in the August grey seal counts in the Humber Estuary SAC (i.e. Donna Nook) and along the coast from Donna Nook to Blakeney point, which are the grey seal haulouts within and adjacent to the Wash and North Norfolk SAC.

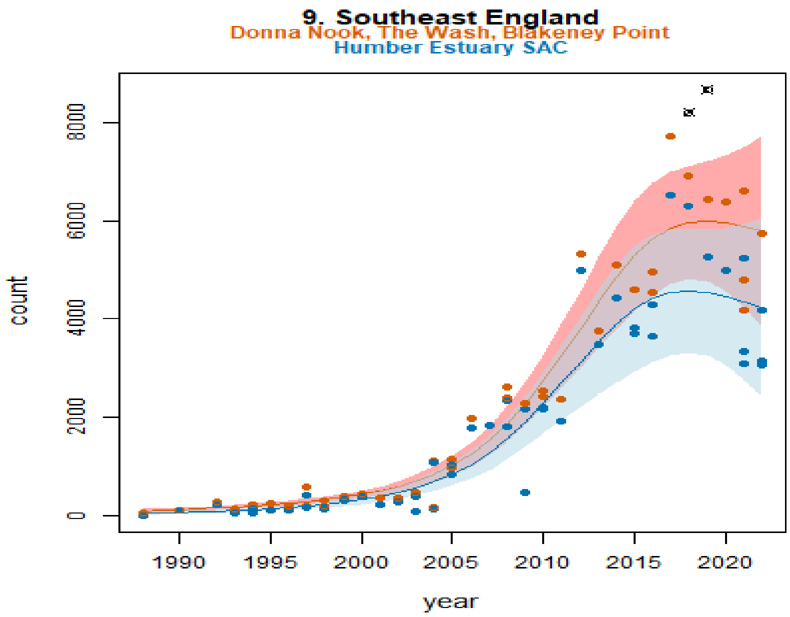

Figure 3 Counts of grey seals on the coast between Donna Nook and Blakeney Point (red), and at Donna Nook (blue) during the August surveys between 1988 and 2022. The red line (and associated 95% confidence intervals) represent the fitted trend for Donna Nook to Blakeney and the blue line (and associated 95% confidence intervals) represent the fitted trend for Donna Nook (see Russell et al. 2022 for more details). The two black open circles indicate the available counts for the SMU as a whole.

The fitted trend (Fig 3) shows that the number of grey seals hauling out in the area increased dramatically since the 2002 PDV epidemic (note that PDV epidemics are not associated with mortality events in grey seals). For the haulout sites in the north of the SEE-SMU (Donna Nook and the Wash & North Norfolk SAC), the counts reached a maximum around 2018 and have begun to decline since. However, the trends in grey seal counts differ between sites (Figs 2 & 3). At Donna Nook, the most northerly site, which until 2012 held the majority of the SEE-SMU grey seal count, there is a clear decrease since 2018. Counts at sites in the Wash, at Blakeney Point, and at Scroby Sands have increased rapidly over the past decade (Fig. 2). Sporadic counts at Horsey dog walkers and Additional surveys of the remainder of the SEE-SMU were carried out in 2021 and 2022. Results will be presented at the next SCOS meeting.

The distribution of grey seals within the Wash has expanded since the late 2000s (Fig 4) and that expansion has been most pronounced in the last 5 years. During the 2008 and 2011 surveys, grey seals were observed on only five sites within the Wash. During the 2021 surveys grey seals were identified on 21 sites. Importantly, the most recent surveys show that grey seals are now present in small numbers at sheltered sites in the creeks along the southern edge of the Wash (Figs 4 & 5).

Although most of the increase in numbers of grey seals has been at the sites on the outer banks at the Northeast corner of the Wash (Fig 5), grey seals are now extending into key harbour seal sites. Indeed, large groups are now found at sites along the edges of the deep channels between the inner sand banks. Small groups of 1 to 5 individual grey seals are now appearing on sites in the upper reaches of the tidal creeks used by harbour seals. To date, harbour seals still appear to use all the sites now also used by grey seals. Grey seals now outnumber harbour seals on the banks in the Northeast corner of the Wash and on the traditionally large harbour seal sites on Toft and Seal Sands in the inner Wash. Given the relative proportions of the population hauled out (approximately 0.72 for harbour seals and 0.25 for grey seals) during the August survey window, there are now equal numbers of grey and harbour seals associated with Wash haulout sites.

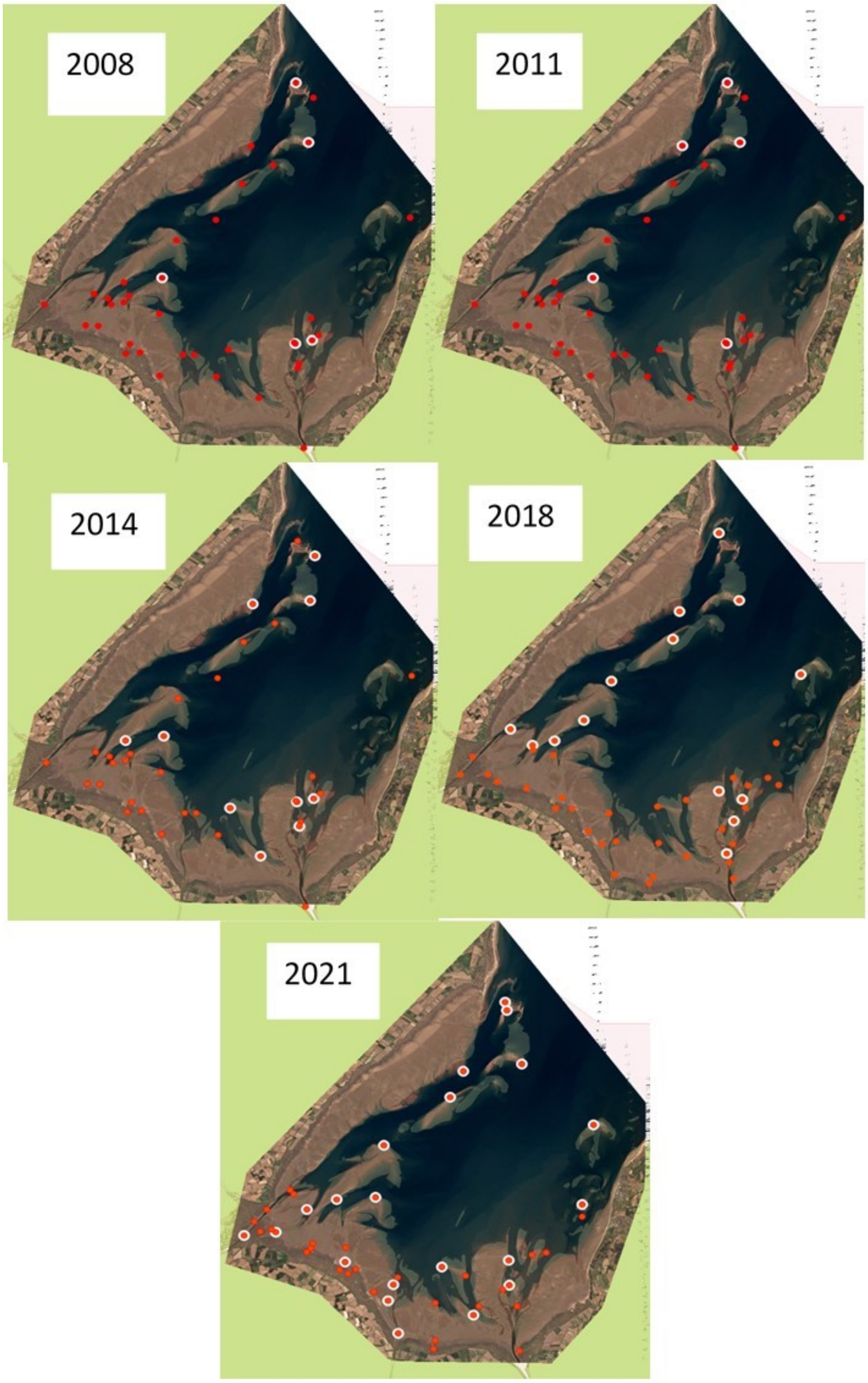

Figure 4 Distribution of harbour (red) and grey (white) seal haulout groups. For clarity the group size has been omitted (see fig 6 below).

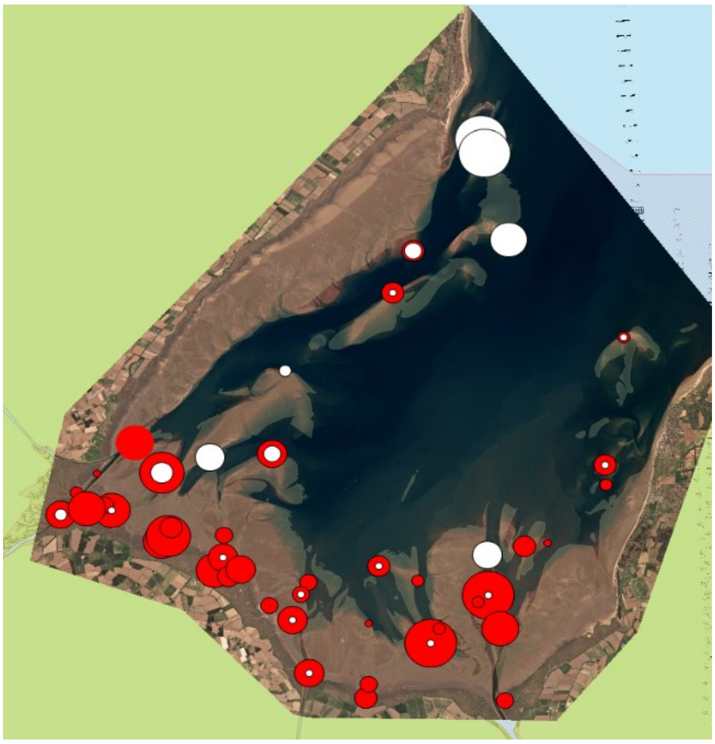

Figure 5 Distribution of harbour seal (red) and grey seal (white) haulout groups in the Wash during the 2021 moult surveys. Group size is indicated by the dot size (max). Grey seal points are superimposed on harbour seal points. All six of the pure white symbols represent sites where grey seal numbers now equal or exceed harbour seal numbers.

On visual inspection, the trends in grey and harbour seal counts by haulout group within the Wash (Fig. 2) does not indicate that the rate of harbour seal decline is closely related to the number of grey seals hauling out in the local area. Further investigation at a finer spatial scale is required, as there are indications that numbers of grey seals may have influenced harbour seal numbers at a limited number of specific sites.

Discussion

The 2020, 2021 and 2022 survey results confirm that there has been a significant decline in numbers of harbour seals along the coast between Donna Nook and Scroby Sands. The population appears to have reached a maximum around 2015 and has declined sharply since. The decline is widespread, with counts in all sub-sections of the SMU declining over the same period.

The recent counts suggest a decline of similar magnitude to that caused by the 2002 PDV epidemic. There are no reports of any disease event of sufficient magnitude to explain the drop in numbers, though un-documented/un-observed mortality from disease cannot be ruled out as a possible factor.

The results also indicate that the rapid increase in the numbers of grey seals in the same region has slowed and the numbers may have begun to decrease. Unlike the harbour seals, this change is currently localised to Donna Nook, the largest and most northerly haulout group. Counts of grey seals in the Wash, Blakeney and Scroby Sands have continued to increase.

The grey seal count has grown rapidly since the 2002 PDV epidemic. The magnitude of this change is dramatic; and when scaled up from counts to population it suggests that in 1988 harbour seals outnumbered grey seals ten to one in the study area, but by 2020, grey seals outnumbered harbour seals by seven to one. Over the same period the total biomass of grey seals associated with these east coast haulout sites increased by at least a factor of 10. Grey and harbour seals generally exploit similar prey resources (Hammond & Wilson 2016; Wilson & Hammond, 2016,2019), and grey seals are known predators of harbour seals (Brownlow et al. 2016), so it is possible that the increasing grey seal population is significantly affecting harbour seal population dynamics.

The distribution of grey seals in the Wash is expanding. Although most of the increase in numbers is accounted for by growth at sites on sand banks in the outer part of the Wash, there has also been a continual increase in the number of sites with grey seals. Importantly greys are appearing at sheltered sites in the tidal creeks in the inner Wash. These are important areas for harbour seal pupping. Unfortunately, there are no pup survey data for 2019,2020 or 2021 so no information on the locations of grey seals at the harbour seal breeding sites during the period of decline.

On visual inspection of the August counts, there is no clear indication that the numbers of grey seals hauling out within an area influences the harbour seal trend. Sub-sections of the Wash with widely differing grey seal numbers all show similar declines in harbour seal numbers.

Grey seals could potentially influence harbour seal haulout numbers by depressing the population through direct competition for prey or through direct predation. In addition, the risk of direct predation could directly influence the choice of haulout site or reduce the frequency of hauling out by harbour seals, but at present the magnitude of any such effects cannot be assessed. The widespread nature of the decline discounts the possibility of local re-distribution being the cause of the observed declines. If redistribution were the cause, it would require movement out of the area. Preliminary results from recent surveys in the Thames (SCOS_BP_21/07) also suggest a decrease in harbour seal counts in 2021. Any redistribution would therefore entail emigration from the SEE-SMU probably into the European mainland population. The adjacent European population in the Wadden Sea has also levelled off and has remained apparently stable since 2013 (Wadden Sea 2021). However, because the Wadden Sea population is 6 to 8 times larger it is unlikely that the immigration of 30% of the SEE-SMU population would have been detected.

The coincident levelling-off of the summer grey seal counts in Donna Nook may indicate that the overall seal population is approaching or has reached the SMU's carrying capacity. If that is the case, the future trajectory of the harbour seal population will be determined by the intensity of and mechanisms of competition. The extent and severity of such effects are unknown, but the magnitude of and coincident timing of the changes means that grey seals must be considered likely drivers of the observed harbour seal population trends.

Over the same period, i.e., since the 2002 PDV epidemic, there has been a rapid increase in construction of offshore wind farms. Figure 6 shows the trend in installed offshore wind generation capacity in the southern North Sea superimposed on the grey and harbour seal population trajectories. Clearly the trends in grey seal populations and wind farm developments are similar. With current information it is not be possible to differentiate between the potential effects of these two stressors, but for conservation and management it is essential that their relative importance can be assessed. It is possible or perhaps likely that more than one natural and/or anthropogenic factor may be implicated in the decline.

Figures 4 highlights another potentially important issue. The 1988 PDV epidemic was unprecedented, but that may be simply a consequence of a lack of historical information. However, the recurrence of PDV in 2002 suggests that the virus may either be in circulation or may be sporadically introduced to the North Sea, e.g., as a result of influxes of Arctic seals. Irrespective of the source, we know that the current European harbour seal population is almost entirely comprised of susceptible animals and another major epidemic is probably imminent (Härkönen & Harding, 2010).

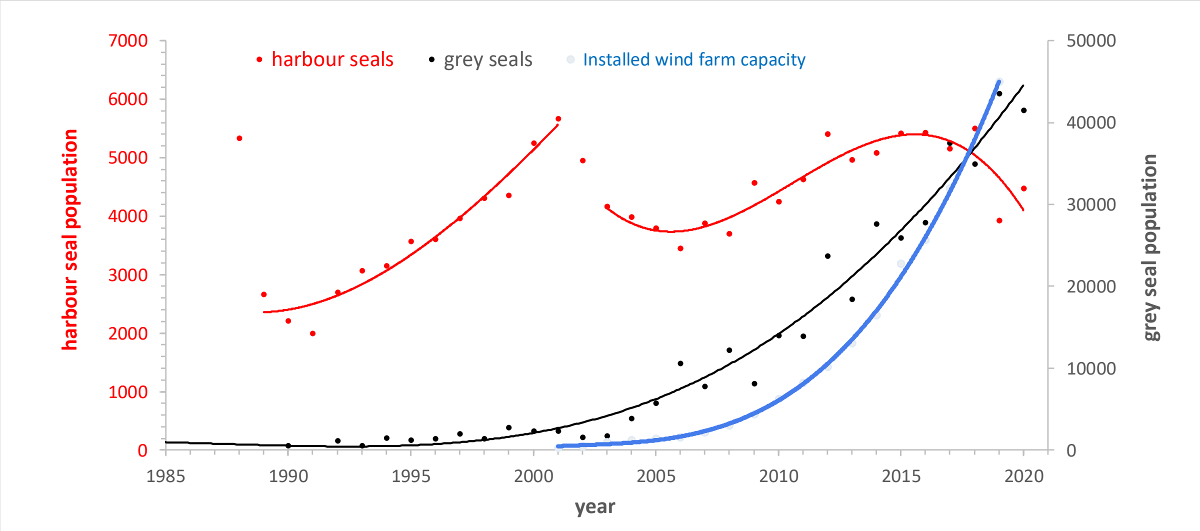

Figure 6. *Population estimates of harbour seals (red) and grey seals (black) associated with haulout sites on the coast between Donna Nook and Scroby Sands during the summer between 1988 and 2020 and the trend in installed offshore wind generation capacity (blue). Fitted lines are polynomials for illustration.*

The harbour seal population recovered from the 1988 and 2002 epizootics and reached pre-epizootic levels within 12-14 years. The post 2002 recovery coincided with the rapid growth of grey seal numbers and preceded the rapid increase in offshore wind farm construction. If a third PDV outbreak occurs soon, the harbour seal population will have to recover in a significantly different environment, with a much larger population of potentially competing grey seals. We do not know what impact the grey seal population will have on the ability of harbour seals to recover.

A report commissioned by Natural England outlined potential future avenues of research and reviewed the current seal telemetry, diet, and health data, which in addition to the survey data, would form the basis for such future work (Russell et al. 2021). In brief, there is a clear and pressing need for additional research in the short to medium term to:

- Reliably assess the scale and timing of the decline and monitor its progress
- identify and if possible, rule out as many potential anthropogenic impacts as possible, especially given the rapidly changes anthropogenic landscape
- identify the mechanisms, scale and intensity of competition between grey and harbour seals in the southern North Sea
- establish the likely impact of grey seals on harbour seal populations and to predict the likely consequences of future grey seal population trends
- to investigate the likely impacts of a recurrence of PDV on harbour seal populations in the southern North Sea.

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Preliminary report on the distribution and abundance of harbour seals (Phoca vitulina) during the 2022 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 2nd July 2022. No surveys were carried out in 2019, 2020 and 2021 due to a combination of aircraft malfunction and travel restrictions due to Covid-19. During this period the moult counts of harbour seals have undergone a marked decrease.

Results suggest that:

•The pup count for the Wash was 1141, which was 24% lower than the mean of the peak counts for the five preceding surveys (2014-2018).

• the peak counts and by implication the pup production had been increasing at an average rate of 5.6% p.a. since 2001. Although the counts appear highly variable, there is now a clear indication that the pup production has stopped increasing. This coincides with the recently observed decrease in the moult population counts for the Wash.

•The ratio of pup counts to the all-age population index has remained high, at around 0.4. The ratio was 2.2 times higher in 2022 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). The effect on the population in Southeast England SMU was similar to the pattern in the rest of Europe (Figure. 1). 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 (Härkönen 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 using the haulout sites between Donna Nook in Lincolnshire and Scroby Sands in Suffolk 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.

The population continued to decline for 4 years after the epizootic and in 2006 the count for the population between Donna Nook and Scroby Sands 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 August counts for the Wash and North Norfolk SAC and adjacent sites at Donna Nook and Blakeney reached a peak around 2015 and have since decreased (SCOS 2021 & SCOS BP 22/05) (Figure 1). The count for the Wash and North Norfolk SAC (i.e., the Wash + Blakeney) has decreased by approximately 20% (2019 – 2022 mean = 2947: 2014-2018 mean= 3658), while Donna Nook showed a 56% decrease and Scroby Sands showed a 71% decrease over the same time periods. This apparent drop occurred in the absence of any indication of a recurrence of PDV or any reported increase in strandings of dead seals.

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 status. 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.

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), a baseline of pup production estimates is required. A programme of regular surveys began in 2001 and annual surveys have been carried out of the coast from Donna Nook to Blakeney point since. Using a combination of NERC and Natural England funds a single annual breeding season survey is carried out in 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.

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 2018. 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 2001, 2004 & 2005 or with a handheld 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.

2022 survey results

In 2022 a survey was carried out on 2nd July, covering the entire coast between Donna Nook and Blakeney Point. A total of 1141 pups and 2893 older seals (1+ age classes) were counted in the Wash. No pups were seen at Blakeney Point or at Donna Nook, similar to results of the 2017 and 2018 surveys where only one pup was seen at Blakeney Point. The 2022 pup count for the Wash was 24% lower than the 2018 count and also 24% lower than the mean of the peak counts for the preceding five surveys (2014 to 2018) The non-pup count, i.e., all 1+ age classes, was 26% lower than the average of the peak counts during the previous five breeding season surveys (2014 – 2018).

The decrease follows a period of sustained increase in pup counts since 2001, albeit with indications of a slowdown in the rate of increase (Table 1 and Figure 2). The average rate of increase from 2001 to 2018 was 5.6% p.a. The pup counts demonstrate significant inter annual variation, but there was little change in the peak count over the previous 5 years suggesting that the increase in pup production had slowed and was likely approaching an asymptote after a period of exponential growth since the Phocine Distemper outbreak in 2002 (Figure 2). The 24% decrease between the 2018 and 2022 surveys coincided with the fall in the moult counts for the same area.

The time series indicates that there was no evidence of a major decline in pup production after the 2002 PDV epidemic and the peak pup 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 3). 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 changed over the early years of the time series (Figure 4). 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 has varied but shown no overall trend over the past 15 years. In 2022 the ratio was approximately 17% lower than the mean of the ratios of the previous 10 years but was still 2.2 times higher than the 2001 estimate.

In 2022, pups were recorded on 56 separate sites and were present on all sites that held more than five adult harbour seals. Although the fine scale distribution and relative sizes of groups varies between surveys there is no clear indication of a contraction or expansion in number of pupping sites. Figure 5 shows the distribution of haulout sites in the Wash used by harbour seals on 2/7/2022.

In previous reports the counts of seals have been allocated to locations of the nearest named haulout site, to allow direct comparison across the extended time series of counts. However, 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 were pooled, and a single count was given at an arbitrary point in the approximate centre of the distribution of observed groups.

Although useful for following trends and large-scale changes in distribution, there was a requirement for more accurate descriptors of haulout sites for designating exclusion zones around important sites, to prevent disturbance to seals from shellfish harvesting activities. These high-resolution maps allow a more detailed examination of changes in seal distribution, but also include substantially more sites with small groups of seals. Historical data from surveys after 2012 will be converted where possible to allow comparison between years. To date surveys in 2016,2017, 2018 and 2022 have been processed.

The relative importance of sites varies between years. Figure 6 shows the fine scale distribution of harbour seals on sand banks in and around the Lynn Channel in the southeast corner of the Wash during the breeding season surveys in 2016, 2017 and 2018. The maps represent the best estimates of the spatial extents of seal haulout sites observed during breeding season surveys and show significant changes in the fine scale distribution of harbour seals between surveys. It is not known to what extent these differences represent short term movements or interannual changes in distribution. Additional data are available for multiple surveys in 2015 and 2016 and these will be examined to determine the level of intra and inter annual changes.

Data from the moult surveys shows that the numbers of grey seals using haulout sites in the Wash has increased dramatically since 2002, and the high-resolution maps indicate that they are spreading further into the Wash during the harbour seal moult in August. Figure 7 shows the distribution of grey seals on haulout sites in the Wash during the 2022 breeding season survey. at present the large groups of grey seals are only found on the Outer banks and there is little overlap between grey seal haulout locations and harbour seal pup sites. However, close inspection of Figure 7 reveals that individual grey seals are present on at least eight of the harbour seal pup sites in the inner banks and tidal creeks.

Discussion

The 2022 breeding season survey counts for both pups and associated 1+ age classes at the estimated peak of the breeding season were 24% lower than 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 has stopped and is likely declining. The absence of pup counts in 2019, 2020 and 2021 means that it will not be possible to confirm the timing of the onset of the decrease, but it appears to be coincident with the onset of the decrease in moult counts.

At present it is not possible to confirm whether the observed decreases represent a step change decrease or the onset of a continuing decline. Further survey data will be required to confirm the status of the population. At present the causes of the decreases in pup and moult counts are unknown. A research program to investigate potential causes is being developed, but the importance of maintaining the time series of both population and pup production estimates to act as a base line for such studies is clear.

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, so the observed trends should accurately describe the population changes.

The recent low intensity pup survey effort has produced two interesting results that highlight the advantage of a two-pronged approach to seal monitoring, capturing both the population trend and a productivity index. 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. Interestingly, although the moult counts in recent years, 2012 to 2018 were 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 the crude fecundity index remained high, as the pup production and moult counts levelled off suggests that may indicate that whatever was constraining the population growth was not acting through changes in fecundity. The observation that the fecundity index has decreased, coincident with significant drop in pup and moult counts requires further investigation.

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 from the area. At present we do not have information on pregnancy rates from the SEE_SMU harbour seal population. Telemetry data from both the English and Netherlands populations suggests that there is limited movement between the two areas, but the data have little power to detect such movements around the time of breeding or moult.

The observed large increase in pup production relative to the moult count index after the 2002 epizootic is unexplained. 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 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 2022 indicate that the relative importance of the SE corner of the Wash is still increasing.

The distribution of grey seals throughout the Wash is a potentially important factor. Grey seals are known predators of adult harbour seals and presumably pose a threat to harbour seal pups. The presence of individual grey seals on several sites in the inner banks and creeks should be monitored. Any significant increase in grey seal presence on these sheltered sites may indicate a potential new and increasing predation risk.

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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	2022
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351	1586	1289	1498	1141
1+ age classes	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	4539	3905	3443	3747	2893

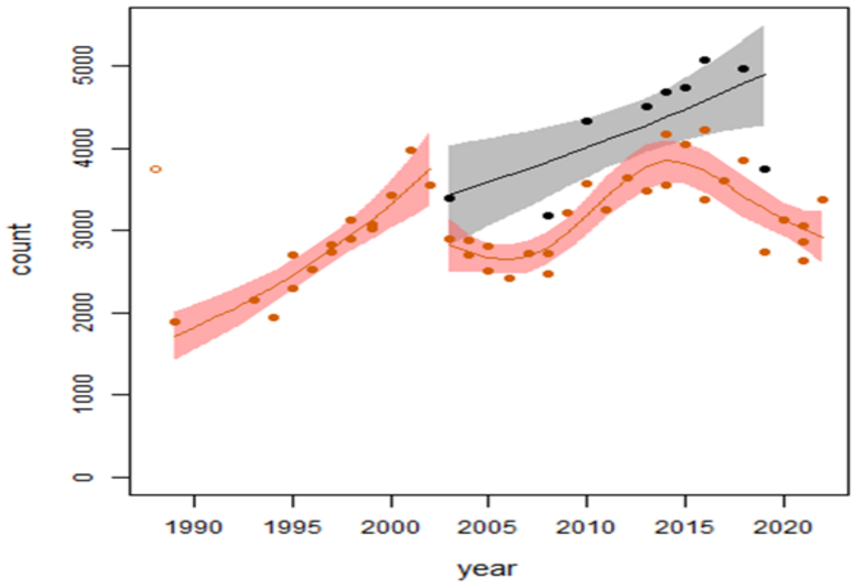

Figure 1. Counts of harbour seals in the Wash and North Norfolk SAC (red) and the total for the Southeast England SMU (grey) during the harbour seal moult in August, between 1988 and 2022. Separate trend lines are fitted (see Russell et al. 2022 SCOP BP) to the 1989-2002 counts and post 2002 counts showing recoveries from the two PDV epidemic in 1988 and 2002. Red lines illustrate the mean trend in harbour seal counts (and associated 95 % confidence intervals) for The Wash and North Norfolk SAC and the grey lines show the same for the SMU as a whole (between Donna Nook, Lincolnshire and Goodwin Sands, Kent).

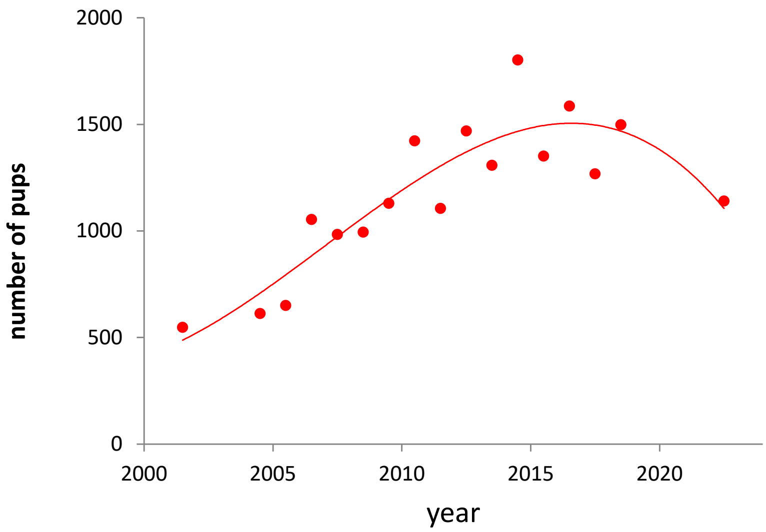

Figure 10. Maximum counts of pups in The Wash between 2001 and 2022. As a preliminary step a simple 3 factor polynomial has been fitted to indicate the trend. The pup counts increased at an average rate of approximately 5.6% p.a. from 2001 to 2018. The most recent count indicates that the pup production has stopped increasing and is now likely declining. A formal model fitting exercise will be carried out and results will be included in a revised BP before the SCOS meeting

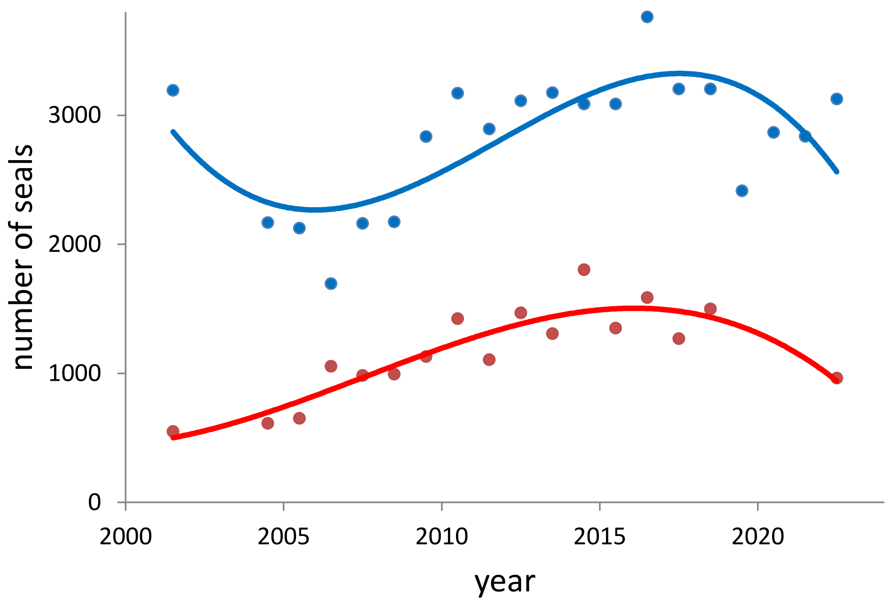

Figure 11 Maximum counts of pups in The Wash between 2001 and 2018 alongside the annual moult count over the same period.

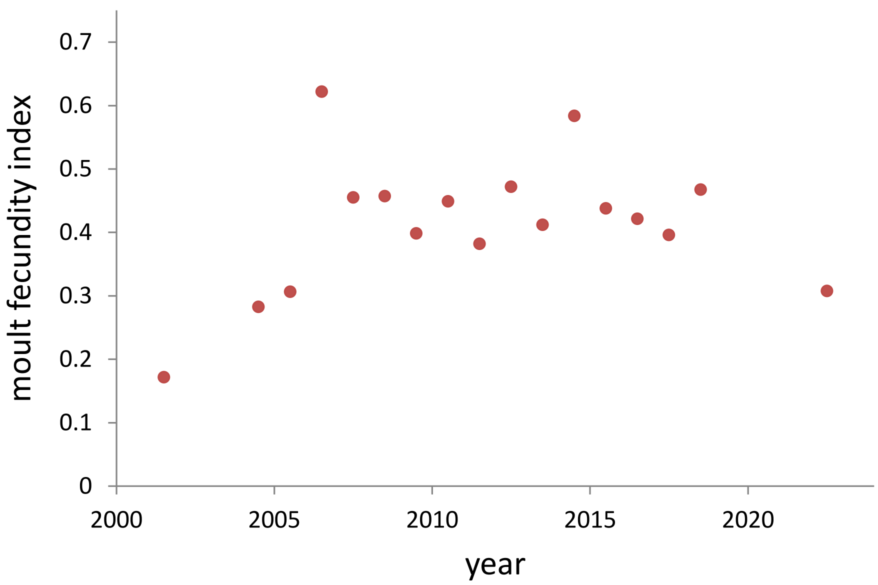

Figure 12 An index of fecundity, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size) increased between 2001 and around 2007 after which it appears relatively stable.

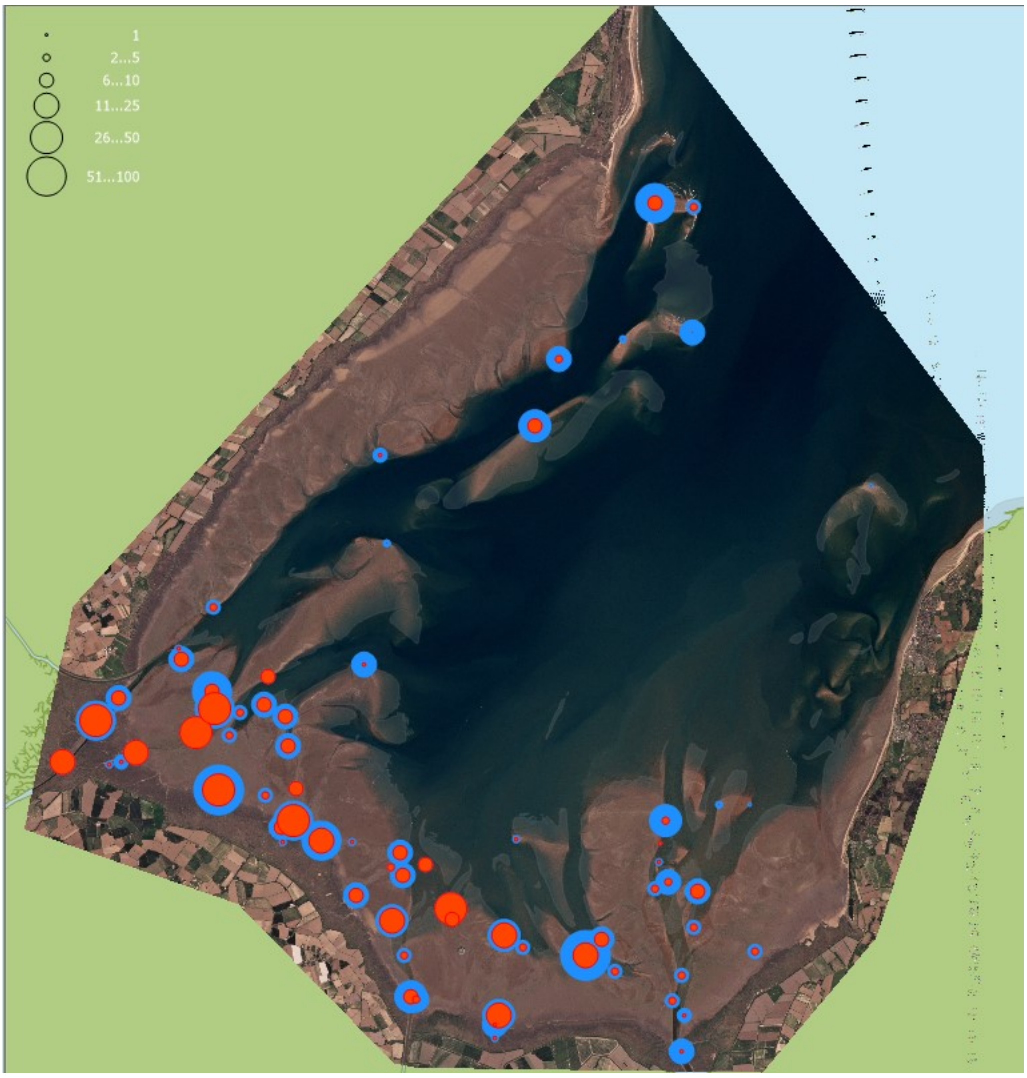

Figure 13 Distribution of pups (red circles) and 1+ age class harbour seals in the Wash on 2/07/2022. Numbers of seals are represented by the areas of the circles on each site.

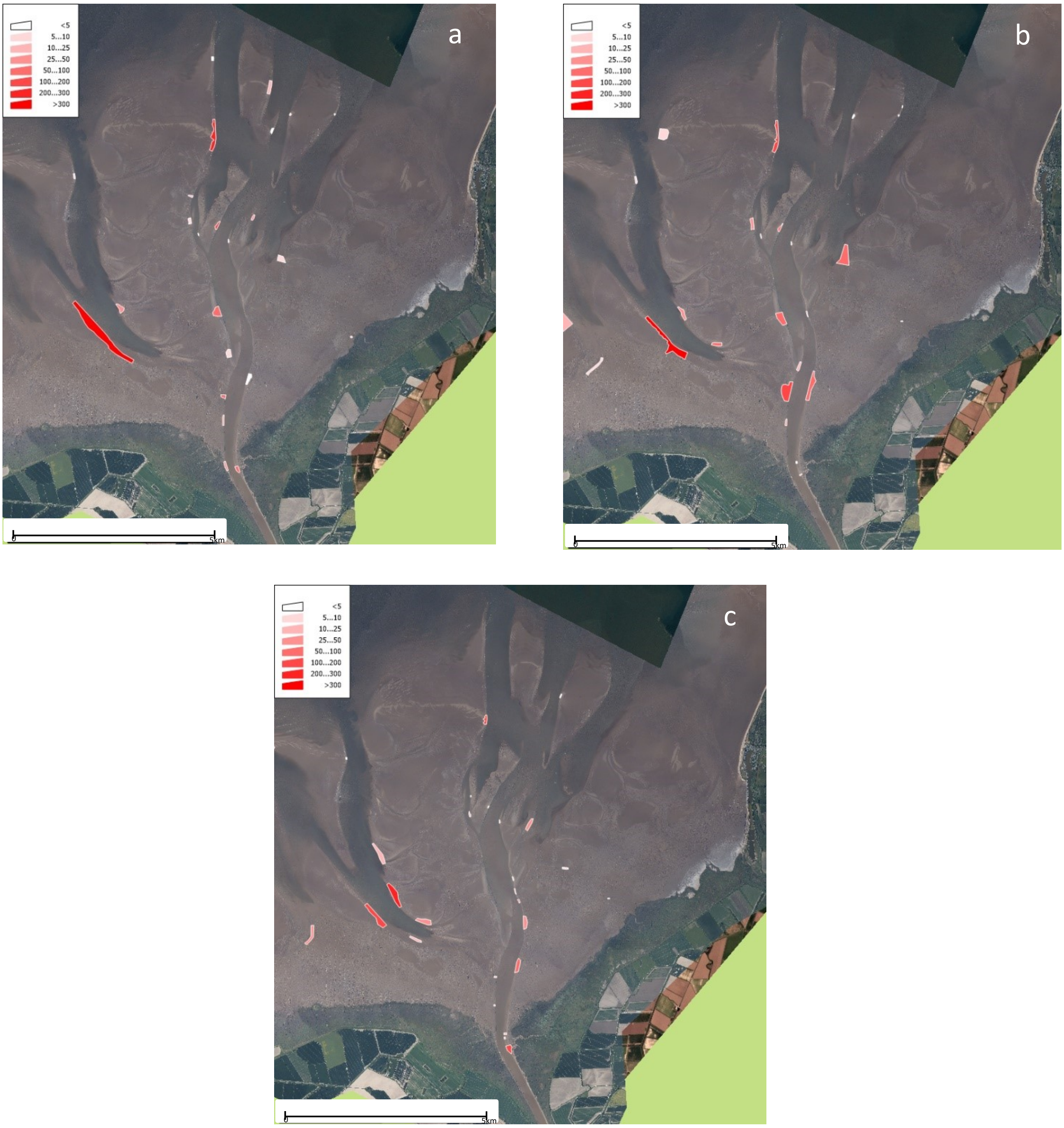

Figure 14 Example of the haulout extent maps for sites in the Great Ouse/Kings Lynn Channel during the breeding season in a) 2016, b)2017, c) 2018. The maps represent the best estimates of the spatial extents of seal haulout sites observed during breeding season surveys and show significant changes in the fine scale distribution of harbour seals between surveys. Sites are colour coded according to the number of seals counted, in this case the number of adult harbour seals.

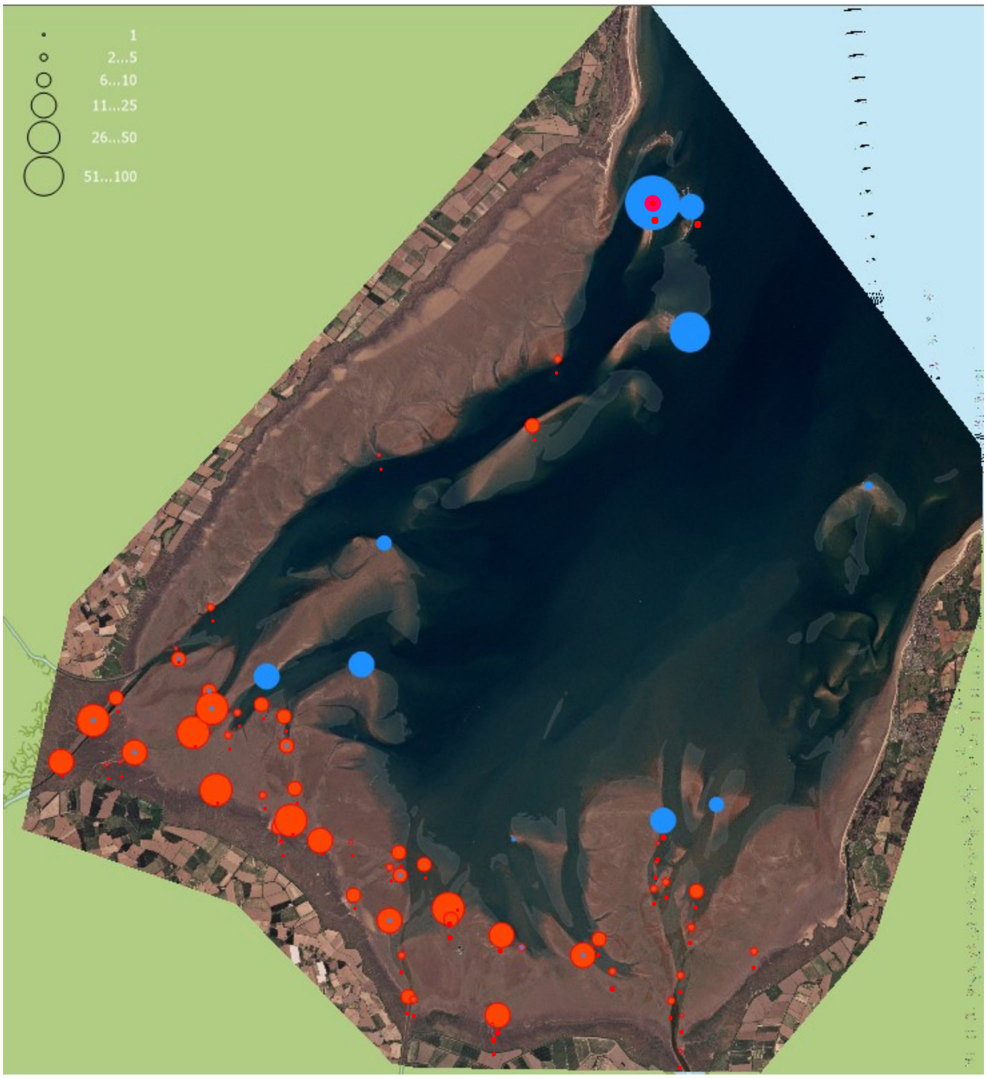

Figure 15. Distribution of harbour seal pups (RED) and grey seals (BLUE) in the Wash on 2/7/2022 Numbers of seals are represented by the areas of the circles on each site.

Provisional Regional PBR values for Scottish seals in 2023

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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: In 2021 surveys were carried out in the Moray Firth and the East Scotland SMUs. Counts of harbour seals were 35% and 24% lower respectively than in previous surveys so PBR for harbour seals is reduced from 6 to 4 in Moray Firth and from 2 to 1 in East Scotland. Counts of grey seals were 12% higher and 24% lower respectively than previous surveys so PBR for grey seals is increased from 370 to 414 in Moray Firth and reduced from 823 to 605 in East Scotland.

Recovery factors are unchanged from 2021.

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:

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

where:

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

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

$\mathbf{R_{max}}$ 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.

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:

N_{min} 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 N_{min}. (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: A revised analysis of GPS/GSM telemetry data from 60 grey seals tagged between 2005 and 2018, allowed more accurate identification of haulout times and of proportion of time spent hauled out (SCOS-BP 21/02). The revised estimate of proportion of seals hauled out during the survey window was 25.15% (95% CI: 21.5 – 29.1%), compared with the previous estimate of 23.9% (95% CI: 19.2 - 28.6%) (Russell et al. 2016 SCOS-BP 16/03). The 20th centile of the distribution of multipliers from counts to abundances implied by the revised estimate is 3.73, approximately 3.5% lower than the previous scalar.

R_{max} 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. for long periods(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 and have not shown any signs of recovery.

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 2021 in the Moray Firth were approximately 35% lower than the counts for the previous 5 years. The neighbouring Orkney and East Scotland populations are continuing to undergo unexplained, declines in abundance. Data available from tracking studies suggest there is movement between these three areas. In the absence of a sustained 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; Thomas et al., 2019; Russell et al., 2019). 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 for with the full range of F_R values from 0.1 to 1.0 are given in table 1 for harbour seals and table 2 for grey seals. In each table the value corresponding to the recommended F_R is highlighted

Table 1. Potential Biological Removal (PBR) values for harbour seals in Scotland by Seal Management Unit for the year 2023. Recommended F_R values are highlighted in grey cells.

	2016-2021		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	3,532	3,532	21	42	63	84	105	127	148	169	190	211	0.5	105
4 North Coast & Orkney	1,405	1,405	8	16	25	33	42	50	59	67	75	84	0.1	8
5 Shetland	3,180	3,180	19	38	57	76	95	114	133	152	171	190	0.1	19
6 Moray Firth	690	690	4	8	12	16	20	24	28	33	37	41	0.1	4
7 East Scotland	262	262	1	3	4	6	7	9	11	12	14	15	0.1	1
SCOTLAND TOTAL	26,378	26,378	156	314	471	630	788	946	1,105	1,263	1,421	1,579		1,144

Table 2. Potential Biological Removal (PBR) values for grey seals in Scotland by Seal Management Unit for the year 2023. Recommended F_R values are highlighted in grey cells.

	2016-2021		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	517	1,927	11	23	34	46	57	69	80	92	104	115	1.0	115
2 West Scotland	4,174	15,554	93	186	279	373	466	559	653	746	839	933	1.0	933
3 Western Isles	5,773	21,512	129	258	387	516	645	774	903	1,032	1,161	1,290	1.0	1,290
4 North Coast & Orkney	8,599	32,043	192	384	576	769	961	1,153	1,345	1,538	1,730	1,922	1.0	1,922
5 Shetland	1,009	3,760	22	45	67	90	112	135	157	180	203	225	1.0	225
6 Moray Firth	1,856	6,916	41	82	124	165	207	248	290	331	373	414	1.0	414
7 East Scotland	2,712	10,106	60	121	181	242	303	363	424	485	545	606	1.0	606
SCOTLAND TOTAL	24,640	91,818	548	1,099	1,648	2,201	2,751	3,301	3,852	4,404	4,955	5,505		5,505

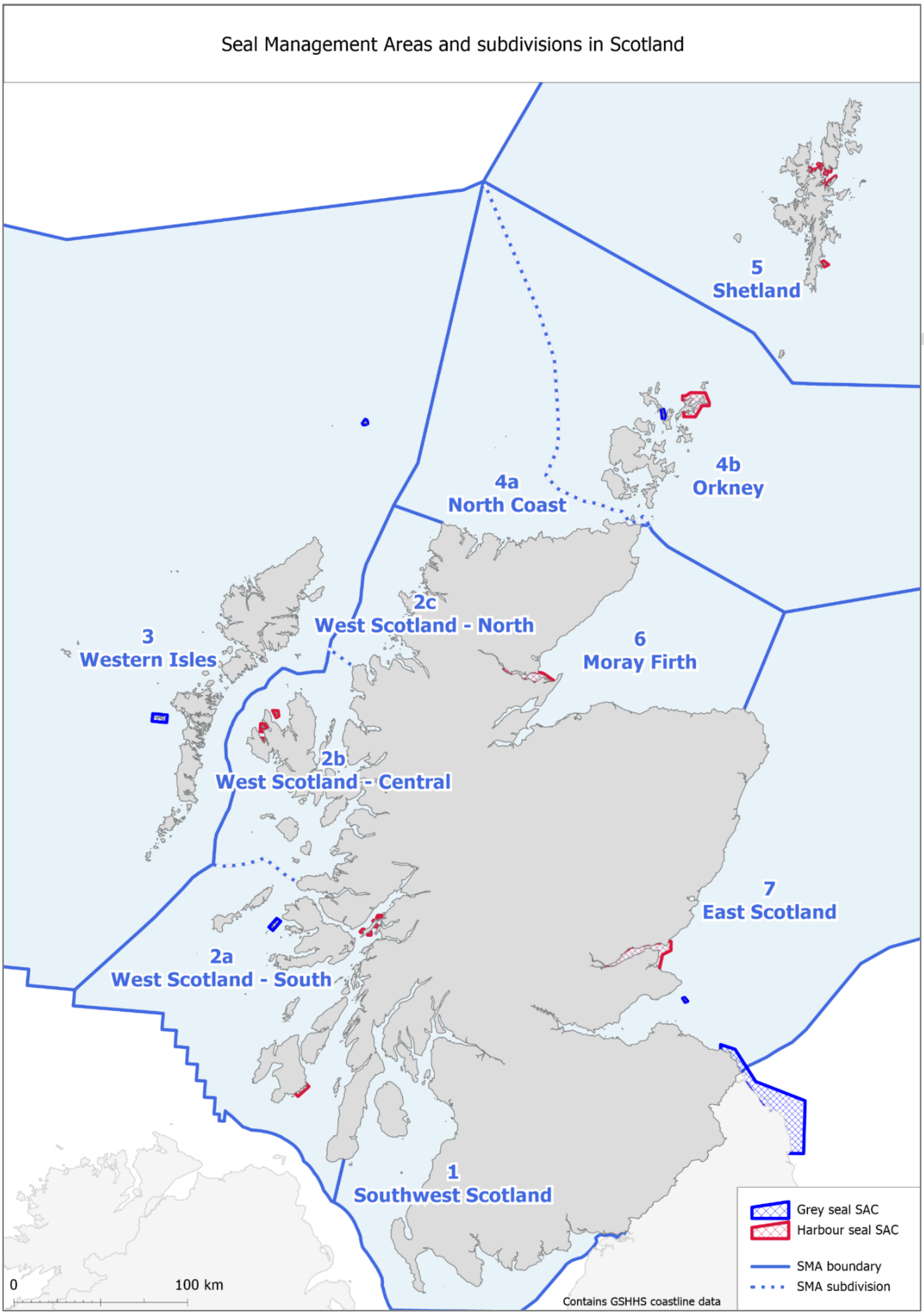

Figure 1. Seal management areas in Scotland.

ANNEX I Terms of reference and SCOS membership

NERC SPECIAL COMMITTEE ON SEALS

Terms of Reference

a. To undertake, on behalf of NERC Council, the provision of scientific advice relating to the status of grey and harbour seals in United Kingdom 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, and all subsequent amendments to those Acts. This advice will be provided to the Scottish Government, the Department for Environment Food & Rural Affairs (Defra), Natural Resource Wales (NRW) and the Department of Agriculture, Environment and Rural Affairs Northern Ireland (DAERA).

b. To comment on the Sea Mammal Research Unit's (SMRU) 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(a).

c. To report to NERC Council through the NERC Executive Chair.

Current membership

Dr J. London (Chair)	Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle.
Dr C. Sparling	Sea Mammal Research Unit, University of St Andrews.
Dr J. Armstrong	Freshwater Fisheries Laboratory, Marine Scotland Science, Pitlochry, Perth.
Dr K. Bennett	Abertay University, Dundee.
Dr M. Biuw	Institute of Marine Research in Norway, Tromsø.
Dr G. Engelhard	Centre for Environment Fisheries and Aquaculture Science, Lowestoft.
Prof. B. Wilson	Scottish Association for Marine Science, Dunstaffnage, Oban.
Dr K. Frior (Secretary)	UKRI Natural Environment Research Council, Swindon.