# Scientific Advice on Matters Related to the Management of Seal Populations: 2024

# Natural Environment Research Council Special Committee on Seals

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# Executive summary

There are two species of seal that live and breed in UK waters: harbour (also called common) seals (*Phoca vitulina vitulina*) and grey seals (*Halichoerus grypus*). 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 seals. This advice is based on the latest scientific research conducted and collated by the Sea Mammal Research Unit, University of St Andrews. NERC appointed a Special Committee on Seals (SCOS) to review and formally issue this advice.

In 2024, 39 questions covering a wide range of management and conservation issues were received from Scottish Government, Defra and Natural Resources Wales. Answers to these questions are provided in detail in the main Advice below, and the main points and recommendations are summarised here.

### Harbour Seals

The total harbour seal population is estimated based on counts of seals during the annual moult in August, scaled using an estimate of the proportion of harbour seals hauled out during the aerial survey window (0.72; 95% CI: 0.54-0.88). Based on surveys between 2016 and 2023, the total UK harbour seal population is estimated at **40,525** (95% CI: 33,157-54,033). This represents a decrease of approximately **6.5%** (**2%** and **27%** for Scotland and England, respectively) compared to the previous composite counts covering the years 2011-2019 ). This decrease is largely due to the recent decline in Southeast England.

There are significant differences in harbour seal population trends between Seal Monitoring Units (SMUs). Trends for the SMUs which represent > 99% of UK harbour seal abundance are summarised here. Southwest Scotland and the West Scotland SMUs are stable or increasing slightly. The most recent count for the Western Isles SMU (2023) indicated a decline from the previous count, but the trend over a longer period is stable or increasing. All other SMUs are either a) stable at a depleted level after declines in the early 2000s (Shetland, Moray Firth), b) depleted and still declining (North Coast and Orkney, East Scotland) or c) have recently declined after periods of increase (Southeast England). Northern Ireland is in a continued but slow decline.

*Table S1. UK harbour seal population estimates with 95% Confidence Intervals based on counts during the August moult.*

| Location | Composite Count (2016-2023) | Total Population Estimate (95% CI) |
|---|---:|---:|
| **England** | **3,537** | **4,913 (4,019-6,550)** |
| **Wales** | **1** | **1 (1-2)** |
| **Scotland** | **24,822** | **34,475 (28,207-45,967)** |
| **Northern Ireland** | **818** | **1,136 (930-1,515)** |
| **Total UK** | **29,178** | **40,525 (33,157-54,033)** |

## Grey Seals

UK grey seal abundance and trends are primarily assessed through a combination of estimates of pup production (number of pups born) and August haulout counts. UK grey seal pup production (number of pups born each year) has continued to increase. The most recent estimate of ~75,950 pups is the highest total estimate on record; over 95% of these were produced in Scotland and the east coast of England. The trends in these SMUs vary. Pup production in West Scotland and Western Isles SMUs is increasing after a period of stability. Pup production in North Coast & Orkney SMU is stable and is still increasing rapidly in the UK coast of the North Sea (East Scotland, Northeast England and Southeast England SMUs).

While pup production time-series provide the main index population change at a UK level, August counts are also critical. Distribution during the foraging season (represented by August counts) indicate where adults acquire the resources necessary for pup production. The foraging season is also when seals are most at risk from threats at sea (e.g. bycatch), and thus consistent August counts are required for robust Potential Biological Removal estimates. Moreover, August counts, scaled using the proportion of grey seals hauled out during the aerial survey window (from telemetry data), provide estimates of total population that are independent from pup production; these feed into the population model.

The total UK grey seal population at the start of the 2023 breeding season (before pups are born) is estimated via a Bayesian population dynamics model incorporating the time-series of pup production estimates, and three population estimates (scaled August counts).

For SCOS 2024, three alternative time series for pup production encompassing the range of possibilities were generated to address the jump in pup production associated with the switch from film to digital aerial surveys between 2010 and 2012; 1) a mix of film and digital estimates (uncorrected), 2) all digital estimates scaled down to the level of film estimates (low) and 3) all film estimates scaled up to digital level (high).

The resulting UK population estimates were **168,400** (approximate 95% CI 149,500 - 187,700) for the uncorrected time-series; **166,900** (137,900 – 196,400) for the low, and **169,500** (143,500 – 198,200) for the high.

Although the true value of pup production and population estimates likely sit between the low and high level, comparisons between aerial surveys and ground counts indicate that the high level is likely nearer the true value.

The rate of population increase is estimated to be **1.5%** per year in the uncorrected scenario and **0.7%** in both low and high scenarios.

With the addition of the most recent pup production estimates, the population dynamics model is no longer producing a good fit to the data. Two aspects of the pup production time series were not adequately accounted for by the model: the recent increase in pup production in West Scotland and Western Isles after a period of stability and the near-exponential increase in pup production in the North Sea region.

## Seal Conservation and Management

For both species, trends within Special Areas of Conservation (SACs) are generally less favourable than trends for the associated wider regions that encompass them.

The most recent estimate of bycatch of harbour and grey seals in UK fisheries was **458** animals in 2021 (95% CI 356-836). While this is higher than in 2020 (356), the confidence intervals are wide, overlap with previous estimates, and are similar to recent pre-Covid estimates. Spatially, an estimated 70% of the bycatch occurs in the south-west of the UK and most bycaught seals are young grey seals. These estimates exclude bycatch by non UK vessels.

There are growing concerns being raised by fisheries organisations about the interactions between seals and fisheries, including the presence of seals in rivers, impacting on recreational fisheries and salmonid conservation. There is anecdotal evidence that the presence of seals in rivers is increasing, but as far as SCOS is aware, no systematic, effort-based recording has been conducted.

There remain concerns about future disease outbreaks in UK seal populations. As it is now 22 years since the last epizootic, the majority of UK harbour seals are likely susceptible to Phocine Distemper Virus (PDV), so an epizootic outbreak may be imminent. There are also concerns about the potential for an outbreak of Highly Pathogenic Avian Influenza (HPAI) in UK seals, given the detection of HPAI in dead UK seals and occurrences of HPAI in seals on the east coast of the US and Canada and the potential for further outbreaks in UK seabird populations.

SMRU's long-term funding has recently seen a substantial reduction, and further reductions are expected. This is having an impact on the frequency and types of advice that SMRU will be able to deliver, and also impacts SMRU's capacity to carry out critical research underpinning our understanding of changes in UK seal populations. Research and advisory activities continue to be reprioritised as necessary, but there must be recognition that continuing increases in the number and complexity of advice requests cannot be supported given current levels of resource and capacity.

The delay between application and granting of authority to conduct studies requiring capture and/or sampling of seals has been impacting SMRU's ability to conduct research and precludes a rapid response to the onset of a disease event or any other response to acute environmental perturbations.

## Summary of recommendations of SCOS in 2024

- The conversion factor used to estimate population size from August counts of harbour seals is based on a sample of 22 tracked adult seals from a single year. SCOS recommends that when resources and methodology allow this conversion factor should be further investigated specifically in terms of spatial, sex and age differences as well as to facilitate potential extension to surveys outside the moult.
- Recent studies suggest that fecundity or reproductive performance in grey seals is influenced by prevailing environmental conditions. Our methods for estimating grey seal population size depend on good estimates of these parameters. SCOS therefore 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. While the proximate cause must include a decline in adult survival and/or emigration to continental Europe, the possible underlying drivers of the decline include interactions with grey seals, anthropogenic activities, increased disease and/or increased biotoxin levels. Funding has been secured for a programme of research which is now underway at SMRU investigating these factors, however further resources are needed to synthesise the outcomes from this work, and to draw conclusions and provide recommendations.

- In relation to seal bycatch, effort should be directed towards improved species determination and, when possible, the sex and age class of bycaught seals. Additionally, genetic samples should be collected and analysed to identify the source populations.
- A co-ordinated research effort is required to update knowledge on seal diet around the UK, particularly where fish stocks and seal populations have undergone changes. The most recent information for Scotland is more than ten years old. Efforts around the rest of the UK will complement research that is underway in Southeast England as part of efforts to understand the drivers of the harbour sea decline.
- Potential Biological Removal (PBR) is the currently accepted method for estimating safe takes from UK seal populations. SCOS therefore recommends that management should, where possible, be based on PBR estimates for individual Seal Monitoring Units. These should be combined where necessary to produce PBR estimates appropriate to the scale of the management issue under consideration. Alternative methods of estimating safe levels of removal require additional work to develop a better understanding of the metapopulation structure and degree of movement between regions.
- Continued investigation is required of non-lethal measures for control of seals in rivers to reduce impacts on recreational fisheries and the conservation of salmonid species. Triggered deterrents and modified physical barriers remain the most promising methods, but significant resources will be required to implement and trial these in a wide range of environments and evaluate efficacy in the long term.
- Information is still lacking about the fine scale behaviour of seals around tidal turbine renewable energy devices, and SCOS therefore 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. However, recent research in this area should provide information on behaviour of seals at the range of spatial scales required to effectively derive empirical avoidance rates to operating turbines.
- There is a need for 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 draft PDV contingency plan that could form the basis of such a response plan. SCOS encourages UK nations to build on the work done by Scottish Government and SMRU to develop response plans and, given the evolving situation with HPAI, some urgency should be applied to this effort.
- Routine disease surveillance of stranded animals and rescues would ensure the early detection and monitoring of infectious diseases in the UK**.**
- The delay between application and granting of authority to conduct studies requiring capture and/or sampling of seals precludes a rapid response to the onset of a disease event or any other response to acute environmental perturbations. A mechanism by which there is a fast-response for granting of authority to conduct studies in the event of time-critical investigations should be a priority.

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# 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 that 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 and conservation of marine mammals in general.

This report provides scientific advice on matters related to the management of seal populations for the year 2024. It begins with some general information on UK 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, and further reductions are expected. This is having an impact on the frequency and types of advice that SMRU are able to deliver and also impacts SMRU's capacity to carry out underpinning research to understand changes in UK seal populations. Research and advisory activities continue to be reprioritised as necessary, but there must be recognition that continuing increases in the number and complexity of advice requests cannot be supported given current levels of resource and capacity.

## General information on UK seals

Two species of seal live and breed in UK waters: harbour (also called common) seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*).

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*).

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.

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.

### Population Monitoring in the UK

In the UK, harbour seals are members of two metapopulations. The populations in Scotland, and likely Northern Ireland, are part of one metapopulation, whereas the population in the east coast of

England are part of the continental European metapopulation (Carroll *et al.* 2022). In contrast, all grey seals in the UK are part of a Northeast Atlantic metapopulation although there is genetic structure at a finer scale.

For the purposes of population monitoring and reporting, the UK is split in 14 Seal Monitoring Units (SMUs; Figure 1). The SMUs are arranged clockwise around the UK starting in southwest Scotland: 1-7 are in Scotland, 8-11 & 13 are in England, 12 is Wales, and 14 is in Northern Ireland. In Scotland, these SMUs align with the Seal Management Areas (SMAs). Recognising the requirement for reporting and management on the national level, SMUs do not transect national boundaries. With the exception of those that follow national boundaries, SMU boundaries were placed with the aim of avoiding splitting of haulouts or grey seal breeding colonies across SMUs. However, these SMUs are primarily for the purposes of monitoring and reporting; they do not necessarily represent ecological units for either species. The results for SMUs should be combined, if and when appropriate, in line with the spatial scale of the risk or management action.

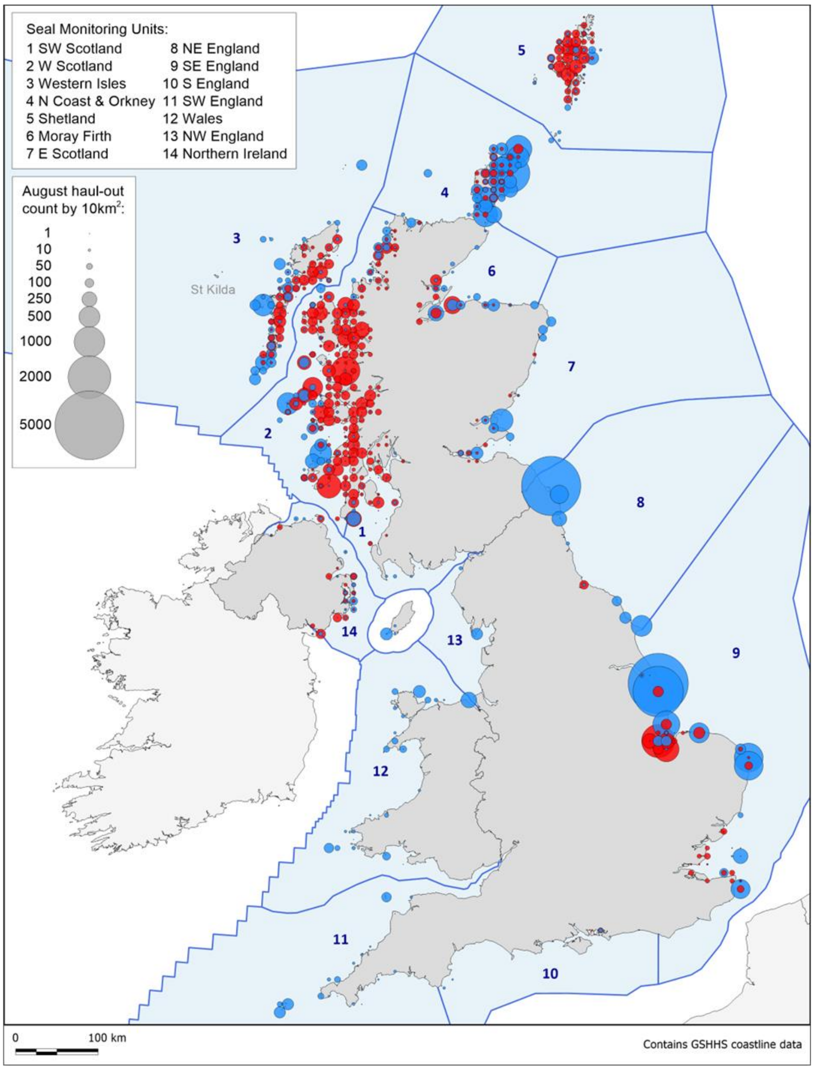


*Figure 1. The 14 Seal Monitoring Units (SMUs) used for monitoring and reporting seal abundance and trends. Counts in August (2023 or latest prior year for which data were available) for harbour (red) and grey (blue) seals are shown on a 10km² grid scale. Data are collected from surveys conducted by SMRU and other organisations (see Table 2 and SCOS-BP 24/01).*

## 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 haul-out sites. Foraging ranges vary substantially both regionally and within sites. Some harbour seals forage >100km from their nearest haul-out sites while others remain very close inshore within only a few kilometres of haul-out sites. They take a wide variety of prey including sandeels, gadoids, herring and sprat, flatfish, octopus, and squid. Diet varies seasonally and from region to region. Because of their smaller size, harbour seals eat less food than grey seals, 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 and northern Russia in the east. The largest population of harbour seals in Europe is in the Wadden Sea.

Approximately 30% of European harbour seals are found in the UK; this proportion has 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 Moray Firth, Firths of Forth and Tay (East Scotland SMU), and The Wash and Thames Southeast England SMU). 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 around a half following the 1988 phocine distemper virus (PDV) epizootic. A second epizootic in 2002 resulted in a decline of around a third in The Wash but appeared to have limited impact elsewhere in Britain. Counts of harbour seals in The Wash and eastern England did not demonstrate 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 there is now an indication of a decline.

Major declines have been documented in several harbour seal areas around Scotland since the late 1990s. However, the pattern of declines is not universal. In Shetland, Orkney and Moray Firth, abundance appeared stable in the late 1990s but by the next survey (mid 2000s) abundance had declined markedly. In Shetland and Moray Firth there has been no significant trend since, but in Orkney there has been a continued sustained decline. 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. In contrast to these observed declines, the West Scotland population has more than doubled from the mid-1990s to now, hosting the largest number of harbour seals in the UK.

## 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 150-200 kg. 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 haul-out 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 haul-out site although they can feed up to several hundred kilometres offshore. Individual grey seals based at a specific haul-out site often make repeated trips to the same foraging region offshore but will occasionally move to a new haul-out site and begin foraging in a new region. Movements of grey seals between haulout sites in the North Sea and haul-out sites in the Western Isles SMU have been recorded as well as movements from sites in Wales and NW France, to the West Scotland SMU.

Globally there are three centres of high grey seal abundance: one on the coast of 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 Canada, there are clear indications of a slowing down in population growth in recent years.

Approximately 34% of the world's grey seals breed in the UK and 70% of them breed at colonies in Scotland with the main concentrations in the Western Isles 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 7,000 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 (Southeast England), 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.

## Historical status

There is 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, which started in the late 1950s and early 1960s, 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.

## Legislation protecting wild 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 which, for the most part, encompass part of single or multiple SMUs: Western Isles (mostly within Western Isles SMU), Northern Isles (within Orkney & North Coast and Shetland SMUs), Moray Firth (within Moray Firth SMU), and East coast (within East Scotland SMU). 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 is now also an offence to 'intentionally or recklessly harass' seals at designated haul-out sites. NERC (through SMRU) provides advice on all licence applications and haul-out designations.

In Northern Ireland it is an offence to intentionally, or recklessly disturb seals at any haul-out 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. This requirement was transposed into UK law and therefore remains post-Brexit. 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?** | Scot Gov Q1<br>Defra Q1a<br>NRW Q1 |
|---|---|

## Status of harbour seals in the UK

**The main method for assessing harbour seal populations, both in the UK and elsewhere, is through aerial surveys of seals on land during their annual moult. In the UK, moult predominantly occurs in August; multiple survey years are required to cover the key harbour seal haul-out sites. The new count data reported for this SCOS are from August moult surveys in 2022 and 2023 (SCOS 24/01). In 2022, helicopter surveys were conducted covering the whole of the Western Isles SMU and part of the West Scotland SMU (mainly central and northern subunits). In 2022 and 2023, surveys carried out using a fixed-wing aircraft covered the Moray Firth SMU, Tay & Eden SAC (East Scotland SMU), and Donna Nook to Scroby Sands (Southeast England SMU; in 2022 the whole SMU was covered). In addition, Southwest England, Wales, and Scottish offshore islands were also surveyed in 2023 (predominantly grey seal haulouts). Harbour seal pup surveys were conducted in 2022 and 2023 in The Wash. In 2023, helicopter surveys covered the rest of West Scotland SMU as well as Southwest Scotland SMUs; the results of these will be reported in SCOS 2025.**

**Based on all surveys, up to and including 2023 where available (Table 1), the current estimate of the UK harbour seal population is 40,525 (95% CI: 33,157-54,033). This is derived from the most recent composite count of 29,178 (based on surveys between 2016 and 2023;** Error! Reference source not found.**), divided by the estimated proportion of the population hauled out during the surveys (0.72; 95% CI: 0.54-0.88). The total population estimate is 34,475 in Scotland, 4,913 in England, 1,136 in Northern Ireland, and less than 10 for Wales.**

**The survey frequency varies by SMU from once every five years to multiple times each survey season. Thus, to examine trends at a national scale, periods of composite counts covering several years are used. The longest time-series is for Britain (i.e. UK excluding Northern Ireland); the current (2016-2023) British harbour seal population is estimated to be around 13% lower than in the late 1990s;16% lower for Scotland due to declines in northern and eastern SMUs, but 8% higher for England, where the population in the late 1990s was still recovering following the 1988 PDV epidemic. Compared to the previous composite count (2011-2015), on both the British and UK scale, the current population is around 6.5% lower (2% and 27% for Scotland and England respectively), largely due to the recent decline in Southeast England.**

**To assess trends on a SMU and SAC scale, counts from individual surveys are used (rather than composite counts) to maximize the use of data available (Figure 2; see SCOS 24/03 for more detail). Southwest Scotland and West Scotland SMU are all showing increasing trends. The current trend (one year) for Western Isles is of a slight decline. The latest count (2022) was the second highest of the time-series, but substantially lower (~450) than the previous count (2017). North Coast & Orkney and East Scotland SMUs are depleted and still declining, whereas Shetland and Moray Firth SMUs are depleted but stable. It should be noted that the latest data for North Coast & Orkney and Shetland SMUs was in 2019. Southeast England SMU is depleted (since 2018) and showing no sign of recovery. Northern Ireland SMU is in continued but slow decline.**

The main method for assessing harbour seal populations, both in the UK and elsewhere, is through aerial surveys of seals on land during their annual moult. However, multiple years are typically required to aerially survey key UK harbour seal haul-out sites, as the available time-window (during August moult) is relatively short. The time series of August moult counts considered here started in the late 1980s. SMRU aerial surveys cover SMUs 1-9 (Scotland and east coast of England) and SMU 14 (Northern Ireland). The staff resource is funded by NERC; the majority of funding for the surveys comes from NERC, NatureScot and the Department of Agriculture, Environment and Rural Affairs (DAERA), Northern Ireland (see Table 2). In addition, key data are also provided by The Industry Nature Conservation Association (INCA; Tees; SMU 8) and Zoological Society of London (Thames; SMU 9). SMUs 1-9 and 14 represent over 99% of the UK harbour seal population (Table 2); less than 100 harbour seals are counted in the other SMUs (Table 2). The length of the mainly rocky coastline around north and west Scotland (SMUs 1-5) means it is not possible to survey the whole coastline every August; SMRU aims to survey this entire coast every five years. Most SMUs are surveyed using combined thermographic, video, and high resolution (HR) still aerial imagery to identify seals along the coastline. However, the sandy habitat of the estuaries of the English and Scottish east coasts means that conventional photography in a fixed-wing aircraft can be used to survey these areas; this is substantially cheaper than helicopter surveys. Where there are indications of significant changes, and resource allows, the survey effort is higher. Indeed, Moray Firth SMU, Firth of Tay & Eden SAC in East Scotland SMU, parts of Southeast England SMU are generally surveyed at least annually by fixed-wing aircraft.

Harbour seals spend a higher proportion of their time on land during the August moult than at other times of the year and thus counts during the moult represent the highest proportion of the population, with the lowest variance. To maximise the consistency of counts, surveys are restricted in both time and environmental conditions; they are carried out within 2 hours either side of low tides that occur between 12:00 and 19:00 during the first three weeks of August, and only in appropriate weather conditions (no heavy or prolonged rain). 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 account for seals not hauled out at the time of the survey and scale the counts to total population size. This estimate of proportion ashore was derived from haul out patterns of 22 adult harbour seals fitted with flipper-mounted ARGOS tags in Scotland (Lonergan *et al.* 2013). The estimated variation in proportion of the population hauled out results in considerable uncertainty in the final population estimates (Table 2). The conversion factor used here is based on a sample from a single year, and two sites. Nevertheless, it is 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 *et al.,* 2001; Ries *et al.,* 1998; Simpkins *et al*., 2003). SCOS has recommended that this conversion factor should be re-investigated when resources allow, to examine regional, sex and age differences as well as potential extension to surveys outside the moult survey window. Although surveys outside the moult would be associated with higher variability in the proportion of the population hauled out, additional logistical flexibility could be beneficial in eras of reduced funding and the potential impact of change in timing of moult on trends could be evaluated.

The new count data reported for this SCOS report are from surveys in 2022 and 2023 (see Table 1; SCOS-BP 24/01 for more details). In 2022, helicopter surveys were conducted in Western Isles and West Scotland SMUs (mainly the central and northern subunits). In 2022 and 2023, fixed wing surveys covered the Moray Firth SMU, Tay & Eden SAC (East Scotland SMU), and Donna Nook to Scroby Sands (Southeast England SMU; in 2022 the whole SMU was covered). In addition, Southwest England, Wales, and Scottish offshore islands were also surveyed in 2023 (predominantly grey seal haulouts). Harbour seal pup surveys were conducted in 2022 and 2023 in The Wash (see SCOS-BP 24/07). Results of the 2023 helicopter survey of the rest of West Scotland SMU (not already covered in 2022) as well as of Southwest Scotland SMU will be reported in 2025.

Based on the latest surveys (Table 1), up to and including 2023 where available, the current best estimate of the UK harbour seal population in 2023 is 40,525 (95% CI: 33,157-54,033). This is derived from the most recent composite count of 29,178 (based on surveys between 2016 and 2023; Table 2), divided by the estimated proportion of the population hauled out during the surveys (0.72; 95% CI: 0.54-0.88). By nation, the total population estimate is 34,475 in Scotland, 4,913 in England, and 1,136 in Northern Ireland, with less than 10 estimated in Wales. The frequency of counts varies by SMU from once every five years to multiple times in a single survey season. Thus, at a national scale, periods of composite counts are used to examine trends, generally representing consecutive 5-year periods. The longest time-series is for Britain (i.e. UK excluding Northern Ireland); the current (2016-2023) British harbour seal population is estimated to be around 13% lower than in the late 1990s;16% lower for Scotland due to declines in northern and eastern SMUs, but 8% higher for England, where the population in the late 1990s was still recovering following the 1988 PDV epidemic. Compared to the previous composite count (2011-2015), on both the British and UK scale, the current population is around 6.5% lower (2% and 27% for Scotland and England respectively), largely due to the recent decline in Southeast England.

*Table 1. Coverage of August surveys conducted and/or reported since SCOS 2022 (last report on counts). Italics indicate areas surveyed annually. Surveys included are those conducted by, or reported to, SMRU.*

| Seal monitoring Unit | | Area surveyed | Survey year | Survey method | Surveyed by | Reporting year |
|---|---|---|---|---|---|---|
| 1 | Southwest Scotland | Entire coastline | 2023 | Helicopter TI | SMRU | SCOS 2025 |
| 2 | West Scotland | Cape Wrath to Loch Hourn | 2022 | Helicopter TI | SMRU | SCOS 2024 |
| | | Loch Hourn to Mull of Kintyre | 2023 | Helicopter TI | SMRU | SCOS 2025 |
| | | Offshore islands (Dubh Artach and Skerryvore) | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 3 | Western Isles | Entire coastline excl. offshore islands | 2022 | Helicopter TI | SMRU | SCOS 2024 |
| | | Offshore islands (Flannan Isles, North Rona & Sula Sgeir) | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 4 | North Coast & Orkney | Offshore islands (Sule Skerry) | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 6 | Moray Firth | *Helmsdale to Findhorn* | 2022, 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 7 | East Scotland | *Firth of Tay and Eden Estuary SAC* | 2022, 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 8 | Northeast England | *Tees Estuary* | 2022, 2023 | Ground counts | INCA | SCOS 2024 |
| 9 | Southeast England | *Donna Nook to Scroby Sands* | 2022, 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| | | *Greater Thames* | 2022 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 10 | South England | *The Solent* | 2022, 2023 | Ground counts | Langstone Harbour Board, Chichester Harbour Conservancy, RSPB | SCOS 2024 |
| 11 | Southwest England | Entire coastline | 2023 | Fixed-wing oblique / ground counts | SMRU, Seal Research Trust | SCOS 2024 |
| 12 | Wales | Entire coastline | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 13 | Northwest England | *South Walney* | 2023 | Ground counts/drone | Cumbria Wildlife Trust | SCOS 2024 |
| 14 | Northern Ireland | Entire coastline | 2024 | Helicopter TI | SMRU | SCOS 2025 |

*Table 2. Composite August counts of harbour seals, and associated estimates of population size (with 95% confidence intervals), by SMU (SCOS-BP 24/01).*

| | | | **Harbour seal counts** | | | | | | | **Latest population estimate** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Seal Monitoring Unit / Country** | | | **1996-1997** | **2000-2006** | **2007-2009** | **2011-2015** | **2016-2019** | **Most recent count data (2016-2023)** | | **mean** | **95% CIs** | |
| 1 | Southwest Scotland | | 929 | 623 | 923 | 1,200 | 1,709 | 1,709 | (2018) | 2,374 | 1,942; | 3,165 |
| 2 | West Scotland | a | 8,811 | 11,666 | 10,626 | 15,184 | 15,600 | 14,189 | (2018; 2022) | 19,707 | 16,124; | 26,276 |
| 3 | Western Isles | | 2,820 | 1,920 | 1,804 | 2,739 | 3,532 | 3,080 | (2022) | 4,278 | 3,500; | 5,704 |
| 4 | North Coast & Orkney | | 8,787 | 4,388 | 2,979 | 1,938 | 1,405 | 1,405 | (2016; 2019) | 1,951 | 1,597; | 2,602 |
| 5 | Shetland | | 5,994 | 3,038 | 3,039 | 3,369 | 3,180 | 3,180 | (2019) | 4,417 | 3,614; | 5,889 |
| 6 | Moray Firth | | 1,409 | 1,028 | 776 | 745 | 1,077 | 983 | (2019; 2021; 2023) | 1,365 | 1,117; | 1,820 |
| 7 | East Scotland | | 764 | 667 | 283 | 224 | 343 | 276 | (2021; 2023) | 383 | 314; | 511 |
| SCOTLAND total | | | 29,514 | 23,330 | 20,430 | 25,399 | 26,846 | 24,822 | (2016; 2018: 2019; 2021-2023) | 34,475 | 28,207; | 45,967 |
| 8 | Northeast England | b | 54 | 62 | 58 | 91 | 79 | 106 | (2020; 2022; 2023) | 147 | 120; | 196 |
| 9 | Southeast England | c | 3,222 | 2,964 | 3,952 | 4,740 | 3,752 | 3,361 | (2022; 2023) | 4,668 | 3,819; | 6,224 |
| 10 | South England | d | 10 | 15 | 15 | 25 | 40 | 65 | (estimate) | 90 | 74; | 120 |
| 11 | Southwest England | d | 0 | 0 | 0 | 0 | 0 | 0 | (2023) | 0 | 0; | 0 |
| 13 | Northwest England | d | 2 | 5 | 5 | 5 | 5 | 5 | (estimate) | 7 | 6; | 9 |
| ENGLAND total | | | 3,288 | 3,046 | 4,030 | 4,861 | 3,876 | 3,5533,557 | (2020; 2022; 2023) | 4,913 | 4,019; | 6,550 |
| WALES | | e | 2 | 5 | 5 | 10 | 10 | 1 | (2023) | 1 | 1; | 2 |
| BRITAIN total | | | 32,804 | 26,381 | 24,465 | 30,270 | 30,732 | 28,360 | (2016; 2018-2023) | 39,389 | 32,227; | 52,519 |
| 14. NORTHERN IRELAND | | f | | 1,176 | 1,101 | 948 | 1,062 | 818 | (2021) | 1,136 | 930; | 1,515 |
| UK total | | | | 27,557 | 25,566 | 31,218 | 31,794 | 29,178 | (2016; 2018-2023) | 40,525 | 33,157; | 54,033 |

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by Nature Scot 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, 2023). 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 a predecessor to the Department of Energy Security & Net Zero. **c** Thames data 2015 and 2019 collected and provided by Zoological Society London (Cox *et al*., 2020). **d** Grey values are 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). **e** For Wales, counts up until 2022 were estimates collated from various sources; the 2023 count was from a SMRU survey covering the whole of Wales. The change in numbers does not indicate a change in abundance. **f** Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002, 2011, 2018, and 2021, and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

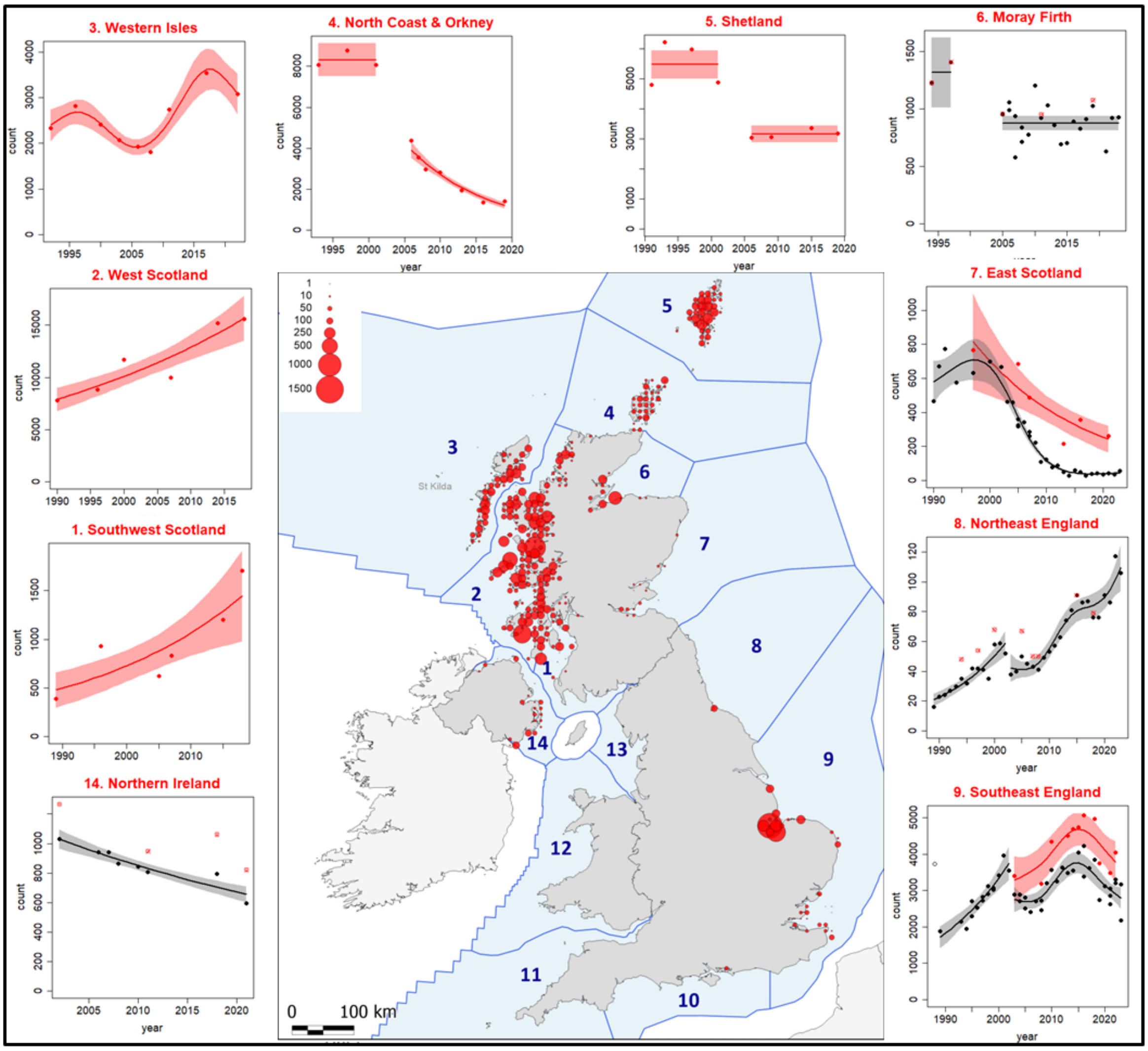


*Figure 2. Map of August haulout density of harbour seals around the UK per 10 km² based on the most recent available count data collected up until 2023 (coastline from GSHHS). Less than 100 harbour seals are in SMUs 10-13. For SMUs 1-9 and 14, the counts by year, and trend lines and associated 95% confidence intervals are shown in red. The black lines indicate the use of a subset of the SMU. For more details see SCOS-BP 24/01 and 24/03. Note the differences in both the x and y-axes across the plots.*

## Trends by Seal Monitoring Unit (SMU)

On a SMU level, to maximise the use of the data available, counts from individual surveys are included in statistical models to generate trends, rather than using multi-year composite counts as described above. These models follow the approach taken in Thompson *et al.* (2019) but include updated 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/SAC: 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 Generalised Additive Model (GAM). See SCOS-BP 24/03 for more details.

Northeast and Southeast England SMU populations have generally shown increasing overall trends, interrupted by sudden, drastic declines in 1988 and 2002 caused by Phocine Distemper Virus (PDV) outbreaks. 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 declines in Shetland and North Coast & Orkney SMUs during multi-year gaps in surveys that spanned 2002, and a sudden change in the count trajectory 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 some SMUs, a subset of the SMU is surveyed more frequently than the SMU as a whole; where these subsets encompass the majority of the SMU abundance, the subsets are modelled as a proxy for the SMU as a whole. This is the case for Helmsdale to Findhorn in the Moray Firth SMU, and Carlingford Lough to Copeland Islands in the Northern Ireland SMU. The Wash SAC has a longer temporal extent than the Southeast SMU as a whole, more frequent surveys, and accounts for the majority of the harbour seals in this SMU.

Southwest Scotland and West Scotland SMU are all showing increasing trends. The current trend (one year) for Western Isles is of a slight decline. The latest count (2022) was the second highest of the time-series, but substantially lower (~450) than the previous count (2017). North Coast & Orkney and East Scotland SMUs are depleted and still declining, whereas Shetland and Moray Firth SMUs are depleted but stable. It should be noted that the latest data for North Coast & Orkney and Shetland SMUs was from 2019. Southeast England SMU is depleted (since 2018) and showing no sign of recovery. Northern Ireland SMU is in continued but slow decline.

*Pup production*

The only harbour seal pup surveys SMRU regularly conduct are of The Wash in Southeast England (SCOS-BP 24/07). These are fixed-wing aerial surveys which have been conducted annually since 2004, except for 2019-2021 when no surveys were conducted (due to Covid restrictions, limited aircraft availability and poor weather conditions). Multiple flights within the season (most recently in 2015 and 2016; Thompson et al. 2016) indicate that the peak number of pups on the sandbanks is in early July. Therefore, in most years, single flights are conducted in early July. The Wash accounts for the majority of harbour seal pup production in the Southeast England SMU. In 2023, the pup count was 1417, compared to 1141 in 2022. Analyses of these annual maximum pup counts suggest a decline since the 2014 peak, but it is not significant (-12%; 95% CIs: -31, 11). However, it should be noted that the mean maximum pup count (2022-2023: 1279 pups) since the drop in the moult count (between 2018 and 2019) is substantially lower (~15%) than the mean maximum number of pups in the 5 years preceding the decline (2014-2018: 1505 pups).

The ratio of pup to moult counts remained high in 2022 and 2023 -- approximately double the ratio in 2001. Under an assumption of negligible seasonal movements (i.e. moult and breeding numbers representing the same population), this ratio can be seen as an index of the productivity of the population. Until recently, the ratio for The Wash was higher than for the much larger Wadden Sea population, indicating that the high ratio may have been a result of seasonal movements between The Wash and Wadden Sea. However, since 2008, the ratio (between pup and moult counts) has also increased in the Wadden Sea population; the increase in the moult counts slowed while pup counts continued to grow. The ratio in The Wash and Wadden Sea are now similar (Galatius *et al.* 2023), and thus seasonal movement cannot explain the relatively high ratio in The Wash.

This apparent high index of the productivity of the population suggests that either the fecundity has increased in both The Wash and Wadden Sea populations or that the proportion of the harbour seal population counted during the moult has changed. The Wash is part of the continental European metapopulation (Carroll *et al.* 2022) but seasonal movements between The Wash and continent have not been observed in tracking data. 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 causes of the observed changes.

### UK harbour seal populations in a European context

The UK harbour seal population represents approximately 30% of the total population of the eastern Atlantic harbour seals (

*Table* 3). Since the early 2000s, the declines in some SMUs in Scotland and coincident dramatic increases in the Wadden Sea (following the 2002 epidemic) meant that the relative proportion of the European population hosted in the UK harbour seal population decreased. Even though the Wadden Sea population looks to be starting to decline (Galatius *et al.* 2023), the magnitude of declines in the Southeast England-SMU since 2018 mean that the relative proportion of the UK population in the greater European context has continued to decrease.

*Table 3. Size and status of European populations of harbour seals. Data are counts of seals hauled out during the moult. Counts are rounded to the nearest 50. They are minimum estimates of population size as they do not account for proportion at sea.*

| Region | Number of seals counted | Most recent survey years | Source |
|---|---|---|---|
| **Scotland** | **24,800** | 2016-2023 | SCOS-BP 24/01 |
| **England** | **3,550** | 2020, 2022, 2023 | SCOS-BP 24/01 |
| **Northern Ireland** | **800** | 2021 | Morris & Duck (2019a) |
| **UK** | **29,200** | 2016-2023 | SCOS-BP 24/01 |
| Ireland | 4,000 | 2017-18 | Morris and Duck (2019b) |
| France | 1,550 | 2023 | Poncet *et al.* (In Press) |
| Wadden Sea - Denmark | 2,250 | 2023 | Galatius *et al.* (2023) |
| Wadden Sea - Germany | 13,650 | 2023 | Galatius *et al.* (2023) |
| Wadden Sea - Netherlands | 6,700 | 2023 | Galatius *et al.* (2023) |
| Delta – Netherlands | 1,550 | 2022-2023 | Hoekstein *et al.* (2023; 2024) |
| Limfjorden | 1,400 | 2023 | ICES 2024 |
| Kattegat | 9,050 | 2023 | ICES 2024 |
| Skagerrak | 4,300 | 2023 | ICES 2024 |
| Baltic – Kalmarsund | 2,500 | 2023 | ICES 2024 |
| Baltic – Southwestern | 1,650 | 2023 | ICES 2024 |
| Norway | 7,900 | 2009-2010, 2016-2023 | Nilssen (2021), ICES (2024) |
| Svalbard | 1,900 | 2010 | Merkel *et al.* (2013) |
| Iceland | 10,300 | 2020 | Granquist (2022) |
| **Europe excluding UK** | **68,700** | | |
| **Europe – total** | **97,850** | | |

## Status of grey seals in the UK

**UK grey seal abundance and trends are primarily assessed through a combination of pup production estimates and August haulout counts. Pup production from aerially-surveyed colonies is estimated by combining count data from 4 to 5 surveys with life history and observation parameters. Estimates for Shetland, Southwest England, Wales, and Northwest England are generally from boat-/ground-surveys. Pup production estimates from SMRU 2021/2022 surveys, combined with estimates from other colonies (surveyed by others or SMRU in previous years), indicated that the total number of pups born across all UK colonies was 75,947 (Table 3): 54,974 in Scotland, 17,973 in England, 2,500 in Wales, and 500 in Northern Ireland. This represents approximately 34% of the global grey seal pup production (Table 4).**

**For SCOS 2024, a single time series is presented for eastern England SMUs that incorporates ground- and aerial-based (from 2018) pup production estimates (SCOS-BP 24/08). In Scotland, change in aerial survey methodology, i.e. a move from conventional film (up to 2010) to (higher-resolution) digital photography (from 2012 onwards), was associated with a ~22.5% step-wise increase in pup counts (SCOS-BP 24/03). To assess how the change in survey methodology might have affected the population model, three versions of the time-series of pup production were generated for these SMUs for input into the population model (SCOS-BP 24/05): (1) a mix of film and digital estimates ('uncorrected' estimates); (2) all digital estimates scaled down to the level of film estimates ('low' estimates); and (3) all film estimates scaled up to digital level ('high' estimates). Although the true value of pup production likely sits between the low and high level, ground comparisons indicate that the high (i.e. digital) level is likely nearer the truth.The total UK grey seal population at the start of the 2023 breeding season (before pups are born) is estimated via a Bayesian population dynamics model at 168,400 (approximate 95% CI: 149,500 - 187,700) for the uncorrected time-series; 166,900 (95% CI: 137,900 – 196,400) for the 'low' estimates, and 169,500 (95% CI: 143,500 – 198,200) for the 'high' estimates. In addition to the time series of pup production estimates, the model also incorporates three estimates of population size from August haulout counts. These estimates of total population size are lower than estimates derived from pup production alone and have a strong influence on the population model, essentially reducing the difference between the population estimates based on the three different versions of the pup production time-series.**

**The total UK grey seal population model does not produce a good fit to pup production estimates for West Scotland or the Western Isles; the model assumes a static regional carrying capacity but production in these SMUs is increasing after a sustained period at presumed carrying capacity. Furthermore, the model is not able to keep up with the rapid increase in the North Sea, where the rapid increase in pup production is very likely, in part, driven by recruitment from Orkney (such movement is not incorporated into the model). Substantial work would be required to modify the model to appropriately handle the observed changes in pup production.**

**The current population growth rate, based on the population model is estimated to be ~1.5% (0.7% for both the low and high corrected pup production data series). Trends at an SMU level focus on pup production data (accounting for the change in film to digital methods). Pup production is concentrated at a limited number of colonies. While pup production time-series provide the main index of the UK population changes, August counts are also critical. Distribution during the foraging season (represented by August counts) indicate where adults acquire the resources necessary for pup production. The foraging season is also when seals are most at risk from threats at sea (e.g. bycatch), and thus consistent August counts are required for robust Potential Biological Removal estimates. Moreover, August counts, scaled using proportion of grey seals hauled out during the aerial survey window (from telemetry data), provide estimates of total**

**population that are independent from pup production; these feed into the population model. . It should be noted that the high variability around the proportion of the population hauled out in August means the power to detect trends is relatively low in SMUs that are not monitored annually.**

**After a long period of stability, pup production in West Scotland and Western Isles has increased to the highest level since surveys began. In Southwest Scotland (where very few pups are born annually) and West Scotland, summer abundance is also increasing. In contrast, August counts in the Western Isles are variable, without any apparent trend. Pup production and August counts in North Coast and Orkney are both stable since early 2000s. For Shetland, while there is an indication of a decline in pup production, the August count (latest count 2019) shows no trend. Production in all east coast SMUs (Moray Firth, East Scotland, Northeast England, Southeast England) continues to increase. August counts are stable for the Moray Firth and East Scotland, but increasing in eastern England. Limited data are available to quantify trends in other SMUs. In Southwest England, Wales, and Northern Ireland, there are indications that pup production is either stable or increasing. August haul-out counts in Northern Ireland appear stable at a time-series high.**

*Pup Production*

UK grey seal abundance and trends are primarily assessed based on pup production estimates, though numbers counted during August are also considered and included in the population model. The temporal extent of the grey seal breeding season means that any one pup count represents an unknown proportion of the number of pups produced. Thus, SMRU conduct multiple aerial surveys through a season (usually 4 or 5), and pups are classified as either ‘whitecoat’ or ‘moulted’. Pup production from aerial-surveyed colonies is estimated by combining count data with life history and observation parameters (see Russell *et al.* (2019) for details). Estimates for Shetland, Wales, Northwest England, and Southwest England are, for the most part, from boat-/ground-surveys.

For most SMUs, the time-series of pup production estimates began in 1984. Up until 2010, these surveys were conducted annually at regularly monitored colonies in Scotland. However, from 2012, the surveys were conducted biennially. With the recent inclusion of eastern England (see below), major grey seal colonies in Scotland and on the east coast of England (Figure 3) are now currently surveyed every two to three years. The most recent available production estimates are from surveys carried out in 2021 for the UK North Sea region (here East Scotland, Northeast England and Southeast England SMUs), and from 2022 for the other key SMUs surveyed (West Scotland, Western Isles, North Coast & Orkney, and Moray Firth). The results of these surveys are summarised below and covered in detail in SCOS-BP 24/02. SCOS-BP 24/02 also provides pup production estimates for the time-series as a whole and it should be noted that estimates from 2019 have been updated from previous SCOS reports (SCOS-BP 21/01, SCOS-BP 22/03). In 2023, surveys of the UK North Sea region were conducted. The extensive data collected in these surveys are currently being analysed, and updated figures based on these surveys will be provided in the 2025 SCOS report.

Pup production estimates from the SMRU 2021/2022 surveys, combined with estimates from other colonies (surveyed by others, or by SMRU in previous years), indicated that the total number of pups born across all UK colonies was approximately 75,947 (Table 3); 54,974 in Scotland, 17,973 in England, 2500 in Wales, and 500 in Northern Ireland.

Trends in pup production are assessed on a SMU scale (SMUs 2-4, 7-9) using generalised linear or additive models (as described in Russell *et al.* 2019). However, interpretation of the trends in pup production over the entire time-series is complicated by a change in survey methodology from film to digital aerial surveys for most Scottish SMUs (from 2012) and from ground to aerial surveys for eastern England (from 2018). For logistical and technical reasons, it was not possible to directly cross-calibrate the film and digital aerial surveys. In all SMUs where the pup production time-series is entirely derived from aerial survey counts, there was an apparent jump in observed production coinciding with the change in methods. To account for this, a step increase in pup production was offered between 2010 (the last film survey) and 2012 (the first digital survey). To maximise the data available to fit this step, all applicable SMUs (2-4, 7) 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. The final model estimating trends in grey seal pup production for aerially surveyed SMUs included an estimated 22.5% jump (95% CI: 14.3, 30.7) in pup production associated with the change from film to digital. This analysis allowed an examination of the trends in pup production, between 1984 and 2023, robust to the change in methods. It is likely that the true pup production lies between the low (film) and high (digital) estimate. However, recent comparison with ground-based pup production estimates (see below), indicates that true pup production is most likely nearer to the estimates associated with digital (compared to film) based estimates. Trends in Moray Firth (with the above step change applied) and for Shetland (ground-surveyed) were also quantified. The map of the SMU boundaries and the distribution of grey seal pups born within them is presented in Figure 3. The trend analyses and results are summarised at the end of this answer (see SCOS-BP 24/03 for more details).

Pup production estimates at grey seal colonies in Northeast (NEE; Farne Islands) and Southeast England (SEE; Donna Nook, Blakeney and Horsey) SMUs have traditionally been generated from ground surveys (National Trust, Lincolnshire Wildlife Trust, and Friends of Horsey Seals). The increasing size of the colonies has made counting increasingly labour intensive, and in some cases, counting is hindered by risk of disturbance and safety concerns for counters. SMRU conducted a single aerial survey in 2014 and a first full set in 2018. These aerial surveys indicated that, at least in some colonies, ground surveys were likely underestimating production. As a result of (1) preliminary comparison of the 2018 ground and aerial survey data; (2) the increasing proportion of the UK population in eastern England; and (3) the cessation of ground-based pup production estimation for the Farne Islands and Blakeney, the eastern England SMUs were incorporated into the SMRU aerial survey programme with surveys conducted in 2021 and 2023. Due to limited capacity and resource, the inclusion of eastern England has resulted in lower frequency of surveys for most of Scotland (from biennial to triennial) but it is possible that drone surveys may eventually replace the aerial surveys in eastern England.

Comparisons (detailed in SCOS-BP 24/08) between ground and aerial data (2014, 2018, 2021) indicated that for SEE-SMU, the ground counts, and likely the associated pup production estimates, were underestimates. For the Farne Islands, Blakeney and Horsey, ground-based production estimates, for comparison with aerial-based, were only available for 2018. For the Farne Islands, although the aerial counts were generally higher than the ground counts, the pup production estimates were more similar; ground-based estimates for the Farne Islands are based on numbers sprayed with dye rather than repeated pup counts.

Based on the findings, the ground- and aerial-based production estimates were integrated into a time-series in a colony-specific way. For the Farne islands and Horsey, the aerial-based production estimates were used to continue the time-series of ground-based estimates. For Donna Nook, a scalar (~25%) was derived to increase the ground-based estimates in line with the aerial. For Blakeney, ground-based production estimates up to 2014, and aerial-based estimates in 2018 and 2021, were used to generate a time-series.

*Table 3. Most recent pup production estimates for UK Seal Monitoring Units (SMU) and subdivisions, along with the percentage of pup production considered in the UK population model. Note that the values for other colonies are approximate. All estimates for colonies used in the population model are newly reported for this SCOS. For more details see SCOS-BP 24/02. Note that the population estimates from the population model are scaled up to UK population estimates.*

| | | Pup production (with year counted) | | | | | |
|---|---|---|---|---|---|---|---|
| **Seal Monitoring Unit (subdivision)** | | **Colonies used in population model** | | **Other colonies** | | **Total** | **% production included in UK population model** |
| 1 SW Scotland | | 0 | | 5 | (2020) | 5 | |
| 2a W Scotland - South | | 4,893 | (2022) | 50 | (2005-2010) | 4,943 | |
| 2b W Scotland - Central | | 0 | | 365 | (2005-2019) | 365 | |
| 2c W Scotland - North | | 0 | | 40 | (2009-2010) | 40 | |
| 3 Western Isles | | 18,272 | (2022) | 300 | (2008) | 18,572 | |
| 4a North Coast | | 0 | | 635 | (2019) | 635 | |
| 4b Orkney | | 20,506 | (2022) | 20 | (2010-2019) | 20,526 | |
| 5 Shetland | | 0 | | 760 | (2012) | 760 | |
| 6 Moray Firth | | 0 | | 1,715 | (2022) | 1,715 | |
| 7 E Scotland | | 7,378 | (2021) | 35 | (2019-2023) | 7,413 | |
| SCOTLAND TOTAL | | 51,049 | | 3,925 | | 54,974 | 92.9% |
| 8 NE England | | 3,198 | (2021) | 40 | (2016-2018) | 3,238 | |
| 9 SE England | | 14,125 | (2021) | 140 | (2023) | 14,265 | |
| 10 S England | a | 0 | | 10 | | 10 | |
| 11 SW England | b | 0 | | 450 | (2016-2023) | 450 | |
| 13 NW England | c | 0 | | 10 | (2023) | 10 | |
| ENGLAND TOTAL | | 17,323 | | 650 | | 17,973 | 96.4% |
| 12 WALES | d | 0 | | 2,500 | (1994 - 2023) | 2,500 | 0.0% |
| 14 NORTHERN IRELAND | e | 0 | | 500 | (2001- 2020) | 500 | 0.0% |
| UK TOTAL | | 68,372 | | 7,575 | | 75,947 | 90.0% |

SOURCES – Unless otherwise indicated most production estimates were derived from aerial surveys conducted by SMRU and were funded by the Natural Environment Research Council (NERC). **a-e** are estimates generated by SMRU on the basis of the resources listed below. **a** Chichester Harbour Conservancy, **b** Sayer & Witt (2017a&b), Sayer *et al.* (2020), Lundy Field Society (2023), **c** Cumbria Wildlife Trust, **d** Natural Resources Wales, Wildlife Trust of South and West Wales, Pembrokeshire Coast National Park Authority, Royal Society for the Protection of Birds. Baines *et al.* (1995); Robinson *et al.* (2020), Stephens (2023), Büche & Bond (2023), **e** Northern Ireland Department of Agriculture, Environment and Rural Affairs.

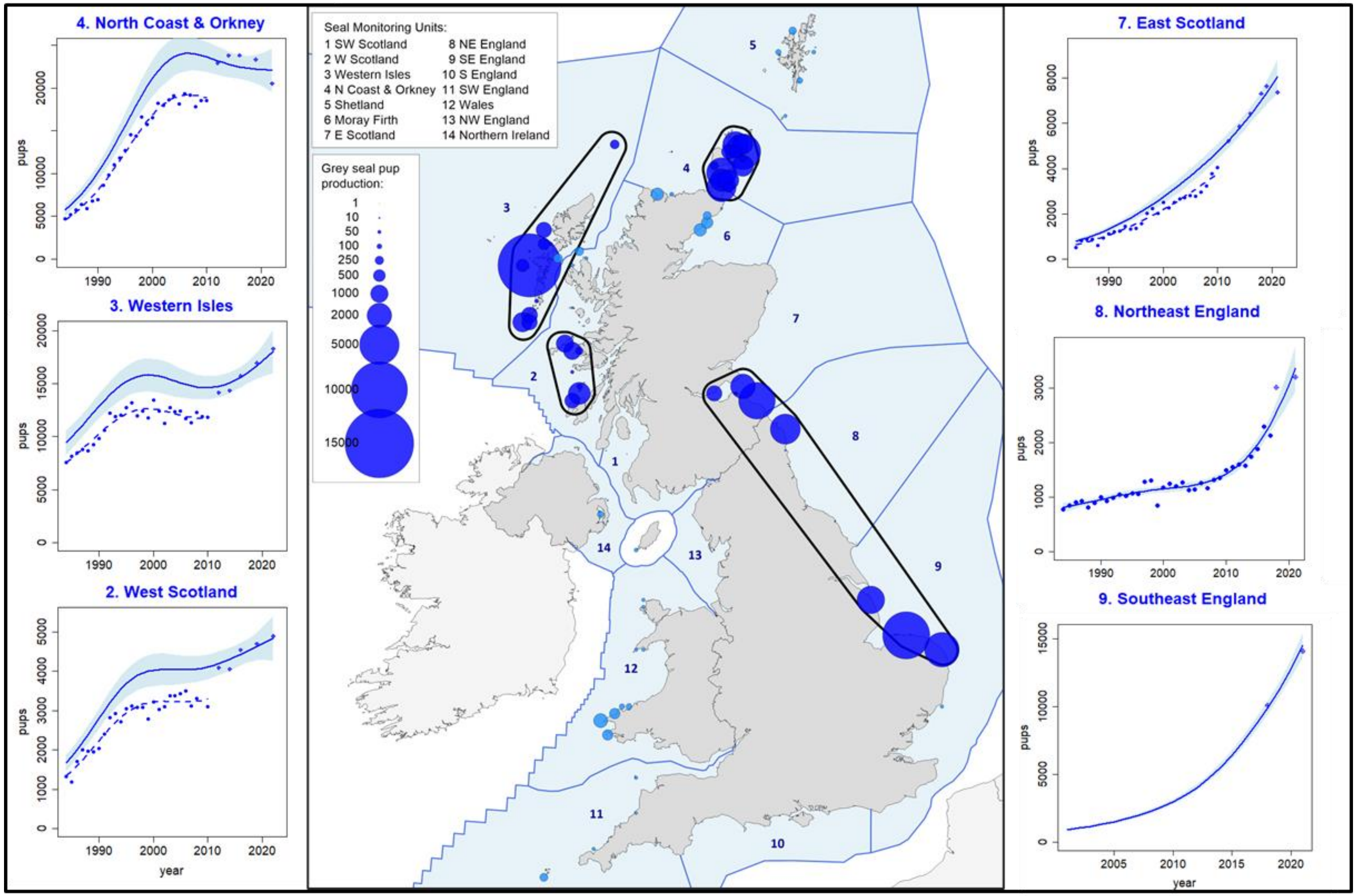


*Figure 3. Distribution and estimated pup production of key UK grey seal breeding colonies; dark blue circles represent colonies included in trend and population analyses. Black polygons indicate regional groups for population model and SMU boundaries are shown in blue. P up production estimates by year, and predicted trend and associated 95% confidence intervals, are shown (dotted lines in Scottish SMU plots are film-derived estimates – 22.5% lower than digital-derived estimates). Note the differences in both the x and y-axes.*

**August Counts**

Grey seals are also surveyed during SMRU August surveys (SMUs 1-9). In 2023, SMRU also conducted a survey of Southwest England and Wales (funded by NRW and JNCC, respectively). This was to provide as near to possible a synoptic count for these SMUs to incorporate with the counts from the other SMUs. It should be noted that the proportion of grey seals hauled out in August is relatively low (compared to harbour seals, which are moulting at that time of year), and is also more variable. Indeed, based on telemetry data, it is estimated that 25.15% (95% CI: 21.45-29.07%) of the population is hauled out during the specific survey window and thus available to be counted (Russell & Carter 2021, updated from Lonergan *et al.* 2011). 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, but it is recognised there is relatively low power (sample size of 60 individuals).

While pup production time-series provide the main index of the UK population changes, August counts are also critical. Distribution during the foraging season (represented by August counts) indicate where adults acquire the resources necessary for pup production. The foraging season is also when seals are most at risk from threats at sea (e.g. bycatch), and thus consistent August counts are required for robust Potential Biological Removal estimates. Moreover, August counts, scaled using proportion of grey seals hauled out during the aerial survey window (from telemetry data), provide estimates of total population that are independent from pup production; these feed into the population model.

The total composite count for grey seals around the UK (mainly from 2016-2023) is 39,000 (see SCOS-BP 24/02 for more details); a total population of c. 158,650 (95% CIs: 137,250, 186,000). The trends in August counts are presented in SCOS-BP 24/03 and briefly summarized at the end of this answer. It should be noted that the high variability around the proportion of the population hauled out in August means the power to detect trends is relatively low in SMUs that are not monitored annually.

## Grey seal population model

The total grey seal population (1+ aged population, referred to as 'adult population') is estimated within a Bayesian state-space population dynamics model (Thomas *et al.* 2019; Figure 4) using a time-series of pup production estimates (1984-2022) from regularly monitored colonies in West Scotland, Western Isles, North Coast & Orkney, East Scotland, Northeast England and Southeast England SMUs; ~90% of UK pup production (Figure 3). The model also uses three estimates of population size from scaled up August counts from years surrounding 2008, 2014 and 2017. These estimates are from composite counts and adjusted to represent the proportion of pup production in SMUs 1-9 included in the model. The model incorporates prior estimates of fecundity rates, survival rates (pup and 1+) and sex ratio.

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 North Sea is made up of East Scotland, Northeast England, and Southeast England SMUs.

The population model has been modified through the years to test the impact of differing priors on demographic parameters (see SCOS 2022 for more information). Work on updating these priors is continuing and information is reviewed annually (SCOS-BP 24/04). The model allows density dependence in pup survival (but not in adult female fecundity) and includes the summer estimates for 2008, 2014 and 2017 (details of this analysis and posterior estimates of the demographic parameters are given in SCOS-BP 24/05). The inclusion of the summer estimates of population size indicated that density dependence was acting through density dependent pup survival rather than fecundity.

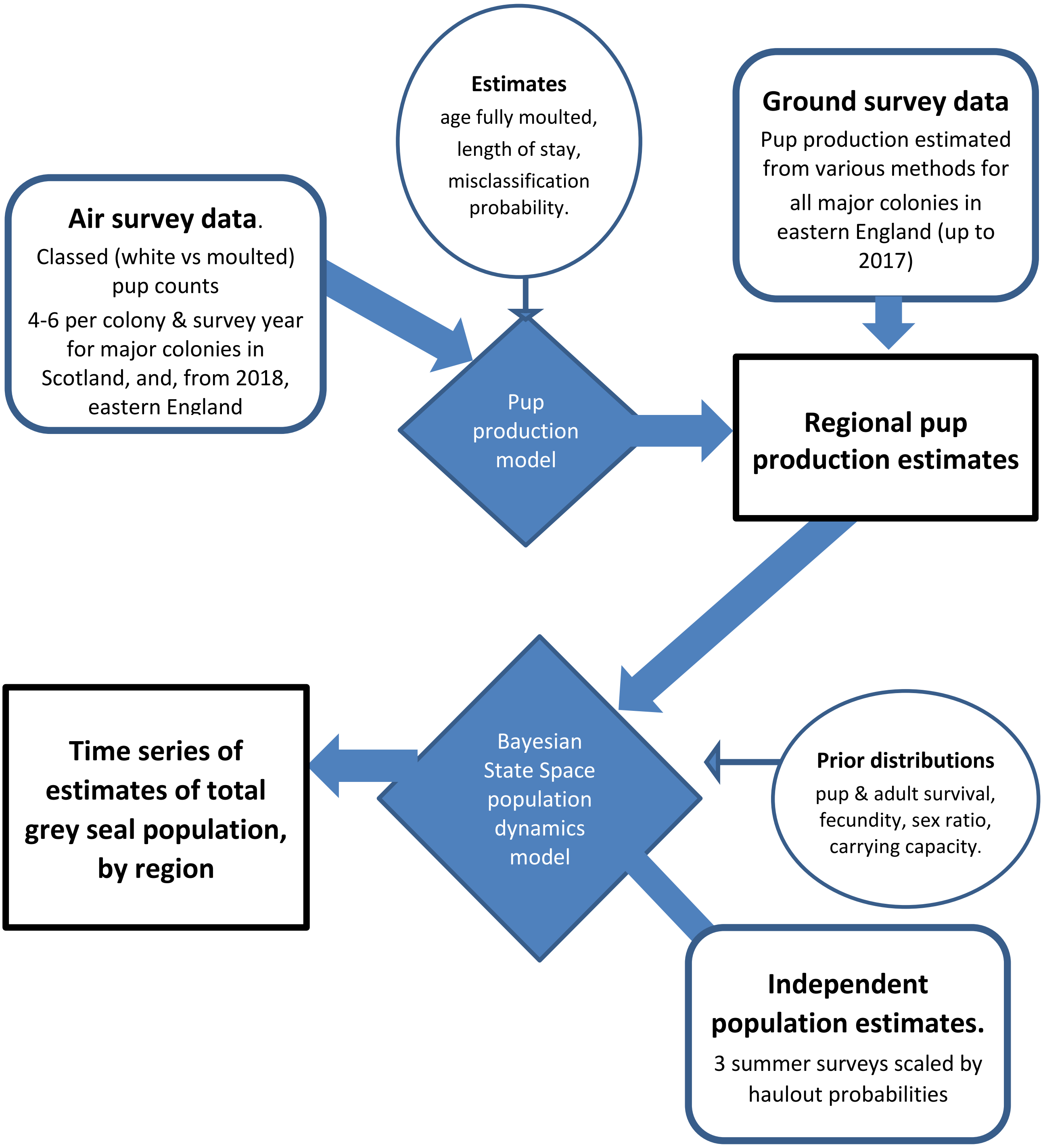


*Figure 4. Schematic diagram of steps involved in estimating total grey seal population size within the population model.*

In previous SCOS reports, the pup production values input into the population model have been a mix of film and digital surveys for Scotland (hereafter uncorrected), and for England has been based on ground-based estimates. From SCOS 2024, the Northeast and Southeast England estimates (which combined with East Scotland SMU represent the North Sea region) are a single time-series based on both ground- and aerial-based estimates (see above and SCOS-BP 24/08). In addition, the population model was also run with adjusted values for the Scottish SMUs: all estimates adjusted to be in line with the film surveys (low level; i.e. digital-based estimates were divided by 1.225), and to be in line with the digital surveys (high level; i.e. film-based estimates were multiplied by 1.225). A current SMRU PhD project aims to increase the robustness of pup production estimates.

There were three runs of the population model (see above). The uncorrected pup production time-series is the data stream used for Scottish colonies in previous SCOS reports. The results based on high and low level pup production time-series essentially provide an upper and lower population estimate, respectively. The true pup production estimate, and thus the resulting population estimate, likely sits between these levels. The indications from the ground comparisons are that the high level time-series is likely closer to the true pup production than the low time-series.

From the standard model run (uncorrected time-series), the estimated adult population size (here taken to mean the total 1+ age population) in the regularly aerially monitored colonies at the start of the 2023 breeding season was 151,400 (approximate 95% CI 134,400 – 168,700), compared to 150,000 (124,000 – 176,600) for low level and 152,400 (129,000 – 178,200) for the high level. Combining these aerially monitored sites with the estimate for other sites (Table 3) gives an estimated 2023 UK grey seal population of 168,400 (approximate 95% CI 149,500 - 187,700) for the uncorrected time-series; 166,900 (137,900 – 196,400) for the low, and 169,500 (143,500 – 198,200) for the high. The influence of these August estimates essentially minimises the difference between the population estimates based on the three different pup production time-series. In absence of the August estimates, the estimate from the 'high run' should be around 22.5% higher than that of the 'low' run.

The fit of the model to the pup production estimates has been poor in some regions in recent years (SCOS 2022). 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. This year, fit issues have been exacerbated by the apparent increase in pup production in West Scotland and Western Isles SMUs after a sustained period at presumed carrying capacity (SCOS-BP 24/03). The population dynamics model assumes a single carrying capacity for each region, and thus is unable to replicate the observed trends. Substantial work would be required for the model to be altered to encompass a second carrying capacity for each region. Furthermore, the model is not able to keep up with the rapid increase in the North Sea. Increasing the prior on North Sea carrying capacity will likely help with this mismatch. However, the rapid increase in pup production is very likely, in part, driven by recruitment from Orkney, which reached carrying capacity in the early 2000s (such movement is not incorporated into the model). Indeed, the rate of increase in pup production in the North Sea region (East Scotland, Northeast England and Southeast England SMUs) is higher than the intrinsic growth rate of pinnipeds (~12%).

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 and 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. A revised pup production model is being developed with the aim of re-estimating pup production for the entire aerial-based time-series.

## Trends

The population model outputs indicate that the population is currently (2022-2023) increasing at ~1.5% p.a. (<1% for both low and high). A corollary of the mechanism of density dependence being through 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. As such, trends on an SMU level are focussed on the pup production data, and the outputs of the trend analyses which explicitly account for the change in methods. Monitoring of pup production is focussed on a limited number of colonies and, once recruited, females often return to the same colony to breed year after year. Although this makes the pup production time-series incredibly useful for looking at change, the summer distribution, and changes therein, are also an important consideration as this represents where the UK population acquire the resources for pup production. It should be noted though that the power to detect trends is relatively low for the August counts, especially in SMUs that are not monitored annually.

Pup production in West Scotland and Western Isles is at an all-time high after a recent period of rapid increase following a long period of stability. In Southwest Scotland (where very few pups are born), and in West Scotland summer abundance is also increasing. In contrast, August counts in the Western Isles are variable but show no apparent trend. Pup production and August counts in North Coast and Orkney have remained stable since early 2000s. For Shetland, the August counts show no trend; there is an indication of a decline in pup production in Shetland. Production in all east coast SMUs (Moray Firth, East Scotland, Northeast England, Southeast England) is continuing to increase. However, the August counts are stable for the Moray Firth and East Scotland, but increasing in eastern England. Limited data are available to quantify trends in other SMUs. In Northern Ireland, August counts appear stable at a historic high. In Southwest England, Wales, and Northern Ireland, there are indications that pup production is either stable or increasing.

## 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). Pup production estimates are used as indices of population size because they represent a directly observable/countable section of the population and are available for much of the range.

*Table 4. Relative sizes and status of grey seal populations using estimated pup production (to nearest 50) as an index of population size.*

| Region | Pup Production | Year | Trend | Source |
|---|---|---|---|---|
| UK | 75,950 | 2021/2022 | Increasing | SCOS 2024 |
| Isle of Man | 100 | 2023 | Increasing | Manx Wildlife Trust (2023) |
| Ireland | 2,100 | 2012 | Increasing | SCOS 2024 |
| Wadden Sea | 1,950 | 2022-2023 | Increasing | Schop *et al.* (2023) |
| Dutch Delta | 50 | 2021-2022 | Increasing | Hoekstein *et al.* (2023) |
| France | 100 | 2023 | increasing | Poncet *et al.* (In press) |
| Norway | 650 | 2021-2023 | Possibly declining | ICES 2024 |
| Russia | 800 | 1994 | Unknown | Ziryanov and Mishin (2007) |
| Iceland | 1,450 | 2017 | Declining | Granquist and Hauksson (2019) |
| Baltic | 16,850 | 2020 | Increasing | HELCOM* |
| Europe excluding UK | 24,050 | | | |
| Canada - Sable Island | 98,200 | 2021 | Increasing | Hammill *et al.* (2023) |
| Canada - Gulf of St Lawrence & eastern Canada | 16,900 | 2021 | Increasing | den Heyer *et al.* (2024) |
| USA | 6,250 | 2019 | Increasing | Wood *et al.* (2019) |
| WORLD TOTAL | 221,350 | | Increasing | |

* Monitoring in the Baltic (HELCOM) is based on moult counts. In Estonia, as well as moult counts, pup production is also estimated. Here the ratio of pups to moult counts for Estonia in 2022 (5,587 moult count: 2,049 pups) was used to scale the Baltic moult count down to pup production. As such, it is assumed a similar proportion of grey seals in the Baltic breed and moult in Estonia.

| 2. **What is the population estimate for grey seals and harbour seals in Wales and Southwest England regions as a result of the summer 2023 aerial survey of hauled out seals and how does this compare to estimates of population size derived from pup counts (pup production)?** | NRW Q2 |
|---|---|

**Surveys in August 2023 produced counts of 1313 grey seals hauled out in the Wales SMU, 756 in the Southwest England SMU and 26 in the west of the South England SMU. These equate to summer population estimates of 5284 (95% CI: 4571-6195) in Wales and 3006 (95% CI: 2600-3524) in Southwest England SMUs. The 2023 counts were 64% and 17% higher than previous estimates for Wales and SW England respectively.**

**The estimated summer population in Wales is similar to the estimated 1+population based on pup production at Welsh colonies. However, in Southwest England the estimated summer population is approximately three times the 1+ population based on pup production. This suggests large scale seasonal migration into the SMU in summer.**

SCOS has previously recommended that a summer census of grey seals be carried out in the Wales and Southwest England SMUs to provide independent estimates of grey seal summer populations. In 2023 NRW and JNCC provided funding for a synoptic census of the summer population of grey seals (*Halichoerus grypus*) in the Wales and the Southwest England SMUs to provide a fuller understanding of grey seal distribution and abundance in the region and enable appropriate management targets in line with the other UK SMUs, to facilitate informed permitting of activities with potential impacts on grey seals.

In August 2023, SMRU carried out a survey of the coast of Southwest England and Wales from Exeter to Hilbre Island in the Dee estuary. Survey methods were the same as used in harbour seal moult surveys (see Thompson *et al*., 2019; SCOS-BP 24/01) on the east coast. Surveys were carried out between the 4$^{th}$ and 13$^{th}$ August, using a fixed-wing aircraft and oblique aerial photography, during time windows of 2 hr before to 2 hrs after local low tide.

A total of 1313 grey seals and one harbour seal (*Phoca vitulina*) were photographed and counted at 58 separate haul-out sites in the Wales SMU (SCOS-BP 24/01, Thompson 2025a). Most seals (935, equivalent to 70% of the total) were found along the North Wales coast between Ynys Tudwal off the Llŷn peninsula and the Dee estuary, and the remaining 30% were concentrated along the Pembrokeshire coast from Caldey Island (near Tenby) to Cardigan. One adult harbour seal was seen on the periphery of a large group of grey seals on Ynys Tudwal.

A total of 756 grey seals were photographed and counted at 41 separate haul out sites in the Southwest England SMU (SCOS-BP 24/01, Thompson 2025b). Most seals (397, equivalent to 53% of the total) were found on uninhabited offshore skerries in the Isles of Scilly, 75 seals were recorded at Lundy Island, and the remaining 284 seals were recorded around the coast of mainland Cornwall (241) and Devon (42). A total of 26 grey seals were counted at two sites in the South England SMU (Start Point and Mew Stone).

Based on simultaneous ground counts of a small sample of mainland sites in west Cornwall (Thompson, 2025b), the air survey missed approximately half of the seals hauled out in coves. However, as a large majority of seals in both SMUs were on easily observable sites, on offshore skerries and open rock platforms the undercounting is estimated to have reduced the overall survey count by approximately 10% (Thompson 2025a,b). The counts therefore represent a minimum estimate of the number of grey seals hauled out around the Wales and Southwest England SMUs in August 2023.

Grey seals have their pups in caves on the Southwest England and Wales coasts, and incidental observations indicate that some haul out in caves during the spring and summer. Those seals would not be available to be counted by aerial surveys. There are no data to allow an estimate of the numbers of seals hauled out in caves during August. However, counts in Wales and Cornwall (e.g. Strong et al. 2005; Sayer et al., 2016, 2019a,b) suggest that use of caves for pupping usually begins in the latter half of August and there may have been few seals at those sites at the times of the aerial surveys. In the absence of independent information on cave use in August there is potential that a number of seals could have been missed by the aerial survey.

The total count of 1313 hauled out seals in Wales and 756 in Southwest England SMUs can be used to generate estimates of the total population of grey seals during the summer. Based on data from high resolution telemetry tracking devices fitted to 60 grey seals caught at sites around the UK, it is estimated that 25.15% (95% CI: 21.45-29.07%) of the total population will be hauled out and available to be counted (SCOS-BP 21/02) during the surveys. Applying this correction factor to the 2023 survey counts produces total summer population estimates of 5284 (95% CI: 4571-6195) in Wales and 2900 (95% CI: 2510-3400) in Southwest England.

This is likely to be an under-estimate given the inability to count seals in caves and the known under-counting of seals in small coves and gullies, and it should be regarded as an absolute minimum number of seals associated haul-out sites during the summer in the Wales and Southwest England SMUs.

**Comparison to population estimated from pup production**

These figures can be compared with an alternative population estimate, referred to as the 1+population, that is derived from a population dynamics model fitted to a long time series of grey seal pup production estimates (Thomas *et al*., 2019; SCOS-BP 24/05). It represents the number of seals alive on the first day of the pupping season and will include all the surviving pups from the previous breeding season. This will be very close to the August population, differing only by the small number of the surviving pups from the previous breeding season that die between August and the start of the next breeding season.

The most recent composite pup production estimate for Wales is 2250 pups (see SCOS -BP 20/04 for derivation). This number is based on data from recent surveys at a small number of regularly monitored sites, combined with estimates from other colonies that have not been surveyed for >20 years which have been scaled by assumed rates of increase. The confidence in the pup production estimate is therefore low. However, notwithstanding these caveats, scaling this pup production by the ratio of pup production to total 1+ population at regularly monitored colonies around Scotland and eastern England (1 : 2.31), produces a 1+ population of 5,200 grey seals in Wales, which is very close to the total population estimate from scaled up 2023 summer air survey counts.

The most recent pup production estimate for the Southwest England SMU is 450 pups (see SCOSBP 20/04 for derivation) which produces a 1+ population of 1040, which is only around a third of the total population estimate from scaled up 2023 summer air survey counts.

The disparity between the summer estimate and the pup production derived 1+ population estimate in the Southwest England SMU suggests that a large proportion of the seals at haul-out sites in the Southwest during the summer do not breed in the SMU. Similar patterns have been observed in the much larger seal populations around Scotland. For example, Russell *et al*. (2013) showed that a significant proportion of female grey seals that forage in Northern Scotland do not breed there. This large-scale redistribution between breeding and foraging regions is the primary reason for using summer survey data to set PBRs for individual SMUs.

The apparent temporary immigration into the Southwest England SMU should be taken into account when calculating the independent grey seal population estimate used in fitting the population dynamics model to the pup production time series (SCOS-BP 24/05). The utility of that estimate relies on the assumption that the ratio of pup production to summer population is the same in the regions included in the grey seal population as in regions not included. Although the number of seals in the Southwest England SMU is relatively small, any such seasonal migration will have an effect on the independent population estimate.

**Comparison with previous counts**

These aerial survey counts represent the first synoptic census of the summer populations in both SMUs, so it is not possible to produce robust trend estimates. However, previous estimates compiled from systematic surveys of sub-sections of the populations and surveys conducted at different times of year have been used in previous assessments (for details see SCOS-BP 20/04).

The count in the Wales SMU was approximately 64% higher than the previously used summer estimate obtained by combining local area counts collected at different times (Russell & Morris, 2020). Westcott and Stringell (2004) presented a series of ground counts of the grey seal haul-out and breeding sites along the North Wales coastline during 2002 where many of the sites were visited in August. Although methodologies differed, e.g. ground versus aerial surveys with the inclusion of some cryptic sites and caves in the 2002 ground surveys, it is clear that the numbers of grey seals hauling out in North Wales in August has increased substantially since 2002; overall, 65% more seals were counted at these sites in 2023 than in 2002 (Thompson, 2025b). If the apparent change is representative, it would equate to an annual rate of increase of 2.4% p.a. since 2002.

The count in the Southwest England SMU was approximately 17% higher than the most recent previous summer estimate of 625 compiled from counts at a subset of regularly monitored sites, and from a synoptic boat survey carried out during the grey seal moult in 2007. The lack of a previous, synoptic August count makes it difficult to estimate trends. However, the previous estimate was strongly influenced by the 2007 moult count, and the proportion of the grey seal population hauled out during the annual moult is expected to be higher than during the summer foraging season. So, comparing a summer count to an earlier moult count would be likely to under-estimate any change, suggesting that the 17% higher count in 2023 probably indicates that the summer grey seal population in the Southwest England SMU has increased since 2007.

# Seal population structure

| | |
|---|---|
| **3. 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?** | Defra Q2 |
| **Can SCOS advise on whether there have been any changes to the population structure, including survival, reproduction and age structure, of grey and harbour seals in European and Scottish waters since advice provided in SCOS 2022?** | Scot Gov 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. These are updated from previous estimates presented in SCOS (2022). 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 2022 SCOS report. Other than a pre-print describing a study of grey seal population genetics, there do not appear to be any new studies of population structure, mortality, age or sex structure, or carrying capacity for UK grey seals. For information the 2022 answer to these questions is included with minor additions.

## 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 published estimates for UK harbour seals are only currently available from one long term study at Loch Fleet in northeast Scotland. Preliminary estimates from recent photo ID studies in Orkney and western Scotland are presented here.**

**Indices of fecundity in both the Wash and Wadden Sea have recently increased suggesting that either demographic rates, or our indices of those rates, have changed 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 in the Moray Firth SMU 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 overwinter survival in harbour seal young of the year in Sweden, was related to body mass and to water temperature.

Updated estimates of survival and fecundity of harbour seals are available from the harbour seal decline project for Orkney and Isle of Skye based on 2016 to 2022 data. Additionally, the same modelling approach has been applied to Loch Fleet data from 2010 to 2021 providing an update from Graham *et al*. (2017).

Results from the three study areas are currently being incorporated into a manuscript for publication on estimation of vital rates of harbour seals at sites of contrasting population trajectories (Arso Civil *et al*., in prep). **These should be treated as preliminary until this manuscript is published**.

All sites showed high recapture probabilities of adult harbour seals (Orkney: constant recapture probability of 0.887, 95%CI 0.824-0.929; Isle of Skye recapture probabilities ranging 0.341 (95%CI 0.256-0.437) to 0.617 (95%CI 0.457-0.756); Loch Fleet recapture probabilities ranging 0.797 (95%CI 0.712-0.861) to 0.885 (95%CI 0.843-0.917)). Estimates of apparent survival in adults were lower in Orkney (0.830 95%CI: 0.782-0.869) than in Isle of Skye (0.938 95% CI: 0.858-0.974) and Loch Fleet (0.932, 95% CI: 0.917-0.950). Sex-specific estimates for Orkney (females 0.844, 95% CI: 0.803-0.878; males 0.826, 95% CI: 0.751-0.883) and for Isle of Skye (females 0.878, 95% CI: 0.810-0.924; males 0.842, 95% CI: 0.756-0.902) were both lower than those for Loch Fleet (females 0.941, 95% CI: 0.922-0.956; males 0.919, 95% CI: 0.888-0.942). Differences in how animals were classed as “adults” between the Loch Fleet study and the Orkney and Skye study might account for some of the differences in estimated survival rates. Seals in Loch Fleet were classed as adults once they had been seen for at least 4 years or since first pup for females, whereas in Orkney and Isle of Skye because the study was over a much shorter duration seals were classified into broad age categories (pup, juvenile, adult) based on body size and pelage characteristics.

Fecundity rates, i.e. the number of pups born per adult female, were also estimated for all sites following the same methods as in Graham *et al*. (2017), where only multiparous females were included, by including sightings of females starting from the year after they were first seen with a pup. Orkney had a fecundity rate of 0.809 (95% CI: 0.737-0.865), with a model incorporating a negative trend also being supported (fecundity ranging 0.869 to 0.715 over 2016 to 2022 period). Isle of Skye and Loch Fleet females had slightly higher fecundity rates at 0.883 (95%CI 0.823-0.924) for Isle of Skye and 0.872 (95%CI 0.847-0.894) for Loch Fleet. A model with a negative trend was also supported in Isle of Skye, with fecundity rate ranging from 0.921 to 0.785 between 2016 and 2022.

Available estimates of survival for harbour seals are otherwise 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).

In Southeast England there is evidence for recent changes in 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 ratio of pup counts to moult counts has remained high in 2022 and 2023. The fact that apparent fecundity of the much larger population in the Wadden Sea has now also increased and is now of a similar level to the Wash (Galatius *et al*. 2023), 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 haul out during the moult. It does however indicate that demographic rates, or our indices of those rates, are changing and require further investigation.

**Growth**

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

A comprehensive length-at-age dataset for UK harbour seals 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 regions with contrasting population trends (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 contrasts with 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 NatureScot) and combined with the population trend and telemetry data to investigate source-sink dynamics of harbour seal populations (Carroll *et al.* 2020).

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 Southwest Scotland, West Scotland, and Western Isles SMUs, and a north-eastern cluster equivalent to North Coast & Orkney, Shetland, 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 based on the observed population trends. The southern UK population equivalent to the English east coast showed continual rapid increase punctuated by major declines associated with PDV epizootics in 1988 and 2002, although has recently undergone a decline (SCOS-BP 24/03). Populations along the East coast of Scotland and in the Northern Isles are depleted and/or declining while populations in western Scotland are either stable or increasing.

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 concluded that the northern metapopulation appears to be in decay.

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.

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 (SCOS-BP 24/03). In both cases this could represent stabilisation at a new carrying capacity but could also indicate that unidentified density independent factors are acting on 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 (Southeast England SMU). In all cases the observed trajectories preclude estimation of robust carrying capacities.

It is likely that carrying capacity for the harbour seal population in SEE-SMU has decreased since the 2002 PDV epidemic. Grey seal summer counts in 2000 suggest a summer foraging population of approximately 2000 animals, whereas by 2023 the counts suggest that this has increased to approximately  42000 (SCOS-BP 24/01). The resulting increase in competition for food would be expected to reduce the carrying capacity for harbour seals by an unknown, but potentially large, amount.

## 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 and dispersal, as they are likely drivers of UK grey seal population dynamics.**

**Grey seal populations in Orkney appear to be close to their carrying capacities. Recent increases in pup production in West Scotland and in the Western Isles indicate a possible increase in carrying capacity in those SMUs. The population in the North Sea is continuing to increase rapidly and shows no sign of density dependent constraint.**

**A new analysis of grey seal genetics suggests that individuals from Ireland are part of a single interbreeding population, with Southwest England being a source of migrants to Ireland, and the southern North Sea (Germany, Denmark) being either a source or sharing a common source of migrants to Ireland. However, this is contrary to previous knowledge.**

**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 24/05). 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 2768 pups that changes in the phenology of breeding had no impact on pup weaning mass, which is a strong predictor of both first year survival and survival to recruitment (Hall et al., 2001; Bowen et al., 2015)

**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 24/04).

***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. 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. 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) and den Heyer & Bowen (2017) used the branded animal data set for Sable Island and estimated 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.

Rossi *et al*. (2021) developed an integrated population model (IPM) for Canadian grey seals that incorporated a demographic model describing sex-specific maturity-at-age, a population dynamics model structured by age, sex, and population (Scotian Shelf and Gulf), and a mark-recapture model describing the sighting and survival probabilities. The IPM was fitted to a time series of pup production estimates from 1960 to 2021, a time series of late pregnancy rate estimates from shot samples, resighting records of 2313 marked seals, and an index of density independent ice-related pup mortality (Hammil *et al*., 2023). The IPM was largely informed by the mark-recapture data and provided similar estimates of female survival to those from the standalone mark recapture analyses (den Heyer & Bowen, 2017; Hammil *et al*., 2023).

In the current UK population estimation model, density dependence acts through pup survival only, so adult survival in the model does not vary with time or between regions (SCOS-BP 24/05). The fitted posterior value for adult survival was a constant rate of 0.96 (SE 0.01) for the model run with the uncorrected and high level pup production time series and 0.94 (SE 0.01) for the low level pup production time series, which is consistent with estimated survival in the Canadian grey seal studies (den Heyer & Bowen, 2017; Rossi *et al.,*2021).

**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). Using similar methods to Sable, UK estimates of fecundity rates 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 UK 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), 0.91 (SE 0.05), and 0.94 (SE 0.04) for the low level, uncorrected, and high level pup production time series respectively (SCOS-BP 24/05).

Several 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*) in the Baltic, 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 link between likelihood of breeding and environmental conditions, a positive relationship with sandeel abundance during the preceding year, and a negative relationship with a lagged North Atlantic Oscillation index.
- 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 through time 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.
- Badger *et al*. (2023) report a positive association between natal length and measures of reproductive performance and suggested that this may be a carry-over effect from the size advantages in the juvenile stage that allow for greater adult performance.
- Weaning masses of grey seal pups at Sable Island in 2024 were the lowest observed in the past 30 years (den Heyer, personal communication). A number of factors could have contributed to this including unusual environmental conditions, exposure to diseases, an increase in predators and resource competition.

All these studies suggest that fecundity or reproductive performance is influenced by differences in individual quality and prevailing environmental conditions.The consequences in terms of population level fecundity estimates are not clear, but SCOS recommends 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 24/04. Mean estimates of pup survival were between 0.54 – 0.76.

In the current UK population estimation model, the fitted posterior value for pup survival was 0.44 (SE 0.07), 0.56 (SE 0.07), and 0.44 (SE 0.05) for the low level, uncorrected, and high level pup production time series respectively (SCOS-BP 24/05).

Mark-recapture based estimates of juvenile survival at Sable Island, (defined as the proportion of weaned pups that survive to age 4) have declined as the rate of increase in pup production has levelled off. Estimates of juvenile survival from IPMs, which are similar to estimates from previous mark recapture (den Heyer and Bowen, 2013), indicate that juvenile survival rates are currently below 0.2 in both the Gulf and Scotian Shelf populations (Hammill *et al*., 2023). Due to the decrease in juvenile survival since 2000, the ratio of total 1+-population to pup production has declined from approximately 4.5 to 2.5.

**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 0.7:1 if maximum age is set to 40, reducing to 0.69:1 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, den Heyer and Bowen 2013) 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 previously reported 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.

A publicly available preprint (submitted and under review in Conservation Genetics) by Steinmetz *et al*., presents an analysis to support the delineation of management units of European grey seals and suggests that individuals from Ireland are part of a single interbreeding population, with Southwest England being a source of migrants to the island of Ireland, and the southern North Sea (Germany, Denmark) being either a source or sharing a common source of migrants to Ireland. However, it should be noted that the Southwest UK represents a smaller population than Ireland. However, one explanation is that this common source population is northwest Scotland, but this appears contrary to previous suggestions of large scale recruitment to the Netherlands and Germany from colonies in the Northern North Sea (Brasseur *et al*., 2015) and the information in the previous paragraph about significant genetic differences between colonies in Scotland and reports of significant genetic differences between the SW of the UK (Devon, Cornwall and Wales) and those breeding around Scotland (Allen *et al*., 1995, Walton and Stanley, 1997).

SCOS is aware of samples of genetic material taken from pups on Skomer in Wales that are being analysed for genetic information as part of a European wide study on grey seal metapopulation dynamics, but no further information is currently available.

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**

Contrary to previous SCOS reports that suggest grey seal populations in the West Scotland and Western Isles have reached their carrying capacities (Figure 3), with little or no increase in pup production since the mid-1990s, the most recent surveys indicate that pup production is increasing in these regions again. This does suggest an increase in carrying capacity for the West Scotland and Western Isles SMUs. The Orkney population also appears to have reached carrying capacity in the early 2000s. 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 24/05). The model fitted to pup production time series up to 2022 produced pup carrying capacity estimates of 23,900 for Orkney for uncorrected time series (17,400 and 21,000 for the low and high corrections respectively), the values for the Outer Hebrides were 14,800 (12,300 and 14,900), 4490 (3340 and 4040) for the Inner Hebrides and 34,800 (26,100 and 37,800) for the North Sea. Because the North Sea pup production shows no sign of approaching carrying capacity, we have little confidence in the estimate.

## SAC estimates and trends

| | |
|---|---|
| **4. What are the latest count/pup production estimates for harbour and grey seals in Scottish SACs, and what are the trends for these sites – both generally and within the SAC relative to trends in the wider seal management unit/pup production area? Furthermore, are pup production estimates for harbour seals required, and if so, how could this be achieved?**<br>**c) What are the estimated population size and pup production in all English SACs, for both seal species, in terms of the short term and long term OSPAR targets?** | SG Q3<br>Defra Q1c |

**Trends in August counts for both harbour and grey seals and in grey seal 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 (see SCOS-BP 24/03 for details). Below, the latest counts/pup production estimates, and associated rates of change, are summarised, with the addition of information on the two English SACs in Southwest England. Trends on SAC and SMU scale were assessed using four metrics of percentage change compared to the latest year of data available for a given SAC/SMU. There were two short-term metrics: 1 year (ST1) and 6 year (ST6), and one long-term (LT) metric: since 1992 or the earliest year thereafter. Finally, change since any historic high in the time series (HH year). Changes in the metrics described below are significant (unless otherwise stated); 95% confidence intervals do not encompass 0.**

**For harbour seals, all SACs and their associated SMUs on the north and east coasts of the UK are declining (ST1) and/or at depleted levels (LT) 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 severely depleted (LT) but no longer in decline (ST1, ST6), and Ascrib, Isay and Dunvegan SAC is depleted compared to a historic high (HH; 2003). A recent comparison of the time-series (generally starting in early 1990s) of harbour seals counts within Scottish SACs compared with those within a 50 km range of the SACs showed that SACs are not reliable indicators of trends in the wider area (Morris *et al.* 2021). The Wash & North Norfolk Coast SAC harbour seal counts, which account for the majority of the Southeast England SMU count have declined (ST6), and are now ~25% lower than in 2015.**

**Recent harbour seal pup counts are only available for The Wash; declines in pup counts are not as marked as in moult counts. For most areas, an index of pup production would be resource intensive (due to spatial variability in the potential peak pup production), and for the west and north coasts would be greatly hindered by the predominantly rocky terrain. Furthermore, the ramifications for SAC site condition assessments of trends in pup counts relative to trends in moult counts would be uncertain.**

**For trend analyses of grey seal pup production, the increase in production estimates associated with a change from film to digital methods was accounted for, and thus the estimated rates of change likely reflect the true population trajectory. In general, the trends in pup production within**

**SACs are less favourable than for the SMUs which encompass them. Pup production in all Scottish and English SMUs is stable or increasing, with the potential exception of Shetland. In contrast, two of the SACs have decreased for all four metrics (North Rona and Faray & Holm of Faray), and one SAC is depleted compared to a historic high (HH; 2004; Isle of May). On a 1-year scale relative to the last count (ST1), pup production has increased only in two SACs (Berwickshire & North Northumberland Coast and Lundy SACs); three (Humber Estuary SAC) if a 6-year scale (ST6) is considered. 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.**

Appropriate baselines for assessing the status of wildlife populations is a complex issue because the true "normal" levels of abundance are simply not known. For seals, there is added complexity associated with recovery following the end of hunting and culling, and also the Phocine Distemper Virus Outbreaks (1988 and 2002) which caused reductions in harbour seal populations. For the OSPAR Quality Status Report (QSR) 2023 (Banga *et al.* 2023), OSPAR considered a set Assessment Year (2019) against which changes were assessed on a short- (six year; ST6) and long- (since 1992; LT) term basis. This maximised comparability spatially, but was relaxed for areas when dictated by a limited temporal extent of data. Indeed, for many Assessment Units, the time series did not go back as far as 1992 so in reality, the long-term assessment was based on differing time periods.

Due to the spatial extent of seal haulouts and colonies in the UK, key haulouts and colonies are surveyed across multiple years. This means that choosing a single Assessment Year would lead to delayed and outdated assessments for some SMUs. Thus, SCOS recommends using the most recent survey year for each SMU/SAC. Given the natural variability in the proportion of seals hauled out during surveys, and the differing frequency of surveys within and across SMUs, the change in abundance is estimated from a model fitted to the count/production data rather than directly from the raw data.

Given the difficulties in selecting a long-term (LT) baseline, here 1992 is considered (or the earliest year thereafter if the time-series began after 1992) following OSPAR. However, in addition, depletion from the highest point in the time series is also estimated (historic high; HH year), recognising that populations may have increased to a higher level than in 1992, and since declined. Finally, an additional short-term (ST) trend was estimated (one year leading up to the latest survey year; ST1), recognising the importance of rapidly detecting declines. This is particularly relevant for SMUs/SACs monitored on an annual basis. So in total, four metrics of percentage change compared to the Assessment Year were considered: 1 year (ST1); 6 year (ST6); since 1992 (LT); and since any historic high (HH) in the time series. Changes in metrics were deemed significant if the 95% confidence intervals do not encompass 0. It should be noted this differs from 80% confidence intervals considered in OSPAR QSR 2023.

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 24/03). Changes in the four metrics for all Scottish and English SACs are discussed. Note that any changes (increases, decreases, depletion) described below are statistically significant changes (at 5% level) unless otherwise stated. All changes described (e.g. stable, increasing) are in the context of the latest survey year rather than the present day. SMUs which do not encompass SACs are not considered here.

## Harbour seal SACs

There are ten harbour seal SACs in Scotland and England; 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. A recent comparison of the time-series (generally starting in early 1990s) of harbour seals counts within Scottish SACs compared with those within a 50km range of the SACs showed that SACs are not reliable indicators of trends in the wider area (Morris *et al.* 2021).

Recent pup counts are only available for The Wash. Such counts provide a useful indicator of apparent fecundity, and provide an indication of the condition of the local population. Indeed, that pup counts appear to have declined less markedly than August counts indicates that decreased fecundity is not a mechanism underlying the current decline in this site. For most SACs, an index of pup production would be resource intensive (due to spatial variability in the potential peak pup production), and for the west and north coasts would be greatly hindered by the predominantly rocky terrain. Furthermore, for the most part the ramifications of trends in pup counts (compared to trends in moult counts), especially in small SACs would not be straightforward. In contrast to grey seals, harbour seals generally do not breed in large colonies and pups can swim from birth so at some sites numbers counted may not be indicative of numbers born at the site. They do show short-range movements between breeding and moult in some place. As such, unless an SAC holds a large proportion of the local population (like in The Wash), and movements in and out of the SAC are well known, pup counts will represent an unknown proportion of the population during the moult, and thus cannot be used as an indicator of apparent fecundity.

***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 (ST1 & ST6) as result of increases in the central subdivision; there is no significant trend in the northern or southern subdivisions. The SACs in the southern subdivision show differing trends; estimated abundance in the Eileanan agus Sgeiran Lios mor SAC is stable (ST1 & ST6 up to 2018) whereas abundance increased in the Southeast Islay Skerries SAC (ST 1 & ST6 up to 2018). Estimated abundance in the Ascrib, Isay and Dunvegan SAC is decreased but not significantly so (ST1 & ST6). It is, however, significantly depleted since its historic high (HH 2003). It should be noted that the latter SAC was surveyed in 2022, but that the latest data available for the central subdivision, as a whole, is 2017, and thus the metrics are not directly comparable.

***Western Isles SMU: Sound of Barra SAC***

Abundance in the Western Isles is estimated to have declined to the last survey in 2022, significantly so for ST1. This follows what was a historic peak, and thus the abundance is still higher than at the start of the time series. In contrast, there is currently no significant trend (ST1 and ST6) in abundance in the SAC and abundance is severely depleted compared to the start of the time-series (LT). The last count (2017) represents around 3% 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 severely depleted compared to historic counts (LT and HH 2002), and are still in decline (ST1 & ST6). The current rate of decline and level of depletion are 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 (LT), estimated abundance in Shetland is currently stable (based on 2019 counts). This is also the case for the Yell Sound SAC. In contrast the Mousa SAC is almost completely depleted (~98%; LT) compared to the start of the time-series (early 1990s), and is still in decline (ST1, ST6), with a count of 7 in the last survey (2019).

***Moray Firth SMU: Dornoch Firth and Morrich More SAC***

Abundance in the Moray Firth is depleted (LT) but stable (ST1, ST6). In contrast, the SAC is more severely depleted and still in decline (ST1 & ST6) representing 5% of the SMU count in 2023 compared to around 50% in the early 1990s.

***East Scotland SMU: Firth of Tay and Eden Estuary SAC***

The East Scotland SMU is depleted (LT) and still in decline (ST1, ST6). The SAC was last surveyed in 2023, and although it is over 90 % depleted compared to the 1990s, it is no longer significantly declining. Indeed, it has shown a slight increase (significant for ST1). In the last count (2021) for the SMU as a whole, the SAC represented around 16% of the SMU total compared to around 83% in the first SMU-wide survey (1997).

***Southeast England SMU: The Wash & North Norfolk Coast SAC***

The SAC accounts for around two thirds of the SMU abundance. Except for during the Phocine Distemper Virus (PDV) outbreaks in 1988 and 2002, the SMU and encompassed SAC increased until levelling off around 2015. However, since 2019, the count was markedly lower than in the preceding years. There is no significant continued decline within the SAC or SMU (ST1). The decrease, since the high in 2015, is ~19.5% for the SMU, and ~25.8 for SAC.

The Wash accounts for the majority of harbour seal pup production in the SEE-SMU. In 2023, the pup count was 1417, compared to 1141 in 2022. Analyses of these annual maximum pup counts suggest a decline since the 2015 peak, but it is not significant (HH2015; -12%; 95% CIs: -31, 11). Similarly, ST1 and ST6 metrics were not significant. However, it should be noted that the mean maximum pup count since the start of the decline in the moult count (2022-2023: 1279) is substantially lower (~15%) than the mean maximum in the 5 years preceding the decline (2014-2018: 1505).

## Grey seal SACs

Nine grey seal breeding colonies are designated as SACs in Scotland & England. Below, for each SAC, the trends relative to the associated SMU are described. Note that SMUs that do not contain SACs are not covered. For trends in grey seal pup production, the trends reported are robust to the change in methods between aerial film and digital, and ground to aerial digital. In general, the trends in pup production within SACs are less favourable than for the SMUs that encompass them. 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 haulouts. Here the August trends quantified in SCOS-BP 24/03 are briefly described.

***West Scotland SMU: Treshnish Isles SAC***

Pup production for West Scotland appears to be increasing (ST1, ST6), after a long period of stability, and is now at a time-series high. Although not significant, there is an indication of an increase in Treshnish Isles SAC (ST1 & ST6), and it is no longer significantly depleted compared to the highs in the late 1990s (when the SMU trend first levelled off). The Treshnish Isles accounts for around ~25% of pup production in the SMU, but is not a key haulout accounting for less than 5% of the SMU count in August.

***Western Isles SMU: Monach Isles SAC and North Rona SAC***

Pup production in the Western Isles is increasing (ST1 & ST6), after a long period of stability, and is now at a record high. The Monach Isles SAC is also at its highest level of production accounting for ~75% of the SMU's production, and although there is an indication of a recent increase, it is not significant (ST1, ST6). In contrast, the North Rona SAC which historically was the biggest colony in the SMU, is severely depleted (LT) and is continuing to decline (ST1, ST6); 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 (~40% of the SMU count) or the SMU as a whole (LT, ST1, ST6). The most recent count (in 2022) for the Monach Isles, and the SMU as a whole, was particularly low. The North Rona SAC is a small haulout (~5% of the SMU).

***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 (HH 1998, ST1, ST6, LT). It is now significantly depleted to around half historic levels, now accounting for ~10% of the SMU production. Haulout counts in August are stable in the SMU. The SAC only encompasses ~ 3% of that count, and is depleted and still declining on the 6-year scale.

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

Pup production in East Scotland is continuing to increase. Production on the Isle of May SAC is ~20% lower than the historic high in 2004, and appears to still be in decline (ST1,ST6). The Isle of May SAC, which until the mid-1990s represented almost 100% of the SMU's pup production, only represents ~ 25%. This is largely due to the rapid increase in pup production at Fast Castle. Around 60% of the pups at Fast Castle are within the Berwickshire and North Northumberland Coast SAC. In the 6 years leading up to the last estimate (2021), the increase in the SAC was more marked than in the colony as a whole (~54 vs 46% increase). However, likely due to the expanding nature of the colony, the current trend (ST1; 2000-2021) shows a significant increase for the colony as a whole, but not the proportion within the SAC. Neither SACs represent key haul-out areas for grey seals during the August survey.

***Northeast England SMU: Berwickshire and North Northumberland Coast SAC***

Pup production in the English portion of the Berwickshire and North Northumberland Coast, for all intents and purposes, represents pup production in the SMU. Pup production and August counts are at record levels and continuing to increase rapidly (ST1, ST6). The English portion of the SAC represents the vast majority (>90%) of the August count of grey seals in the SMU as a whole.

***Southeast England SMU: Humber Estuary SAC***

The Humber Estuary represents a decreasing proportion of the pup production for the SMU as a whole. It accounted for 100% in pup production in 2000, but now accounts for less than 20%. The SAC appears to have recently reached a stable level with no significant increase leading up the last survey (ST1), but still a significant increase compared to 6 years previously (ST6). In contrast, production in the SMU is still increasing rapidly by ~13.4% per annum. The trends for August show a similar pattern; Humber Estuary estimates (2023) are significantly higher for ST6 but not ST1, now accounting for ~65% of the SMU total. At the SMU level, the increase compared to 6 years ago is more marked and although the last count is the highest, the ST1 is not significant.

***Southwest England SMU: Isles of Scilly Complex SAC and Lundy SAC***

The most recent published pup production estimate for the SMU as a whole is 373 pups in 2016 (Sayer & Witt 2017a,b), the majority of which were in the SACs (228 Isles of Scilly Complex SAC; 27 at Lundy SAC in 2015; Lundy Warden). This total is higher than the estimate in 2005 (260; Westcott 2008). The last published estimate (2016) for the Isles of Scilly is higher than the previous estimate of 112 in 2010 (Sayer *et al.* 2012). The majority of the recent August count (2023) was within the SACs; ~ 55 and 10% for Isles of Scilly and Lundy, respectively.

Additional data have been supplied by Lundy wardens. Pup production estimates (2008-2023) and August count data (2009-2023) were analysed following methods in SCOS-BP 24/03. Pup production on Lundy in 2023 was the highest recorded (66; Lundy Field Society 2023) and still increasing with significant increases since the start of the time-series (2008; 110.6%; 95% CI: 50, 193.5), as well as ST1 (11.8; 95% CIs: 0.6, 24.1) and ST6 (113.2; 95% CIs: 61.4, 184.5).

# Regional harbour seal declines

## Scottish waters

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| **5. Please could SCOS provide an update on a) the regional harbour seal declines, including current and projected trends, and b) any new information that could help understand the potential drivers behind UK regional harbour seal declines in light of ongoing work?** | Scot Gov Q4 |
| *Some strands of research into investigating the potential drivers behind regional declines of harbour seals in Scotland should be near completion according to the last SCOS reporting, e.g. killer whale predation and competition with grey seals PhD projects. Other projects e.g. PELAgIO have focused on using harbour seal counts to understand drivers of population change with ecosystem level changes and might provide relevant information. Any new information on potential drivers of the decline would be important to understand.* | |

**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. On the whole, the current population estimate for the Scottish harbour seal population is 2% lower than the estimate presented in SCOS 2022 and is 16% lower than historical highs of abundance in the late 1990s.**

**The Southwest Scotland and West Scotland SMUs are stable or increasing. The change in numbers of the most recent count compared to the previous year for the Western Isles is of a slight decline but it is stable when looking over a slightly longer time frame (6 years). The North Coast & Orkney, and East Scotland SMUs are depleted and still declining whereas the Shetland and Moray Firth SMUs are depleted but appear to be stable (based on the most recent counts for each area which were done in 2019 in Shetland and 2023 in the Moray Firth ).**

**Recent published research indicates that exposure to biotoxins cannot be ruled out as a factor in the harbour seal decline. Several other lines of research regarding the harbour seal declines are nearing completion and results will be published in 2025.**

Trends in Scottish SACs and SMUs are given in answer 3 above. Trends in individual SMUs around Scotland and on the east coast of England are described in more detail in SCOS-BP 24/03.

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.

The current population estimate for all of Scotland, based on composite counts including recent (up to 2023) surveys is 34,475 (approximate 95% CI: 28,207-45,967), this is 2% lower than the composite estimate presented in SCOS (2022) based on surveys between 2016 and 2019, and is approximately 16% lower compared to population estimates in the late 90s.

On an individual SMU basis, the Southwest Scotland and the West Scotland SMUs are both increasing. However, within the large West Scotland SMU only the central sub-division is increasing with the north and south subregions apparently stable over the last 6 years.

The Western Isles SMU shows a decline over the past year, but it is apparently stable over a slightly longer (6 year) time frame. The recent decline is due to the counts from the most recent survey in 2022 being lower than the previous counts for the region in 2017 which was a time-series high.

North Coast & Orkney and East Scotland SMUs are depleted and still declining whereas Shetland and Moray Firth SMUs are depleted but stable.

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 MMSS project and an integrated harbour seal population model is being developed as part of that programme. The current phase of that programme is in the final year and will report on the conclusions from the work in mid 2025 and outcomes will be provided in SCOS 2025.

Since the last SCOS, Hall *et al*. (2024) published the results of a risk assessment exercise carried out to investigate the potential population consequences of the levels of biotoxin exposure estimated for Scottish harbour seals. This work used a risk assessment model incorporating concentrations of domoic acid and saxitoxins, the seasonal persistence of the toxins in the fish and the foraging patterns of seals to estimate the proportion of seals likely to have ingested doses above toxicity thresholds. The results varied depending on toxin type and persistence, the foraging strategy of the seal and the age class of seals. Saxitoxin exposure was unlikely to result in any mortality. Domoic acid exposure was predicted to result in lethal doses to up to ~4% of exposed juveniles and ~5% of exposed adults. Jensen *et al*. (2015) have previously demonstrated that the proportion of animals exposed (based on the proportion of excreta positive for domoic acid) was higher in regions of decline than in stable or increasing regions. Taken together with this finding, although preliminary and with a range of uncertainties inherent in the simulations, the analysis of Hall *et al*. (2024) indicates that exposure to domoic acid cannot be ruled out as a potential factor in the decline of harbour seals.

Preliminary vital rate estimates have been produced from the long term photo identification studies carried out at colonies in Orkney (declining) and Skye (stable), these have been slightly updated compared to the previous estimates presented in SCOS 2022 but are similar in that they indicate that adult survival is lower in Orkney (0.830, 95% CI 0.782-0.869) compared to Skye (0.938, 95%CI 0.858-0.974) and Loch Fleet (0.932, 95% CI 0.917-0.950). These estimates are currently being used in the development of an integrated population model which is being used to explore different hypotheses of change in survival across the three colonies for which photo-ID estimates of vital rates and a time series of count data exist. These hypotheses include linear vs step changes in survival at all sites and changes in survival as a function of local grey seal abundance. Preliminary results indicate that a step-change in survival at Orkney only is best supported by the data. In the coming months this work will be completed and prepared as a manuscript for submission to a peer-reviewed publication.

Since the last SCOS two PhD theses have been submitted that focused on different potential drivers of the decline. These were 1) grey seal competition and predation and, 2) killer whale predation. These analyses suggest that both killer whale predation and grey seal interactions (competition and predation) could be significant contributory factors in the harbour seal decline and/or in the failure of populations to recover in some regions. The outcomes of this research are currently being prepared for publication and further details will be available for SCOS 2025.

Recent studies have incorporated harbour (and grey) seals into ecosystem level models. For example, in the current INSITE II EcoSTAR project led by SMRU, both harbour and grey seals are being incorporated into a North Sea ecosystem model developed by Cefas (Ecopath with Ecosim model). That model will be used to predict, under multiple climate change scenarios, the impact of fisheries management and decommissioning options on fish density and distributions, and ultimately on both seal populations and fisheries. Another study (Trifonova *et al*. 2021; Trifonova & Scott 2023) has taken a Bayesian network approach to examine the potential top-down and bottom-up drivers (and indicators) within four areas around the UK (West of Scotland - broadly SMUs 1-3, and 14; Shetland/Orkney - SMUs 4-6; deep central North Sea – SMU 7, and shallow central North Sea – SMU 8 and northern part of 9 (to northern side of The Wash). Such an approach has the benefit of incorporating both bottom-up environmental changes and top-down relationships (e.g. fisheries) in an area-specific way. This allows examination of the relative importance of such relationships and how they are mediated by the broad habitat types in each area, and importantly can be used to predict the impact of changes in these relationships (e.g. through climate change). Though, as the authors note, this is based on correlative, rather than mechanistic relationships, and thus the relationships and predictions should be interpreted with this in mind. Here, the key findings of Trifonova & Scott (2023) are summarised. For harbour seals, the best fitting models were for West of Scotland and Shetland/Orkney regions. For the West of Scotland region, increasing trends in harbour seal abundance (using moult count data) were most related to sea bottom temperature, Chlorophyll-a levels, and primary productivity. In Shetland/Orkney region, a rapid decline in harbour seal abundance was predicted to occur between the late 1990s and early 2000s, with abundance predicted to be variable but relatively stable thereafter (with a lower mean then predicted post 2013). The decline in these SMUs appeared to have occurred between 2001 (last high count) and 2006 (first low count). However, this apparent mismatch in prediction compared to the historic decline may have, in part, been due to a lagged impact on the counts. This would be expected if the impacts were mediated through juvenile survival. Bottom-up impacts implicated in initial decline are a current avenue for investigation, for example through spatio-temporal examination of trends in direct (e.g. length/mass relationships) and indirect indicators (biochemistry and haematological parameters) of seal condition. The observed trends since the initial decline vary across, and even within, the three SMUs the region encompasses suggesting there is not a single, wide-scale driver of the declines. It should be noted that the input data used (Trifonova & Scott 2023) for some areas, do not align with observed trends on an SMU basis (SCOS-BP 24/03). This is likely due to difficulties in amalgamating counts across SMUs and survey years. In contrast to the harbour seals, Trifonova & Scott (2023) predicted numbers of grey seals in Orkney/Shetland to increase before stabilising around the 2000s. In comparison to moult counts for harbour seals, the study used grey seal pup production as this is the most comprehensive time-series. Nevertheless, the considerable seasonal movements in where grey seals accumulate their resources and breed should be considered.

Such ecosystem level approaches provide novel insights, and complement more species-specific studies. The complexity of such models necessitates simplification of many aspects of individual species and groups, and operate at a large spatial scale. For example, several factors known to potentially impact harbour seal populations, e.g. disease events, biotoxin blooms, and predation, were not considered in Trifanova & Scott (2023). Central placed foragers are notoriously difficult to robustly incorporate into ecosystem level models. Indeed, harbour seals will only utilise a very small proportion of the regions modelled here; their patterns of usage will differ across regions, and they show limited movements between haul-out areas within these regions. For example, for the central shallow North Sea region, the main haulout is intersected by the southern boundary. The haulout has been allocated to the region, but much of the foraging will occur outwith it. Within the Shetland/Orkney region and within the 3 SMUs, there are variable trends in abundance on relatively fine spatial scales which are not captured by this approach. A key example, which is part of a current PhD project, is the differing trajectories of the two Shetland harbour seal SACs.

## English waters

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| **6. Is there any update in evidence to explain trends in common/harbour seal abundance, which are considered to be declining in English waters?** | Defra Q1b |

**The Southeast England Seal Monitoring Unit (SEE-SMU) hosts ~95% of English, and >10% of UK, harbour seal abundance, and an increasing number of grey seals. The Wash & North Norfolk Special Area of Conservation (SAC), accounts for around ~75% of the SEE-SMU total. Abundance in the SEE-SMU is now (2019, 2021, 2022) ~20% lower than the five years leading up to 2018. Survey effort is higher within the SAC, where there appears to have been a drop of ~25% between 2018 and 2019. The cause for this decline remains unknown. Since 2019, surveys do not indicate either a continued decline or a recovery for either the SAC, or the SMU as a whole.**

**Understanding the factors driving the decline of harbour seals in the SEE-SMU is critical to mitigating their effects and to predicting the future of this population . SMRU proposed a programme of work, focussed within the SAC, to investigate the likely key potential factors as well as any interactions between these: (1) inter-specific competition with, and the potential for direct predation by grey seals, (2) changes in the levels of anthropogenic development (e.g. wind farms) that might impact harbour seals; and (3) health drivers (disease, biotoxins). The current programme of funded work continues until 2026, with four of five work packages (WPs) funded. So far, data has been collected pertaining to seal movements, diet and health. Subsequent funding for the fifth WP will be needed to integrate the results of the first four WPs, and ultimately predict the prognosis of the harbour seal population under potential future scenarios.**

# Seal Management and Conservation Advice

## Seal Licensing and PBRs

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| **7. Can SCOS provide updated Potential Biological Removals (PBRs) figures for 2024?** | Scot Gov Q5 |

**In the UK, what is considered a 'safe level of anthropogenic takes' from defined populations (here using the SMUs) is based on the Potential Biological Removals method (Wade, 1998: NOAA 2023). This uses information on intrinsic rates of population increase for the species in question, recent conservative population estimates ($N_{min}$), and a recovery factor $F_R$, the value of which is set between 0 and 1 based on the current population trajectory of the SMU.**

**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 24/06. PBR values for the grey and harbour seal "populations" that haul out in each of the seven SMUs in Scotland are presented in Table 5 and Table 6), based on suggested values for the recovery factor and the latest confirmed counts in each monitoring area.**

**<u>Changes since previous SCOS report</u>**

**Based on surveys carried out in 2022 and 2023, PBRs for harbour seals have been reduced from 936 to 851 in the West Scotland SMU and from 105 to 92 in the Western Isles SMUs, and the PBR has been increased from 4 to 5 in the Moray Firth SMU. Grey seal PBRs have been reduced from**

**1290 to 776 in the Western Isles SMU, from 414 to 302 in the Moray Firth SMU and from 605 to 354 in the East Scotland SMU, and have been increased from 933 to 981 in the West Scotland SMU and from 1922 to 1926 in the North Coast and Orkney SMU.**

**The recovery factor for harbour seals in the Southwest Scotland SMU has been increased from 0.7 to 1.0, to bring it in line with West Scotland, resulting in an increase in PBR from 71 to 102. Recovery factors for harbour seals in all other SMUs, and for grey seals in all SMUs are unchanged from SCOS 2022.**

*Table 5. Potential Biological Removal (PBR) values for **harbour seals** in Scotland by SMU for 2025. The most recent population data, estimates of $N_{min}$ and the recommended FR values are shown.*

| | 2016-2023 | | selected | |
|---|---|---|---|---|
| **Seal Monitoring Unit** | **$N_{min}$** | **latest count** | **$F_R$** | **PBR** |
| 1 Southwest Scotland | 1709 | 2018 | 1.0 | **102** |
| 2 West Scotland | 14189 | 2022 | 1.0 | **851** |
| 3 Western Isles | 3080 | 2022 | 0.5 | **92** |
| 4 North Coast & Orkney | 1405 | 2019 | 0.1 | **8** |
| 5 Shetland | 3180 | 2019 | 0.1 | **19** |
| 6 Moray Firth | 983 | 2023 | 0.1 | **5** |
| 7 East Scotland | 276 | 2023 | 0.1 | **1** |
| **SCOTLAND TOTAL** | 24822 | | | **1078** |

*Table 6. Potential Biological Removal (PBR) values for **grey seals** in Scotland by SMU for 2025. The most recent population data, estimates of $N_{min}$ and the recommended FR values are shown.*

| | 2016-2023 | | | selected | |
|---|---|---|---|---|---|
| **Seal Monitoring Unit** | **count** | **$N_{min}$** | **latest count** | **$F_R$** | **PBR** |
| 1 Southwest Scotland | 517 | 1927 | 2018 | 1.0 | **115** |
| 2 West Scotland | 4388 | 16351 | 2022 | 1.0 | **981** |
| 3 Western Isles | 3473 | 12942 | 2022 | 1.0 | **776** |
| 4 North Coast & Orkney | 8618 | 32114 | 2019 | 1.0 | **1926** |
| 5 Shetland | 1009 | 3760 | 2019 | 1.0 | **225** |
| 6 Moray Firth | 1354 | 5046 | 2023 | 1.0 | **302** |

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|---|---|---|---|---|---|
| 7 East Scotland | 1584 | 5903 | 2023 | 1.0 | **354** |
| **SCOTLAND TOTAL** | **20943** | **78043** | | | **4679** |

## Fisheries interactions - bycatch

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| **8. What are the latest estimates of seal bycatch across both Scottish and UK fisheries (preferably by gear type) and what is the impact of this interaction on seal populations and health. Where there is insufficient information to provide bycatch estimates, it would be helpful if SCOS could identify the key knowledge gaps (e.g., monitoring effort).** | Scot Gov Q10 |
| **9. What are the latest bycatch estimates for grey seals in Southwestern British Isles (including Ireland)?** | NRW Q3 |

**The most recent bycatch estimate for seals in UK fisheries is for 2021. The total estimate is 458 animals (95% CI 356-836). Most bycatch in UK waters occurs in large mesh tangle or trammel net fisheries; rare and sporadic captures in trawl fisheries are discussed below. The bycatch estimate for 2021 is higher than for 2020 (356), but the confidence intervals are wide, overlapping with those of previous estimates, and are similar to recent pre-Covid estimates. Bycatch estimates by ICES Division are presented in Table 14.**

**Sampling under the UK Bycatch Monitoring Programme (BMP) in 2021 continued to be impacted by Covid 19 restrictions. Spatially, bycatch of seals is mainly concentrated in ICES Divisions 7.d-f (English Channel and Bristol Channel) with 70% of all estimated bycatch occurring here, with lower levels in the northern and southern North Sea (4.a, 4.c). The same pattern was evident in previous assessments.**

**Most bycaught seals examined were young grey seals. Although species identification is uncertain where seals cannot be brought on deck, this has so far not been considered a major issue as all the seal bycatch in gillnets occurs in the southwest, where harbour seals are rare. Looking ahead, however, SCOS recommends that effort is 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 species identification of seals bycaught in the North Sea.**

**There is now a mandatory requirement under fishing vessel licence conditions to report any bycatch of marine mammals within UK waters to the Marine Management Organisation (MMO), within 48 hours of the end of the fishing trip. There have been no reports of bycaught seals reported since the reporting requirement came into force in November 2021.**

### Seal bycatch estimates

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

In 2021 no monitoring of netters of over-12m length was carried out in fisheries where ADD use was mandatory, due to the continued impact of Covid-19 on sampling activities, which restricted access to vessels carrying out multi-day trips.

Seal bycatch estimates for the UK are made for both species (grey and harbour seals) combined (Kingston *et al*., 2024). Most bycaught seals 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 2021 is 458 animals (95% confidence limits 356-697). The mean estimate is higher than for the previous year (356), but the confidence intervals are wide and overlapping. Estimates of seal bycatch have generally been in the region of 400-600 seals per year, with no clear trend (

Table 7).

The estimates for 2021 are higher than the 2020 estimates. The inter-annual increase is driven by a return to more typical levels of netting effort in 2021 following lower-than-normal levels in 2020 due to the effects of the Covid-19 pandemic, rather than by changes to underlying bycatch rates.

The calculation of bycatch rates uses sampling data over multiple years. This allows robust estimates of bycatch-related mortality rates to be calculated across metiers [1] 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.

Although the majority of seal bycatch in the UK occurs in the SW, 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 haul-out sites and in inshore waters, in particular. That analysis moreover suggests that bycatch estimates can be significantly biased by the distribution of sampling effort. Netting data for ICES Subarea 7 Divisions d-j (including UK and non-UK portions of these areas) indicate that the total effort from UK fishing vessels was circa 17,000 days whereas the total for all non-UK effort was 29,000 days. While these totals include non-UK areas, this gives some indication of the relative amounts of UK vs non-UK fishing effort. Increased marine mammal bycatch monitoring on French, Irish and other EU registered vessels fishing in UK waters would be helpful to better estimate the total levels of mortality due to bycatch. Sampling of UK registered vessels typically covers all major 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.

[1] A metier is a group of fishing operations that are characterised by a specific set of parameters, including target species, and gear type.

*Table 7. Recent estimates of annual seal bycatch in UK gillnet fisheries with 95% confidence limits (from Kingston et al. 2024).*

| 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 |
| 2021 | 458 | 356-836 |

**Distribution of bycatch**

The published data are not presented at sufficiently high resolution to ascertain whether there are any local hotspots of bycatch within particular ICES Divisions.

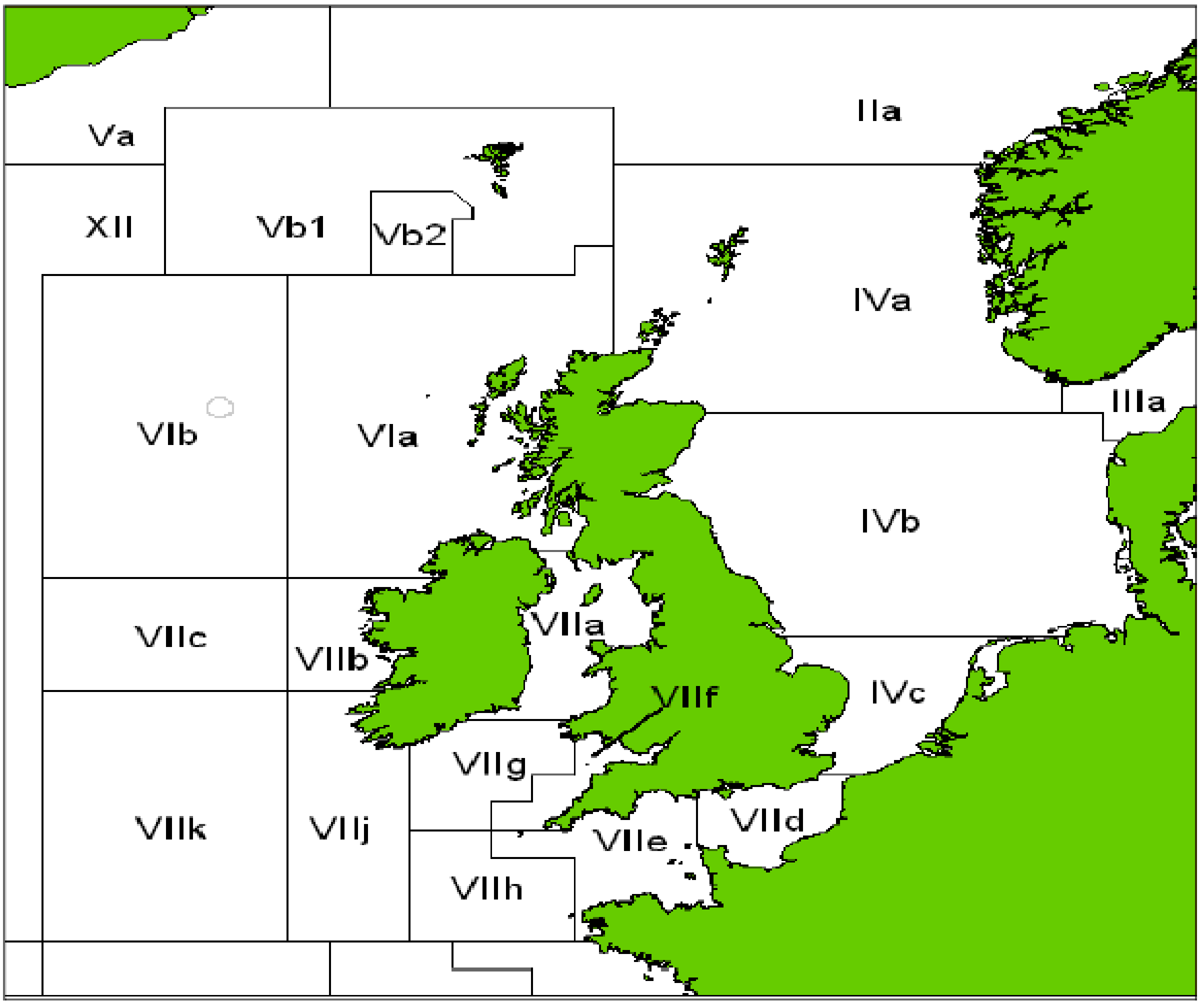


Figure 5. *ICES Subareas and Divisions*

*Table 8* shows the estimates for UK registered vessels by ICES Division and region. Approximately 70% of the bycatch (316 seals) was estimated to have occurred in ICES Subarea 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 245 seals per year), largely due to most UK tangle/trammel net fishing effort being concentrated in this region. 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 in the Eastern Channel was estimated at around 67 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 4.a comprises Scottish waters off the north and east coasts. The combined bycatch estimate for ICES Subarea 6 and Division 4.a in 2021 was 97 seals, representing around 21% of the UK total. Given the greater presence of harbour seals in these areas compared to the SW of the UK, it is possible that these include a proportion of harbour seals but the composition by species is currently unknown.

Since the above bycatch estimate is based on UK registered vessels only, it most likely represents an 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. For the Irish EEZ, Luck *et al.* (2020) estimated total bycatches of between 202 and 349 seals per year between 2011 and 2016 by all vessels. 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 proportion of fishing effort by French vessels within the Irish EEZ (43% of all effort) was similar to the combined effort by Irish (21%) and UK (23%) registered vessels in the same region. Likewise, a number of 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. The extent of effort by non-UK registered vessels in UK waters might have changed in recent years, and hence also the levels of seal bycatch by these vessels in UK waters.

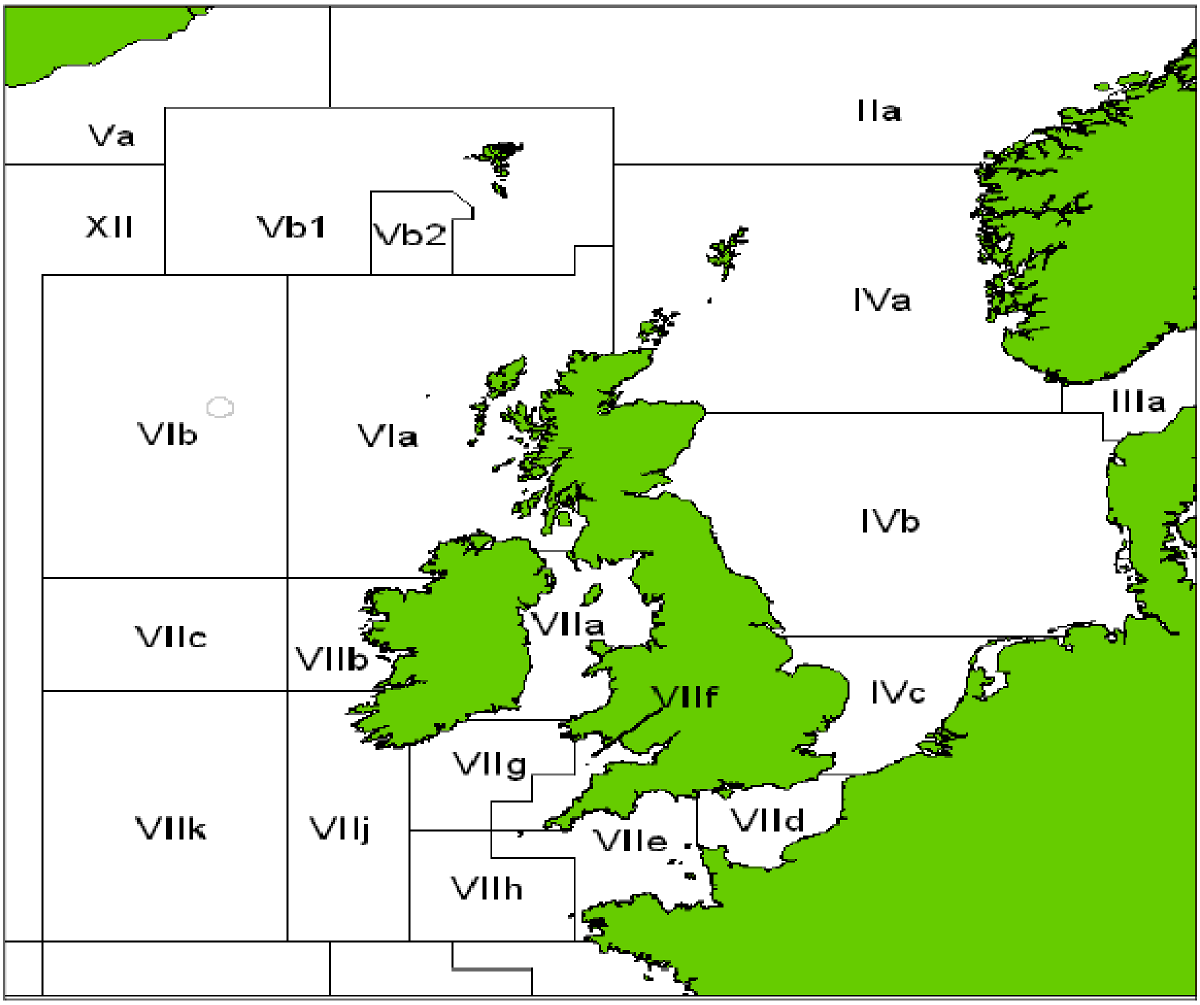


*Figure 5. ICES Subareas and Divisions*

*Table 8. Estimated number of seals bycaught in UK net fisheries in 2021, by ICES Division. Estimates rounded to nearest integer. (From Kingston et al. 2024). NB the difference in the total between this Table and in Table 7 is a result of small differences occurring when rounding the estimates when summing across different categories.*

| Region | ICES Division | Estimated total bycatch | Two-Sided 95% LCL | Two-Sided 95% UCL | One-sided 90% UCL |
|---|---|---|---|---|---|
| **North Sea** | 4.a | 84 | 70 | 101 | 95 |
| | 4.b | 1 | 0 | 1 | 1 |
| | 4.c | 42 | 35 | 63 | 58 |
| **West Scotland offshore** | 6.b | 13 | 11 | 16 | 15 |
| **Irish Sea** | 7.a | 2 | 2 | 9 | 6 |
| | 7.c | 2 | 2 | 3 | 3 |
| **Eastern Channel** | 7.d | 67 | 49 | 129 | 109 |
| **Western Channel and Celtic Sea** | 7.e | 140 | 114 | 202 | 183 |
| | 7.f | 82 | 68 | 117 | 106 |
| | 7.g | 11 | 9 | 26 | 21 |
| | 7.h | 11 | 9 | 17 | 15 |
| | 7.j | 1 | 1 | 2 | 2 |
| **Biscay** | 8 | 1 | 1 | 1 | 1 |
| | Total | **457** | **371** | **687** | **615** |

**Gear type**

Most of the seal bycatch estimates for 2021 was in large mesh tangle 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, observer effort 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, 2020 or 2021. In 2018, six grey seals were reported caught in sandeel trawls in the central North Sea. This fishery is no longer active in UK waters. Seal bycatch records in trawl fisheries are often clumped, 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 produced under the Bycatch Monitoring Programme.

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 BMP is focused on static nets 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.

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| **10. Has there been any further information about the origin of bycaught seals in SW British Isles?** | NRW Q4 |
| *In previous SCOS reports, there was information about a project to identify the origin of bycaught seals from fisheries in SW Britain. The majority of bycaught seals were juvenile grey seals and it was hypothesised that these may have originated from colonies in the Hebrides. Has there been any genetic, stable isotope or similar evidence to support this hypothesis? Is there an update on this project?* | |

**There is little new information about the origin of bycaught seals in SW British Isles. A previous tagging study summarised in SCOS 2022 confirmed significant rates of movements of moulted pups from the Monach Isles in NW Scotland to Ireland, Southwest England and Northern Ireland, one of which was bycaught in an Irish crayfish net.**

**Genetic analysis of samples retrieved from bycaught animals in the region would allow this to be investigated further.**

Further to the update provided in SCOS 2022, largely based on Russell *et al.* 2023, there is little new definitive information available about the origin of bycaught seals from fisheries in the southwest of the UK. Russell *et al.* (2023) was based on tracking 50 moulted pups from the Monach Isles (Outer Hebrides), which is the largest grey seal colony in the Northeast Atlantic with over 13,000 pups born annually. The data indicated a high degree of movement of pups south to Northern Ireland, Ireland and/or Cornwall. However, the fate of these pups is unknown both in terms of survival, and whether they would return to Scotland as pups, juveniles or breeding adults. The fact that one of these seal pups was subsequently reported as having been bycaught in a crayfish net in Ireland certainly indicates that pups moving from other areas can be subject to bycatch but no conclusions as to the proportion of bycaught animals that originate from outside of the region can be drawn. No further tag deployments have been undertaken.

SCOS is aware of samples of genetic material taken from pups on Skomer in Wales that are being analysed for genetic information as part of a European wide study on grey seal metapopulation dynamics but no further information is currently available.

As recommended by SCOS previously (SCOS, 2022), further tracking studies allowing region and immigration status-specific survival rates, and genetic analysis of samples from bycaught seals compared with information from the potential source populations would provide further insight into the source of bycaught seals in this region.

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| **11. How is bycatch in SW British Isles (including Irish Waters) – most of which is outside of the SMU boundaries - best accounted for when assessing against the PBRs in the SW UK SMUs?** | NRW Q5 |

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| *Related to NRW's questions 2 (above) on population estimates derived from aerial counts in Wales and Southwest England, these can now be used for calculating PBR for the relevant SMUs, but using the PBRs to determine the level of additional removals that might be allowable is problematic because it is dependent on the existing bycatch in the region, either within or affecting the SMU(s). Estimates for bycatch in the SW UK SMUs are not yet available, but we know there is high bycatch of seals in the SW approaches, largely outside of the SMU boundaries; how is this bycatch best accounted for when assessing against the PBRs in the SW UK SMUs? (also see NRW's related questions 3 and 4 above)* | |

**There is a clear mismatch between the spatial scale over which bycatch estimates are calculated (by ICES Divisions) and the scale of SMUs (used to calculate PBR values for seals). This can only be addressed by either apportioning bycatch estimates across the individual SMUs, or by amalgamating several SMUs to better match the spatial scale of the data informing bycatch estimates. Neither of these options are straightforward to implement. The former could be approached by breaking down existing bycatch monitoring data to the scale of ICES rectangles which, although they do not completely align with SMU boundaries, may provide less of a mismatch. The second option is further complicated by the large-scale movements of grey seals and the mixing of different SMU populations outside of the breeding season.**

There is a clear mismatch between the scale at which bycatch estimates are calculated and the scale of SMUs for seals for which PBR values are calculated. Bycatch sampling levels are generally low in comparison to the total fishing effort, and are presented by broad area, stratified primarily by the statistical divisions defined by the International Council for the Exploration of the Sea (ICES) and widely used for fishery reporting and assessment purposes ("ICES Divisions"; *Figure 5*). These ICES areas cover different areas to the seal monitoring units and extend beyond the UK's 12 nautical mile limits. It is not currently possible to appropriately calculate bycatch rates for the areas delineated by the seal monitoring units. There are effectively two ways in which this could be addressed. The first option is to combine the bycatch estimates for all the ICES units that overlap with the SMU of interest and then somehow 'apportion' the bycatch estimates across each SMU. This is not straightforward to achieve and is limited by the amount of sampling effort and the number of observations across the area. For example, the Welsh SMU (SMU 12), overlaps with ICES Divisions 7.a, 7.g and 7.f. The total amount of estimated bycatch by UK vessels across these areas for 2021 (the most recent estimate) is 2, 11 and 82 respectively. Appropriately apportioning these totals to their constituent SMUs would require some assessment of the total bycatch that occurred in each SMU and a calculation of the proportion of the population that would be at-risk. Bycatch monitoring effort data is only available at ICES Division scale which also will not completely align with SMU boundaries but apportioning the effort for each division to rectangles based on the proportional effort would be possible.

The second option would be to increase the scale at which PBR is calculated to better match the scale of the data on existing anthropogenic mortality. Previous SCOS discussions have highlighted that appropriate biologically meaningful populations are at a greater scale than the scale at which management decisions are made (SCOS 2020). For grey seals, this is further complicated by the mixing of different SMU populations outside the breeding season. The long-range dispersal of grey seals away from their breeding sites means that the breeding population in any one area may be subject to anthropogenic pressures in several SMUs. The issues associated with pooling SMUs are explained in depth in SCOS 2020 but would require more information on the movements of animals between areas, the origin and age distribution of animals being bycaught and the underlying mortality rates of source populations. Furthermore, pooling PBRs across SMUs to provide more biologically meaningful units and/or to match the scale at which the data on bycatch exists would likely make it difficult for decision makers where a pooled SMU would cross national, jurisdictional borders. This would require significant collaboration between the different nations to agree a common approach to making decisions about the sustainability of any activities in their respective waters. While this might be challenging, there are examples of how shared stocks are managed in fish stock management, so this is possible.

For context, the OSPAR QSR 2023 assessment calculated a combined grey seal bycatch at the scale of OSPAR Region III (all of the continental shelf waters off the west coast between Brittany and North Rona, including the Irish Sea) of 1632 individuals. This compared with a PBR for the same region of 3647, indicating that bycatch is currently estimated to be below a level that would cause significant concern for the conservation status of grey seals in OSPAR Region III. However, a large majority of the bycatch occurs in the southern half of the area (see answer 7 & 8 above) while a large majority of the grey seals breed (82% of pup production) and spend the summer foraging (56% of summer haulout counts) in the northern half of the region. These numbers suggest that neither managing bycatch at this large scale, nor at the smaller SMU scale is ideal. It may not be possible to manage other, more local activities against the background of bycatch mortality at this scale.

There is also the issue that the UK bycatch monitoring programme only includes UK vessels, which as described above, likely leads to an underestimate of total bycatch mortality. As described above, incorporating bycatch from non-UK vessels is not straightforward. A concerted effort to combine bycatch monitoring datasets from the different national bycatch monitoring schemes would be required to generate appropriate estimates that would incorporate all nationalities of fishing vessels. This is likely difficult to achieve and there are differences in data collection protocols across other nations' bycatch monitoring programmes that would need to be considered. Another option would be using the gear specific bycatch rates from the UK BMP and apply them to international fishing effort based on gear types, but given no real knowledge of the operational characteristics of other fleets this would only allow a crude estimate. Previous SCOS advice has highlighted that increased marine mammal bycatch monitoring on French, Irish and other EU registered vessels fishing in this region would be helpful (SCOS, 2022). SCOS 2020 concluded that producing robust estimates of total bycatch in each management region would be possible but will require a specifically targeted and resourced research effort.

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| **12. What are the latest bycatch estimates for seals in static nets associated with protected sites in Scotland (SACs)? Are there instances of seal bycatch in any other gear type in SACs?** | Scot Gov Q11 |
| *We are developing fisheries management measures for seal SACs in Scotland, so it would be good to draw this out from question 10, if evidence is available.* | |

**There are no current estimates of bycatch for seals associated with protected sites in Scotland. Bycatch monitoring is stratified by gear type rather than location and very little monitoring effort has been conducted in areas relevant to seal SACs in Scotland. Bycatch monitoring in Scotland has largely focused on large mesh net gear and sampling effort to date has concentrated on the deepwater net fishery that targets anglerfish. Most of the effort in this fishery in Scottish waters occurs along the shelf break and deep-water banks to the North and West of Scotland, with some**

**effort on the continental shelf around Shetland, relatively remote from seal SACs and high densities of seals. Monitoring of inshore netting activity has recently begun in areas of the Outer Hebrides where some netting is known to be taking place and results from this monitoring may inform this answer further and could be included in future SCOS reports.**

**One option to assess the potential for bycatch to occur in seal SACs or in the at-sea areas used by seals hauling out or breeding at SACs would be to conduct a risk mapping exercise. This would involve a mapping of areas of fishing effort associated with the fishing gears most likely to cause bycatch, which could be combined with SAC specific at sea seal usage maps (Carter *et al*., 2022) and used to generate estimates of the numbers of seals using that area that are also associated with SACs. This would highlight areas of potential greater risk and identify where further dedicated monitoring could be conducted to estimate bycatch in areas that are important for seals using SACs.**

**Another avenue is to examine the mandatory reporting data from fishers operating in Scottish waters to identify any bycatch occurring in SACs and in areas connected with SACs (assessed using telemetry data). There have been no reports of bycaught seals anywhere in Scotland since reporting became mandatory in 2021, however there are known issues with the reliability of self-reporting and this dataset does not provide definitive proof that there is no seal bycatch occurring in static nets in Scotland.**

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| **13. Where there is an interaction between seals and fisheries (bycatch / entanglement), what are the most effective or promising methods of mitigating these interactions in the different fishing gear(s)?** | Scot Gov Q12 |

**As reported in previous years by SCOS, there has been little attention paid to bycatch mitigation methods for UK seals. What little work has been done globally has focused on the mitigation of otariid mortality in trawl fisheries (CCAMLR 2017; Hamilton and Baker 2015; Lyle *et al*., 2016; Tilzey *et al*., 2006). A detailed answer to a similar question was provided in SCOS 2022. Gear modification, alternative methods or acoustic deterrents were the options that were discussed.**

**SCOS are 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. Switching to seal safe pot/trap fishing rather than netting (e.g. Konigson *et al*., 2015) could avoid or reduce seal bycatch. However, there are likely to be significant challenges with this. Any switch in UK fisheries to the use of pots/traps would need to be fully tested and is likely to be totally unsuitable for some target species, might require significant adaptations to vessels, may not be economical and could create safety issues for fishers unfamiliar with using pots. Analysis by Cosgrove et al. (2016) suggested higher rates of seal bycatch in tangle nets were associated with larger mesh sizes. Therefore reduction in net mesh sizes could potentially be considered although would need testing to explore effectiveness at reducing bycatch as well as any potential effect on catches.**

**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 areas of high seal density.**

**Use of acoustic deterrents is another possible mitigation method (e.g. see** Table 9**), but its widespread use on large numbers of nets may raise concerns about effects on non-target species. Although pingers aimed at reducing cetacean bycatch are already required by law for certain**

**vessels, they have not proven effective for the reduction of interactions with seals (see Q15). Trials of seal specific acoustic deterrents have been demonstrated to be effective at reducing depredation in Finnish trap-net fisheries (Lehtonen *et al.,* 2022). Use of startle devices such as the Targeted Acoustic Startle Technology** (TAST) **could go some way to alleviate concerns, but the cost effectiveness of such devices would need careful consideration, and licencing may be required for the introduction of additional noise into the marine environment.**

**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.**

| **14. What information about seals, specifically in the Celtic Sea and Western Channel Pelagic FMP area, will be crucial for the development of the FMP?** | Defra Q3 |
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| *The Celtic Sea and Western Channel Pelagic FMP covers herring, pilchard, greater silver smelt, horse mackerel and anchovy within ICES areas 7e, 7f, 7g, 7h (Welsh and English waters only). This FMP is being coordinated by the mNCEA programme who are taking a natural capital approach to its development. In terms of interactions, it would be good to understand whether the species constitute a significant part of seals diet (or food web understanding), whether there is crossover of fishing activity and important ecosystems for seals, and the key conflict that seals and fishers have in consideration of this fishery such as bycatch.* | |

**The fish species included in the Celtic Sea and Western Channel Pelagic Fisheries Management Plan (FMP) are herring, pilchard, greater silver smelt, horse mackerel and anchovy; these are not considered to be important components of the diet of seals in the UK generally. There is, however, a knowledge gap with regards the diet of seals in the southwest of the UK. SCOS recommends that an improved understanding of diet of seals around the UK, including the southwest, is needed to fully incorporate considerations of the potential for interactions between fisheries and seal populations into the development of FMPs for specific areas and fisheries. As highlighted in the answer to question 28 below, much of our current understanding of UK seal diet is more than ten years old and fish stocks and seal populations have changed considerably since then.**

**The fisheries covered by this FMP are not generally associated with seal bycatch, which is more associated with static net gear used to catch species such as monkfish, turbot, crayfish, pollack and spider crab. The species included in the FMP are typically caught using pelagic trawls, which are not generally associated with any significant seal bycatch.**

Fisheries Management Plans (FMPs) are evidence-based action plans developed in collaboration with the fishing industry and other stakeholders, aimed at delivering long-term sustainable fisheries alongside a productive and healthy marine environment.

There is an absence of detailed ecosystem models for the areas where most UK fisheries operate that would allow detailed exploration of the interactions between seals and fisheries to inform FMPs. A description of the generic information required about seals that would be useful to inform the development of FMPs was provided in SCOS 2023. This included assessment of the degree of overlap in seal diet with the target species and their sizes, the degree of spatial overlap between seal foraging and fishing activity, and the potential for direct interactions in the form of depredation and bycatch.

The species included in the Celtic Sea and Western Channel Pelagic FMP area (herring, pilchard, greater silver smelt, horse mackerel and anchovy) are not considered to be important components of seal diet. Herring does feature in the diet of both species of seals in the UK and Ireland although is not generally significant. According to Wilson and Hammond (2019), across the diet of grey and harbour seals, around the UK, herring did not form a major component of seal diet, although pelagic species such as herring, mackerel and sprat were regionally important in Orkney and Shetland for harbour seals. This may relate to regional differences in availability. Hammond and Wilson (2016) reported that herring consumption by both harbour and grey seals was 2% of the herring stock size in ICES Division 6a (west of Scotland) in 2002, which contrasts to the Baltic where herring comprised more than half of all prey items recovered from grey seals (Scharff-Olsen *et al*., 2019)

There have been few published studies of seal diet in the area covered by the FMP. A study on grey seal diet in Pembrokeshire between 1992 and 1994 found seals ate a wide range of fish species with gadoids and flatfish dominating seal diet (70%) over 3 years in Pembrokeshire (Strong, 1996). Herring comprised 6% of seal diet, with nearly all of the herring otoliths recovered from a single site. Nelms et al. (2019) found that gadids and flounders were the most common prey species identified by metabarcoding of DNA in seal scats collected from Skomer in Wales.

SCOS recommend that an improved understanding of diet of seals around the UK will be required to be able to fully incorporate considerations of the potential for interactions between fisheries and seal populations into the development of FMPs for specific areas and fisheries. As highlighted in Q28, SCOS note that much of this information is now over ten years old and is completely lacking for some regions. Existing data may not provide an accurate description of seal diets in areas where fish stocks and seal populations have changed. As outlined in the answer to Q6 about the harbour seal decline in southeast England, an update assessment of grey and harbour seal diet is underway in the Wash but there remains significant uncertainty in our current understanding of seal diet elsewhere around the UK.

It is worth noting that most of the UK's recorded seal bycatch occurs in the area covered by this FMP (see Q8 and 9). An analysis of causes of death of stranded grey seals in Cornwall and Isles of Scilly indicated that fisheries related trauma - bycatch and entanglement was the cause of death in 14% of all cases examined between 2000 and 2020. However, the fisheries covered by this FMP are not generally associated with seal bycatch. Seal bycatch is more common with static net gear used to catch species such as monkfish, turbot, crayfish, pollack and spider crab. The species included in the FMP are generally caught using pelagic trawls which are not generally associated with any significant seal bycatch.

SCOS 2023 provided details on the risk assessment that would allow managers to identify where potential interactions may pose a risk to fisheries or seal conservation.

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| **15. Can SCOS advise whether there is any evidence that seals are impacted by Acoustic Deterrent Devices (ADDs) which are targeted at other species (i.e., cetaceans) to reduce bycatch?** | Defra Q4a |
| *Research is ongoing on the impacts of ADDs specifically targeted at harbour porpoise, however limited evidence is available on whether seals may be* | |

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| *impacted by these devices, for example disturbance, or whether they act as a "dinner bell"?* | |

**The use of acoustic deterrents or 'pingers' to reduce cetacean bycatch has long been considered to have the potential for a 'dinner bell' effect, whereby seals are thought to associate the noise emitted by pingers with the presence of food (e.g. Bordino *et al*., 2002, Øien & Haug,2017 ). However, evidence from the literature is equivocal with some studies unable to find a direct effect (e.g. Gearin *et al*., 2000, Carreta and Barlow, 2011). More recent designs of pingers claim to be "seal-safe", meaning they are claimed to be inaudible to seals owing to a higher sound frequency, while remaining effective at deterring porpoises. Although these will still be audible, albeit at shorter ranges, tests of these higher frequency pingers so far have not indicated the presence of any dinner bell effect (e.g. Carlén and Cosentino, 2023).**

**The conflicting evidence on the presence of a dinner bell effect, or whether pingers deter seals from nets suggests that factors other than pinger presence have a stronger influence on seal depredation and bycatch, particularly when higher frequency 'seal safe' pingers are used. Given the limited distance that pingers will be audible to seals, it is unlikely that there is any potential for significant disturbance to seals from the use of pingers or for them to act as a "dinner bell" over significant distances.**

There is limited research on the effect on seals of the acoustic deterrent devices used to reduce bycatch of cetaceans. These devices are commonly termed 'pingers' to differentiate from the louder acoustic deterrent or harassment devices used to deter seals away from fish farms or to deter various marine mammal species away from noisy activities in the sea such as pile driving and the detonation of unexploded ordinance to avoid auditory injury. Most of the research on the use of pingers is focused on their effects on rates of cetacean bycatch, including recent and ongoing trials in Cornwall carried out by the UK Clean Catch Initiative. Most of the attention in relation to pingers and seals has been focused on the potential for pingers to aggravate seal depredation or increase rates of bycatch caused by the so called 'dinner bell' effect, whereby it is proposed that seals learn to associate the noise emitted from pingers with the presence of food (Bordino *et al*., 2002)

Grey and harbour seal hearing range overlaps with the frequency range of several commercially available pingers, and therefore these pingers will be audible to seals. Although Bordino *et al.* (2002) concluded that a 'dinner bell' effect explained the result that South American sea-lions (*Otaria flavescens*) damaged fish in active pinger nets significantly more than silent nets, examination of the literature reveals equivocal support for the existence of this effect more widely.

Gearin *et al.* (2000) found there was no significant differences in harbour seal bycatch between alarmed or control nets, nor was there any significant differences in depredation of caught fish by seals or sea lions were noted during the studies, although sample sizes were small. They also concluded that the fact that 20 harbour seals were caught in alarmed nets indicates that they were not deterred by the sounds emitted.

Barlow and Cameron (2003) found that nets with pingers caught significantly fewer Californian sea lions, northern elephant seals and other pinnipeds. Carreta and Barlow (2011) found that bycatch rates of California sea lions in set nets with >30 pingers were nearly double that of sets without pingers. However, when further investigated, depredation was not directly linked to pinger use. The best predictors of depredation were other factors such as the total catch, month, area and nighttime use of deck lights on vessels. Northern elephant seal bycatch significantly reduced with pinger use.

Øien & Haug (2017) reported the results of a small pilot study that indicated that harbour seals were bycaught three times more frequently in nets with a Future Oceans porpoise pinger (10 kHz), suggestive of an attractive effect but no difference in seal bycatch rates when a Fishtek Banana pinger (50-120 kHz) was used.

More recent models of pingers claim to be “seal-safe”, meaning they are claimed to be inaudible to seals while remaining effective at deterring porpoises. Given recent evidence that the upper limit of seals’ underwater hearing range is as high as 180 kHz these pingers will still be audible to seals, but at much lower distances. Königson *et al*. (2022) calculated the maximum audible range of a modified Fishtek Banana pinger (modified to have a lower frequency limit of 59 kHz) as 80 m and concluded this would be sufficient to avoid a significant dinner bell effect. This would also limit any potential for any significant disturbance to seals. This paper makes reference to field trials of the pinger in a commercial fishery in Swedish Kattegat and Skagerak waters, but no further work from this region appears to have been published.

Carlén and Cosentino (2023) demonstrated that the use of two different types of high frequency pingers (the modified Fishtek Banana Pinger and a 70 kHz Future Oceans dolphin pinger) in Baltic Sea static net fisheries did not result in any ‘dinner bell effect’ in fact this study demonstrated a small and negative effect of seal related catch loss when nets are equipped with pingers, although the small extent of the difference (7.23 kg of loss compared to 7.55 kg of loss) does not provide evidence that pingers deter grey seals.

Pilzecker (2022) carried out a study for a Masters thesis that investigated the presence of a dinner bell effect in seals in three different pingers that are marketed as being ‘seal-safe’ (a modified Fishtek Banana pinger, Future Oceans Netguard dolphin pinger (65-69 KHz) and a custom-configured PAL pinger from F3 Maritime Technology (40-156 kHz)). This study tested over a relatively short period of time (~2 weeks) by deploying buoy stations baited with dead herring and cod pots baited with live cod with and without pingers close to a grey seal haulout in Utklippan, Sweden. No indication of a dinner bell effect was found. However, there was very limited seal activity at the stations and the low rate of seal engagement with either treatment or control and the short duration of the study makes it impossible to draw any conclusions.

In Cornwall, UK, a study using captive grey seals by the Cornwall Wildlife Trust, Cornwall Seal Group Research Trust & Cornish Seal Sanctuary (2013) reported no significant attraction of seals to the 50-120 kHz Fishtek Marine banana pinger.

The conflicting evidence on the presence of a dinner bell effect, or whether pingers deter seals from nets suggests that factors other than pinger presence have a stronger influence on seal depredation and bycatch, particularly when higher frequency ‘seal safe’ pingers are used. Given the limited distance that pingers will be audible to seals, it is unlikely that there is any potential for significant disturbance to seals from the use of pingers or for them to act as a “dinner bell” over significant distances.

## Fisheries interactions – seals in rivers

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| **16. Following on from the 2023 interim advice (MD Q2) on planned or ongoing studies into the efficacy of Acoustic Deterrent Devices in rivers (in relation to seal behaviour/predation), can SCOS provide an update on the efficacy of ADDs given the most recent research in rivers?**<br><br>**17. Can SCOS advise on any update in evidence of interactions between seals and Acoustic Startle Devices?** | Scot Gov Q14<br><br>Defra Q4b |
| *The use of non-lethal measures such as ADDs to protect salmon populations and associated river fisheries from seal predation remains a priority given the changes to the Marine (Scotland) Act 2010. However, there is a need for more robust evidence on their efficacy to support decision making for their use, i.e. how do we establish ADDs are or are not efficient deterring seals when* | |

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| *testing recommended non-lethal measures?*<br><br>*MMO and Defra have conducted further studies however evidence gaps remain. It would be helpful to be made aware of any further evidence available.* | |

**Further to the update provided in the 2023 interim SCOS advice, there have been no further SMRU trials of any acoustic deterrent devices in Scottish rivers. A summary is given of other known recent trials of acoustic deterrent devices on pinnipeds, which are exclusively trials of the Genuswave Targeted Acoustic Startle Technology (TAST) device.**

**In general terms, previous research using a variety of ADD types in rivers indicates that ADDs are effective in deterring some seals but not all. Except for the recent SMRU Scottish river trials using a triggered TAST device, ADDs have been rarely shown to be 100% effective. Nevertheless, they can substantially reduce impacts of seals in rivers as demonstrated in scientific trials. However, there are instances where the demonstrated level of effectiveness has been considered to be disappointing and there is a need for further examination of methods to maximise efficiency in a range of deployment scenarios. Early indications are that a triggered approach may result in an increase in efficacy over previous approaches.**

Further to the update provided in the 2023 interim SCOS advice, there have been no further SMRU trials of any acoustic deterrent devices in Scottish rivers. SMRU fieldwork on this project in winter 2023/24 focused on the collection of training data for the development of an automated system to detect seals to trigger deterrents using multibeam sonar. This is to allow the triggering of deterrents only in the presence of seals to increase their effectiveness and reduce potential for impacts on non-target species as recommended by Thompson *et al*. (2021). As reported in SCOS (2023) manual triggering of the TAST signal in the presence of seals approaching the site of the device upriver resulted in 100% effective deterrence with all seals immediately stopping travel upriver and moving back downstream. Further trials in the River North Esk winter 2024/25 will test a prototype linked automated detection and deterrent system, where the deterrent will be triggered automatically when seals are detected on a multibeam sonar device deployed in the rivers. Further resource and capacity would be required to trial this system in a wider range of environments and over the longer term.

There have been several other recent and ongoing trials of the Genuswave TAST device in rivers and fisheries. Table 9 provides a summary of these trials. In general, these studies report reductions in predation associated with the use of the TAST device but with various degrees of effectiveness. No studies report 100% effectiveness in terms of a complete elimination of seal presence or predation. Nevertheless, if the devices are deployed carefully and consistently, then it is likely that substantial reduction in impacts of seals can be achieved. SCOS are not aware of any other scientific trials with acoustic deterrent devices with seals.

In general terms, previous research using a variety of ADD types in rivers indicates that ADDs are effective in deterring some seals but not all; with the exception of the recent Scottish river study mentioned above using a triggered TAST device, ADDs have been rarely shown to be 100% effective (Graham *et al*., 2009, Harris 2011, Harris *et al*., 2014). In part, variation in the performance of ADDs may result from difficulty of deployment in hostile river environments. It can be difficult to maintain and to power ADD equipment at remote river sites, and locations maybe prone to flooding – resulting in damage or loss of apparatus. . There may also be differences in how seals respond to different types of device. Early indications are that a triggered approach may result in an increase in efficacy over previous approaches. Indeed, early trials suggest efficiencies near 100% may be possible.

*Table 9. Summary of global studies testing the efficacy of Targeted Acoustic Startle Technology (TAST) Device in rivers and fisheries*

| Local lead | Institution | Species | Funding | Research topic & reported results |
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| Laurie Jemison | Alaska State Department of Fish & Game, AK, USA | Steller sea lions | NOAA BREP grant. | Preserving catch of salmon troll fishers while reducing interactions with Steller sea lions (SSL): targeted acoustic startle technology (TAST) to deter SSLs from troll gear in Southeast Alaska. Interim report.<br>• Reduction in predation events within 40m of TAST. No effect on foraging behaviour at distances of >40m.<br>• Localised distance increase during sound exposure.<br>• Potential for reducing bycatch of sea lions.<br>• Detailed analysis (including on fishing vessels) is still work in progress. |
| Rob Williams | Oceans Initiative, WA, USA | Harbour seals, Steller sea lions (low numbers) | Puget Sound Partnership, Salish Sea Marine Survival Project | Employing Targeted Acoustic Startle Technology (TAST) to deter harbour seal predation on endangered salmonids at the Ballard Locks, Seattle, WA. Final Report, March 5, 2021<br>• 45% increase in fish passage (i.e. endangered salmon) at fish ladder.<br>• 49% reduction in predation events when TAST was on. |
| Rob Williams | Oceans Initiative, WA, USA | Harbour seals | | Various projects in the Pacific North West (Whatcom, Ballard Locks & Olympia & Nisqually, 2020-2023).<br>Meta-analysis of projects from 2020-2023 :<br>Williams *et al*. (in prep): Mitigating conservation conflicts: non-lethal approaches to reduce seal predation on salmon at human-built bottlenecks. |
| Samantha Cox | University College Cork, Republic of Ireland | Grey seals | Predation: EU (Marie Curie), Marine Institute | Predation data: work in progress<br>PAM: Assessment of acoustic exposure & presence of cetaceans around static-net fisheries equipped with the targeted acoustic startle technology |

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| | | | PAM: SEAFICS, “Seals and Fisheries Co-existing Sustainably” | (TAST) to mitigate seal depredation. Final Report to National Parks and Wildlife Service (NPWS)<br>• No significant change in detection likelihood of harbour porpoise NBHF clicks and *delphinid* whistles and clicks when TAST is ON compared to OFF periods. Higher vocalisation rates during nighttime hours compared to during the day. |
| David Whyte, Thomas Goetz & Vincent Janik | Rosehearty Fishing Association, University of St Andrews, Marine Scotland Science, NECFRIG. UK. | Grey seals | North East Coast Regional Inshore Fishery Group (NECRIFG) | Non-Lethal Seal Deterrent in the North East Scotland Handline Mackerel Fishery (2021). A Trial using Targeted Acoustic Startle Technology (TAST). https://rifg.scot/storage/article/49/Non-Lethal%20Seal%20Deterrent%20in%20the%20North%20East%20Scotland%20Handline%20Mackerel%20Fishery.pdf<br>• deterrence effect of TAST on seal activity directly around fishing vessels<br>• seal detections on the vessels’ fish finder (sonar) decreased by 97% |
| MMO (Marine Management Organisation),<br>ABPmer: Suzannah Walmsley, UK | DEFRA/MMO | Grey seals | | MMO (2020). Assessing Non-Lethal Seal Deterrent Options: Fishing Trials Technical<br>Report. A report produced for the Marine Management Organisation. MMO Project<br>No: 1131, February 2020, 41pp.<br>https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/873280/MMO1131_Trials_Tech_Report_PubCopy_200203.pdf<br>• 74% increase in catch in the test net compared to control nets |
| Kathleen A. McKeegan, Alejandro Acevedo-Gutiérrez | Western Washington University, Bellingham, WA, USA | Harbour seals | MSc project | McKeegan, K.A., Clayton, K., Williams, R. *et al.* The effect of a startle-eliciting device on the foraging success of individual harbor seals (*Phoca vitulina*). *Sci Rep* **14**, 3719 (2024). https://doi.org/10.1038/s41598-024-54175-w<br>• 43.8% reduction in predation events on endangered salmon |

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| **18. Current stakeholder view is that any seal(s) found within river systems are there for the purpose of predating on Atlantic salmon. Can SCOS advise on whether the current scientific evidence base supports this view, appreciating that this can vary dependent on where the seals are in the river (e.g., tidal reaches) and the river itself. Furthermore, what are the current estimates of the amount of juvenile and adult salmon consumed by seals in rivers and how robust are those estimates? Where there is limited evidence, what data can be gathered to help address these questions?** | Scot Gov Q15 |
| *There is a perception by river fishing interests that any seal in a river is there to predate on salmon (juveniles and adults) and that removal of (specific) seals can help Atlantic salmon which have been classified as an endangered species. It would be helpful to understand whether the current evidence supports this – for example, how often seals enter rivers and what they do when they are there (splitting this into the estuary/tidal reaches and higher up into the river itself), and what the current estimates of the amount of juvenile and adult salmon consumed by seals in rivers and how robust are those estimates? We need to establish this point to help to support our licensing process as advice on data collection to provide this evidence would be helpful for licence applicants in establishing their evidence base.* | |

**There are extensive reports of seal activity in rivers in Scotland and eastern England. Seal activity in rivers is likely to represent foraging behaviour. In Scottish and Northern English rivers seals are likely to be targeting salmonids, but in rivers in south-east England, it is unlikely that salmonids form a significant part of the diet.**

**Evidence that seals travel into rivers to eat salmonid fish has been reported in many rivers globally and in Scotland over several decades. Evidence includes the presence of seal damage on fish, visual observations of seals eating salmonids in rivers and the analysis of diet through scat and stomach content analysis and evidence that both the likelihood of seeing harbour seals in a river and occurrence of salmonids in the seal diet increased with numbers of salmon. Observations of predation in the tidal reaches of Scottish rivers indicate that seals l consumed salmon, sea trout, eels, flatfish and a number of unidentified prey items. Dedicated observations are rarer beyond the tidal limits, but seals have been observed feeding on salmonids. There are no recent estimates of the total amount of salmon or salmonid prey taken by seals in any Scottish rivers, however there are published estimates from the mid 1990s for the River Don and Dee.**

**Observations have demonstrated that it is generally a small number of seals that become specialist river users, with individuals seen across multiple years of study.**

**To provide updated estimates of seal predation on salmon in Scottish rivers, a number of parameters would need to be measured or estimated. These include: the numbers, species and sizes of seals present in a river, along with estimates of the species, number, sizes and life stages of salmon consumed by them. To scale up from observations of individual seals to total predation requires information on the average energy requirements of seals and the overall proportion that salmon make up in the diet. There are some existing data from observational studies on the River Dee that could inform an estimate of the minimum amount of salmon consumed. In cases where a salmon population is so weak that insufficient eggs are spawned to use the available rearing habitat fully, any reduction in losses of adult salmon and emigrating smolts to seals (and other predators) would improve the salmon conservation status.**

If a seal regularly returns to a location in a river and that location is not used for breeding or resting, then the most likely explanation is that the seal is there to forage. Evidence that seals travel into rivers to eat salmonid fish has been reported globally (e.g. Roffe, 1980, Brown and Mate, 1983, Bigg *et al*., 1990, Zamon, 2001, Naughton *et al*., 2011, Kusnierz *et al*., 2014) and in Scotland (e.g. Carter *et al.,* 2001, Middlemas *et al*., 2006., Graham *et al.*, 2011) for several decades. Evidence includes the presence of seal damage on fish, visual observations of seals eating salmonids in rivers and the analysis of diet through scat and stomach content analysis. The likelihood of seeing harbour seals in a river increased with numbers of salmon (a numerical response) as did occurrence of salmonids in the seal diet (a functional response) (Middlemas *et al.,* 2006).

The dominant prey species may differ between seal species, time of year and location in the river. A wide range of prey species exist in the tidal reaches of rivers; accordingly, seals are seen to feed on a wide range of species in these areas (Graham *et al.,* 2011). Above the tidal reaches fish species diversity is lower; the main prey biomass available to seals is likely salmon and brown trout in northern Scottish rivers, but comprises a wider range of fish species in more southern rivers.

Reports of extensive seal activity in rivers in eastern England are presented in answer 19 below. In several of those rivers, particularly in south-east England, it is unlikely that salmonids form a significant part of the diet, but there is a general absence of information on the prey consumed.

The predation of salmonid fishes in rivers, is a significant pressure affecting conservation status of salmonid fishes and threatening economic benefits of recreational fishing in many countries. Salmon and sea trout are at their most highly aggregated in the narrow riverine environment and, furthermore, are a rapidly replenishing food source as they move past predators on their out- and in-going migrations. In many locations seals have clearly learned to use the riverine habitats to exploit opportunities to eat salmon and sea trout.

In Scotland, observational studies have focused on the tidal reaches of east coast rivers, however, some data are available from above tidal reaches. Graham *et al.* (2011) carried out observations at a short section of the tidal reaches of three rivers in the Moray Firth, over three years. Seals were observed to consume salmonids, eels, flatfish and various unidentified prey items. There were seasonal differences with salmonid consumption being observed more frequently over the winter months, matching the pattern in seal occurrence. Digestive tract samples were also taken from eight seals shot in rivers under licence and from one live caught seal – analysis of these samples indicated that 22% of these samples tested positive for salmon and 44% tested positive for trout, a significantly higher rate for both species than scat samples taken from coastal sites where the relative proportions were 7 and 8 % respectively. This suggests that individuals in rivers where salmon are abundant are more likely to consume salmonids than those in the general population.

Carter *et al.* (2001) carried out observations of seals on the River Don and the River Dee and observed both grey and harbour seals feeding on salmonids, as well as on flounder, unidentified roundfish and other unidentified prey.

The study documented in Harris and Northridge (2017) and Harris *et al*. (2019) recorded predation events in Aberdeen Harbour and the river Dee over a period of 12 months between April 2016 and March 2017 and documented 124 predation events of fish brought to the surface by seals in Aberdeen Harbour and the river Dee over the 12 month period. The largest number of predation events related to salmonids (60%), primarily eaten by grey seals. Seventy-five salmonid predation events were recorded; events were highest in winter, with another peak in June. Other species were observed being eaten, including flatfish, eels, eelpouts and sea bass, these species together comprising 10% of all observed predation events. Unidentified species comprised 22.5% of all predation events observed. Most predation events, during dedicated effort related observation periods, were within Aberdeen Harbour (Harris & Northridge 2017). Observed predation rates at sites above the harbour were low, particularly above the Normal Tidal Limit (NTL), but observation effort was also considerably lower here. Seals are known to forage at sites throughout the lower 35km of the river.

Graham *et al.* (2011) indicated, using photo-ID, that at that time it was a small number of seals using the surveyed river areas, suggesting that individuals become specialised as river users. They also found that the majority of the identified grey seals and a third of the harbour seals, were seen across multiple years of the study, further supporting the idea of river specialists. This study concluded that at that time "*Only a few individual harbour and grey seals have been shown to use rivers suggesting that the maximum limit of seals permitted to be shot annually in rivers is sufficient to provide acceptable protection against interactions with fisheries in these areas. Moreover, the small proportion of the overall population seen in rivers and the existence of 'rogue' individuals indicates that, given that only a small number of seals can be shot, the greatest benefit to fish stocks will be achieved by focusing control on those individuals that use rivers most extensively and have the greatest per capita consumption of salmon and sea trout*." Harris *et al*. (2019) identified a minimum estimate of 19 grey seals and 17 harbour seals using Aberdeen Harbour and the river Dee from observations using photo ID over a period of 12 months between April 2016 and March 2017. When supporting information from river staff was included a total of three individual harbour seals were identified using sites above the NTL although the majority of the sightings here were of a single juvenile female harbour seal. No grey seals were seen above the NTL during observation periods or incidental sightings by river staff. It is clear from these studies that detailed observations of seals in individual rivers, using photo-ID, is required to quantify the number and turnover of seals using any river.

There are no recent estimates of the amount of salmonid prey taken by seals in any Scottish rivers. Carter *et al*. 2001 estimated, based on their observations of surface feeding, that a total of 864 large salmonid fishes were consumed annually in 1993-1994 in the River Dee with 531 being taken annually over 1995-1996. The equivalent figures for the River Don were 97 and 258. Based on these estimates, Carter *et al*. (2001) concluded that seal predation was an order of magnitude less than the numbers of salmonids caught and killed by anglers at that time. Subsequently, catches of salmon have decreased substantially and in most cases those salmon caught by anglers are released and not killed.

To provide updated estimates of seal predation on salmonids in Scottish rivers, several parameters would need to be measured or estimated (e.g. Butler *et al.*2006). These include estimates of the species and numbers of seals present in a river, along with an estimate of the species, number and life stages of salmonids consumed by them. To scale up from observations of individual seals to total predation would require information on the average energy requirements of seals and the overall proportion that each salmonid species makes up in the diet. As outlined above, new approaches will be required to assess impacts of seals on pre-marine stages of the salmon life cycle. There is also a need to distinguish between predation on salmon and on trout, rather than grouping these two species as "salmonids" as tends to be done in observational studies. There are existing data that could inform an estimate of the extent of salmonid predation by seals in rivers, but this is restricted to a very small number of rivers. For example, Harris et al. (2020) modelled observed predation events with respect to various explanatory covariates to enable hour by hour predictions of the probability of predation events over the whole 12-month period of their study. To provide a minimum estimate of salmonid predation for the River Dee, these data could be combined with observed rates of consumption of salmonids, independent information on the proportion of salmonids in seal diet (e.g. from scat analysis or digestive tract samples), published estimates of the energy requirements of seals, and an estimate of the total number of seals in the river over the study period. Extrapolating this estimate of salmonid predation of the River Dee to the level of across multiple rivers, and separating impacts on salmon and trout, would be associated with significant uncertainty.

In cases where a salmon population is so weak that insufficient eggs are spawned to use the available rearing habitat fully, any reduction in the losses of adult salmon or of emigrating smolts to seals (and other predators) would improve the salmon conservation status. Currently salmon populations are so weak in upper spawning tributaries and in many whole Scottish rivers that killing of salmon by angling is prohibited. Furthermore, a general trend of decline in numbers of salmon has been observed across rivers in Scotland and indeed throughout countries bordering the N Atlantic basin. Scottish Government has introduced a Wild Salmon Strategy to seek to manage and reduce pressures on Atlantic salmon. Seals in rivers constitute one such pressure. Management of seal impacts on wild Atlantic salmon requires a consideration of the conservation of two important and protected species.

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| **19. Noting the findings of Thompson *et al* (2021) and the results of ongoing research (including SMRU, 2023) can SCOS advise on the most effective and practical methods to address seal interactions in rivers, noting that some seals have now been found a considerable way up rivers?** | Scot Gov Q16 |
| *Seal interactions in some rivers are becoming a significant problem, with some DSFBs reporting seals up to 50km up rivers. It is therefore important that we find timely solutions that are effective, practical and cost effective to allow investment in the most promising solutions.* | |

**There is no single, effective non-lethal solution to address the problem of seal depredation in rivers. The most commonly used methods involve relatively simple harassment methods to drive seals away from predation areas, but are generally not effective at addressing problem interactions in the long term. Most methods employed involve deterring individual 'specialist' seals from rivers or preventing them from accessing predation locations.**

**The most effective methods are likely to be those which lead to the prevention of seals travelling up rivers including physical or acoustic barriers. There are several practical issues to be addressed with these measures, as detailed in Thompson *et al*. (2021).**

**As noted above, initial trials with a triggered TAST device have shown promise and further work is necessary to demonstrate effectiveness in a wider range of environments and over the longer term.**

As highlighted in Thompson *et al*. (2021) there is no single, effective non-lethal solution to address the problem of seal depredation in rivers. According to Thompson *et al*. (2021) the most common methods involve relatively simple harassment methods to drive seals away from predation areas, but are generally not effective at addressing problem interactions in the long term. Most methods employed involve deterring individual 'specialist' seals from rivers or preventing them from accessing predation locations. The most effective methods are likely to be those which lead to the prevention of seals travelling up rivers including physical or acoustic barriers. There are several practical issues to be addressed with these measures, as detailed in Thompson *et al*. (2021).

Physical exclusion remains a potentially useful measure, for example using resistance board weirs, which are used to count fish migrating upstream in rivers, or to trap and process fish, to block or segregate species. Existing models would require additional developments, for example to stop seals climbing over them or to operate in higher river flow rates when seals may be more likely to try to pass upstream. However, how this engineering might be tailored to meet seal exclusion needs or seal capture needs requires investigation. Given the continuing effort to remove barriers to fish passage, any such measure would require investigation of the behavioural responses of migrating salmon to a barrier, and investigation of engineering solutions such as increasing bar/picket spacing to reduce both water resistance and impact on salmon. Other issues that require investigation include: the identification of suitable sites; guidance would be required on the river width and depths that a weir could be suitably installed in, and whether they would be suitable for year round use; the cost of installation and ongoing maintenance (recent estimates for the installation of resistance weirs in Scottish rivers have ranged from £60k to £120k), as well as the cost of consultancy support and fees associated with obtaining statutory consents; various consents would be required, including NatureScot licenses for use in SACs, and from SEPA. The effect of any such barrier on recreational river users, such as canoeists should also be considered.

A summary of research on the effectiveness of acoustic deterrents in rivers is provided above in response to question 5. Active deterrence will likely be made more effective by timely detection of seals and triggering deterrents in their presence. Compared with use of physical barriers, this approach has a substantial advantage of minimal disturbance to non-target animals and recreational river users. Minimising the use of deterrents and targeting them only at times when seals are actively involved in predation or when they are at sensitive locations, should reduce the likelihood of seals habituating to the deterrents and reduce the frequency and duration of disturbance to non-target species. As noted above, manual triggering of the TAST signal in the presence of seals swimming upriver towards the device resulted in 100% effective deterrence, with all seals immediately stopping travel upriver and moving back downstream. Further trials in the River North Esk in winter 2024/25 will test a prototype linked automated detection system to trigger the deterrent signal in the presence of seals. Further resource and capacity is required to trial this system in a wider range of environments and over the longer term.

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| **20. Can SCOS advise on whether there is evidence that seals are increasingly entering rivers and freshwater environments?** | Defra Q6a |
| *Population dynamics, climate change or other factors appear to be resulting in more animals being observed in rivers and in new locations- the result is impacts in freshwaters especially on resident fish stocks and conflicts with angling interests* | |

**Seals have been known to frequent rivers and freshwater environments in the UK and globally for decades. Grey seal populations are increasing rapidly in the North Sea, so the number of seals available to explore east coast river systems is also increasing. Higher levels of competition for prey resources in the North Sea may increase the likelihood of seals entering rivers.**

**There does not appear to be any published scientific evidence or systematic data available to support or reject the conclusion that the rate of occurrence of seals in rivers and freshwater environments in the UK has increased. There have been anecdotal reports of increasing presence of seals, with one public reporting scheme in Scotland reporting year on year increases in the number of records submitted since 2022. This observation cannot be used to confidently indicate a real trend due to confounding with increase in effort and awareness of the app. However, it is consistent with reported anecdotal impressions.**

Seals have long been known to frequent rivers and freshwater environments in the UK and globally. Anderson, (1990) highlights anecdotal reports of seals in several rivers in the east coast of the UK over previous decades, mentioning the Don, Trent, Humber, Witham, Ouse, Nene, Welland and Thames. Some of these reports were considerable distances from the tidal limits, e.g. between 1995 and 2017 harbour seals were regularly recorded pupping on the banks of the river Ouse in Cambridgeshire, approximately 60 km upstream of the tidal reaches of The Wash (SMRU unpublished; Hows, 2017)). Lyman *et al*. (2002) describe archaeological records indicating harbour seals and Steller sea lions present as far as 324 km upstream on the Columbia River during the 19th and early 20th centuries. Harbour seals were in the lower Columbia River as much as 10,000 years ago.

Seal predation in rivers has been documented in many studies throughout the Pacific Northwest in North America (Roffe and Mate 1984, Bigg *et al.,* 1990, Stanley and Shaffer 1995, Yurk and Trites 2000, Orr *et al.,* 2004) and in the United Kingdom (Carter *et al.,* 2001, Middlemas *et al.,* 2005).

There doesn't appear to be any published evidence or data available to support the conclusion that the rate of occurrence of seals in rivers and freshwater environments in the UK has increased, although there is an absence of any systematic data collection that would allow this possibility to be confidently evaluated. There have been anecdotal reports of increasing presence of seals, both from river fisheries in England, as well as from district salmon fishery boards and angling associations in Scotland, with an apparent increasing number of public sightings being reported. For example, the citizen science reporting scheme developed by Fisheries Management Scotland collates publicly submitted sightings of seals in rivers in Scotland https://fms.scot/in-river-seal-sightings/. Sightings submitted to the app totalled 55 observations of seals in Scottish rivers in 2022, 103 in 2023 and 67 so far in 2024. While citizen science efforts such as this can be useful in gathering information on the extent of seal occurrence in rivers, trends must be interpreted with caution given potential biases associated with such presence-only data and effects of changes in effort. However, citizen science approaches are increasingly being designed to take these issues into account (e.g. Walker and Taylor, 2017, Feldman *et al*., 2021, Carlen *et al*., 2023).

The increase in the grey seal population on North Sea coasts has likely increased resource competition, and under such circumstances even a static proportion of 'river specialists' (e.g. 1% as reported by Graham et al., 2011) would naturally result in more grey seals using rivers. Conversely, a decline in harbour seals near the large east coast rivers might be expected to result in an opposite trend. However, it is also possible that interactions with grey seals may force harbour seals into more marginal habitats, including rivers. It is also possible that such specialised river use may increase in the population through social learning, although there is little evidence to evaluate this. Furthermore, increased use of rivers might result from reduced foraging efficiency at sea, both through competition and reduction in suitable prey. In short, anecdotal observation of increased movement of seals into rivers is important and requires scientific scrutiny.

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| **21. Is there a risk of these animals either becoming 'naturalised' in locations where there are initially good feeding opportunities or becoming trapped in these environments?** | Defra Q6b |

**There are many examples of seals swimming up rivers in the UK and remaining upstream to forage. Although there are many reports of seal sightings in rivers and lochs in Scotland, there are few reports of individuals being present for extended periods of time and being unable to return to sea. In Cambridgeshire there are repeated records of harbour seals pupping up to 70 km upstream in the River Ouse and reports of seals present throughout the year, although without compelling evidence that individuals remain for long periods. The length of stay in such**

**environments is likely related to food availability and opportunity to haul out. The likelihood of entrapment will vary on case-by-case basis and will depend on the characteristics of the site. However, seals are adept at moving on land and can climb onto riverbanks to avoid in-water obstacles such as dams and weirs, and have been known to navigate lock systems.**

Evidence from Scottish studies, and elsewhere, suggests the repeated presence of individual ‘specialist seals’ in rivers, observed predating largely on salmonids in Scotland (see answer to Q16 above), and small cyprinid fishes in southeast English rivers. However, these seals do not generally become permanently resident in rivers and are likely to also exploit prey in the marine environment. In Scotland, seal presence in rivers is generally seasonal, with peak activity coinciding with peak run times of salmon arriving in rivers on their return migrations to spawn or with salmon kelts leaving rivers after having spawned (Graham *et al*., 2011, Harris *et al*., 2020). Conversely, in southeast England there are repeated records of harbour seals present in rivers throughout the year, although without compelling evidence that individuals remain for long periods. Seal presence in rivers has also been reported to be seasonal elsewhere, and has been related to the seasonal presence of salmonid prey, e.g. in the Pacific Northwest, USA (Roffe and Mate, 1984, Brown and Mate 1983).

There is very little published information on the occurrence or patterns of seals in rivers in England. The residency of seals in rivers will likely be influenced by the availability of prey. Anderson, (1990) highlighted several anecdotal reports of seals in several rivers on the east coast of the UK over previous decades, including in the Don, Trent, Humber, Witham, Ouse, Nene, Welland and Thames. Some of the reports were considerable distances from the tidal limits. For example, between 1995 and 2017 harbour seals were regularly recorded pupping on the banks of the river Ouse in Cambridgeshire, approximately 60km upstream of the tidal reaches of The Wash, and several harbour seals appeared to be present in that section of river for long periods each year (SMRU unpublished; Hows, 2017)). An attempt to relocate a harbour seal from that section of the river Ouse in the early 1980s failed when the seal returned to its capture site within a week of being translocated to the open sea (Thompson *et al*., 2021).

There are anecdotal reports of seals becoming habituated to human presence and being present in rivers for extended periods of time. For example, a known adult female grey sea in the river Dee in Aberdeen regularly hauls out on the riverbanks with people walking past within a few metres. Williamson (1988) reports a seal present in Loch Ness for several months. A harbour seal was present in Rochford Reservoir in Essex in December 2022 and was reported to be ‘trapped’ by news outlets. The seal initially evaded multiple attempts at capture using nets but later died when it was darted with anaesthetic and subsequently drowned. This incident highlights the well-known, extreme drowning risk posed to seals by attempting to use anaesthetic darting of free swimming seals in the water, as noted in previous SCOS advice (SCOS 2020).

SCOS are aware of reports of seals within the River Nene from anglers and the local angling association with claims that ‘at least one of these seals have been present for over 13 months ’. Presumably this is based on individual identification from pelage markings or visible flipper tag.

The question of seals becoming ‘naturalised’ implies that foraging in freshwater rivers is an unnatural behaviour. This is not the case. Throughout their range harbour seals frequent rivers, in some cases swimming >100km upstream to forage (see Q20 above). If a seal has moved up a river to feed it is unlikely to stay if there is insufficient prey. Harbour and grey seals can easily swim 100km in a day (for example see: Thompson *et al.,* 1991; McConnell *et al.,* 1999). And both species routinely undergo protracted periods of fasting without suffering any harm, so returning to the sea if foraging opportunities disappear is not a problem for individual seals. Removing a seal from a river is unlikely to be required for the welfare of that seal and is therefore a management decision that would need to be justified under an existing  licensable purpose as set out in the Marine (Scotland) Act 2010 in Scotland and the Conservation of Seals Act (1970) in England, Wales and Northern Ireland.

It is difficult to comment on the risk of entrapment without knowledge of the specific river setting and how any structures such as dams or locks could lead to such entrapment, hence this risk is best assessed and addressed on a case-by-case basis. Seals are generally adept at moving on land and have the option of climbing onto riverbanks and moving around any in-water obstructions and have been known to navigate lock systems.

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| **22. Can SCOS advise how to minimise the risks of initial entry and/or then managing individuals who have become residents (in some cases for more than 12 months)? Linked to question 5 (below), is there an increased risk with rehabilitated animals?** | Defra Q6c |

**Methods to prevent seals from entering rivers and moving upstream are discussed in the answers to questions from the Scottish Government above (Q15 and Q18). Methods for the prevention of entry of seals to rivers and for the non-lethal control of seals in rivers are extensively reviewed in Thompson *et al.* (2021). Physical barriers or triggered deterrents are considered the most potentially effective methods to prevent seals entering rivers. Trials with triggered acoustic deterrents have indicated some promise in Scottish rivers but further work is required to demonstrate long term efficacy in a range of environments. SCOS advice would be that based on the Thompson *et al*. (2021) review, removing or eliminating seals that have learned to exploit prey in rivers is extremely challenging.**

**It is unknown whether rehabilitated seals are any more likely to enter rivers relative to the rest of the population although there are several reports of rehabilitated seals entering rivers in Scotland and England. The presence of five seals in the River Nene upriver of a release site several kilometres upstream from the sea may suggest that the release site is also a factor.**

Methods to prevent seals from entering rivers and moving upstream are discussed in the answers to questions from the Scottish Government above (Q15 and Q18). Methods for the prevention of entry of seals to rivers and for the non-lethal control of seals in rivers are extensively reviewed in Thompson *et al*. (2021)  Physical barriers or triggered deterrents are considered the most potentially effective methods to prevent seals entering rivers and some success has been had with physical barriers in the US but nothing yet has been demonstrated to be 100% effective across a wide range of UK river environments and as discussed above there are a number of considerations to be resolved for the installation of physical barriers in rivers. Trials with triggered acoustic deterrents have indicated some promise in Scottish rivers but further work is required to demonstrate long term efficacy in a range of environments. SCOS advice would be that based on the Thompson *et al*. review, removing or eliminating seals that have learned to exploit prey in rivers is extremely challenging and likely to require substantial investment of resources.

Attempts to capture and relocate animals have had limited success where this has been tried globally (NMFS, 1997, Oliver *et al*., 1998, Brown *et al*., 2016, Robinson *et al*., 2008; reviewed in Thopson *et al*., 2021). There is one anecdotal report from the early 1980s of a translocation of one harbour seal from a site approximately 60 km up the River Ouse, Cambridgeshire to a release site in The Wash, Lincolnshire. However, the seal was observed back in the river close to the capture site less than a week later (M. Fedak (SMRU) pers. comm.). Furthermore, any removals would likely require an observational study to learn the habits of these individual seals to develop a targeted capture approach.

There is scant evidence to suggest that rehabilitated seals are more likely to travel up rivers compared to the general population. SCOS are aware that five individual seals which have been regularly sighted in the River Nene in Lincolnshire in England have been identified as being released rehabilitated animals so there is clearly the potential for this to occur. Although reports of seals far upstream in rivers surrounding the Wash area are not new, Anderson (1990) reports on two harbour seals 64 km (40 miles) up the river Ouse at St Ives. The rehabilitated seals found up the river Nene were released at Sutton Bridge, a location approximately 7 km upstream on the River Nene so there is the possibility that these seals may be more likely to move upriver than wild seals using more coastal areas. These five seals represent a low percentage of all released rehabilitated seals, although this is higher than the proportion of 'river specialist' seals from the general population of <1% (Graham *et al*., 2011).

Grey seals along the east coast of England have become generally less wary of humans over the past 30 years and may now be more likely to enter environments where there is a greater human presence than previously. It is also possible that rehabilitated seals which have been hand reared will be less sensitive to human activity than wild seals.

There have been anecdotal reports of rehabilitated seals in rivers and freshwater environments in Scotland, including a juvenile female grey seal who had been rescued in Devon and subsequently released from Norfolk and was then seen in the Ythan at Newburgh before then regularly being seen in the River Deveron, including approaching fishers. There was also a female harbour seal, apparently a released rehabilitated seal (flipper tag 61650) that travelled to the Lake of Menteith in 2007. The fishery was issued a licence to shoot this seal and when recovered, it had recently been feeding on rainbow trout.

Ensuring that rehabilitated seals are released some distance away from the mouths of rivers of conservation or interaction concern will potentially reduce these risks.

## Fisheries interactions – fish farms

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| **23. Can SCOS advise on types of research methods that can be used to demonstrate the efficacy of Acoustic Deterrent Devices (ADDs) as a method of managing seal interactions at fish farms.** | Scot Gov Q17 |
| *When considering licence applications in relation to the use of ADDs at fish farms, ADDs must be proven to be effective as a deterrent tool. It is therefore important that we understand what evidence could be provided that could assist in decision making. This ask is not in relation to individual trials, but to aid in the design of robust research by businesses seeking an EPS licence, and to help decision makers identify where sufficient evidence of efficacy has been demonstrated.* | |

**Recommendations for research required to demonstrate the efficacy of ADDs as a method of managing seal interactions are outlined in Coram *et al*. (2021) and a detailed description of a suggested approach is provided in that report. In summary, a large scale, long term, randomized control/treatment trial is recommended to incorporate variability across multiple sites and ensure sufficient power to detect effects. However, achieving a trial at this scale is challenging in practice due to the need for co-ordination across multiple sites and the licensing challenges involved in permitting ADD research across enough sites given the proximity and overlap with many protected sites for seabirds and marine mammals.**

**There have been a small number of published, peer reviewed, experimental studies indicating the efficacy of ADDs at single sites, which may be more feasible for fish farm operators, although single sites are more susceptible to the effects of variability in predation.**

**Ideally the direct impact on fish predation and resulting mortality should be measured although some studies have presented evidence in the form of reductions in seal presence. Indirect measures on the effect on fish health can also be made, such as feeding rates or growth rates.**

**It is important that results from such studies undergo robust independent review before being relied upon as evidence to inform decisions. The degree of effectiveness that is required to satisfy licensing may need some consideration. How effective an ADD must be to justify its use is a management decision that should take into account the value of the reductions in mortality and damage, against the costs of purchasing, operating and maintaining ADDs.**

Recommendations for research required to demonstrate the efficacy of ADDs as a method of managing seal interactions are outlined in Coram *et al*. (2021) and a detailed description of a suggested approach is provided in that report. In summary, a large scale, long term, randomized control/treatment trial is recommended to incorporate variability across multiple sites and ensure sufficient power to detect effects. Randomised control/treatment trials are widely accepted as a suitable way to determine whether there is an effect of an intervention, where it is ethically and financially possible to achieve them.

An example treatment regime would involve regular periods of one week to a month, timed to coincide with typical inspection and mortality removal routine. Each time period within a stocking period would be randomly allocated to ADD on or ADD off. Mortality to fish would be recorded each period with depredation rate ideally quantified by a trained member of staff consistently throughout the trial (or interindividual variation between recorders examined). A power analysis conducted by Coram *et al*. (2021) indicates that at least 15 finfish farms would be needed if using a monthly on/off ADD treatment cycle for the length of a typical stocking cycle (typically 12 to 18 months) to detect a significant effect. If treatments could be carried out at a weekly, instead of monthly cycle this could reduce the length of the monitoring period required.

However, this scale of a trial is challenging to achieve in practice due to the need to co-ordinate across multiple commercial sites, and the licensing challenges involved in permitting ADD research across several aquaculture sites given the proximity and overlap with many protected sites for seabirds and marine mammals. Furthermore, the resources required to carry out such a study are substantial. However, it is clear that an experimental approach is required at a suitable scale to provide enough statistical power to demonstrate an effect.

There have been a small number of peer reviewed experimental studies indicating the efficacy of specific ADDs at single aquaculture sites, which may be a more feasible sites for individual operators. However, studies at single sites are more susceptible to the effects of random variability in predation. Götz and Janik (2015) describe field tests of an acoustic startle device carried out over a 2 month period on a fish farm on the west coast and reported a significant decline (91%) in seal numbers within 250m of the device during periods of exposure relative to control periods but they did not report any metrics of fish mortality or health. Their methods involved randomized control/treatment periods averaging 3.5 hours. Visual observers from the shore used theodolites to track seals around the fish farm.

Götz and Janik (2016) carried out a longer-term study at another fish farm over a full production cycle (19 months) and found a 91% reduction in fish mortality when comparing predation levels within the test site between treatment and control and a 97% reduction in comparison to control sites with no deterrent use. In contrast to the findings of Götz and Janik (2015) visual monitoring demonstrated that the number of seal sightings within 100m was only slightly lower during sound exposure, indicating that significant reductions in predation can occur without eliminating seals from the area around the fish farm.

This highlights that there should be consideration of the metric to be measured. Ideally the direct impact on fish mortality should be quantified, though some studies have only presented information on reductions of seal presence. If ADDs are also being used to keep seals away from a fish farm with the additional aim of reducing stress to fish from predator presence, measuring seal presence itself is a useful metric, as are indirect measures of fish health such as feeding rates or growth rates, and effects of stress may also be evident in mortality rates of fish.

Similar approaches have been taken at studies investigating the effectiveness of ADDs to reduce seal interactions with other fisheries e.g. the tests of the Lofitech ADD to reduce depredation of salmon-trap net fisheries carried out by Fjälling *et al*. (2006). In this study, up to nine ADDs were deployed per year during the test period from 1998 to 2001 in the northern Baltic Sea in collaboration with eight commercial fishers. Each fisher operated several fishing days with and without ADDs in operation leading to a total of 600 days with ADD operation and 406 days without ADD operation. The study demonstrated a significant reduction in seal damaged catches related to ADD operation (44% damaged trap lifts without ADDs compared to 24%). This study also indicated that the effect of ADD operation diminished over time, which highlights that efforts must be taken to ensure the duration of the study is sufficient to examine the potential for habituation and that continuous use should be avoided.

It is important that studies are reported in sufficient detail to allow for independent review and scrutiny, before being relied upon as evidence to inform licencing decisions. It would be useful if there was a mechanism to provide protocols for independent review ahead of any trials.

It may be helpful to define a standard for the level of reduction in seal presence that might be desirable, which would make measurement and communication of this easier, however, how effective an ADD must be to meet the test required for licencing is not currently defined by the legislation. Clearly the level of effectiveness required to be demonstrated is a critical part of study design with respect to the power required to detect a particular effect size.

There is also the separate question for operators of how effective does an ADD have to be to justify its use. Any statistically significant change in the metric under measurement could be used to indicate effectiveness but relatively small effects may not justify the costs associated with their use. How effective an ADD has to be to justify its use is a management decision for operators that should take into account the economic value of the reductions in mortality and gear damage,against the cost of purchasing, operating and maintaining ADDs.

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| **24. If an ADD is proven to be an effective deterrent tool at one site, in what scenarios could such evidence be valid for application at another site?** | Scot Gov Q18 |
| *It is unfeasible for every fish farm to carry out a full scientific trial at each site where they wish to deploy an ADD. It is therefore important to understand in what situations evidence collected at one site/ from one type of ADD can be applied to other sites/ other ADDs.* | |

**There are a multitude of factors that may influence the levels of depredation at a particular site, and therefore the degree to which ADDs are effective. These include site infrastructure e.g. predator nets and how well they are installed and maintained, to local factors and seasonal, such as the proximity of seal haulouts and the abundance, experience, age and motivation of local seals. The topography of the site and how this influences sound propagation may also be**

**important in influencing the received levels of sound to seals around the fish farm, which may influence the effectiveness of any device. A suitable experimental design would allow an understanding of the variability in efficacy, and potential covariates influencing efficacy, including temporal and environmental variables, included in the statistical modelling of the response variable in relation to treatment effect. This would assist in determining the generality of findings from any one study to another, which is why an approach involving multiple sites is recommended above (SG Q17). It is difficult to determine in general how transferable results from one study might be to another without a detailed consideration of the similarities or differences between individual sites but given the same sound signal and the same species of seal and similar site characteristics, it would be reasonable to assume some degree of transferability.**

**However, it is perhaps not necessarily unfeasible for individual fish farm operators to carry out robust studies with sufficient power to demonstrate efficacy of a particular device at a particular site. For example, the study by Gotz and Janik (2016) indicated an effect at a single site over a production cycle.**

## Rehabilitation and rescue

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| **25. a) Can SCOS advise on circumstances when movement of a seal is appropriate in order to prevent the seal becoming disabled?** | Defra Q5a |
| *Animal rescue organisations can come across situations where a seal is not in immediate danger, but there is a possibility of risk. For example, seals hauling out to areas close to humans. We are aware of risks identified by SCOS associated with moving seals (disease spread, high levels of stress etc.) but we request formal advice on this matter, and what risks are involved with moving seals unnecessarily.* | |

**SCOS would consider that moving otherwise healthy seals should be an absolute last resort and should only be attempted when either significant risks to the welfare of the seal are present, significant risks to public health and safety are present, and where all other possible mitigations have been attempted or are deemed unfeasible. Handling seals poses several risks, both for the health and safety of the persons involved and for the seals themselves. Seals can be aggressive, their neck/heads are very mobile and they can inflict severe and infected bites. For persons handling seals, risks include injuries from bites, exposure to disease and infection, trapping of limbs in nets used for capture. These can lead to serious injuries and illness. For example, 'seal finger' which is a bacterial infection that can occur from the bite of a seal or from exposure to a contaminated surface through broken skin (White and Jewer, 2009), can lead to hospitalization and the need for extensive treatment by antibiotics and can have long term and permanent consequences. Other pathogens/zoonotics carried by seals include Brucella, Influenza viruses, Salmonella, Cryptosporidium, Clostridium and pox virus. Risks to seals include the risk of injury and stress, and resulting impacts on welfare. For smaller animals there is a risk of suffocation under restraint.**

**In the US, relocation of otherwise healthy seals is rarely considered. If a seal or sea lion is in a location that is a public nuisance or threat to safety, or on private property, then the typical course of action is to 'haze' the animal away from its chosen location back to the sea. This serves**

**two purposes: 1) the animal returns to its natural habitat, and 2) it discourages the animal from future problematic behaviour.**

**These actions are specifically authorized within the US Marine Mammal Protection Act and the hazing is typically done by trained, authorized personnel. US guidance on this can be found here: [https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/deterring-nuisance-pinnipeds](https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/deterring-nuisance-pinnipeds)**

**SCOS would support the development of best practice guidelines and appropriate approvals for the handling and movement of wild seals in the UK. Animal capture and handling expertise at SMRU, which has been developed over several decades and operates under strict home office licensing procedures and veterinary supervision under the Animals (Scientific Procedures) Act 1986 (ASPA), would be of value in such an exercise.**

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| **26. b) What is the advised best practice for releasing rehabilitated seals? Could the release of one seal species into an area of importance/concern for another species lead to negative impacts?** | Defra Q5 b |
| *There does not appear to be a consistent methodology on how seals should be released after being rehabilitated. For example, what are the impacts of releasing seals significant distances from their capture site? We also have specific concerns regarding the current practice of releasing rehabilitated juvenile grey seals into the Wash area, and whether this could add to the increasing population of grey seals in the Wash, and/or negatively impact the harbour seal population in the Wash (which is a current conservation concern).* | |

**There is currently a lack of detailed formal guidance on post-rehabilitation release for seals in the UK, The UK guidance on post-rehabilitation release that does exist is not specific to seals (British Veterinary Zoological Society and RSPCA; see below), though information on marine mammals is available from the US (NOAA; [https://repository.library.noaa.gov/view/noaa/48559](https://repository.library.noaa.gov/view/noaa/48559) ). SCOS recommends that guidance is developed for seal rehabilitation in the UK. SCOS understands that RSPCA is currently engaging with stakeholders to create a best practice protocol for the release of rehabilitated seals and would recommend consideration of the points made below.**

**Seals should be released at, or as close as possible to the site that they were captured. This is important to minimize the risk of spread of new pathogens into the release area and to maintain the genetic structure of populations. If that is not possible, the site should be assessed as suitable habitat for seals. It is also important to ensure that conditions at the release site do not pose any obvious threat to the released animal, for example release in areas of high public use and/or high levels of commercial or recreational fishery activity should be avoided.**

**Releasing seals to a different location could also influence intra/inter-specific competition for prey, particularly where current seal populations may be in decline and/or competition for resource is already high. In areas where harbour seals are depleted or in decline, for unknown reasons, there is potential that interactions with grey seals have a role to play in the decline or lack of recovery of harbour seal populations (see Q5 & Q6). In such areas, the addition of any grey seals, especially ones recovered from another location, would potentially have an additional negative impact on harbour seals.**

There is a lack of detailed formal guidance on post-rehabilitation release for seals in the UK. The UK guidance that does exist is not specific to seals (British Veterinary Zoological Society and RSPCA; see below), though information on marine mammals is available from the US (NOAA; see below). A useful summary of the effects of seal rehabilitation in terms of population dynamics, inter- and intra-specific competition, population genetics, disease, and animal welfare is presented in the Advice of the Scientific Committee on Seal Rehabilitation in the Netherlands (Zande *et al*., 2018).

There is little documented evidence to inform decisions about the choice of release site. Although a large body of work has been conducted on the fate of released rehabilitated pinnipeds (e.g. Gaydos *et al*., 2013; Greig *et al*., 2019; Lander & Gulland, 2003; Morrison *et al.,* 2012; Norris *et al*., 2011; Vincent *et al*., 2002) none of these studies have examined the influence of the choice of release site on outcomes for rehabilitated seals or their wild counterparts. Sayer *et al*. (2022) reported on the probability of seals using specific haul-out sites in the southwest of England dependent on their release location and reported no significant association between release site and locations where seals were subsequently resighted at the regional scale. This study did not detail where the seals had been captured and did not draw any conclusions to inform the methodology for release.

There is general universal agreement that rehabilitated seals should be released at, or as close as possible to the site that they were captured for multiple reasons including to maintain genetic population structures (see Q3 for more detail on current understanding of UK seal genetic structure) and maximise seal health (see below).

Or if that is not possible, the site should be assessed as suitable. For seals, the suitability of release sites will involve an appraisal of the proximity to the sea, the likelihood of public presence, the presence of an existing haulout with conspecifics nearby, as well as logistical considerations (e.g. vehicular access and landowner permission). It is also important to ensure that conditions at the release site do not pose any obvious threat to the release animal, for example release in areas of high public use and/or high levels of commercial or recreational fishery activity should be avoided. The welfare of animals during transportation must be considered to provide the best chances of successful post-release survival but distance to the site from the rehabilitation centre should not be the primary consideration as the temporary stress of a longer period of transport and confinement would be preferable over release to an unsuitable or unfavourable site. Measures such as air-conditioning may be required to ensure that seals do not overheat during transportation.

The management of disease is an important consideration both to maximise the health of the rehabilitated animal but also to minimize the risk of introducing a new pathogen to the release area. Indeed, seals from areas which are ecologically isolated from each other should be housed separately, and released back into the area in which they were found. For grey seals, such regions are large; telemetry data indicate connectivity along the length of both the west and east coast of the UK. However, connectivity between the two coasts is much more limited, so grey seals from east and west coasts should be housed separately and released on the coast from which they were taken. For harbour seals, the relevant spatial scale is much smaller; for the most part housing and releasing harbour seals according to their SMU would be appropriate. However, due to the length of coastline associated with West Scotland, the SMU subdivision should be considered instead for this SMU. However, these recommendations should be reviewed as and when more information becomes available. These considerations are particularly pertinent given existing concerns around the potential for a future disease outbreak, such as Phocine Distemper and HPAI (see Q32),. There is also the possibility that seals introduced into a different area may encounter novel pathogens at the destination site. . Furthermore, adult seals often have established foraging areas or prey groups. Releasing seals to a different location could also influence intra/inter-specific competition for prey, particularly where current seal populations may be in decline and/or competition for resource is already high. In areas where seals are depleted or in decline, for unknown reasons, there is potential that interactions with grey seals influence the decline or lack of recovery of harbour seal populations (see Q5 & Q6). In such areas, the addition of any grey seals, especially ones recovered from another location, would potentially have an additional negative impact on harbour seals. The potential for increased competition and interspecific interactions from the presence of rehabilitated seals is highly uncertain, but in areas where existing seal populations are depleted, a precautionary approach would be advised. In a population at carrying capacity, the addition of one seal will, on average, lead to the loss of an equivalent seal. If grey seals have a competitive advantage over harbour seals, the results of releasing grey seals into areas where harbour seals are experiencing density dependent constraints could have disproportionate impacts on harbour seal survival. A specific area of recent decline in England is The Wash & North Norfolk Coast SAC, a key population centre of harbour seals in England (see Q6). It is possible that releases of harbour seals to this area could have a positive conservation impact. Nevertheless, SCOS recommend release of rehabilitated seals into this SAC should be restricted to those recovered from the SAC itself. Harbour seals recovered within the SAC should be released into the SAC; tracking data indicates that many harbour seals that haul out in The Wash do not haul out elsewhere. As grey seals are wide-ranging, and the harbour seal population in the SAC is depleted for unknown reasons, with grey seals potentially having a role, where possible grey seals (recovered within or outwith the SAC) should be released elsewhere in Southeast England to minimise the potential for further impact on harbour seals in the SAC. Tracking data from grey seals tagged within the SAC indicates that many haul out in multiple locations (e.g. Donna Nook, Scroby Sands). As such, releasing grey seals outwith the SAC is unlikely to negatively impact them but would minimise the likelihood they remain within the SAC, although given that grey seals do often travel long distances, there is some uncertainty about this.

If the source location is not possible, or is not selected for a specific reason (i.e. to minimise the impact of releasing grey seals in areas of concern for harbour seals as above), in addition to considerations of welfare, decisions on release sites should be informed by a knowledge of seal distribution, seal species and age, current trends in abundance, and the degree of movement including rates of movements between areas. For example, harbour seals often show limited inter-haul-out area movements, and thus release sites should be as close to the rescue site as possible. . However, grey seals, particularly young-of-the-year are wide ranging, and thus release sites over a wider scale, would likely be appropriate.

The guidance that does currently exist on this in the UK is relatively generic, e.g. the British Veterinary Zoological Society Good Practice Guidelines for Wildlife Centres state:

"*The aim of wildlife rehabilitation is to release the animal back into its original environment, or another suitable area. For adult animals release into its original area is ideal, as the animal is familiar with it, may hold territory, etc. Release to another suitable area is another option, with potential issues arising for the animal (lack of familiarity with the area, an existing occupant or social group, and the likelihood of sustaining injury attempting to return to familiar areas)*."

The RSPCA standards for Wildlife Rehabilitation state (not specific to seals):

"*For the majority of species, adult animals must be released in the area from which they came and into their own territory. You should not release an animal into a new area even if you think the area where the animal was found is unsuitable. However, for juvenile animals it is often necessary to find a new release site away from where the animals were found. Release sites must be selected with care. Where practicable, all releases must be undertaken with the consent of the landowner. There may also be occasions when they will be asked to co-operate in some way, such as feeding the animal at the release site. Care should be taken that the release site is not protected under the Wildlife and Countryside Act, because the release of even a native species onto such a site may constitute an offence. Such areas include Sites of Special Scientific Interest (SSSIs) or Areas of Special Protection (ASPs). The site for release must be suitable for the species concerned. Particular attention must be paid to the following:*

- *suitability of habitat;*
- *habitat carrying capacity;*
- *territories already established in the habitat;*

- *food availability;*
- *man-made hazards, e.g. roads, pest control operations, power cables, oil spillage, hunting, etc.*

*Weather conditions must be appropriate for the particular animal and type of release proposed; generally, no animal should be released in heavy snow or rain, high wind, or extended wet, dry, hot or cold periods or if such conditions are imminent*."

The Netherlands have a "Seal Rehabilitation Agreement" which sets out high level responsibilities and principles governing the practice of seal rehabilitation in the Netherlands. Article 16 of the Agreement "Release of Seals" provides the following stipulations that those undertaking rehabilitation must sign up to:

1. *The Parties endorse the view that seals must be kept at rehabilitation centres for the shortest possible time. As soon as an animal has regained its vigour and the attending veterinarian is of the opinion that it has a satisfactory chance of survival, it can in principle be released. There are no minimum weight requirements for the release of animals.*
2. *Before seals are released they must be free of medication in accordance with the specifications set out in the Seal Rehabilitation centres' joint quality protocol as referred to in article 15.*
3. *Seals will be released where they were found or, if this is not possible, in a suitable natural habitat close to the place where they were found. In many cases this will mean that the animal is released close to a rehabilitation centre.*
4. *All seals to be released will be chipped and/or tagged for the purposes of scientific research to determine the long-term survival chances of each category admitted.*
5. *The Seal Rehabilitation Centres are prepared to participate in a study using transmitters, for a 'post-release' distribution study for example, provided such a study is in line with the objectives of this Agreement on Seals and all the legal requirements pertaining to animal welfare have been met.*

There are also detailed considerations that are relevant to rehabilitation in the Wadden Sea Seal Management Plan which is a trilateral agreement between the Netherlands, Denmark and Germany which details that all three Wadden Sea States strongly affirmed that the rehabilitation of seals is not necessary from a conservation perspective and that the taking of seals should be reduced to a minimum. The following guidelines are agreed:

> *60.1 only a very limited number of persons in each country shall be authorised to decide on the handling of diseased or weakened seals or abandoned pups, including taking and releasing of the animals, and only such animals may be taken which have a chance to survive;*
>
> *60.2 seals rehabilitated shall only be released into the wild on a permit granted by the national authority responsible for nature conservation and management if the following criteria are met: (i) the seal has not been treated with specific groups of medicine to be further specified, (ii) the seal does not carry pathogens alien* to the wild population; (*Definition of alien pathogen: Pathogens which are normally not found in the Wadden Sea area.), (iii) the seal is released as soon as possible but no later than half a year after it has been brought in for rehabilitation, and (iv) the seal has not been kept in a centre where species of animals alien to the Wadden Sea, or marine mammals not resident in the Wadden Sea, are held;*

In the US, NOAA Fisheries release standards (NOAA, 2022) require: "*that a marine mammal in rehabilitation be released back to the wild within 6 months unless:*

- *An attending veterinarian determines the release is unlikely to be successful due to the physical condition and behavior of the animal*
- *More time is needed for assessment and medical treatment*
- *The release might adversely affect wild populations*

*Prior to release in the wild, marine mammals must be marked or tagged to monitor their survival or identify them in the future, unless they have distinct natural markings. Scientists use tags or markings to evaluate rehabilitation success and to recognize individuals to monitor their growth, development, and behavior. Marking can be temporary, such as using bleach on a seal's fur or attaching a plastic tag to a dolphin's dorsal fin. More permanent marking methods include making a notch on a dolphin's fin, inserting a scannable microchip, or freeze branding. NOAA Fisheries and our partners also use radio or satellite tracking tags to temporarily assess the movement and survival of an animal post-release.*

*Rehabilitated marine mammals are released under conditions that maximize the likelihood for their survival. For example, they are released within their home range or with another individual of the same species when possible. These conditions vary with species, age, and sex of the individual."*

The NOAA release standards also recommend that the release site selection is considered on a case-by-case basis and requires consultation with the National Marine Fisheries Service. NOAA recommend that release near the original stranding site is preferable in the case where a pinniped has recovered from an infectious disease to minimize the risk of the spread of disease to wild pinniped populations : "*As rehabilitation centers cannot always perform definitive diagnostic tests for all viral agents, moving rehabilitated pinnipeds from the general region of their stranding to distant locations for release may pose some risk to wild marine mammals. NMFS is to be consulted regarding the preferred release site when pinnipeds recovering from an infectious disease cannot be released near their original stranding site."*

The NOAA release standards provide a useful Decision Tree process for decisions about the release of animals and assessment of release logistics.

As suggested above under Q22, SCOS would support the development of best practice guidance for all aspects of the rehabilitation and release of rescued UK seals.

## Designated sites

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| **27. Could SCOS consider the current methodology used to identify seal haul-out sites under section 117 of the Marine (Scotland) Act 2010, and make suggestions for any potential changes to the methodology, including their respective costs and benefits** | Scot Gov Q6 |
| *SG will be undertaking a review of seal haul-out sites in Scotland which is planned to commence in 2024 To inform this review, SG wishes to review the methodology to determine if it is fit for purpose or whether there are different methodologies that could be applied (should include the rationale and relevant benefits etc).* | |

**Section 117 of the Marine (Scotland) Act 2010 (the Act) gives Scottish Ministers, after consulting UKRI), the power to designate haul-out sites that are considered suitable to protect seals from harassment, through an order in the Scottish Parliament.**

**The purpose of the haul-out site designations is to achieve a balance between maximising protection for the largest number of seals from intentional or reckless harassment, while minimising possible impacts on other sustainable activities around the coast. The method used to identify haulouts for designation is detailed in Morris *et al.* (2014) and summarised below. The method generated a list of 149 seal haul-out sites. Of these 149 sites, 115 sites were selected for harbour seals only, 27 sites were selected for grey seals only, and 7 sites were selected for both species. After a consultation exercise, a further 45 sites were added, all for the protection of breeding grey seals.**

**There is a requirement to review these designations periodically but several concerns have been raised about this update. These include:**

**1) Due to the variability in seal haulout distribution between surveys, any update with new data will result in many additional sites being identified each time.**

**2) The data used to inform site designation is limited to August surveys, which for some regions are only carried out every five years. This means that sites that hold significant haulouts at other times of year, or changes from year to year could be missed.**

**3) Despite being one of the main drivers behind this legislation, the risk of harassment is not explicitly incorporated into the criteria for site selection.**

**4) There is uncertainty about the appropriate time period to use; the current designations are based on the time series between 1996 and 2010 and we now have new data representing a further 10+ years.**

**Potential alternative approaches and solutions are discussed below. However, clear limitations remain. For example, given the inherent variability in seal haulout distribution, it is unlikely to be feasible to develop a methodology that does not result in significant changes each time the process is repeated using new data. Furthermore, to our knowledge, there are very few data sets that provide an understanding of within and between year variation in seal haulout distribution at the scale required to inform a different approach. Explicitly incorporating potential for harassment into site selection was dismissed during the original process due to the lack of information to inform this, and it is difficult to see how this could be done now.**

Section 117 of the Marine (Scotland) Act 2010 (the Act) gives Scottish Ministers, after consulting the Natural Environment Research Council (NERC), the power to designate haul-out sites that are considered suitable to protect seals from harassment while they are onshore, through an order in the Scottish Parliament.

The purpose of the haul-out site designations is to achieve a balance between maximising protection for the largest number of seals from intentional or reckless harassment while on land, and minimising possible impacts on other sustainable activities around the coast.

The method used to identify and select haul-out sites for this purpose is detailed in Morris *et al.* (2014) and was developed in consultation with Marine Scotland (now Marine Directorate). In summary, the data from SMRU regular aerial surveys - August surveys (both species counted during harbour seal moult) and in addition autumn surveys (grey seals only) - were used to identify high density areas or ‘hot spots’ for seals around the Scottish coasts. Haulouts were selected in a stepwise manner to ensure that enough seals would be covered by this protection. A summary of the method is provided here.

The first step was to create several Virtual Observation Points (VOPs) at 100m intervals around a simplified coastline. The next step was to compile sighting histories of both species for each individual VOP. This was done by creating buffers with 300m radii around each VOP and calculating the sum of all sightings of each species that lie within the buffer boundary by year. This is equivalent to having an observer positioned at each VOP and recording all sightings within a 300m radius every time that part of the coast is surveyed. The individual sighting histories were then used to calculate a Time Weighted Average (TWA) count of each species for each VOP. This placed more emphasis on more recent counts while recognising and using a long time series of data that takes into account variation and changes in seal distribution between years. A weighting factor of 0.8 was used which reduces the weight of a sighting by 20% for every one year step back in time. The aim was to strike a balance between supporting sites which have experienced a decline without disadvantaging sites that have increased.

The final list of sites for designation was produced using the site selection criteria described below.

> **Primary selection criterion**: For each Seal Management Area and subdivision, a minimum population coverage target was set for each species. A minimum of at least 50% was set in all Seal Management Areas and subdivisions where seal populations were either stable or increasing. A significantly larger proportion of the population (80%) was set for harbour seals in Seal Management Areas and subdivisions where this species' populations have declined significantly and which feature seal conservation areas. Starting with the site with the highest TWA in each Seal Management Area and subdivision, sites were added to the lists until the target minimum population coverage was achieved for each species.
> **Secondary selection criteria**: In addition to the sites selected by the primary selection criterion, all sites that contained above a threshold of the Seal Management Area's TWA population were also added to the list: - for harbour seals: sites ≥ 5% of the Seal Management Area population - for grey seals: sites ≥ 10% of the Seal Management Area population based on August counts. These criteria were added to ensure the inclusion of any sites considered to be significant to that Seal Management Area's wider population.

This selection process produced a list of 149 seal haul-out sites. Of these 149 sites, 115 sites were selected for harbour seals only; 27 sites were selected for grey seals only, and 7 sites were selected for both species. Most sites (144) were selected under the primary selection criteria; only 5 sites were added under the secondary selection criteria. Note that several sites were considered to contain enough of the other species for them to be identified as shared sites in the final list.

The list of sites was consulted upon to obtain stakeholder views. As a result of the input received, several additional sites were added to provide a final total of 194 sites. These additions were largely based on input from NGOs who considered that the proposed list did not offer enough protection to grey seal breeding sites and that greater protection was necessary in areas of declining numbers of seals. Additional grey seal breeding colonies were therefore added using the criteria of at least 20 seal pups are born each year and which are not already covered by seal SACs or on the original list of key haul-out sites identified using August survey data. This identified a list of 45 additional grey seal breeding colonies.

In September 2015, the Scottish Government consulted on a proposed new site to be designated, this was based on a recently expanded site for grey seals located at the mouth of the River Ythan. As a result of this consultation, the Protection of Seals (Designation of Haul-Out Sites) (Scotland) Amendment Order 2017 formally designated the River Ythan haul-out site.

Given the nature of the available data and the inherent variability in seal haul out behaviour, there are several limitations and stakeholder concerns about the current methodology. These are summarised here:

*Variability in seal haulout distribution – longevity of site designation*

The number of sites produced by this method is large and given the temporal variability in haulout use, the total number of locations and the location of identified sites will change significantly each time this method is repeated with new survey data. This has been highlighted as a particular concern for projects that are going through the consenting process, where sites may change throughout the licencing process for a particular project or across construction process for projects that span several years. However, given that the original intention of this designation was to protect seals against deliberate harassment, as opposed to incidental disturbance SCOS would question whether changes in designation will really pose a problem for activities applying for consent or licences.

It has been suggested that a smaller number of larger sites created by grouping together several haul-out sites across a wider area would be more efficient to maintain through reviews. This had been considered early in original selection process but a preference for smaller sites was identified to avoid unnecessarily affecting other activities as much as possible. As a result of the public consultation and discussions between, Marine Scotland (now Marine Directorate), Scottish Natural Heritage (now NatureScot) and SMRU, some sites were merged into larger sites. However, it is fundamental to recognise that due to the inherent variability in the haul out behaviour of seals, seal haulout locations cannot be considered as discrete, static sites. As such it is unlikely to be feasible to develop a methodology where the required outcome is the designation of discrete sites that will not result in significant changes each time the process is repeated with new survey data. Indeed, a review was conducted in 2019 with updated survey data, which would have led to the designation of around 50 new sites. It is likely that a similar magnitude of change would occur if this methodology was repeated with more recent data.

*Using August only counts*

The majority of the sites have been selected based on counts in August only and most regions are only covered by these surveys once every five years. This is because the only seal count dataset that covers the whole of Scotland is exclusively from August surveys that cover the whole of Scotland over a five year period. This could mean that sites that are significant haulouts at other times of year could be missed from this process and that significant changes from year to year could be missed. There are very few areas of the Scottish coastline where seal haulouts are monitored regularly and systematically year round. Furthermore, given the complexities in incorporating annual data and year to year variability, SCOS considers that developing a methodology that adequately considers the within year variability in haulout locations would be even more challenging.

*Risk of harassment*

This methodology considers seal numbers only. This likely means that many of the protected sites do not actually have a significant risk of harassment. Explicitly incorporating potential for harassment into site selection was considered during the development of the original methodology. However, it was dismissed due to the lack of information to inform an assessment of how risk varies across sites to enable the identification of sites at a higher risk of harassment. This was considered a positive factor as this provides protection against the future possibility of harassment. Where information is available on the occurrence or prevalence of harassment at specific sites this could be considered, and individual sites added to the designation on this basis, but it would be difficult to incorporate this as a quantitative criteria to inform site designation more universally. Although the intention of this legislation is to protect seals in areas where they are likely to interact with human activities, with consideration of their wider conservation, it is very challenging to incorporate a robust criteria for evaluating this risk which may vary over time.

*Site boundaries*

The current boundaries are coarse rectangles which in many cases means that large areas of sea or areas of land where seals do not haul out, are included. Initially intertidal polygons had been created for each site, but this posed problems with listing the co-ordinates of each site in associated documentation. Another issue is with the difficulty in drawing boundaries around intertidal sand and mudbanks that change shape/size/position over time and cannot be reliably defined (over several years) by the most recent available OS maps. After an initial suggestion to use convex polygons to reduce the number of coordinates per site, it was agreed to use Minimum Bounding Rectangles (MBRs) with 4 coordinates each. Each site was also described by text. Any concerns regarding interpretation on a site-by-site basis in a consenting context could be dealt with by examining the most recent haul-out data for any specific area and a consideration of the proposed activities. The legislation protects seals that are located on land only, within the defined area, so, independent of how the boundaries are drawn, the seals will normally be in the intertidal zone (except for grey seal breeding sites) and more complex site boundaries would generally make no difference. The defined site boundaries are not relevant to where a potentially harassing activity is being carried out. The activity can be taking place within the site boundaries or outside of them, and still cause seals to leave a designated haulout, so site boundaries producing smaller total area sizes, that only include the rocks and sandy areas where the seals might actually lie, should not make a difference to consenting decisions (or to prosecution of harassment behaviour).

*Appropriate time series to use*

The current designations are based on the time series between 1996 and 2010 and there is the question of how far back to go when reviewing the designations considering new data representing a further 10+ years. Due to the variability in seal distribution over time, using as long a time series as possible will help to include most possible haulout locations, ensuring that all locations that have historically been important and therefore represent potential habitat for seals are considered. However, the existing weighting factor used (0.8) means that counts that are 15 years older than another more recent count will have very little influence (e.g. a count from 2000 will have only 1.2% the weight of a count from 2020).

**Alternative approaches and recommendations**

Several alternative suggested approaches or additional data sources have been considered to address some of these limitations.

*Alternative data sets*

SCOS are not aware of any comprehensive data sets that would allow an identification of important seal haul-out sites at other times of year. There are areas in Scotland where volunteer and research organisations regularly carry out counts of hauled out seals at other times of year, but these can be patchy in time and generally focus on specific individual sites rather than providing more complete coverage of an area to allow an understanding of how distribution may vary over time. While these datasets are valuable for understanding how abundance varies over time at specific sites, and sometimes allowing an understanding of the relative use of different sites in close proximity, they will be unlikely to allow identification of important sites on the basis of overall distribution within a region or area.

It is also important to note, however, that there is a precedent for incorporating local knowledge to inform additional site designation – for example the Ythan estuary site became known for having significant numbers of grey seals haul out there despite not being selected on the basis of existing SMRU August counts when sites were initially selected.

It has also been suggested that telemetry data could be used to inform haulout use. While this method provides a detailed picture of the haul-out sites used by the individual tagged seals, this would not be considered appropriate to inform the designation of important haul out locations. Such data represent variable effort across space and seasons, and years. Indeed, a concern with the current designated haulout selection method is the reliance on August counts to determine the distribution and relative importance of haul-out sites; due to the loss of tags during moult there are no telemetry data linking the use of haulouts during August to other times of year Even within a tagging study area, the individuals tagged represent a small proportion of the population, and it would not be possible to estimate the relative importance of haulouts (on a population level) within the area from such data.

*Sensitivity analyses of selected criteria*

An analysis could be carried out to assess the potential impact of changing the current criteria and thresholds used in the methodology and to identify how large these changes would need to be to meet defined different desired outcomes. These could include changing the size of the buffer zone, changing the weighting factor, changing the duration of the data series included, changing the threshold proportion of the population required to be protected in any SMU. Such analysis would need additional resource. This would also require input from Scottish Government and appropriate stakeholders to define and prioritise desired outcomes on the primary concerns and objectives of such an evaluation in terms of the limitations described above – i.e. what are the most important concerns from a management perspective? For example, requiring an outcome that is less likely to result in a large change in the number of sites selected when new data is incorporated will require targeting different criteria than if the desired outcome was to better characterise the threat of harassment.

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| **28. Is there any further evidence following the 2021 SCOS report (Q33) on the effects of disturbance on seals which may impact on seals as features of MPAs?** | Defra Q7 |
| *MMO has powers to introduce management measures within MPAs in English waters where non-licensable activities are adversely affecting the MPA, and management is required. Evidence on the impact of these activities (e.g., paddleboarding, diving, recreational boat tours) on seals is lacking. Is there any further evidence following the 2021 report which could support the case for management measures for seals in MPAs?* | |

**Since the review of evidence for the effects of disturbance on seals presented in SCOS 2021, there have been several studies published documenting the short-term behavioural responses of seals to a variety of human activities. A summary of these is provided below with specific attention to the effects of recreational activities. As far as SCOS are aware, there have been no published studies directly linking disturbance to any changes in the vital rates of seals. Although one study reported effects on suckling behaviour and mother/pup separation that indicates the potential for a population effect via effects on pup survival if this was severe enough. The studies reviewed here confirm conclusions presented in SCOS (2021) that the effects of disturbance are highly site specific and context dependent. SCOS would therefore recommend targeted evidence gathering at any MPAs where this is a potential concern. Decisions about the need for management measures can then be made based on this evidence. A more conservative approach would be to manage recreational activities due to the potential for impacts, which may be more appropriate where seals are in a poor conservation status already. However, balanced decisions on the implementation of such regulation are outwith the scope of SCOS.**

Available information on the effects of disturbance on seals was reviewed in detail in SCOS 2021. Since the review of evidence for the effects of disturbance on seals presented in SCOS 2021, there have been several studies published documenting behavioural responses of phocid seals to a variety of human activities and these are summarised here.

Loseva *et al*. (2023) examined the effects of recreational activities on grey seals hauled out in the Baltic. They observed flushing and reduced haulout numbers in response to powerboats and stand up paddleboarders and concluded that although the grey seals demonstrated a high degree of tolerance in an area of considerable human activity, further increases in human activity, particularly associated with the growing popularity of stand-up paddle boarding could threaten specific haul-out sites.

Ruiz-Mar *et al*. (2022) reported on a study of disturbance from recreational activities on harbour seals in Baja, California over three pupping seasons. They found that terrestrial vehicles and pedestrians approaching the haulout had the greatest effect on seals. Activities on the sea such as motorised boats and jet skis, had less of an impact on hauled out seals. Effects noted included flushing and disruption of nursing. They also investigated recovery time, in terms of seals hauling out again after flushing. In 2017, the mean recovery time was 16.38 minutes, which was shorter than in 2015 (32.34 minutes) and 2016 (35.92 minutes). However, 34% of disturbance events resulted in a return to pre-disturbance levels. They did not measure the distance of disturbance events but estimated that all occurred within at least 100 m from the seals. The reduction in nursing time reported in relation to disturbance could potentially have an impact on the level of energy transfer between mother and pup and ultimately on pup survival but this was not investigated in this study. More significantly, the authors observed nine permanent mother/pup separations over the three years of study.

Bankhead *et al*. (2023) examined the effects of ambient noise on the number of harbour seals hauled out at two sites in northwestern Washington USA. They found that noise did not impact numbers at the site where human activity was generally high but noted a significant negative relationship between noise levels and the number of seals hauled out at a less busy site. This indicates a degree of tolerance of activity at the busier site.

A study by Milesi-Gaches *et al*. (2024) explored the behavioural responses of harbour seals to various disturbances while hauled out close to a port in Iceland and reported the effects of various activities on hauled out seals. The most frequent response to various triggers was increased vigilance (53% of all observed responses) with flushing occurring on only a small number of occasions. Kayaks caused the majority of the flushing responses, although this only accounted for 2.3% of the observed behaviours.

The recent studies reviewed here confirm conclusions presented in SCOS (2021) that the effects of disturbance can be variable and are highly site specific and context dependent. SCOS would therefore recommend targeted evidence gathering at any sites where this is a potential concern. Decisions about the need for management measures can then be made based on this evidence. A more conservative approach would be to manage recreational activities due to the *potential* for impacts, which may be more appropriate where seals are in a poor conservation status already. However, balanced decisions on the implementation of such regulation are outwith the scope of SCOS.

## Seal usage maps

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| **29. Further to the publication of seal usage maps in 2022 (Carter *et al.* (2022), please can SCOS advise whether any updates to these maps are anticipated which would alter our current understanding on areas of importance for seals (e.g., foraging areas) in Scottish waters. Furthermore, it would be helpful to understand how these data could be used in moving** | Scot Gov Q7 |

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| **forward.** | |
| *Telemetry is useful for showing connectivity between sites and 'management units'; use of potential development areas and potentially highlighting important foraging areas.* | |

**Several research activities are planned or underway relating to telemetry data, and specifically the distribution maps, which will affect their utility for Scottish waters.**

**In brief, the seal distribution maps combine seal telemetry data with environmental data to model habitat association. These models are combined with haulout count data to predict the at-sea distribution of seals. An updated version of the distribution maps for grey and harbour seals in Scottish waters is forthcoming (Carter *et al.* In Press), benefitting from updated haulout count data, updated telemetry data (for both species in Shetland), and refined methods from that of Carter *et al.* (2022). Estimates for Shetland are now based on the habitat preference of seals hauling out in Shetland, derived from recent telemetry deployments, i.e.no longer based on data from seals in North Coast & Orkney SMU (as in Carter *et al.,* 2022). While Carter *et al.* (2022) included temporally dynamic covariates (e.g. sea surface temperature; SST), the new maps were generated using only static covariates including representations of dynamic processes (e.g. summer mean water column stratification under typical conditions). This provides a distribution that is not restricted to the single year of prediction.**

**To facilitate access to, and appropriate interpretation of, the seal distribution estimates for specific user selected areas, a Graphical User Interface (GUI) is being developed for the distribution of seals hauling out in Scotland (funded by Scottish Government).**

**Work is also underway, through the EcoSTAR project, to combine the latest distribution estimates for Scottish waters with estimates for seals hauling out in the rest of the UK, Ireland, France, Belgium, the Netherlands, and the Wadden Sea coastline of Germany and Denmark to give a more comprehensive map of seal distribution for most of the major centres of abundance across Northwest Europe. This will allow estimates for UK nations to be placed in an international context. Specifically, it will allow a more robust estimate of total abundance of seals within at-sea areas, as well as an understanding of country-specific contributions.**

**Several research priorities for future distribution maps remain. Telemetry data are needed from both species for haulouts in East Scotland to ensure that estimates are robust, in light of recent population changes in the region. Much work has been done on identifying foraging behaviour from the telemetry data, and this has opened the potential to generate maps of important foraging areas (the current maps do not distinguish between at-sea behaviours such as foraging and travelling). For some areas and questions, (e.g fine scale distribution in Pentland Firth, an area of rapid tidal currents), with a relatively high sample of telemetry data, maps from more fine resolution area-specific models would be more robust.**

**Telemetry data have a range of potential uses beyond the distribution maps. Although a comprehensive review of such uses is outwith of the scope of this answer, ongoing projects include: modelling the potential effects of climate change on foraging seals in the UK; examining the potential for interspecific competition to drive regional harbour seal declines; modelling the activity budgets of seals, and understanding how natural and anthropogenic features (e.g. seabed geomorphology, offshore energy structures) influence foraging behaviour; understanding the connectivity between foraging areas and coastal sites such as breeding grounds and designated protection sites (i.e. SACs); and modelling the dispersal of grey seal pups to inform understanding of metapopulation dynamics in Scotland and neighbouring regions.**

Several research activities are planned or underway relating to the distribution maps, which will affect their use for Scottish waters. An updated version of the seal distribution maps for grey and harbour seals in Scottish waters is forthcoming (Carter *et al.,* In Press), benefitting from updated data and refined methods from that of Carter *et al*. (2022). This work was funded by Scottish Government; Department of Energy Security & Net Zero (DESNZ) Offshore Energy Strategic Environmental Assessment Programme (OESEA), and NERC INSITE programme (EcoSTAR project). The new estimates benefit from the incorporation of telemetry data collected from tags deployed on both species in Shetland in 2022 (funded by Scottish Government, NatureScot, and DESNZ). Estimates for Shetland have been based on models fitted to tracking data from the North Coast & Orkney SMU (Carter *et al.* 2022) due to a lack of recent high-resolution data for Shetland. In the Carter *et al.* (In Press), Shetland was modelled as a discrete region, providing a more representative estimate of seal distribution emanating from Shetland.

In addition to incorporating new telemetry data, the haulout count data for predictions and methods were also updated from those used in Carter *et al.* (2022). A key methodological difference is that only static covariates, or static representations of dynamic covariates (such as water column stratification under typical conditions), were included in the models. Annual variation in dynamic covariates such as sea surface temperature (SST; incorporated in Carter *et al.* 2022) meant that the maps were representative of the year of prediction. While dynamic covariates, such as SST likely impact fish, and thus seal distributions especially over longer timeframes, the relationship is complex. SST conditions may vary among years, and this may lead to unrealistic distribution estimates especially if predictions fall outside of the range of data values used to fit the model. The new approach should be more robust to interannual variation in the environment and should facilitate easier updates when new count data become available. Nevertheless, it should be noted that the new maps represent density estimates under “typical” conditions for a given time of year (summer for grey seals, autumn-winter-spring for harbour seals). Recent work also demonstrated the importance of seabed geomorphological features for grey seals in the North Sea (Wyles et al., 2022), thus this covariate was added to the models to improve distribution estimates.

The resulting maps have some notable differences to those of Carter *et al*. (2022). Primarily, at-sea density of seals hauling out in Shetland is more tightly concentrated around the coastline, particularly for harbour seals. This is consistent with coast-hugging behaviour prevalent in the Shetland telemetry data, presumably in response to predation pressure from orca. Elsewhere, hotspots of density at sea were broadly comparable to those revealed by Carter *et al.* (2022). For example, the shelf edge west of Scotland remains an important area for grey seals, while inshore waters of West Scotland host high densities of harbour seals.

To facilitate access to, and appropriate interpretation of, the distribution estimates by end users, work will shortly begin on developing a Graphical User Interface (GUI; funded by Scottish Government) for the distribution maps for Scotland. The aim for the GUI platform is to allow users to delineate an area of interest (AOI; e.g. windfarm boundary) and output the number of seals estimated to be present within that area at any one time, with robust area-based confidence intervals. This will remove any barriers associated with the necessity for users to have skills and experience in geospatial analysis, and ensure that users are accessing the most recent version of the maps, with easily interpretable estimates of uncertainty. The resulting data download will be accompanied by a readme file highlighting the necessary considerations when interpreting the estimates. Moreover, this interface could possibly be extended to include apportioning of seals within an AOI to designated sites, such as SACs. Interactive plots of the density estimates will also be featured so that users can explore the data without having to download it.

Work is also underway (funded NERC INSITE programmes (EcoSTAR project and DESNZ OESEA) to combine the latest distribution estimates for Scottish waters with estimates for seals hauling out in the rest of the UK, Ireland, France, Belgium, the Netherlands, and the Wadden Sea coastline of Germany and Denmark to give a more comprehensive map of seal distribution for most of the major centres of abundance across Europe (excluding Norway, Iceland, Faroes, Northern Denmark and the Baltic; Carter *et al.* In Prep a). These European maps will encapsulate approximately 80% and 60% of all grey and harbour seals in the Northeast Atlantic, respectively (SCOS 2024 Q1), and will allow estimates for Scotland, and other UK nations, to be placed in an international context. A major benefit of these pan-European distribution estimates will be the ability to quantify how many seals on foraging trips from haulouts in one country are likely present in the territorial waters of other countries. This will allow stakeholders to apportion seals estimated to be present within an area of interest (e.g. windfarm development zone) to the countries where those seals haul out, highlighting the need to consider potential impacts across international borders.

The distribution maps derived from habitat association models are the most robust available. However, some important limitations with regard data availability and methods remain, which give rise to a number of research priorities (reviewed in Russell & Carter 2020). In terms of tracking data, East Scotland remains a key data gap for both species. Data used to fit models for harbour seals in this region were from 12 tags deployed over 10 years ago. Data from grey seals for this region (n=13) are largely from a deployment in 2008 (n = 9) supplemented by 9 individuals tagged in other SMUs between 2014 – 2018 that subsequently hauled out in East Scotland. Predictions for this SMU should therefore be treated with caution as predictions likely contain a high degree of unmodelled uncertainty (i.e., uncertainty not incorporated in the confidence intervals). Since the deployment of tags in this region, harbour seal numbers have continued to decline while grey seals have increased (SCOS-BP 24/03). Most data for East Scotland are from individuals tagged in the Firth of Tay & Eden Estuary. This harbour seal SAC is depleted by over 90% (since early 2000s), and no longer hosts the majority of the East Scotland SMU harbour seals (SCOS-BP 24/03). To better represent distribution of harbour seals from East Scotland, any tagging efforts should be focussed within the Firth of Forth. Since the deployments on grey seals at Abertay Sands (mouth of the Tay Estuary), large haulouts have developed ~100 km north in Cruden Bay and the Ythan Estuary. The differences in habitat between Abertay Sands and these northern sites, likely result in different habitat associations. Combined with the age of deployments in East Scotland SMU, this means these northern East Scotland sites are a research priority.

The current maps (Carter *et al.* 2022; Carter *et al.* In Press) are based on all at-sea telemetry locations, regardless of behaviour. As such, an implicit assumption of the habitat association modelling is that foraging, and all other activities are associated with the same habitat. Further, while it can be concluded that high density areas identified in the distribution maps are important for seals, they cannot readily be classified as foraging areas; seals display multiple behaviours at sea (e.g. travelling, resting and foraging), and the modelling does not account for differences in habitat use. Work is underway (under the EcoSTAR project) to quantify foraging behaviour from tracking data for seals in the North Sea using hidden Markov models (Carter *et al.* In Prep b), but predictive maps of foraging areas are outwith the scope of that project. Nevertheless, the work under EcoSTAR has opened up this possibility. Accounting for activity specific habitat associations would increase the robustness of the maps, and allow predictions of foraging hotspots (see Russell & Carter 2020).

The utility of the seal distribution maps (based on habitat association) depends on both the question and scale of interest (reviewed in Russell & Carter 2020). They provide a spatially consistent representation of seal distribution across a large area, including distribution emanating from haulouts which have not be visited by a tagged seal. However, for some areas and questions, (e.g fine scale distribution in Pentland Firth, an area of particularly rapid tidal currents, where the environmental characteristics used by seals, and thus relevant covariates, are distinct from the broader region), maps from area-specific models would be more robust. Such fine-scale models would allow local habitat associations to be taken into account; incorporation of environmental covariates not available at a larger spatial extent, and individual variation in habitat association to be modelled.

In addition to its use for the distribution maps, telemetry data have a wide range of applications within the sphere of applied ecology. For example, work is currently underway using telemetry data to model the potential effects of climate change on foraging areas of UK seals. This work has been the focus of a PhD project at SMRU (funded by DESNZ OESEA programme), and results should be forthcoming. Telemetry data have also been used extensively to study interactions between seals and industrial developments, and quantify risks from human activities. For example, location data have been used to model changes in distributions and behaviour of seals in response to offshore renewable energy construction (Russell *et al.* 2016) and operation (Russell *et al.* 2014; Hastie *et al.* 2018), and estimate risks of auditory damage from pile driving (Hastie *et al.* 2015). Dive data from tags have also been used to quantify the overlap between tidal turbine rotors and seal dive depths to estimate collision risk (e.g., Evers *et al.,* 2017; Joy *et al.,* 2018). Another PhD project at SMRU has focussed on understanding the potential role of grey seals in regional harbour seal declines. Telemetry data have been used to examine the scope for interspecific competition as a potential driver of the declines. Under the EcoSTAR project, the telemetry data are being modelled to determine seal activity budgets, and understand how natural and anthropogenic habitat features, such as seabed geomorphology and offshore wind energy structures, influence the foraging behaviour of grey and harbour seals in the North Sea. A synergistic SMRU PhD project is focussed on the fine-scale interactions between tracked seals, offshore energy structures and fishing vessels. Telemetry also informs the understanding of connectivity on various scales; between offshore foraging grounds and coastal sites such as haulouts, breeding sites and protected areas (i.e. SACs). On a larger scale, telemetry data can be used to understand how regional dispersal and movements might influence metapopulation dynamics. For example, telemetry data from tags deployed on recently weaned grey seal pups at the largest colony in Northeast Atlantic (Monach Isles) are being used to understand how dispersal patterns might influence regional population dynamics in Scotland and adjoining areas.

## Seal diet

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| **30. Can SCOS provide an updated picture on seal diet, in particular any overlap with commercial fish species, and what the impact of this predation is on these stocks? Furthermore, could SCOS advise whether any such fish species a predominant component of harbour and grey seal diet and therefore could other pressures (including fishing and climate change) acting on these fish species have implications for seals in terms of access to sufficient prey and survival?** | Scot Gov Q8 |
| *There is a raft of work relating to fisheries management for Marine Protected Areas underway along with a review of Priority Marine Features and other conservation work. The importance of prey availability to seals (in terms of seal conservation) and the impact of seals on fish stocks (fisheries implications) are key factors that we need to understand.* | |

**There is very little recent data collection to inform our understanding of current UK seal diet, most of the existing information was summarised in SCOS 2021.**

**Here updates since SCOS 2021 in terms of data collection, processing, and analyses are summarised. A study based on stable isotope analysis has been published which indicates that the**

**diet of grey seal females that bred on the Isle of May, East Scotland (2016) had been dominated by sand eels and flatfish, with harbour seals sampled from Orkney (2017) having a more generalist diet comprising of more species. There has been recent data collection from Shetland; samples were taken from harbour and grey seals captured for telemetry tagging for various funded projects. Researchers from the University of Exeter conducted stable isotope analyses on blood (red blood cells and plasma) of captured seals, as well on fish (collected by University of Highlands and Islands Shetland), allowing estimation of seal diet composition and its temporal variations. The results are currently being written up for publication. Faecal material from captured seals could be processed for metabarcoding with appropriate funding. Under a new workstream under the Scottish Marine Animal Strandings Scheme 'Priority Species Investigations' the analysis of diet from the stomach contents of stranded seals has begun but sample sizes are small and inference will be limited until this has been underway for some time.**

**A key factor in predicting the impact of changing fish stocks on seals is by considering the energetic value of different prey species and sizes. This is currently the focus of part of a SMRU PhD project. There is a SMRU study currently underway in Southeast England investigating harbour and grey seal diet in the region. There is also work focussed on the Farnes Islands, Northeast England led by Newcastle University. SCOS are not aware of any other dedicated studies elsewhere across the UK.**

**Historic diet data (up to 2012) is being used in various projects; outputs are not yet available. Specifically, another SMRU PhD project has looked at spatio-temporal trends in seal diet diversity in the context of changing harbour and grey seal populations, using data from SMRU and collaborators. Multispecies functional response models have been developed for both seal species to allow predictions of how consumption of a given fish species will vary with its availability and the availability of other fish species. Such models are key to predicting seal diet and consumption under different management scenarios and could be used to answer the questions posed here. Through the EcoSTAR project, the latest seal diet information has been integrated into an ecosystem model, with the aim to predict the impact of the current and projected future scenarios (climate, seal populations, fisheries management) on fish distribution, fisheries catch and seal prey consumption. Such models will inform the potential magnitude of bottom up impacts on seals, as well as the top down impacts of seals. However, such models are on broad spatial and temporal scales, and to robustly address specific questions relating to such impacts would require a bespoke study with up-to-date diet data.**

**Critically, most of the available data is over ten years old and may not provide an accurate description of seal diet, particularly in areas where there have been significant changes in fish stocks and seal populations. SCOS recommends a co-ordinated programme of research across the UK to provide an updated picture of seal diet would be required to fully answer the question posed here. It is also noted that a streamlined process of permissions to conduct the necessary fieldwork over such a large number of sites would be required.**

There have been very few published studies of seal diet in the UK since previous comprehensive summaries on UK seal diet were provided in SCOS 2019 and 2021. SMRU carried out three major diet studies in the mid-1980s, 2002, and 2010/11 to sample scats seasonally around the coast of Scotland and eastern England to estimate diet composition and prey consumption of grey seals and, in 2010/11, harbour seals. The results of these are described in detail in a series of reports to Scottish Government (Hammond & Wilson, 2016; Wilson *et al*., 2016; Wilson & Hammond, 2016 a, b). The results of the most recent study based on sampling between 2010 and 2011 are summarised in Wilson and Hammond (2019), in the context of regional variation in trends in population size of both species of seal. The results of these are described in detail in a series of reports to Scottish Government (Hammond & Wilson, 2016; Wilson *et al*., 2016; Wilson & Hammond, 2016 a, b). The results of the most recent study based on sampling between 2010 and 2011 are summarised in Wilson and Hammond (2019), in the context of regional variation in trends in population size of both species of seal. Overall, sandeels and large gadids were the two main prey types, but results showed considerable seasonal and regional variability.

In terms of diet composition, in the southern North Sea, sandeel dominates grey seal diet, whereas flatfish, gadids and sandy benthic species are more important for harbour seals. In the Moray Firth, the diet of both species is dominated by sandeel. In the Northern Isles, sandeel and gadids are important in both species' diets, with pelagic prey also important for harbour seals. Gadids are the main prey of both species in the Inner Hebrides. In the Outer Hebrides, sandeel and gadids are the main prey of grey seals and pelagic species and gadid featuring in harbour seal diet (Wilson and Hammond, 2019).

Here updates since SCOS 2021 in terms of data collection, processing, and analyses are summarised. Stable isotope analysis by Damseaux *et al*. (2021) which indicates that grey seals sampled from the Isle of May, East Scotland (2016) had a relatively more selective diet compared to harbour seals sampled in Orkney (2017). Based on comparisons with prey species profiles, Damseaux *et al*. concluded that diet of grey seals that breed in East Scotland was comprised mainly of flatfish and sandeels compared to harbour seals in Orkney that present a more generalist diet including cod, flatfish, monkfish, hake and haddock.

There has been recent data collection has been from Shetland; harbour and grey seals captured for telemetry tagging. Sampling was undertaken for various funded projects. Stable isotope analyses was conducted on blood by University of Exeter (University of Highlands & Islands). The results are currently being written up for publication. Both plasma and red blood cells were used to allow SIA estimates to be compared on different time scales. In addition, SIA analyses on a range of potential prey species (provided by University of Highlands and Islands, Shetland) were used to increase the robustness of inference from SIA. Faecal material from captured seals (25 harbour seals, 10 grey seals) could be processed for metabarcoding with appropriate funding. As well as providing diet data for both seal species within a declining and stable harbour sea SAC (on the level of individual fish species), such data would increase the robustness of the SIA estimates, and allow diet on multiple time scales to be linked to subsequent movements. Under a new workstream under the Scottish Marine Animal Strandings Scheme 'Priority Species Investigations' the analysis of diet from the stomach contents of stranded seals has begun but sample sizes are small and inference will be limited until this has been underway for some time.

A key factor in predicting the impact of changing fish stocks on seals is by considering the energetic value of different prey species and sizes. This is currently the focus of part of a SMRU PhD project. Bomb calorimetry is being used to process fish from Marine Directorate trawl samples from the Moray Firth and Firth of Forth to derive length/energy density relationships for important prey species for harbour and grey seals (as identified through previous diet studies; Wilson and Hammond 2019). These species-specific relationships will be applied to fish lengths estimated from otoliths scat measurements from previous diet studies in the UK to estimate the energetic value of different diets and investigate the potential energetic consequences of inter-annual changes in diet.

There is a SMRU study currently underway in Southeast England investigating harbour and grey seal diet in the region (see Q*). There is also work focussed on the Farnes Islands, Northeast England led by Newcastle University; scats collected during the breeding season over the last 20 years have shown a gradual switch from a diet mainly consisting of sandeels to one of gadoids (Bevan pers comm). SCOS are not aware of any other dedicated studies elsewhere across the UK.

Historic diet data (up to 2012) is being used in various projects; outputs are not yet available but are in preparation for publication. Specifically, another SMRU PhD project has looked at spatio-temporal trends in seal diet diversity in the context of changing harbour and grey seal populations, using data from the three Scotland-wide SMRU study and others (Langley *et al*., In Prep). Specifically the following data was incorporated and processed into a consistent format: Shetland (late 1990s; Brown & Pierce 1997; Brown *et al.,* 2001, Brown & Pierce unpublished); Moray Firth (late 1980s to mid 1990s; Pierce *et al.,* 1991a, 1991b; Thompson unpublished), and East Scotland (late 1990s- early 2000s; Hall 1999; Sharples *et al*., 2009).

Multispecies functional response models have been developed for both seal species to allow predictions of how consumption of a given fish species will vary with its availability and the availability of other fish species (Ransijn *et al.* In Prep as for porpoise; Ransijn *et al.* 2021). Such models are key to predicting seal diet and consumption under different management scenarios. Indeed, these models can be used to predict the impact of various scenarios of fish abundance in a specific area on consumption. Through the EcoSTAR project, information about seal haulout abundance (through time), movements at sea, and diet (assigned to the relevant year) have been integrated into an ecosystem model. The aim is to then predict the impact of the current and projected future scenarios (climate, seal populations, fisheries management) on fish distribution, fisheries catch and seal prey consumption (Lynam *et al*., In Prep). Such models will inform the potential magnitude of bottom-up impacts on seals, as well as the top-down impacts of seals. However, such models are on broad spatial and temporal scales, and to robustly address specific questions relating to such impacts would require a bespoke study with up-to-date diet data, and more explicit consideration of how such impacts are mediated by prey size.

SCOS note that the majority of UK seal diet information is now more than 10 years old and is unlikely to provide an accurate description of seal diets in areas where fish stocks and seal populations have changed. Understanding ongoing changes in seal populations and the implications of other pressures (including fishing and climate change) acting on these fish species for seals necessitates an understanding of diet and how it has changed. There is an ongoing study in Southeast England that will provide an update on seal diet in this region (see Q6) but nothing similar is currently planned for Scotland.

Given the changes observed in several UK regions in trends in both seal species, and ongoing concerns about interactions with fisheries and other anthropogenic activities, SCOS recommends a comprehensive programme of research to update the current understanding of seal diet around the UK. This should be combined with recent and future telemetry studies to understand the spatial distribution of foraging effort. Particular attention should be paid to characterising areas of contrasting population trends and areas undergoing changes in the underlying trends. Traditional approaches such as scat collection and hard part identification should be complemented with DNA metabarcoding techniques. The relative merits of these techniques are beyond the scope of this report, but a key advantage of hard-part analyses is its consistency with previous UK diet studies and the ability to estimate the size, and thus biomass, of fish consumed. Metabarcoding allows the identification of prey species for which hard part may not be retained or identifiable. It is also noted that a streamlined process of permissions to conduct the necessary fieldwork over such a large number of sites would be required.

## Climate change

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| **31. Can SCOS provide an update on any potential impacts to seals from the Marine Heat Wave that occurred in June 2023 since the last interim advice in August 2023?** | Scot Gov Q13 |
| *The coastal regions off the east coast of the UK experienced a category 4 MHW in June 2023 which could potentially have had direct or indirect effects on seal species. MD would appreciate any updated information collected* | |

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| *since August 2023 that would help get a better understanding of potential impacts of this event on UK seal populations.* | |

**Sea surface temperatures (SST) off the UK and Ireland were as much as 4-5°C above normal in June 2023 during a category 4 Marine Heat Wave (MHW). Two further less extreme SST anomalies occurred in September 2023 and May 2024. Similar MHWs have occurred off the Canadian east coast and the west coast of Norway, such that most Atlantic grey and harbour seals have been subjected to MHW conditions in the past year.**

**A preliminary analysis of seal stranding reports suggests that the number of stranded seals in Scotland was 17% lower in 2023 than in 2022, but there was an apparent uptick in strandings reports, in July and August coincident with the harbour seal breeding season which is probably within the inter-annual range of number of summer strandings (SMASS in press).**

**Air surveys were carried out in August 2022 and 2023 suggest that harbour seal counts at the main sites in east Scotland and east England did not show a significant fall between 2022 and 2023. Conversely, grey seal counts were much lower in 2023 in east Scotland. Grey seal numbers were also similar between years except at Donna Nook, the largest grey seal haulout on the UK east coast, where the count increased from approximately 3500 to 6000.**

**The harbour seal pup count in The Wash in 2023 (1417) was approximately 25% higher than the 2022 count and equal to the mean count over the preceding decade. Seal counts were therefore equivocal and do not show a consistent decline coincident with the MHW.**

**In all the SST anomalies, the observed temperatures fell within the thermo-neutral range of both grey and harbour seals and were unlikely to have had significant direct physiological or energetic impacts on either species in the water. Short to medium term consequences for seals are most likely to result from changes in prey availability, as fish and their prey species are likely to be more sensitive to such temperature changes.**

**In January 2024, coincident with a prolonged MHW event on the Scotian Shelf, the grey seal breeding colony on Sable Island saw the lowest pup weaning masses in the 30 year time series. Other factors such as exposure to diseases, an increase in predators, and resource competition could have contributed to this reduced weaning mass effect.**

**So far, the effects of the 2023 MHW on fish in UK waters are unknown. A wide range of demersal fisheries in Europe and North America showed no detectable effects of sea bottom heatwaves. Abnormally low wind speeds in 2023 resulted in strong stratification that reduced the heating of the bottom of the water column in the central and northern North Sea. This suggests that the June 2023 MHW may have had limited effects on the benthic and demersal fish populations which provide a large proportion of the diets of both grey and harbour seals in UK waters.**

**There was evidence of a *Noctiluca scintillans* bloom at localities in the central North Sea. Intense blooms of this species can be responsible for environmental hazards, such as toxic red tides and resulting fish-kills. It is not known if this event had any impact on seals or their prey.**

Sea surface temperatures (SST) off the UK and Ireland were as much as 4-5°C above normal in June 2023 during a category 4 Marine Heat Wave (MHW). The coastal regions off the east coast of the UK, from Durham to Aberdeen saw the highest SST anomaly. SST values returned to levels close to the long-term average by mid July 2023, before rising again in early September 2023. SST was close to the long-term average through the winter of 2023/2024, but was again anomalously high during May 2024. The September 2023 and May 2024 anomalies were neither as extreme nor as long lasting as the June 2023 MHW (Figure 65). Over the same period, an extreme MHW event developed in the Northwest Atlantic in July 2023 covering the entire at sea distribution of the eastern Canadian harbour and grey seal populations, and another intense SST anomaly has developed in the same area in July 2024 (Figure 6). An ongoing, extreme MHW developed in August 2024, covering most of the Norwegian Sea and extending along the central and northern sections of the West coast of Norway, where a large proportion of the Norwegian grey and harbour seal population are concentrated (Figure 6). The exposure of both grey and harbour seal populations to repeated extreme MHW events throughout their ranges in the North Atlantic is a cause for concern and potential impacts should be monitored.

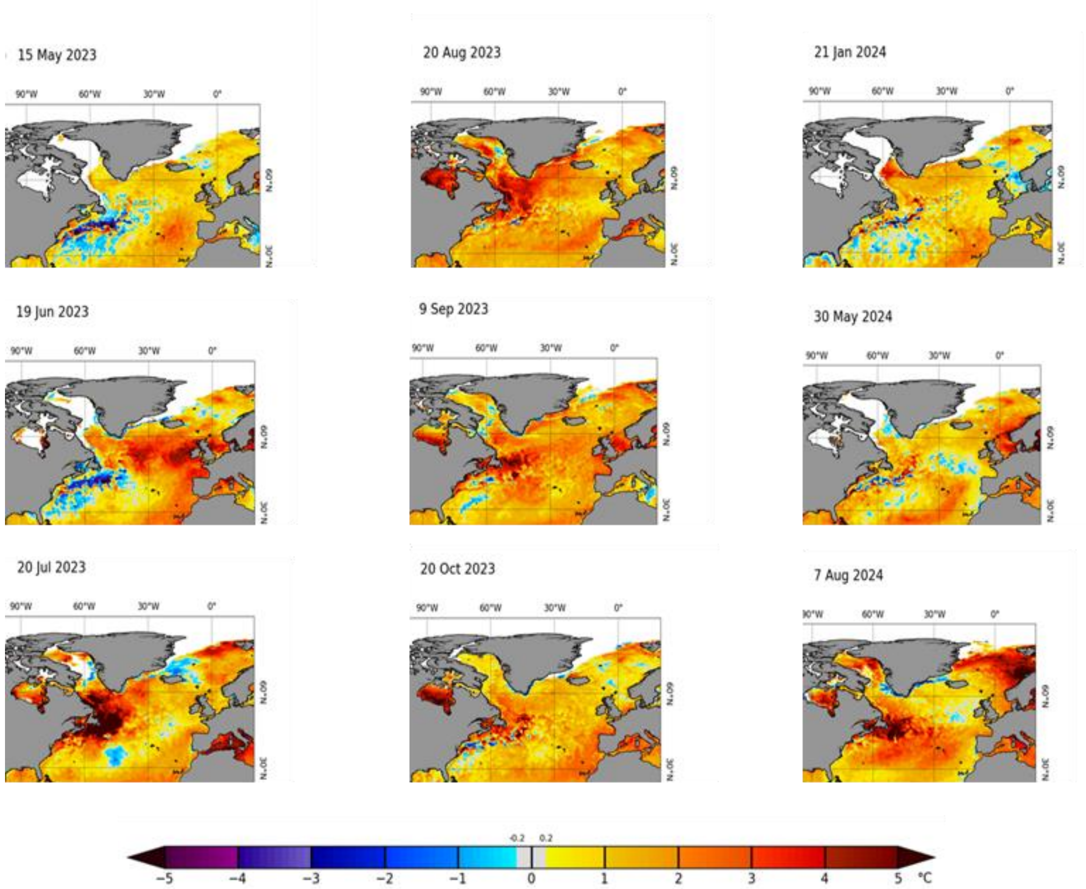


*Figure 6. Maps of SST anomalies in the North Atlantic between spring 2023 and summer 2024 (modified from NOAA, 2024*)

Strandings data
A preliminary analysis of seal stranding reports suggests that the number of stranded seal carcasses reported to the Scottish Marine Animal Stranding Scheme (SMASS) was 17% lower in 2023 than in 2022. There was no apparent increase in seal strandings reports in Scotland during the MHW, but there was an apparent uptick in strandings reports, mainly of harbour seals, in July and August (SMASS in press). Increased strandings reports associated with harbour seal pups is usual in late summer, and results of ongoing analyses to determine whether this is significantly higher than expected will be presented to future SCOS meeting. Because of ongoing HPAI precautions, no seal

postmortems have been carried out in 2023 or in 2024 to date, so cause of death has not been established for most of these animals.

Population surveys

Air surveys were carried out in August 2022 and 2023 of haul-out sites on sections of the east coast of Scotland and England. Detailed counts are presented in SCOS-BP 24/01. There was no indication of a decrease in counts of harbour seals in either the Moray Firth or the Tay & Eden SAC, between 2022 and 2023. Conversely, grey seal counts were much lower in 2023 in the area; numbers fell from approximately 2200 to 810 in the Moray Firth and from 1760 to 820 in the Firth of Tay and Eden between 2022 and 2023 respectively. Preliminary counts for the coast between the Moray Firth and the Firth of Tay show a similar pattern, with no decrease in harbour seals but a decrease in grey seal count from 1470 to 1217 between 2022 and 2023. However, large interannual changes in grey seal haulout numbers have been observed previously and may not be related to the MHW event. Harbour seal counts were also relatively stable between 2022 and 2023 at surveyed sites on the east coast of England; the Tees estuary, Donna Nook, the Wash and North Norfolk SAC, and Scroby Sands Grey seal numbers were also similar between years except at Donna Nook, the largest grey seal haulout on the UK east coast, where the counts increased from approximately 3500 to 6000 (SCOS-BP 24/01). The harbour seal pup count in The Wash in 2023 (1417) was approximately 25% higher than the 2022 count and equal to the mean count over the preceding decade (SCOS-BP 24/07).

Potential effects

In all the SST anomalies, the observed water temperatures were within the thermo-neutral range of both grey and harbour seals and were unlikely to have had significant direct physiological or energetic impacts on either species. Short to medium term consequences for seals are most likely to result from changes in prey availability, as fish and their prey species are likely to be more sensitive to such temperature changes. So far, the effects of the 2023 MHW on fish in UK waters are unknown. Previous, less intense MHW events in the North Sea did not appear to directly impact catches in a range of fisheries, but there were lagged effects on catches of some species occurring up to 5 years after MHW events (Wakelin *et al*., 2021). A wide range of demersal fisheries in Europe and North America showed no detectable effects of sea bottom heatwaves. Abnormally low wind speeds in 2023 resulted in strong stratification which reduced the heating of the bottom of the water column in the central and northern North Sea. This suggests that the June 2023 MHW may have had limited effects on the benthic and demersal fish populations that form a large proportion of the diets of both grey and harbour seals in UK waters.

During the summer heatwave of 2023, there was evidence of a *Noctiluca scintillans* bloom at localities in the central North Sea. Intense blooms of this species can be responsible for environmental hazards, such as toxic red tides and resulting fish-kills. On 19th June 2023, oceanographers at Plymouth Marine Laboratory released images from the NEODAAS satellite system, that showed thin red strands offshore of the Dutch coast that were indicative of *Noctiluca* (Pinnegar, 2024). It is not known if this red tide event had any direct impact on seals or their prey.

MHWs have been shown to affect the timing, geographical distribution and long term dynamics of Psuedo-nitzschia blooms in the North Pacific, with the establishment of novel algal reservoirs that have expanded the temporal and geographical extent of subsequent HABs (Trainer et al., 2020). Given the reported increase in potential for mortalities of harbour seals (Hall et al. 2024) due to Domoic acid accumulation, any such effects are a cause for concern. To date we are not aware of any indications that the 2023 North Sea MHW event has caused similar changes in UK waters.

In January 2024, the breeding colony on Sable Island saw the lowest pup weaning masses in the 30 year time series (den Heyer, personal communication). A number of factors could have contributed to this including exposure to diseases, an increase in predators and resource competition. However, the fact that poor maternal investment, with associated potential impacts on pup survival, in the

Sable Island grey seal population coincided with the occurrence of unusual environmental conditions due to a long lasting severe MHW event is a cause for concern.

## Renewable energy

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| **32. Is there any further information (since last SCOS) on seal interactions with tidal energy devices?** | NRW Q6 |
| *Knowledge of the latest information about interactions and behaviours of grey seals around operational tidal stream installations is key to assessing consenting risk for the tidal industry in Wales. Currently, most evidence is based on harbour seal. Please can SCOS highlight any new information (since the last SCOS) and summarise the status of present empirical knowledge on seal interactions with tidal turbines, noting that harbour seal is likely to be used as a proxy for grey seal.* | |

**There is currently no published information available on grey seal interactions with tidal energy devices. However, there are several studies that report changes in harbour seal distributions and behaviour in response to operational tidal turbines. Although existing studies represent good progress in our understanding how harbour seals behave in response to operating turbines at scales of 100's to 1,000's of metres, information on the fine scale underwater movements (at a scale of metres) of seals around turbines has remained a critical research gap with respect to deriving avoidance/evasion rates. However, a SMRU research project recently deployed a combined active sonar and passive acoustic tracking system alongside an operating tidal turbine off the north of Scotland; initial results confirm that seals are regularly detected and tracked within several tens of metres of the operational turbine (713 seals detected during 338 days of monitoring. Note this includes periods of rotation as well as non-rotation).. Preliminary analysis of the seal tracks show that some seals appear to exhibit avoidance of the rotor swept area.**

There is currently no empirical 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. However, as reported previously to SCOS, there are several studies that report changes in harbour seals 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.,* 2018; 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 reported in SCOS, 2022 (included here for reference: *Table 10).*

*Table 10: 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 |
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| -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) |

Although these studies represent good progress in our understanding how harbour seals behave in response to operating turbines 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 has remained a critical research gap with respect to deriving avoidance/evasion rates and understanding the potential impacts of tidal turbines. However, a NERC and Scottish Government funded research project recently deployed a combined active sonar and passive acoustic tracking system (Gillespie *et al.* 2022) alongside an operating tidal turbine (AR1500) at the MeyGen turbine array off the north of Scotland and collected data over a period of 12 months (June 2022-May 2023). This system tracks individual seals in high resolution (metres) within ~30 m of the turbine and will provide data to quantify occurrence and movements patterns around the turbine. Initial results confirm that seals are regularly detected and tracked within several tens of metres of the operational turbine (713 seals detected during 338 days of monitoring). Importantly, 64 (9%) of the detected seals were tracked relatively close (within 2m) to the rotor swept area, both when the turbine was rotating (13 seals) and not rotating (51 seals). Preliminary analysis of the seal tracks show that some seals appear to exhibit avoidance of the rotor swept area when the rotors are rotating. Further analysis of these tracks is ongoing and a finalised workflow for quantifying avoidance behaviour is currently in development. It is important to highlight that seal species differentiation is not currently possible in the sonar data and, given that both grey and harbour seals are present in the study area, the derived tracks likely reflect a combination of both species; when interpreting the results with respect to grey seals, it therefore seems reasonable to assume that a proportion of the detections will be grey seals.

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| **33. Based on the latest observations of seal interactions with tidal turbines, 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 |
| *When assessing the predicted risk of collisions with tidal turbines through encounter rate (ERM) or collision risk modelling (CRM), a single avoidance rate/factor is applied, which ranges from 0 to 100%. This single factor typically incorporates near-field evasion and far-field avoidance. For marine birds, an avoidance rate of >99% is often used. Existing guidance (SNH 2016) recommends a range of avoidance rates are used to generate a range of collision risk/encounter rate estimates, but this results in a range of plausible values which can make consenting advice variable. The guidance is now 8 years old, with many years of observations collected since publication (see NRW question 6 above). Building on previous SCOS answers to similar questions (eg q23 SCOS 2020, p92), can SCOS recommend what the most appropriate avoidance rate should now be in CRM/ERMs for grey seals around tidal turbines*? | |

**Previous studies including the preliminary data from the sonar tracking indicate that there is a degree of variability in the extent that seals exhibit avoidance behaviour, such that there does not appear to be a scientific basis on which to move away from the 'present a range of potential avoidance rates' currently recommended in existing guidance (Scottish Natural Heritage 2016). However, in future, the combination of the new sonar tracking data and the results of the previous studies (Hastie *et al.* 2018; Joy *et al.* 2018; Robertson *et al.* 2018) should provide sufficient information on behaviour of seals at the range of spatial scales required to effectively derive empirical avoidance rates to operating turbines.**

## Health and disease

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| **34. Following recent reports of widespread mortality of seals in South Georgia which has been attributed to HPAI, can SCOS advise 1) whether there have been similar instances of HPAI in the NE Atlantic seal population and, 2) the potential for an outbreak in UK seal populations. It would be helpful to understand what the implications could be for seals in Scotland, including declining harbour seal populations to the north and east coast of Scotland.** | SG Q9 |

**There are currently no similar instances of large scale Highly Pathogenic Avian Influenza (HPAI) outbreaks in UK seals, but in the absence of any testing, it is currently unknown to what extent HPAI may be circulating.**

**There is evidence of a small number of isolated bird-mammal spill-over events in the UK and Europe associated with the H5N1 virus. In contrast, in the NW Atlantic, infection with H5N1 has resulted in large scale mortalities in both grey and harbour seals.**

**The presence of large numbers of bird carcasses infected with H5N1 at haul-out sites most likely contributed to the spill-over of infection to seals in the mass mortalities of pinnipeds around the world so far, so there is potential for an outbreak in UK seal populations given the mass mortalities of seabirds here as well. However, the potential for an outbreak now may be lessened**

**compared to previous years, as in June 2024, Europe has recorded the lowest number of HPAI cases in poultry and wild birds since 2019/2020.**

**The implications of a potential outbreak in Scotland largely depend on whether 1) infection occurs through a series of spill-over events from infected birds to seals, 2) whether viral changes ultimately result in effective seal-seal transmission, or 3) whether both scenarios occur simultaneously. SEIR modelling (i.e. Susceptible–Exposed–Infected–Recovered) could be used to model these scenarios and predict the potential magnitude of impact associated with future HPAI outbreaks in Scotland. This approach, however, requires accurate parameterisation of epidemiological models as well as information on population specific levels of immunity that are currently unknown. For harbour seals, multiple potential sources of virus transmission from bird migrations during the summer pupping season and the August moult could potentially lead to changes in viral exposure, and thus result in the largest impact through infection of all age classes and both sexes.**

No similar instances of HPAI large scale outbreaks have been seen in the NE Atlantic. However, there have been a handful of positive cases. In Scotland, several samples collected from dead seals found on shores were sent by the Scottish Marine Animal Strandings Scheme (SMASS) to the UK Animal and Plant Health Agency (APHA) for testing. Three out of the four dead harbour seals and one of two dead grey seals fsampled in 2021 and early 2022 tested positive for H5N1. The animals were found in Aberdeenshire, Highland, Fife and Orkney. However, HPAI infection was only thought to be a potential contributing factor to the animal's death in one of the harbour seals, and not in the other cases (SMASS, pers. comm.). There as been no active surveillance involving the testing of apparently healthy seals , so it is unknown if other spill-over events have taken place in the last 2 years in Scotland. In Europe, two grey seals with encephalitis from The Netherlands and Germany, collected in December 2022 and February 2023 respectively, tested positive for H5N1 (Mirolo *et al*., 2023). Importantly, antibody screening of historical serum samples collected in Germany between 2020 and 2023 showed no evidence of influenza A virus-specific antibodies. Together these results indicate that individual seals are sporadically infected with HPAI H5N1 with no evidence thus far of onward spread between seals in this population in the southern North Sea (Mirolo *et al*., 2023).

In the NW Atlantic however, infection with HPAI H5N1 has resulted in large scale mortalities in eastern Quebec and along the coast of Maine. An Unusual Mortality Event was declared in 2022 for both grey and harbour seals in Maine. Carcasses were tested and 49% ( 17/35) of harbour, and 33% (2/6) of grey seals were positive for H5N1 (Puryer *et al.,* 2023). Similarly, 60% (15/25) of the harbour and grey seals recovered from the Gulf of St. Lawrence, Canada, between April and September 2022, were considered to be fatally infected by H5N1 (Lair *et al*., 2023).

Small numbers of HPAI positive cases associated with a different H5 subtype have been previously identified in other areas across the UK and Europe. For example, H5N8 has been recently reported to cause an unusual neurological infection with a fatal outcome in four harbour seals and one grey seal in a wildlife rehabilitation centre in the UK in 2020 (Floyd *et al.,* 2021). In Germany, during the outbreak in wild birds across Europe in 2021, three dead harbour seals tested positive for H5N8 (Postel *et al.,* 2021), and H5N8 infection was also found in two dead grey seals along the Polish Baltic coast in 2016 (Shin *et al.,* 2017).

**(1) Potential for an outbreak**

The presence of large numbers of bird carcasses infected with H5N1 at haul-out sites most likely contributed to the spill-over of infection to seals in the mass mortalities of pinnipeds seen so far in South Georgia, South America and the United States. Seals in Scotland have likely come into contact with infected seabirds as a result of the mass mortalities around the UK since 2022 (Tremlet *et al*., 2024). After an initial spill-over event, should transmission then also occur between seals, an outbreak is more likely where seals haul out in close proximity to each other. The key risk periods for seals are therefore likely to be periods where individuals spend protracted periods of time onshore such as during the breeding season or during the moult. In fact, as harbour seals are more prone to infectious diseases than grey seals, it has been hypothesised that lower density haulouts seen in harbour seals might be a behavioural response to reduce pathogen transmission (Hoekendijk *et al*., 2023).

However, the potential for an outbreak now may be lessened compared to in previous years. Currently, the main findings of the latest report published in July 2024 on avian influenza by the European Food Safety Authority (EFSA), the European Centre for Disease Prevention and Control (ECDC), and the EU reference laboratory (EURL), based on reported data between April and June 2024 show that Europe has recorded the lowest number of HPAI cases in poultry and wild birds since 2019/2020. The improvement of the situation in Europe may be linked to several factors which include: immunity developed by wild birds following previous infection; reduction of certain wild bird populations which now limits disease spread; decreased environmental contamination; and changes in the composition of viral genotypes.

**Implications for Scottish seals**

The implications of an outbreak in Scottish seals largely depend on whether 1) infection occurs through a series of spill-over events from infected birds to seals, 2) whether viral changes ultimately result in effective seal-seal transmission, or 3) whether both scenarios occur simultaneously. Implications will also be affected by the severity of the disease in seals, specifically by the potential for widespread transmission to result in severe disease and mortality through high viral virulence and/or low levels of population immunity. Should there continue to only be isolated cases of spill-over events involving HPAI, as have been seen in the UK, Germany, the Netherlands and in the Baltic, there are unlikely to be population-level implications for Scottish seals. However, should seal-seal transmission and/or multiple spill-overs take place of a highly virulent strain, an outbreak could impact on Scottish seal populations. This is believed to have been the case in South America where combined ecological and phylogenetic data support mammal-to-mammal transmission as well as occasional mammal-to-bird spill-over (Urhart *et al*., 2024).

For historical outbreaks or those that are currently occurring, observed levels of mortality and counts can be used to estimate the direct population impact. Modelling can also be used to investigate infectious disease dynamics (Bjørnstad *et al*., 2020), and population level consequences of future disease outbreaks. For example, the basic SEIR model has four groups: susceptible (S), exposed (E), infectious (I) and recovered (R), with a total population size N = S + E + I + R. It is parametrized by the infectious period, the basic reproduction number $R_0$ (the number of secondary cases for each infection in a completely susceptible population), and the contact rate (*Bjørnstad et al*., 2020). SEIR modelling could be used to predict the potential magnitude of impact associated with future HPAI outbreaks in Scottish seals, but requires accurate parameterisation of epidemiological parameters as well as appropriate information on population specific levels of immunity that are currently unknown. Initially a feasible range of these parameters could be considered, with the ranges being refined as more information became available. Additionally, to be able to predict the spread of the disease, reliable estimates of the rates of movements between regions (SMUs) and between haul-out sites within regions will be needed for both species. Such information can most effectively be derived from telemetry data.

**Implications for declining harbour seal populations on the north and east coast?**

As described above, HPAI infection can be fatal in harbour seals. To predict the potential implications of infection for declining harbour seal populations, developing an understanding of how population dynamics, population connectivity and social behaviour interact to determine the vulnerability of small and declining populations to new pathogens is crucial. New developments in epidemiological modelling that combine behaviour and demographic parameters offer a predictive framework that could be used (Silk *et al*., 2019). Currently, the potential impacts of infections on small (eg. east coast) and declining (eg. Shetland) harbour seal populations are hard to predict given that smaller population sizes could result in a lower potential for seal-seal transmission, and therefore a large-scale disease outbreak may be unlikely. However, if the virus is introduced through multiple spill-over events from birds, or through multiple points of contact with other marine mammal carriers (like grey seals for example), then there is the potential for a disease outbreak even in the smaller, declining populations in Scotland. Multiple sources of virus transmission during the August moult could potentially result in the largest impact through infection of all age classes and both sexes. Equally, infection spread during the June pupping season could have a huge impact on pup survival given the ~95% mortality rate observed in southern elephant seal pups born in the 2023 breeding season in Península Valdés (Urhart *et al.,* 2024). Adult female elephant seals also left the breeding beaches early, likely before being impregnated, so this population is also predicted to experience an atypically low birth rate in 2024 (Urhart *et al.,* 2024). If such high pup mortality rates were seen in declining harbour seal populations, with the loss of an entire cohort of young animals, together with the loss of reproductive potential for the following season, this could have a significant impact on these populations.

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| **35. Can SCOS advise on the need for enhanced strategic disease and health surveillance across seal colonies, what actions this could encompass, and how they should be prioritised?** | Defra – emerging issue recieved 12th July 2024 |
| *Considering SCOS's previously raised concerns of the high likelihood of future disease outbreaks in UK seal populations, efforts from Devolved Administrations to draft contingency plans for specific disease outbreaks (PDV and Avian Flu), and previously unexplained declines in some seal populations, we would like to understand how disease and health surveillance could be further enhanced across seal populations. In addition, where priorities should lie from a monitoring and/or scientific perspective, for example whether there would be focus populations, and potential hotspots for disease spread.* | |

**Routine disease surveillance through coordinated efforts involving strandings schemes, rescue and rehabilitation centres and live captures is critical to determine epidemic potential of influenza A viruses and other viral diseases in seals. This routine surveillance should involve (but is not limited to) the collection of respiratory/mouth swab samples to establish the presence of active infections, and blood samples for antibody testing for evidence of previous pathogen exposure. Furthermore, there is a need to better understand population health more broadly such that we can investigate potential underlying drivers of poor immune system function, poor condition or the impacts of exposure to a range of environmental and anthropogenic pressures.**

**The Scottish Marine Animal Stranding Scheme (SMASS) has always included seals. In the rest of the UK, seals have only recently been incorporated into the strandings programme (UK Cetacean Investigation Programme; CSIP). With the exception of Cornwall, there is a lack of public awareness regarding reporting of seals to CSIP, and a lack of infrastructure in place to deal with such reports. This hinders effort to understand the health and disease status of seals in England and Wales, and any association with local declines.In addition, the delay between application and granting of authority to conduct studies requiring capture and/or sampling of seals precludes a rapid response to the onset of a disease event or any other response to acute environmental perturbations. A mechanism by which there is a fast-response for granting of authority to conduct studies in the event of time-critical investigations should be a priority.**

There is a need for disease surveillance and information sharing regarding both wild coastal and seabird populations as well as marine mammals, as this is critical to determine epidemic potential of influenza A viruses and other viral diseases in seals. However, there are currently significant challenges with laboratory capacity and resources for the testing of seal samples, particularly with regards to concerns about domestic animal and public health because of the wider epidemic in birds. Additionally, we currently have no information regarding changes in strandings or reported causes of death in seals from England or Wales due to very little reporting, carcass recovery or sampling of seals by the Cetacean Strandings Investigation Programme (CSIP). With the exception of Cornwall, there is a lack of public awareness regarding reporting of seals to CSIP, and a lack of infrastructure in place to deal with such reports. This hinders effort to understand the health and disease status of seals in England and Wales, and any association with local declines. Indeed, up to date information on disease prevalence and the susceptibility of populations around the UK to infection is critical for future epidemic planning and response. This information would help us to establish potentially vulnerable populations, rather than solely being responsive when an outbreak has already occurred.

Moreover, there is a need to better measure and understand population health through live-captures such that we can investigate potential underlying drivers of poor immune system function, poor condition or exposure to a range of environmental and anthropogenic pressures impacting health. Sampling live animals contributes to a body of previous and ongoing research assessing nutritional stress, biotoxin exposure (which has been linked to neurological deficits), contaminant exposure (which impacts reproduction), as well exposure to infectious diseases in harbour seals. For example, nutritional status is assessed through morphometric measurements and blood-based clinical chemistry biomarkers. Other clinical chemistry and haematological parameters are indicative of organ status, immune system function and/or specific disease condition. Blood samples from live captures can therefore be analysed for a suite of haematological and clinical chemistry parameters for comparison with historic data collected by SMRU to establish "baselines" and identify changes over time in the health of individuals from populations with differing trajectories around the UK. Understanding these baselines can then help identify changes, and thus if drivers of declines in some areas are linked to nutritional stress, compromised immune system function or disease exposure, for example. This enhanced health surveillance is particularly valuable when ongoing declines are not associated with visible mass mortalities; for example, as is the case in Shetland and Orkney where there has been no reported increase in the number of dead seals over the period of major population declines. This enhanced disease surveillance is also particularly valuable to improve our ability to rapidly respond to declines and collect additional information before unusual mortality event (UME) die-off levels.

**Actions:**

Reporting of changes in seal strandings as well as active routine disease surveillance should be implemented. Standardised protocols for sampling should be developed and agreed between the different organisations involved including strandings schemes, rescue and rehabilitation centres and researchers. This should include, firstly, mechanisms for stranding scheme personnel at the Scottish Marine Animal Strandings Scheme as well as the Cetacean Strandings Investigation Program in England to report increases in the number of seal carcasses. Secondly, this should include mechanisms for personnel working at rescue and rehabilitation centres to report any increases in the number of seals admitted to their centres as well as changes in the causes of death for those that are not rehabilitated and released. Thirdly, there should be regular swab, tissue and pericardial fluid sampling of beach-cast seals collected by the stranding schemes for both disease screening and antibody testing (including but not restricted to HPAI), as well as swab, tissue and blood sampling of seals brought into rehabilitation centres for the same purposes. This routine surveillance should be extended to any live captures of healthy animals where swab samples should be collected to establish the presence of active infections, and blood should be taken for antibody testing for evidence of previous pathogen exposure. Data could be shared and communicated online through a centralised reporting system. Importantly, these actions cannot currently be met due to a lack of funding, personnel and laboratory capacity, which would need to be addressed.

**Priorities:**

**Unusual Mortality Event identification criteria and sampling plans:** Combining up-to-date information from the strandings schemes and from rehabilitation centres would allow a process to be put in place for identifying unusual mortality events. As with previous advice, 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 United States under the Marine Mammal Protection Act (SCOS, 2022). Determination of an **U**nusual Mortality Event should then trigger an immediate response plan and investigation, making available additional resources to collect and process data, as well as to respond to further strandings should they occur. Co-ordinated response and sampling protocols should be developed in preparation for any future infectious disease outbreak in the UK. This will help to maximise the chances of collection of the information necessary to determine event cause and to determine the effect on the population(s) concerned. SCOS has previously 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. This delay also precludes fast-response sampling when other perturbations to the environment are reported, such as harmful algal blooms or water contamination events, for example. This limits our ability to understand impacts of these events on seals because only sampling “survivors” after an event has taken place, makes linking population changes to the impacts of an acute environmental perturbation very difficult. As previously recommended, SCOS recommend that a mechanism to allow rapid permitting should be a priority as there are currently no mechanisms in place that would allow a timely response to an unusual mortality event (SCOS, 2022), or to an acute change in environmental conditions that can impact seals.

**Routine disease surveillance:** The ongoing challenges posed by HPAI H5N1 necessitate a proactive approach to address future trends. In the UK, there is no national routine surveillance of marine mammals for any disease, including for HPAI such that early identification of any outbreak is not possible. The observed cross-species transmission between mammalian species and bird populations raises concerns about the establishment of viral reservoirs and ongoing risks to both marine mammals and seabirds, and requires active surveillance. As detailed above, routine sampling to identify active infections (through PCR) as well as antibody testing to understand current levels of immunity of seals to both influenza A viruses and PDV are important priorities. Through this work, there should be a particular emphasis on identifying potential reservoir species and understanding the dynamics of transmission in these populations. This would enable the identification of focus populations, and potential hotspots for disease spread.

# References


Allen, P.J., Amos, W., Pomeroy, P. & Twiss S.D. (1995). Microsatellite variation in grey seals (*Halichoerus grypus*) shows evidence of genetic differentiation between two British breeding colonies. *Molecular Ecology* 4(6): 653-662.

Anderson, S.S. (1990) Seals (British Natural History Series). Whittet Books Ltd. 128 PP. ISBN 0905483804

Badger, J., Bowen, W.D., den Heyer, C. & Breed, G.A. (2020). Variation in individual performance amplified with population size in a long-lived carnivore. Ecology. doi: 10.1002/ECY.3024.

Badger, J. J., Bowen, W. D., den Heyer, C. E., & Breed, G. A. (In Press). Reproductive success is influenced by early development: the covariation of natal body size and reproductive performance in grey seals (Halichoerus grypus). *bioRxiv*, 2021-07.

Badger, J., Bowen, W., den Heyer, N. & Breed, G. (2023). Large offspring have enhanced lifetime reproductive success: Long-term carry-over effects of weaning size in gray seals (Halichoerus grypus). Ecology and evolution. 13. e10095. 10.1002/ece3.10095.

Baines, M., Earl, S., Pierpoint, C. & Poole, J. (1995) The west Wales grey seal census. CCW Contract. Science Report, no. 131, 238 pp.

Banga R, Russell DJF, Carter MID, Chaudry F, Gilles A, Abel C, Ahola M, Authier M, Bjørge, A, Brasseur S, Carlsson A, Carlstrom J, Christensen AH, Dinis A, Engene N, Galatius A, Geelhoed S, Granquist S, Haelters J, Jess A, Morris C, Murphy S, Ó Cadhla O, Persson S, Pierce G, Poncet S, Rosing-Asvid A, Saavedra C, Taylor N, Teixeira A, van Neer A, Vasconcelos R. and Vincent C. (2022). Seal Abundance and Distribution. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/seal-abundance-and-distribution

Bankhead, K., Freeman, G., Heimbichner Goebel, W. and Acevedo-Gutiérrez, A., (2023). Effects of anthropogenic noise on haul-out numbers of harbor seals (Phoca vitulina). *Canadian Journal of Zoology*, *101*(9), pp.720-728.

Berta, A. & Churchill, M. (2012) Pinniped taxonomy: review of currently recognized species and subspecies, and evidence used for their description. Mammal Rev 42:207–234

Bigg, M. A., G. M. Ellis, P. Cottrell, and L. Milette . (1990). Predation by harbour seals and sea lions on adult salmon in Comox Harbour and Cowichan Bay, British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences 1769. Fisheries and Oceans Canada, Nanaimo, British Columbia, Canada

Bjørnstad, O.N., Shea, K., Krzywinski, M. *et al.* (2020) The SEIRS model for infectious disease dynamics. *Nat Methods* 17, 557–558. https://doi.org/10.1038/s41592-020-0856-2

Bordino, P., Kraus, S., Albareda, D., Fazio, A., Palmerio, A., Mendez, M. et al. (2002). Reducing incidental mortality of Franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. *Marine Mammal Science*, **18**(4), 833–842. https://doi.org/10.1111/j.1748-7692.2002.tb01076.x

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

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

Bowen, W. D., den Heyer, C. E., McMillan, J. I., & Iverson, S. J. (2015). Offspring size at weaning affects survival to recruitment and reproductive performance of primiparous gray seals. *Ecology and evolution*, *5*(7), 1412–1424. https://doi.org/10.1002/ece3.1450

Brown, R. and B. Mate. 1983. Abundance, movements and feeding habits of Harbor Seals, Phoca vitulina, at Netarts and Tillamook Bays, Oregon. Seattle, Washington: Fishery Bulletin 81(2):291-300.

Brownlow, A., Onoufriou, J., Bishop, A., Davison, N. & Thompson, D. (2016). Corkscrew seals: grey seal (*Halichoerus grypus*) infanticide and cannibalism may indicate the cause of spiral lacerations in seals. PLoS One. 11: p.1-14.

Büche, B. & Bond, S. 2023. Grey Seal Breeding Census Skomer Island 2023. NRW Evidence Report number 750 The Wildlife Trust of South and West Wales.

Bull, J.C., Jones OR, Börger L, Franconi N, Banga R, Lock K, Stringell TB. (2021) Climate causes shifts in grey seal phenology by modifying age structure. *Proc. R. Soc. B* 288: 20212284. https://doi.org/10.1098/rspb.2021.2284

Butler, J.R.A., Middlemas, S.J., Graham, I.M., Thompson, P.M. and Armstrong, J.D. (2006) Modelling the impacts of removing seal predation from Atlantic salmon, Salmosalar, rivers in Scotland: A tool for targeting conflict resolution. Fisheries Management and Ecology, 13, 285291. doi:10.1111/j.1365-2400.2006.00504.x

Carlen, E. J., Estien, C. O., Caspi, T., Perkins, D., Goldstein, B. R., Kreling, S. E., ... & Schell, C. J. (2024). A framework for contextualizing social-ecological biases in contributory science data. *People and Nature*, *6*(2), 377-390.

Carlén, I., & Cosentino, M. (2023). High‐frequency pingers do not increase catch loss owing to seals in the Baltic Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *33*(4), 389-396.

Carroll, E. L., Hall, A., Olsen, M. T., Onoufriou, A. B., Gaggiotti, O. E., & Russell, D. J. (2020). Perturbation drives changing metapopulation dynamics in a top marine predator. *Proceedings of the Royal Society B: Biological Sciences*, 287(1928), 20200318. doi:10.1098/rspb.2020.0318

Carter, M.I.D., Russell, D.J.F., Embling, C.B., Blight, C.J., Thompson, D., Hosegood, P.J. & Bennett, K.A. (2017). 'Intrinsic and extrinsic factors drive ontogeny of early-life at-sea behaviour in a marine top predator' *Scientific Reports*, 7, 5505. DOI: 10.1038/s41598-017-15859-8.

Carter, M.I.D., Boehme, L., Duck, C.D., Grecian, W.J., Hastie, G.D., McConnell, B.J., Miller, D.L., Morris, C.D., Moss, S.E.W., Thompson, D., Thompson, P.M. & Russell, D.J.F. (2020) Habitat-based predictions of at-sea distribution for grey and harbour seals in the British Isles. Report to BEIS. Available at : https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/959723/SMRU_2020_Habitat based_predictions_of_at_sea_distribution_for_grey_and_harbour_seals in_the_British_Isles.pdf

Carter, M. I. D., Boehme, L., Cronin, M. A., Duck, C. D., Grecian, W. J., Hastie, G. D., Jessopp, M., Matthiopoulos, J., McConnell, B. J., Miller, D. L., Morris, C. D., Moss, S. E. W., Thompson, D., Thompson, P. M., & Russell, D. J. F. (2022). Sympatric seals, satellite tracking and protected areas: habitat-based distribution estimates for conservation and management. Frontiers in Marine Science, 9, [875869]. https://doi.org/10.3389/fmars.2022.875869

Carter, M. I. D., Bivins, M., Duck, C. D., Hastie, G. D., Morris, C. D., Moss, S. E. W., Thompson, D., Thompson, P. M., Vincent, C., Russell, D. J. F. (In Press) Updated habitat-based at-sea distribution maps for harbour and grey seals in Scotland. Sea Mammal Research Unit, University of St Andrews, Commissioned Report to Scottish Government.

Carter et al. (In Prep a) At-Sea distribution of grey and harbour seals on the Northwest European Shelf.

Carter et al. (In Prep b) Quantifying environmental drivers of foraging behaviour for grey and harbour seals in the North Sea using hidden Markov models.

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

Cornwall Wildlife Trust, Cornwall Seal Group. & Cornish Seal Sanctuary. (2013). *Investigation into the attraction of Atlantic grey seals* (Halichoerus grypus) *to the Fishtek Banana Pinger*.

Cosgrove, R., Gosch, M., Reid, D., Sheridan, M., Chopin, N., Jessopp, M. and Cronin, M., 2016. Seal bycatch in gillnet and entangling net fisheries in Irish waters. *Fisheries Research*, *183*, pp.192-199.

Cox, T., Barker, J., Bramley, J., Debney, A., Thompson, D. & Cucknell, A. (2020) Population trends of harbour and grey seals in the Greater Thames Estuary. *Mammal Communications* Vol 6. ISSN 2056-872X

Cronin, M., Jessop, M. and Reid, D. (2020) Seals and fish stocks in Irish waters. Report to the European Parliament's Committee on Fisheries. https://www.europarl.europa.eu/RegData/etudes/note/join/2010/438612/IPOL-PECH_NT(2010)438612_EN.pdf

den Heyer, C.E, Bowen, W.D., and McMillan, J.I. (2013). Long-term Changes in Grey Seal Vital Rates at Sable Island Estimated from POPAN Mark-resighting Analysis of Branded Seals. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/021. v + 21 p.

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

den Heyer, C.E., Mosnier, A., Stenson, G.B., Lidgard, D.C., Bowen, W.D., and Hammill, M.O. 2024. Grey Seal Pup Production in Canada. DFO Can. Sci. Advis. Sec. Res Doc. 2023/078. iv + 35 p.

EFSA (European Food Safety Authority), ECDC (European Centre for Disease Prevention and Control), EURL (European Union Reference Laboratory for Avian Influenza), Alexakis L, Fusaro A, Kuiken T, Mirinavičiūtė G, Ståhl K, Staubach C, Svartström O, Terregino C, Willgert K, Delacourt R, Goudjihounde SM, Tampach S and Kohnle L, 2024. Scientific report: Avian influenza overview March–June 2024. *EFSA Journal* 2024; 22(7):8930, 72 pp. https://doi.org/10.2903/j.efsa.2024.8930

Evers, C., Blight, C., Thompson, D., Onoufriou, J. & Hastie, G. (2017) Determining the water column usage by seals in the Brims lease site. Scottish Marine and Freshwater Science, 8, pp. 36.

Feldman MJ, Imbeau L, Marchand P, Mazerolle MJ, Darveau M, Fenton NJ. (2021) Trends and gaps in the use of citizen science derived data as input for species distribution models: A quantitative review. PLoS One. 2021 Mar 11;16(3):e0234587. doi: 10.1371/journal.pone.0234587. PMID: 33705414; PMCID: PMC7951830.

Fietz, K., Galatius, A., Teilmann, J., Dietz, R>, Frie, A.K., Klimova, A., Palsbøll, P.J., Jensen, L.F., Graves, J.A., Hoffman, J.I. & Olsen, M.T. (2016). 'Shift of grey seal subspecies boundaries in response to climate, culling and conservation' *Molecular Ecology*, 25( 17), 4097-4112. https://doi.org/10.1111/mec.13748

Floyd, T., Banyard, A.C., Lean, F.Z., Byrne, A.M., Fullick, E., Whittard, E., Mollett, B.C., Bexton, S., Swinson, V., Macrelli, M. & Lewis, N.S., 2021. Systemic infection with highly pathogenic H5N8 of avian origin produces encephalitis and mortality in wild mammals at a UK rehabilitation centre. *BioRxiv*.

Galatius, A., Brasseur, S., Hamm, T., Jeß, A., Meise, K., Meyer, J., Schop, J., *et al. (*2023). Survey Results of Harbour Seals in the Wadden Sea in 2023.

Gaydos, J. K., Ignacio Vilchis, L., Lance, M. M., Jeffries, S. J., Thomas, A., Greenwood, V., Harner, P., & Ziccardi, M. H. (2013). Postrelease movement of rehabilitated harbor seal (Phoca vitulina richardii) pups compared with cohort matched wild seal pups. Marine Mammal Science, 29(3), E282–E294. https://doi.org/10.1111/mms.12002

Gearin, P.J., Gosho, M.E., Laake, J.L., Cooke, L., DeLong, R. and Hughes, K.M., 2000. Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise, Phocoena phocoena, in the state of Washington. *J. Cetacean Res. Manage.*, *2*(1), pp.1-9.

Gillespie, D., Oswald, M., Hastie, G. & Sparling, C. (2022) Marine Mammal HiCUP: A High Current Underwater Platform for the Long-Term Monitoring of Fine-Scale Marine Mammal Behavior Around Tidal Turbines. *Frontiers in Marine Science,* **9**.

Graham, et al. (2017) Strategic Regional Pre-Construction Marine Mammal Monitoring Programme 2017. Annual Report for the Moray Firth Regional Advisory Group.

Granquist, S. M. 2022. The Icelandic harbour seal (Phoca vitulina) population: trends over 40 years (1980–2020) and current threats to the population. NAMMCO Scientific Publications, 12.

Greig, D. J., Gulland, F. M., Harvey, J. T., Lonergan, M., & Hall, A. J. (2019). Harbor seal pup dispersal and individual morphology, hematology, and contaminant factors affecting survival. Marine Mammal Science, 35(1), 187–209. https://doi.org/ 10.1111/mms.12541

Hall, A. J. (1999). The diet of grey seals using faecal analysis. Final report of European Commission project 95/78 of DGXIV. Effects of large-scale industrial fisheries on nontarget species (ELIFONTS). University of St Andrews, 6.5–6.51.

Hall, A. J., McConnell, B. & Barker, R. (2001). Factors affecting first-year survival in grey seals and their implications for life history strategy. J. Anim. Ecol. 70:138-149.

Hall, A. J., Dietz, R., Reijnders, P. J. H., Teilmann, J., Harding, K., Hall, A. J., Brasseur, S. M. J. M., Siebert, U., Goodman, S. J., Jepson, P. D., Dau Rasmussen, T., & Thompson, P. M. (2006). A review of the 1988 and 2002 phocine distemper virus epidemics in European harbour seals. *Diseases of Aquatic Organisms*, 68, 115 - 130.

Hall, A.J., Mackey, B., Kershaw, J. & Thompson, P. (2019). Age-length relationships in UK harbour seals during a period of decline in abundance. *Aquatic Conservation: Marine and Freshwater Ecosystems.* DOI: 10.1002/aqc.3104.

Hall, A. J., Kershaw, J. L., Fraser, S., Davidson, K., Rowland-Pilgrim, S., Turner, A. D., & McConnell, B. (2024). Estimating the risks of exposure to harmful algal toxins among Scottish harbour seals. *Harmful Algae*, 102653.

Hamilton, S. & Baker, G.B. (2015) Review of research and assessments on the efficacy of sea lion exclusion devices in reducing the incidental mortality of New Zealand sea lions Phocarctos hookeri in the Auckland Islands squid trawl fishery. *Fisheries Research*. 161 , pp.200-206

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

Hammill, M.O., den Heyer, C.E., Bowen, W.D., & Lang, S.L.C. (2017). Grey Seal PopulationTrends in Canadian Waters, 1960-2016 and harvest advice. *DFO Can. Sci. Advis. Sec. Res.Doc.* 2017/052. v + 30 p.

Hammill, M.O., Rossi, S.P., Mosnier, A., den Heyer, C.E., Bowen, W.D., and Stenson, G.B.2023. Grey Seal Abundance in Canadian Waters and Harvest Advice. DFO Can.Sci.Advis.Sec.Res.Doc. 2023/053. iv + 40 p.

Hammond, P. S., & Grellier, K. (2005). Grey seal diet composition and fish consumption in the North Sea. http://sciencesearch.defra.gov.uk/Document.aspx?Document=MF0319_3908_FRP.doc

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

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

Harding, K., Fujiwara, M., Axberg, Y., & Härkönen, T. (2005). Mass dependent energetics and survival in harbour seal pups. *Funct. Ecol*. 19, 129–135. doi: 10.1111/j.0269-8463.2005.00945.x.

Harding K .C., Salmon, M., Teilmann, J., Dietz, R. & Harkonen, T. (2018). Population Wide Decline in Somatic Growth in Harbor Seals—Early Signs of Density Dependence. *Frontiers in Ecology and Evolution*. 6:59. DOI=10.3389/fevo.2018.00059.

Harvey, J. T., & Goley, D. (2011). Determining a correction factor for aerial surveys of harbor seals in California. Marine Mammal Science,27,719–735. https://doi.org/10.1111/j.1748-7692.2010.00446.x

Härkönen, T., Dietz, R., Reijnders, P., Teilmann, J., Harding, K., Hall, A., Brasseur, S., Siebert, U., Goodman, S.J., Jepson, P.D., Rasmussen, T.D. & Thompson, P. (2006). The 1988 and 2002 phocine distemper virus epidemics in European harbour seals. *Dis. Aquat Organisms* 68, 115–130.

Harris, R. N. (2012a) Marine mammals and salmon bag-nets. Report to Marine Scotland, Sea Mammal Research Unit, University of St Andrews, St Andrews.

Harvey, J. T., & Goley, D. (2011). Determining a correction factor for aerial surveys of harbor seals in California. *Marine Mammal Science*,27,719–735. https://doi.org/10.1111/j.1748-7692.2010.00446.x

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

Hastie, G. D., Russell, D. J. F., Lepper, P., Elliot, J., Wilson, B., Benjamins, S., & Thompson, D. (2017). Harbour seals avoid tidal turbine noise: implications for collision risk. *Journal of Applied Ecology*, 55(2), 684-693. doi:https://doi.org/10.1111/1365-2664.12981.

Hastie, G. D., Russell, D. J. F., McConnell, B. J., Moss, S., Thompson, D., & Janik, V. M. (2015). Sound exposure in harbour seals during the installation of an offshore wind farm: predictions of auditory damage. *Journal of Applied Ecology*, *52*(3), 631-640. https://doi.org/10.1111/1365-2664.12403

Hastings,K.K., Small, R.J., & Pendleton, G.W. (2012) Sex- and age-specific survival of harbor seals (*Phoca vitulina*) from Tugidak Island, Alaska, *Journal of Mammalogy*, 93(5), 1368–1379. https://doi.org/10.1644/11-MAMM-A-291.1

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

Hoekstein, M., Janse, W., and Sluijter, M. (2023). Watervogels en zeehonden in de Zoute Delta in 2021/2022.

Hoekendijk JPA, Grundlehner A, Brasseur S, Kellenberger B, Tuia D, Aarts G. Stay close, but not too close: aerial image analysis reveals patterns of social distancing in seal colonies. R Soc Open Sci. 2023 Aug 9;10(8):230269. doi: 10.1098/rsos.230269. PMID: 37564067; PMCID: PMC10410205.

Huber, H.R., Jeffries, S. J., Brown, R.F., DeLong, R.L., & VanBlaricom, G.(2001). Correcting aerial survey counts of harbor seals (Phoca vitulinarichardsi) in Washington and Oregon. *Marine Mammal Science*,17,276–293. https://doi.org/10.1111/j.1748-7692.2001.tb01271.x

ICES. 2022. Working Group on Bycatch of Protected Species (WGBYC). ICES Scientific Reports. 4:91. 265 pp. https://doi.org/10.17895/ices.pub.21602322

ICES_WGMME. 2024. Working Group on Marine Mammal Ecology (WGMME) ICES Scientific Reports. In Press.

Joy, R., Wood, J. D., Sparling, C. E., Tollit, D. J., Copping, A. E., & McConnell, B. (2018). Empirical measures of harbor seal behavior and avoidance of an operational tidal turbine. *Marine Pollution Bulletin*, 136, 92-106. doi:https://doi.org/10.1016/j.marpolbul.2018.08.052.

Kauhala,K., Korpinen, S., Lehtiniemi,M. & Raitaniemi, J. (2019). Reproductive rate of a top predator, the grey seal, as an indicator of the changes in the Baltic food web, *Ecological Indicators*. 102 : 693-703.

Kingston, A. R. Thomas, L. J. & Northridge, S. P., (2021). UK Bycatch Monitoring Programme Report for 2019, Report to Defra. 44 pp. Available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=19943&FromSearch=Y&Publisher=1&SearchText=ME6004&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Kingston, A. R. Thomas, L. J. & Northridge, S. P., (2024). UK Bycatch Monitoring Programme Report for 2021, Report to Defra.

Kingston, A. R. Thomas, L. J. & Northridge, S. P., (2023). UK Bycatch Monitoring Programme Report for 2020, Report to Defra.

Kusnierz, P.C., Trial, J.G., Cox, O.N. and Saunders, R., 2014. Seal-induced injuries on adult Atlantic salmon returning to Maine. *Marine and Coastal Fisheries*, *6*(1), pp.119-126. Lander, M. E., & Gulland, F. M. (2003). Rehabilitation and post-release monitoring of Steller sea lion pups raised in captivity. Wildlife Society Bulletin, 31(4), 1047–1053. https://doi.org/10.2307/3784450

Lair, S. Louise Quesnel, Yohannes Berhane, Pauline Delnatte, Carissa Embury-Hyatt, Marie-Soleil Nadeau, Oliver Lung, Shannon T. Ferrell, Robert Michaud (2023). Outbreak of Highly Pathogenic Avian Influenza Virus H5N1 in Seals in the St. Lawrence Estuary, Quebec, Canada. bioRxiv 2023.11.16.567398; doi: https://doi.org/10.1101/2023.11.16.567398

Lehtonen, E., Lehmonen, R., Kostensalo, J., Kurkilahti, M. and Suuronen, P., (2022). Feasibility and effectiveness of seal deterrent in coastal trap-net fishing–development of a novel mobile deterrent. *Fisheries Research*, *252*, p.106328.

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

Lonergan, M, Duck, C. , Moss, S., Morris, C. & Thompson, D. (2013). Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. *Aquatic Conservation-Marine and Freshwater Ecosystems* 23 (1):135-144.

Loseva, A., Chirkova, O. and Shakhnazarova, V., (2023). Haul-out patterns of the Baltic grey seal (Halichoerus grypus) in the suburbs of a metropolis. *Regional Studies in Marine Science*, *65*, p.103104.

Luck, C., Jessop, M., Tully, O., Cosgrove, R., Rogan, E. & Cronin, M. (2020). Estimating protected species bycatch from limited observer coverage: A case study of seal bycatch in static net fisheries. *Global Ecology and Conservation*. 24 e012213.

Lundy Field Society. (2023) Annual Report No. 72. ISSN 0143-8026. www.lundy.org.uk

Lyle, J.M., Willcox, S.T. & Hartmann, K. (2016) Underwater observations of seal–fishery interactions and the effectiveness of an exclusion device in reducing bycatch in a midwater trawl fishery. Canadian Journal of Fisheries and Aquatic Sciences. 73(3): 436-444. https://doi.org/10.1139/cjfas-2015-0273

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

Merkel, B., Lydersen, C., Yoccoz, N. G., and Kovacs, K. M. 2013. The World's Northernmost Harbour Seal Population–How Many Are There? PLoS ONE, 8: e67576.

Milesi-Gaches, David Pierre, and Alexandre Lhériau-Nice. (2024). "Assessing the Impact of Transportation on Seal Behaviour: A Case Study from Ísafjörður, Iceland." *Findings*, June. https://doi.org/10.32866/001c.120040.

Mirolo M, Pohlmann A, Ahrens AK, et al. Highly pathogenic avian influenza A virus (HPAIV) H5N1 infection in two European grey seals (*Halichoerus grypus*) with encephalitis. (2023) *Emerg Microbes Infect*. 2023;12(2):e2257810. doi:10.1080/22221751.2023.2257810

MMO (2020). Assessing Non-lethal seal deterrent options: Summary Report (MMO1131). https://www.gov.uk/government/publications/non-lethal-deterrents-suitable-for-control-of-seals-from-fishing-vessels-mmo1131.

Morris, C.D., Duck, C.D. & Thompson, D. (2021). Aerial surveys of seals in Scotland during the harbour seal moult, 2016-2019. NatureScot Research Report 1256.

Morris, C. & Duck, C. (2019a). Aerial thermal-imaging surveys of harbour and grey seals in Northern Ireland, August 2018. Report for the Department of Agriculture, Environment and Rural Affairs, Northern Ireland.

Morris, C. & Duck, C. (2019b). Aerial thermal-imaging survey of seals in Ireland, 2017 to 2018. Irish Wildlife Manuals, No. 111, National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland.

Morrison, C., Sparling, C., Sadler, L., Charles, A., Sharples, R., & McConnell, B. (2012). Post-release dive ability in rehabilitated harbor seals. Marine Mammal Science, 28(2), E110–E123. https://doi.org/10.1111/j.1748-7692.2011.00510.x

Naughton, G.P., M.L. Keefer, T.S. Clabough, M.A. Jepson, S.R. Lee, C.A. Peery, and C.C. Caudill. 2011. Influence of pinniped-caused injuries on the survival of adult Chinook Salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss) in the Columbia River basin. Canadian Journal of Fisheries and Aquatic Sciences 68:1615–1624.

Nikolic, N., Thompson, P., de Bruyn, M., Macé, M., & Chevalet, C. (2020). Evolutionary history of a Scottish harbour seal population. *PeerJ,* 8, e9167.

NOAA (2022). Standards for Release of Marine Mammals Following Rehabilitation. Corporate Authors(s) : Marine Mammal Health and Stranding Response Program (U.S.);United States. National Marine Fisheries Service. Office of Protected Resources; https://repository.library.noaa.gov/view/noaa/48559

NOAA (2023). Guidelines for Preparing Stock Assessment Reports Pursuant to the Marine Mammal Protection Act. National Marine Fisheries Service Procedure 02-204-01. https://www.fisheries.noaa.gov/s3/2023-05/02-204-01-Final-GAMMS-IV-Revisions-clean-1-kdr.pdf

Norris, T. A., Littnan, C. L., & Gulland, F. M. (2011). Evaluation of the captive care and post-release behavior and survival of seven juvenile female Hawaiian monk seals (Monachus schauinslandi). Aquatic Mammals, 37(3), 342–353. https:// doi.org/10.1578/AM.37.3.2011.342

Øien, N. & Haug, T. (2017). *Norway - Progress report on marine mammals 2017*. NAMMCO. Report number: NAMMCO/26/NPR-N-17

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

Onoufriou, J. A. R., Russell, D. JF., Thompson, D., Moss, S., & Hastie, G. D. (2021). Quantifying the effects of tidal turbine array operations on the distribution of marine mammals: implications for collision risk. *Renewable Energy***,** 180**,** 157-165. https://doi.org/10.1016/j.renene.2021.08.052

Orr, A. J., A. S. Banks, S. Mellman, H. R. Huber, and R. L. DeLong . 2004. Examination of the foraging habits of Pacific harbor seal (*Phoca vitulina richardsi*) to describe their use of the Umpqua River, Oregon and their predation on salmonids. *Fishery Bulletin* **102**: 108–117.Puryear, W., Sawatzki, K., Bogomolni, A., Hill, N., Foss, A., Stokholm, I., Olsen, M.T., Nielsen, O., Waltzek, T., Goldstein, T. & Subramaniam, K., (2021). Longitudinal analysis of pinnipeds in the northwest Atlantic provides insights on endemic circulation of phocine distemper virus. *Proceedings of the Royal Society B*, 288(1962), p.20211841.

Pierce, G. J., Miller, A., Thompson, P. M., & Hislop, J. (1991b). Prey remains in grey seal (*Halichoerus grypus*) faeces from the Moray Firth, north-east Scotland. *Journal of Zoology*, 224, 337–341.

Pierce, G. J., Thompson, P. M., Miller, A., Diack, J. S. W., Miller, D., & Boyle, P. R. (1991a). Seasonal variation in the diet of common seals (*Phoca vitulina*) in the Moray Firth area of Scotland. *Journal of Zoology*, 223(4), 641-652.

Postel, A., King, J., Kaiser, F. K., Kennedy, J., Lombardo, M. S., Reineking, W., … Becher, P. (2022). Infections with highly pathogenic avian influenza A virus (HPAIV) H5N8 in harbor seals at the German North Sea coast, 2021. *Emerging Microbes & Infections*, *11*(1), 725–729. https://doi.org/10.1080/22221751.2022.2043726

Ries, E. H., Hiby, L. R., & Reijnders, P. J. H. (1998). Maximum likelihoodpopulation size estimation of harbour seals in the Dutch Wadden Seabased on a mark–recapture experiment.*Journal of Applied Ecology*, 35,332–339. https://doi.org/10.1046/j.1365-2664.1998.00305.

Robertson, F., Wood, J., Joslin, J., Joy, R. & Polagye, B. (2018). Marine mammal behavioral response to tidal turbine sound. *Final technical report for DE-EE0006385*.

Roffe, T. J., and B. R. Mate . (1984). Abundances and feeding habits of pinnipeds in the Rogue River, Oregon. *Journal of Wildlife Management* **48**: 1262–1274

Rossi, S.P., Cox, S.P, Hammill, M.O., den Heyer, C.E., Swain, D.P., Mosnier, A. and Benoit,H.P. (2021). Forecasting the response of a recovered pinniped population to sustainableharvest strategies that reduce their impact as predators. ICES J. Mar. Sci. 78:1804–1814.

Ruiz-Mar, M.G., Heckel, G., Solana-Arellano, E., Schramm, Y., García-Aguilar, M.C. and Arteaga, M.C., (2022). Human activities disturb haul out and nursing behavior of Pacific harbor seals at Punta Banda Estuary, Mexico. Plos one, 17(7), p.e0270129.

Russell, D. J., McConnell, B. J., Thompson, D., Duck, C. D., Morris, C., Harwood, J., & Matthiopoulos, J. (2013). Uncovering the links between foraging and breeding regions in a highly mobile mammal. *Journal of Applied* Ecology, 50(2), 499-509. https://doi.org/10.1111/1365-2664.12048.

Russell, D.J.F., Hastie, G.D., Thompson, D., Janik, V.M., Hammond, P.S., Scott-Hayward, L.A.S., Matthiopoulos, J., Jones, E.L. & McConnell, B.J. (2016) Avoidance of wind farms by harbour seals is limited to pile driving activities. Journal of Applied Ecology, 53, 1642-1652.

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

Russell, D. J. F., & Carter, M. I. D. (2021). Estimating the proportion of grey seals hauled out during August surveys. SCOS Briefing Paper 21/03, Sea Mammal Research Unit, University of St Andrews.

Russell & Carter (2020). Seal abundance and distribution in the Scottish Northern North Sea region and Scottish Atlantic waters In Regional baseline for mammal knowledge across the North Sea and Atlantic areas of Scottish waters. Scottish Marine and Freshwater Science Vol 11 No 12

Russell, D.J.F., Brasseur, S.M.J.M., Thompson, D., Hastie, G.D., Janik, V.M., Aarts, G., McClintock, B.T., Matthiopoulos, J., Moss, S.E.W. & McConnell, B. (2014) Marine mammals trace anthropogenic structures at sea. Current Biology, 24, R638--R639.

Russell, D.J.F. & Moss, S.E.W. (2023). Estimating dispersal and survival of grey seal pups. Preliminary Report to BEIS. OESEA-20-122/OESEA-21-131. Sea Mammal Research Unit, University of St Andrews

Sayer S, Millward S, Witt M (2020). Monitoring grey seal (Halichoerus grypus) pupping sites in Cornwall 2019/2020. Natural England Commissioned Report (PO 10070016704)

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

Sayer, S., Witt M.J. (2017a) Monitoring grey seal (Halichoerus grypus) pupping sites in Cornwall 2016. Natural England commissioned report.

Sayer, S., Witt M.J. (2017b) Grey seals in the Isles of Scilly during the 2016 pupping season. Natural England commissioned report.

Scharff-Olsen, C.H., Galatius, A., Teilmann, J., Dietz, R., Andersen, S.M., Jarnit, S., Kroner, A.M., Botnen, A.B., Lundström, K., Møller, P.R. and Olsen, M.T., 2019. Diet of seals in the Baltic Sea region: a synthesis of published and new data from 1968 to 2013. ICES Journal of Marine Science, 76(1), pp.284-297.

Schop, J., Brasseur, S. M., Galatius, A., Hamm, T., Jess, A., Meise, K., Meyer, J., et al. 2023. Grey seal numbers in the Wadden Sea an on Helgoland in 2022-2023 Common Wadden Sea Secretariat.

SCOS. (2020). Scientific advice on matters related to the management of seal populations: 2020. Natural Environmental Research Council, Sea Mammal Research Unit. University of St Andrews, St Andrews: http://www.smru.st-andrews.ac.uk/files/2021/06/SCOS-2020.pdf

SCOS, (2022). Scientific Advice on Matters Related to the Management of Seal Populations: 2022. Natural Environment Research Council Special Committee on Seals. Sea Mammal Research Unit. University of St Andrews, St Andrews

Scottish Natural Heritage (2016) Assessing collision risk between underwater turbines and marine wildlife. SNH Guidance Note Series. http://www.snh.gov.uk/docs/A1982680.pdf.

Sharples, R. J., Arrizabalaga, B., & Hammond, P. S. (2009). Seals, sandeels and salmon: diet of harbour seals in St. Andrews Bay and the Tay Estuary, southeast Scotland. *Marine Ecology Progress Series*, 390, 265-276

Simpkins, M., Withrow, D. E., Cesarone, J. C., & Boveng, P. L. (2003). Stability in the proportion of harbor seals hauled out under locally ideal conditions. *Marine Mammal Science*,19, 791–805. https://doi.org/10.1111/j.1748-7692.2003.tb01130.

Shin DL, Siebert U, Lakemeyer J, et al. (2019) Highly pathogenic avian influenza A (H5N8) virus in gray seals, Baltic Sea. Emerg Infect Dis. Dec;25(12):2295–2298.

Stanley, W. T., and K. E. Shaffer . 1995. Harbor seal (Phoca vitulina) predation on seined salmonids in the lower Klamath River, California. *Marine Mammal Science* **11**: 376–385. Stephens N (2023). Ramsey Island Breeding Grey Seal Report 2023. Royal Society for the Protection of Birds.

Smout, S., King, R. & Pomeroy, P. (2019). Environment-sensitive mass changes influence breeding frequency in a capital breeding marine top predator. *J Anim.Ecol*. 2019;00:1–13. https ://doi.org/10.1111/13652656.13128

Steinmetz, K., Murphy, S., Cadhla, O. Ó., Carroll, E. L., Onoufriou, A. B., Russell, D. J. F., Cronin, M., & Mirimin, L. (2023). Population structure and genetic connectivity reveals distinctiveness of Irish harbour seals (*Phoca vitulina*) and implications for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, ***33*(2)**, 160-178. https://doi.org/10.1002/aqc.3909

Steinmetz, K., Murphy, S., Cadhla, O.Ó., Hoffman, J.I., Jung, J.L., Barnett, J., Cronin, M., Galatius, A., Hassani, S., Jessopp, M. and Pomeroy, P., (Preprint: 2024). Genetic analysis in aid of delineation of Management Units for a wide-ranging marine mammal, the grey seal (Halichoerus grypus), in European waters. 10.21203/rs.3.rs-4243253/v1

Thomas, L., Hammill, H. O. & Bowen, W. D. (2011). Assessment of Population Consequences of Harvest Strategies for the Northwest Atlantic grey seal population. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/007.iv+ 7p.

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

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

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

Thompson, D., A J Coram, R N Harris & C E Sparling. (2021). Review of non-lethal seal control options to limit seal predation on salmonids in rivers and at finfish farms. Scottish Marine and Freshwater Science. 12:6, 136pp. DOI: 10.7489/12369-1

Thompson, D. (in press a.) Census of grey seals (Halichoerus grypus) around Wales during August 2023 using aerial survey. NRW Evidence Report. Natural Resources Wales, Bangor.

Thompson, D. (in press b.) Census of grey seals (Halichoerus grypus) around the Southwest England Seal Monitoring Unit by aerial survey during August 2023. JNCC Report ###, Peterborough.

Tilzey, R. Goldsworthy, S. Cawthorn, M., Calvert,N., Hamer,D., Russell,S., Shaughnessy,P., Wise, B., & Stewardson, C. (2006). Assessment of seal–fishery interactions in the winter blue grenadier fishery off west Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers. Final report to Fisheries Research and Development Corporation (FRDC). Project no. 2001/008. February 2006. 69pp

Trainer, Vera L., Kudela, Raphael M., Hunter, Matthew V., Adams, Nicolaus G., and McCabe, Ryan M. 2020. Climate Extreme Seeds a New Domoic Acid Hotspot on the US West Coast. Frontiers in Climate. https://doi.org/10.3389/fclim.2020.571836

Tremlett, C.J., Morley, N., and Wilson, L.J. (2024). UK seabird colony counts in 2023 following the 2021- 22 outbreak of Highly Pathogenic Avian Influenza. RSPB Research Report 76. RSPB Centre for Conservation Science, RSPB, The Lodge, Sandy, Bedfordshire, SG19 2DL

Uhart M, Vanstreels RET, Nelson MI, Olivera V, Campagna J, Zavattieri V, Lemey P, Campagna C, Falabella V, Rimondi A. (2024). Massive outbreak of Influenza A H5N1 in elephant seals at Península Valdés, Argentina: increased evidence for mammal-to-mammal transmission. bioRxiv 2024.05.31.596774; doi: https://doi.org/10.1101/2024.05.31.596774

Vincent, C., Ridoux, V., Fedak, M. A., & Hassani, S. (2002). Mark-recapture and satellite tracking in rehabilitated juvenile grey seals (Halichoerus grypus): dispersal and potential effects on wild populations. Aquatic Mammals, 28(2), 121–130.

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

Walker, J., Taylor, P.D., 2017. Using eBird data to model population change of migratory bird species. Avian. Conserv. Ecol. 12 (1), 4.Walton, M. & Stanley, H.F. (1997). Population structure of some grey seal breeding colonies around the UK and Norway. European Research on Cetaceans. Proceedings 11th Annual Conference of European Cetacean Society. 293-296.

Wakelin S, Townhill B, Engelhard G, Holt J, Renshaw R (2021) Marine heatwaves and cold-spells, and their impact on fisheries in the North Sea. In: Copernicus Marine Service Ocean State Report, Issue 5. Journal of Operational Oceanography 14 (Suppl. 1): s91-s96. doi: 10.1080/1755876X.2021.1946240.

Wilson, L. J., & Hammond, P. S. (2019). The diet of harbour and grey seals around Britain: Examining the role of prey as a potential cause of harbour seal declines. Aquatic Conservation: Marine and Freshwater Ecosystems, 29, 71-85.

Wood, S., Frasier, T., Mcleod, B., Gilbert, J.R., White, B.N., Bowen, W.D., Hammill, M.O., Waring, G.T. & Brault, S.(2011). The genetics of recolonization: An analysis of the stock structure of grey seals (Halichoerus grypus) in the Northwest Atlantic. Canadian Journal of Zoology. 89. 490-497. Doi:10.1139/z11-012.

Wood, S. A., Murray, K. T., Josephson, E., and Gilbert, J. 2019. Rates of increase in gray seal (Halichoerus grypus atlantica) pupping at recolonized sites in the United States, 1988–2019. Journal of Mammalogy.

Wyles, H. M. E., Boehme, L., Russell, D. J. F., Carter, M. I. D. (2022) A novel approach to using seabed geomorphology as a predictor of habitat use in highly mobile marine predators: implications for ecology and conservation. Frontiers in Marine Science, 9, 818635. 10.3389/fmars.2022.818635.

Yurk, H., and A. W. Trites . 2000. Experimental attempts to reduce predation by harbor seals on out-migrating juvenile salmonids. *Transactions of the American Fisheries Society* **129**: 1360–1366.

Zande, A.N. van der; Alphen, J.J.M. van; Goodman, S.J.; Meijboom, F.L.B.; Stegeman, A.J.; Thompson, D.; Kuindersma, W.; Latour, J.B. (2018) Advice of the Scientific Advisory Committee on Seal Rehabilitation in the Netherlands. Wageningen Environmental Research. 90p#. available at - https://library.wur.nl/WebQuery/wurpubs/535588

Zyryanov S and Mishin VL 2013. Grey seals on the Murman coast, Russia: status and present knowledge.NAMMCO Scientific Publications 6:13

# List of 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.

## Recent counts and distribution of UK seals during August surveys

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### Abstract

SMRU conduct, and collate data from, August surveys of seal haulout sites across the UK. Harbour seals moult in August in the UK, and a high and consistent proportion of the population is hauled out and available to survey. For grey seals, August represents a key foraging month, and thus counts represent the haulout distribution during foraging season complementing estimates of pup production (number of pups born) from breeding season surveys.

In August 2022 and 2023, the Sea Mammal Research Unit (SMRU) carried out helicopter surveys using a thermal imager of the entire west coast of Scotland from Cape Wrath to the border (Southwest Scotland and West Scotland Seal Monitoring Units; SMUs) and of the Western Isles SMU. Part of the Moray Firth SMU and the Firth of Tay and Eden Estuary SAC in East Scotland SMU are surveyed annually by fixed-wing aircraft. In August 2023, an additional fixed-wing survey also covered the offshore islands (West Scotland, Western Isles, and North Coast & Orkney SMUs) which are not included during helicopter surveys. In England, the annual SMRU fixed-wing surveys cover the Lincolnshire and Norfolk coasts and ZSL cover the Essex and Kent coasts (Southeast England SMU). In 2023, for the first time, SMRU conducted a fixed-wing survey of Southwest England and Wales. Various organisations around England and Wales contribute additional local ground counts or boat-based counts.

Here the following new results from these surveys are presented: West Scotland SMU (2022; northern half); Western Isles SMU (2022); Southwest England SMU; Wales SMU and surveyed areas of Moray Firth, East Scotland and Southeast England SMUs (2022 & 2023). The surveys from Southwest Scotland SMU and West Scotland SMU (southern half; 2023) will be presented in SCOS 2025.

Based on the most recent available August count data for all SMUs, the number of harbour seals counted in Scotland was **24,822**, and in England it was **3,537**. Including **818** harbour seals counted in Northern Ireland in 2021, the most recent UK harbour seal total count is **29,178**.

The number of grey seals counted in Scotland was **20,943**, in England it was **17,097,** and in Wales it was **1,313**. Including **549** grey seals counted in Northern Ireland in 2021, the UK grey seal total count for this period was **39,902**.

### Introduction

The main method for assessing harbour seal populations, both in the UK and elsewhere, is through aerial surveys of seals on land during their annual moult. In the UK, moult predominantly occurs in August. 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 significant 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. A scalar derived from telemetry tag data collected during the harbour seal moult period can be used to estimate total population size. Lonergan *et al*. (2013) estimated the proportion of harbour seals hauled out during the standard August survey window to be 72% (95% CI: 54-88%).

Grey seals are also surveyed during August. It should be noted that the proportion of grey seals hauled out in August is relatively low (compared to harbour seals), and is also more variable. Based on telemetry data, it is estimated that 25.15% (95% CI: 21.45-29.07%) of the population is hauled out during the specific survey window and thus available to be counted (Russell & Carter 2021, updated from Lonergan *et al.* 2011). 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, but it is recognised there is relatively low power (sample size of 60 individuals). Nevertheless, such August counts are important for two reasons. First, they provide an indication of the distribution of seals during their key foraging season, and second, they can provide estimates of total population that is independent from pup production (SCOS BP 24/02), to feed into the population model (SCOS BP 24/05). Specifically, in conjunction with grey seal telemetry data, the grey seal summer counts from 2007-2009, 2011-2015, and 2016-2019 have been used to generate independent estimates of the size of the grey seal population (SCOS BP 21/02).

For the purposes of population monitoring and reporting, the UK is split in 14 Seal Monitoring Units (SMUs; Figure 1). The SMUs are arranged clockwise around the UK starting in Southwest Scotland: 1-7 are in Scotland, 8-11 & 13 are in England, 12 is Wales, and 14 is Northern Ireland. In Scotland, these SMUs align with the Seal Management Areas (SMAs).

Although both seal species can occur all around the UK coast, they are not evenly distributed. Their main concentrations are currently found in the following Seal Monitoring Units (SMUs): West Scotland, Western Isles, North Coast & Orkney, Shetland, Moray Firth, East Scotland and Southeast England (largely between Lincolnshire and Kent ;Figure 1). In addition, there are large numbers of grey seals in Northeast England. Grey seals, but very few harbour seals, are also found in Southwest England and in Wales. The frequency of the surveys varies around the coast. Since 1988, SMRU's August surveys around the Scottish coast 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 (East Scotland SMU). These aerial surveys in Scotland are part funded by NatureScot (previously Scottish Natural Heritage) and NERC, with additional irregular contributions from Marine Directorate. Most of the harbour seals in England are found on the Lincolnshire and Norfolk coast (Southeast England SMU) which is surveyed at least once annually during the August moult. The wider Thames area in Essex and Kent has been surveyed almost annually since 2013 by the Thames Harbour Seal Conservation Project, run by the Zoological Society of London, or by SMRU. Aerial surveys of Northeast England SMU are conducted less frequently.The August surveys in eastern England are funded by NERC. In 2023, SMRU also conducted a survey of Southwest England and Wales (funded by NRW,JNCC and NERC).

August aerial surveys in Northern Ireland are conducted approximately every three years and are part funded by the Department of Agriculture, Environment and Rural Affairs (DAERA) and NERC.

Several sites in England and Wales are ground counted by various organisations, e.g. the seals in the Tees Estuary have been monitored by the Industry Nature Conservation Association (INCA). Counts from these locations are also included in the reported totals where available.

See SCOS BP 24/03 for trend analyses of the August counts for Seal Monitoring Units 1 to 9.

**Aerial Survey 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 can detect groups of seals at distances of over 3km. 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.

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 300 mm 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 are 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. A fixed-wing aircraft and hand-held oblique photography were also used to survey the Wales and Southwest England SMUs in 2023. Comparisons with coincident ground counts indicate that surveys missed approximately half of seals in coves and gullies, but the overall effect on the survey was small because the majority of seals haul out on open coastlines or offshore skerries (Thompson, 2025 a,b).

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

### *1.1. Harbour seals in the UK during August*

The overall distribution of harbour seals around the UK from August surveys carried out between 2016 and 2023 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 August haul-out count for UK Seal Monitoring Units (SMUs) in 2016-2023 are provided in Table 1 and are compared with four or five previous periods between 1996 and 2019.

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

The most recent count of harbour seals in Scotland, obtained from counts carried out between 2016 and 2023, is **24,822** (Table 1).

The most recent count of harbour seals in England, obtained from surveys carried out mainly in 2022 and 2023, is **3,537** (Table 1).

Only one harbour seal was counted during the aerial survey of Wales in 2023.

The most recent count of harbour seals in Northern Ireland in 2018 was **818** (Table 1).

The sum of all the most recent counts carried out between 2016 and 2023 gives a UK total of **29,178** harbour seals (Table 1).

Counts for the annually surveyed areas in the Moray Firth, the Firth of Tay and Eden Estuary SAC (East Scotland), in the Tees (Northeast England, ground counts by INCA), and from Donna Nook to the Thames (Southeast England) are given in Tables 3 and 4.

Figure 3 shows a comparison of August harbour seal counts in Scottish SMUs since 1991. Because SMU totals represent counts of seals distributed over large areas, individual data points may contain counts made in more than one year.

Table 6 lists all the areas surveyed in recent years and reported here for the first time.

Only one harbour seal was detected during the Wales survey, and none were seen in Southwest England(Thompson 2025a).

### *1.2. Grey seals in the UK in August*

The overall UK distribution of grey seals from the most recent August surveys carried out up until 2023 is shown in Figure 2. For ease of viewing at this scale, counts have been aggregated by 10km squares.

The most recent total haul-out count of grey seals in Scotland, obtained from August surveys carried out between 2016 and 2023 is **20,943** (Table 2).

There were **17,097** grey seals counted in England between 2020 and 2023 (Table 2). In Wales, **1,313** grey seals were counted in 2023, and in Northern Ireland **549** were counted in 2021 (Table 2), the most recent UK total count of grey seals in August is **39,902** (Table 2).

Counts for the annually surveyed areas in the Moray Firth, the Firth of Tay and Eden Estuary SAC (East Scotland), in the Tees (Northeast England, ground counts INCA), and from Donna Nook to the Thames (Southeast England) are given in Tables 3 and 5.

More detailed information on the first SMRU aerial survey carried out in Southwest England and in Wales in August 2023 can be found in Thompson (2025, a & b).

### References

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

Bond, I. (2023). Tees Seals Research Programme, Monitoring Report No. 33. (1989–2023). Unpublished report to the Industry Nature Conservation Association.

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

Cox, T., Barker, J., Bramley, J., Debney, A., Thompson, D. & Cucknell, A. (2020). Population trends of harbour and grey seals in the Greater Thames Estuary. Mammal Communications 6: 42-51, London.

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

Lonergan, M., Duck, C., Moss, S., Morris, C., Thompson, D. (2013). Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. Aquatic Conservation: Marine & Freshwater Ecosystems 23:135-144.

Russell, D.J.F., Duck, C.D., Morris, C.D. & Thompson, D. (2016). Independent estimated of grey seal population size: 2008 and 2014: Special Committee on Seals. Briefing Paper 16/03.

Russell, D.J.F. & Carter M.I.D. (2021) Grey seal independent estimate scalar: converting counts to population estimates. SCOS-BP 21/02

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

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

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

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

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

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

Thompson, D. (in press a.) Census of grey seals (Halichoerus grypus) around Wales during August 2023 using aerial survey. NRW Evidence Report. Natural Resources Wales, Bangor.

Thompson, D. (in press b.) Census of grey seals (Halichoerus grypus) around the Southwest England Seal Monitoring Unit by aerial survey during August 2023. JNCC Report ###, Peterborough.

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

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

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

**Table 1**. The most recent August counts of harbour seals at haul-out sites in the UK by Seal Monitoring Unit and country compared with previous periods. The grey values given for SMUs 10-13 are estimates. The light grey italic values in the most recent count column don't contain any new data compared to the 2016-2019 period.

| Seal Monitoring Unit / Country | | | Harbour seal counts 1996-1997 | 2000-2006 | 2007-2009 | 2011-2015 | 2016-2019 | Most recent count data (2016-2023) | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Southwest Scotland | | 929 | 623 | 923 | 1,200 | 1,709 | *1,709* | *(2018)* |
| 2 | West Scotland | a | 8,811 | 11,666 | 10,626 | 15,184 | 15,600 | 14,189 | (2018; 2022) |
| 3 | Western Isles | | 2,820 | 1,920 | 1,804 | 2,739 | 3,532 | 3,080 | (2022) |
| 4 | North Coast & Orkney | | 8,787 | 4,388 | 2,979 | 1,938 | 1,405 | *1,405* | *(2016; 2019)* |
| 5 | Shetland | | 5,994 | 3,038 | 3,039 | 3,369 | 3,180 | *3,180* | *(2019)* |
| 6 | Moray Firth | | 1,409 | 1,028 | 776 | 745 | 1,077 | 983 | (2019; 2021; 2023) |
| 7 | East Scotland | | 764 | 667 | 283 | 224 | 343 | 276 | (2021; 2023) |
| SCOTLAND total | | | 29,514 | 23,330 | 20,430 | 25,399 | 26,846 | 24,822 | (2016; 2018: 2019; 2021-2023) |
| 8 | Northeast England | b | 54 | 62 | 58 | 91 | 79 | 106 | (2020; 2022; 2023) |
| 9 | Southeast England | c | 3,222 | 2,964 | 3,952 | 4,740 | 3,752 | 3,361 | (2022; 2023) |
| 10 | South England | d | 10 | 15 | 15 | 25 | 40 | 65 | (estimate) |
| 11 | Southwest England | d | 0 | 0 | 0 | 0 | 0 | 0 | (2023) |
| 13 | Northwest England | d | 2 | 5 | 5 | 5 | 5 | 5 | (estimate) |
| ENGLAND total | | | 3,288 | 3,046 | 4,030 | 4,861 | 3,876 | 3,537 | (2020; 2022; 2023) |
| WALES | | e | 2 | 5 | 5 | 10 | 10 | 1 | (2023) |
| BRITAIN total | | | 32,804 | 26,381 | 24,465 | 30,270 | 30,732 | 28,360 | (2016; 2018-2023) |
| NORTHERN IRELAND | | f | | 1,176 | 1,101 | 948 | 1,062 | 818 | (2021) |
| UK total | | | | 27,557 | 25,566 | 31,218 | 31,794 | 29,178 | (2016; 2018-2023) |

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by NatureScot 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, 2023). 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 a predecessor to the Department of Energy Security & Net Zero.c Thames data 2015 and 2019 collected and provided by Zoological Society London (Cox et al., 2020).

d Grey values are 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).

e For Wales, counts up until 2022 were estimates collated from various sources (grey values); the 2023 count was from a SMRU survey covering the whole of Wales. The change in numbers does not indicate a change in abundance.

f Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002, 2011, 2018, and 2021, and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

**Table 2**. The most recent August counts of grey seals at haul-out sites in the UK by Seal Monitoring Unit and country compared with previous periods. The grey values given for SMUs 10-13 are estimates. The light grey italic values in the most recent count column don't contain any new data compared to the 2016-2019 period. Grey seal summer counts are known to be more variable than harbour seal summer counts. Caution is advised when interpreting these numbers.

| Seal Monitoring Unit / Country | | | Grey seal counts 1996-1997 | 2000-2006 | 2007-2009 | 2011-2015 | 2016-2019 | Most recent count data (2016-2023) | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Southwest Scotland | | 75 | 206 | 233 | 374 | 517 | *517* | *(2018)* |
| 2 | West Scotland | a | 3,435 | 2,383 | 2,524 | 5,064 | 4,174 | 4,388 | (2018; 2022) |
| 3 | Western Isles | | 4,062 | 3,674 | 3,808 | 4,085 | 5,773 | 3,473 | (2022) |
| 4 | North Coast & Orkney | | 9,427 | 10,315 | 8,525 | 8,106 | 8,599 | *8,618* | *(2016; 2019)* |
| 5 | Shetland | | 1,724 | 1,371 | 1,536 | 1,558 | 1,009 | *1,009* | *(2019)* |
| 6 | Moray Firth | | 551 | 1,272 | 1113 | 1917 | 1,657 | 1354 | (2019; 2021; 2023) |
| 7 | East Scotland | | 2328 | 1898 | 1238 | 2296 | 3683 | 1584 | (2021; 2023) |
| SCOTLAND total | | | 21,602 | 21,119 | 18,977 | 23,400 | 25,412 | 20,943 | (2016; 2018: 2019; 2021-2023) |
| 8 | Northeast England | b | 613 | 1,100 | 2,350 | 6,942 | 6,501 | 5,446 | (2020; 2022; 2023) |
| 9 | Southeast England | c | 417 | 2,266 | 1,786 | 5,637 | 8,667 | 10,692 | (2022; 2023) |
| 10 | South England | d | | 2 | 2 | 5 | 30 | 50 | (estimate) |
| 11 | Southwest England | d | | 425 | 425 | 500 | 500 | 729 | (2023) |
| 13 | Northwest England | d | | 30 | 30 | 50 | 250 | 180 | (2023) |
| ENGLAND total | | | | 3,823 | 4,593 | 13,134 | 15,948 | 17,097 | (2020; 2022; 2023) |
| WALES | | d | | 750 | 750 | 850 | 900 | 1,313 | (2023) |
| BRITAIN total | | | | 25,692 | 24,320 | 37,384 | 42,260 | 39,473 | (2016; 2018-2023) |
| NORTHERN IRELAND | | e | | 272 | 243 | 468 | 505 | 549 | (2021) |
| UK total | | | | 25,964 | 24,563 | 37,852 | 42,765 | 39,902 | (2016; 2018-2023) |

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by NatureScot 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, 2023). 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 a predecessor to the Department of Energy Security & Net Zero.

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

d Grey values are estimates compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Cornwall Seal Group Research Trust, Natural England, Landmark Trust, Natural Resources Wales, RSPB, Hilbre Bird Observatory) or found in reports & on websites (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).

e For Wales, counts up until 2022 were estimates collated from various sources; the 2023 count was from a SMRU survey covering the whole of Wales. The change in numbers does not necessarily indicate a change in abundance.

f Surveys carried out by SMRU and funded by Northern Ireland Environment Agency (NIEA) in 2002, 2011, 2018, and 2021, and Marine Current Turbines Ltd in 2006-2008 & 2010 (SMRU Ltd, 2010).

**Table 3**. August counts of seals within the annually surveyed areas of the western Moray Firth and the Firth of Tay and Eden Estuary SAC. Mean values are given for areas surveyed more than once in a single season.

| | Western Moray Firth (Helmsdale to Findhorn) | | Firth of Tay and Eden Estuary SAC | |
|---|---|---|---|---|
| **Year** | **Harbour seals** | **Grey seals** | **Harbour seals** | **Grey seals** |
| 1990 | | | 467 | 912 |
| 1991 | | | 670 | 1,549 |
| 1992 | | | 773 | 1,226 |
| 1993 | | | | |
| 1994 | | | 575 | 1,468 |
| 1995 | | | | |
| 1996 | | | | |
| 1997 | 1,407 | 486 | 633 | 1,891 |
| 1998 | | | | |
| 1999 | | | | |
| 2000 | | | 700 | 2,253 |
| 2001 | | | | |
| 2002 | 829 | 327 | 668 | 1,593 |
| 2003 | | | 461 | 1,663 |
| 2004 | | | 459 | |
| 2005 | 911 | 598 | 335 | 843 |
| 2006 | 1,024 | 1,008 | 342 | 1,379 |
| 2007 | 762 | 677 | 275 | 1,519 |
| 2008 | 777 | 1,190 | 222 | 557 |
| 2009 | 775 | 1,043 | 111 | 450 |
| 2010 | 1,205 | 1,751 | 124 | 1,555 |
| 2011 | 924 | 1,100 | 77 | 1,322 |
| 2012 | 1,033 | 557 | 88 | 1,202 |
| 2013 | 858 | 1,038 | 50 | 482 |
| 2014 | 693 | 259 | 29 | 634 |
| 2015 | 705 | 1,644 | 60 | 836 |
| 2016 | 892 | 1,194 | 51 | 936 |
| 2017 | 831 | 1,131 | 29 | 750 |
| 2018 | 914 | 711 | 40 | 765 |
| 2019 | 1,025 | 1,564 | 41 | 686 |
| 2020 | | | 36 | 883 |
| 2021 | 633 | 1,322 | 41 | 1,940 |
| 2022 | 925 | 1,762 | 34 | 2,197 |
| 2023 | 926 | 820 | 55 | 812 |

**Table 4**. August counts of harbour seals within annually surveyed areas on the east coast of England. Mean values are given for areas surveyed more than once in a single season.

| | Northeast England | Southeast England | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **The Tees** | **Donna Nook** | **The Wash** | **Blakeney Point** | **Horsey** | **Scroby Sands** | **Greater Thames** |
| 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 | 35 | 103 | 2,011 | 196 | | 61 | |
| 1995 | 33 | 115 | 2,084 | 415 | | 49 | *130* |
| 1996 | 42 | 162 | 2,151 | 372 | | 51 | |
| 1997 | 42 | 251 | 2,466 | 311 | | 65 | |
| 1998 | 41 | 248 | 2,374 | 637 | | 52 | |
| 1999 | 36 | 304 | 2,392 | 659 | | 72 | |
| 2000 | 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 |
| 2004 | 40 | 294 | 2,147 | 646 | | 57 | |
| 2005 | 50 | 421 | 1,946 | 709 | | 56 | |
| 2006 | 45 | 299 | 1,695 | 719 | | 71 | |
| 2007 | 43 | 214 | 2,162 | 550 | | | |
| 2008 | 41 | 191 | 2,011 | 581 | | 81 | 319 |
| 2009 | 49 | 267 | 2,829 | 372 | | 165 | |
| 2010 | 53 | 176 | 2,586 | 391 | | 201 | 379 |
| 2011 | 57 | 205 | 2,894 | 349 | | 119 | |
| 2012 | 63 | 192 | 3,372 | 409 | | 161 | |
| 2013 | 74 | 396 | 3,174 | 304 | | 148 | 482 |
| 2014 | 81 | 353 | 3,086 | 468 | | 285 | 489 |
| 2015 | 91 | 228 | 3,336 | 455 | | 270 | 451 |
| 2016 | 86 | 369 | 3,377 | 424 | | 198 | 694 |
| 2017 | 87 | 290 | 3,210 | 399 | | 271 | 795 |
| 2018 | 76 | 146 | 3,632 | 218 | 17 | 210 | 738 |
| 2019 | 76 | 128 | 2,415 | 329 | 16 | 193 | 671 |
| 2020 | 91 | 157 | 2,866 | 258 | 1 | 45 | |
| 2021 | 86 | 122 | 2,667 | 181 | 12 | 25 | 498 |
| 2022 | 117 | 123 | 3,033 | 180 | 12 | 80 | 499 |
| 2023 | 106 | 97 | 2,500 | 153 | 17 | 32 | |

SOURCES - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
**The Tees** - Ground counts by Industry Nature Conservation Agency (Bond, 2023). Single SMRU fixed-wing count in 1994.
**Greater Thames** - 2013-2017, 2019, and 2021 surveys carried out by the Zoological Society of London (Barker & Obregon, 2015; Cox *et al*., 2020).

**Table 5**. August counts of grey seals within annually surveyed areas on the east coast of England. Mean values are given for areas surveyed more than once in a single season.

| | Northeast England | Southeast England | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **The Tees** | **Donna Nook** | **The Wash** | **Blakeney Point** | **Horsey** | **Scroby Sands** | **Greater Thames** |
| 1988 | | | 52 | 1 | | | |
| 1989 | 7 | | | | | | |
| 1990 | 9 | 115 | 10 | | | | |
| 1991 | 8 | | 48 | | | | |
| 1992 | 9 | 235 | 35 | 6 | | | |
| 1993 | 9 | 59 | 64 | 7 | | | |
| 1994 | 6 | 100 | 94 | 40 | | 43 | |
| 1995 | 10 | 123 | 66 | 18 | | 32 | |
| 1996 | 11 | 119 | 60 | 11 | | 46 | |
| 1997 | 10 | 289 | 49 | 45 | | 34 | |
| 1998 | 11 | 174 | 53 | 33 | | 23 | |
| 1999 | 12 | 317 | 57 | 14 | | 89 | |
| 2000 | 11 | 390 | 40 | 17 | | 40 | |
| 2001 | 11 | 214 | 111 | 30 | | 70 | |
| 2002 | 12 | 291 | 75 | 11 | | | |
| 2003 | 11 | 232 | 58 | 18 | | 36 | 96 |
| 2004 | 13 | 609 | 30 | 10 | | 93 | |
| 2005 | 12 | 927 | 49 | 86 | | 106 | |
| 2006 | 8 | 1,789 | 52 | 142 | | 187 | |
| 2007 | 8 | 1,834 | 42 | | | | |
| 2008 | 12 | 2,068 | 68 | 375 | | 137 | 160 |
| 2009 | 12 | 1,329 | 118 | 22 | | 157 | |
| 2010 | 14 | 2,188 | 240 | 49 | | 292 | 393 |
| 2011 | 14 | 1,930 | 142 | 300 | | 323 | |
| 2012 | 18 | 4,978 | 258 | 65 | | 126 | |
| 2013 | 16 | 3,474 | 219 | 63 | | 219 | 203 |
| 2014 | 16 | 4,437 | 223 | 445 | | 509 | 449 |
| 2015 | 16 | 3,766 | 369 | 528 | | 520 | 454 |
| 2016 | 22 | 3,964 | 431 | 355 | | 642 | 481 |
| 2017 | 27 | 6,526 | 688 | 502 | | 425 | 575 |
| 2018 | 15 | 6,288 | 253 | 360 | 205 | 497 | 596 |
| 2019 | 14 | 5,265 | 540 | 635 | 119 | 1,333 | 775 |
| 2020 | 22 | 4,982 | 644 | 765 | 504 | 1,191 | |
| 2021 | 30 | 3,897 | 799 | 493 | 380 | 1,377 | 749 |
| 2022 | 51 | 3,517 | 1,074 | 370 | 237 | 2,099 | 854 |
| 2023 | 26 | 6,008 | 1,092 | 504 | 219 | 1,971 | |

SOURCES - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
**The Tees** - Ground counts by Industry Nature Conservation Agency (Bond, 2023). 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.
**Greater Thames** - 2013-2017, 2019, and 2021 surveys carried out by the Zoological Society of London (Barker & Obregon, 2015; Cox *et al*., 2020).

**Table 6**. Coverage of August conducted and/or reported since SCOS 2022 (last report on counts). Italics indicate areas surveyed annually.

| Seal monitoring Unit | | Area surveyed | Survey year | Survey method | Surveyed by | Reporting year |
|---|---|---|---|---|---|---|
| 1 | Southwest Scotland | Entire coastline | 2023 | Helicopter TI | SMRU | SCOS 2025 |
| 2 | West Scotland | Cape Wrath to Loch Hourn | 2022 | Helicopter TI | SMRU | SCOS 2024 |
| | | Loch Hourn to Mull of Kintyre | 2023 | Helicopter TI | SMRU | SCOS 2025 |
| | | Offshore islands (Dubh Artach and Skerryvore) | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 3 | Western Isles | Entire coastline excl. offshore islands | 2022 | Helicopter TI | SMRU | SCOS 2024 |
| | | Offshore islands (Flannan Isles, North Rona & Sula Sgeir) | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 4 | North Coast & Orkney | Offshore islands (Sule Skerry) | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 5 | Shetland | *No surveys/updates* | | | | |
| 6 | Moray Firth | *Helmsdale to Findhorn* | 2022, 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 7 | East Scotland | *Firth of Tay and Eden Estuary SAC* | 2022, 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 8 | Northeast England | *Tees Estuary* | 2022, 2023 | Ground counts | INCA | SCOS 2024 |
| 9 | Southeast England | *Donna Nook to Scroby Sands* | 2022, 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| | | *Greater Thames* | 2022 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 10 | South England | *The Solent* | 2022, 2023 | Ground counts | Langstone Harbour Board, Chichester Harbour Conservancy, RSPB | SCOS 2024 |
| 11 | Southwest England | Entire coastline | 2023 | Fixed-wing oblique/ ground counts | SMRU, Seal Research Trust | SCOS 2024 |
| 12 | Wales | Entire coastline | 2023 | Fixed-wing oblique | SMRU | SCOS 2024 |
| 13 | Northwest England | *South Walney* | 2023 | Ground counts/drone | Cumbria Wildlife Trust | SCOS 2024 |
| 14 | Northern Ireland | Entire coastline | 2024 | Helicopter TI | SMRU | SCOS 2025 |

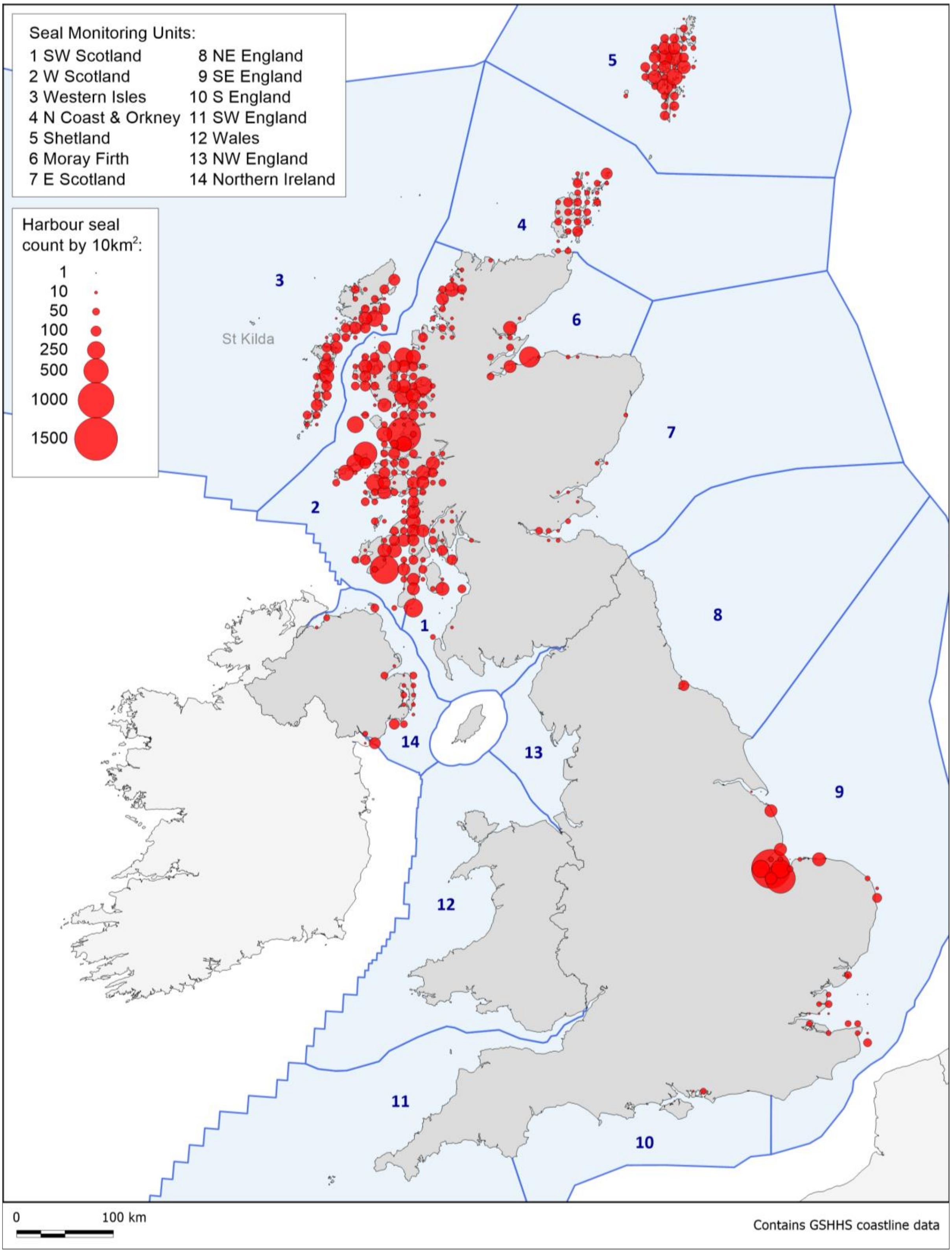


**Figure 7**. *Map of August haulout density of harbour seals around the UK per 10 km² based on the most recent available count data collected up until 2023 (coastline from GSHHS). Less than 100 harbour seals are in SMUs 10-13..* Tees data from the INCA Tees Seal Research Programme, The Solent data from Langstone Harbour Board & Chichester Harbour Conservancy. All other data from SMRU aerial surveys.

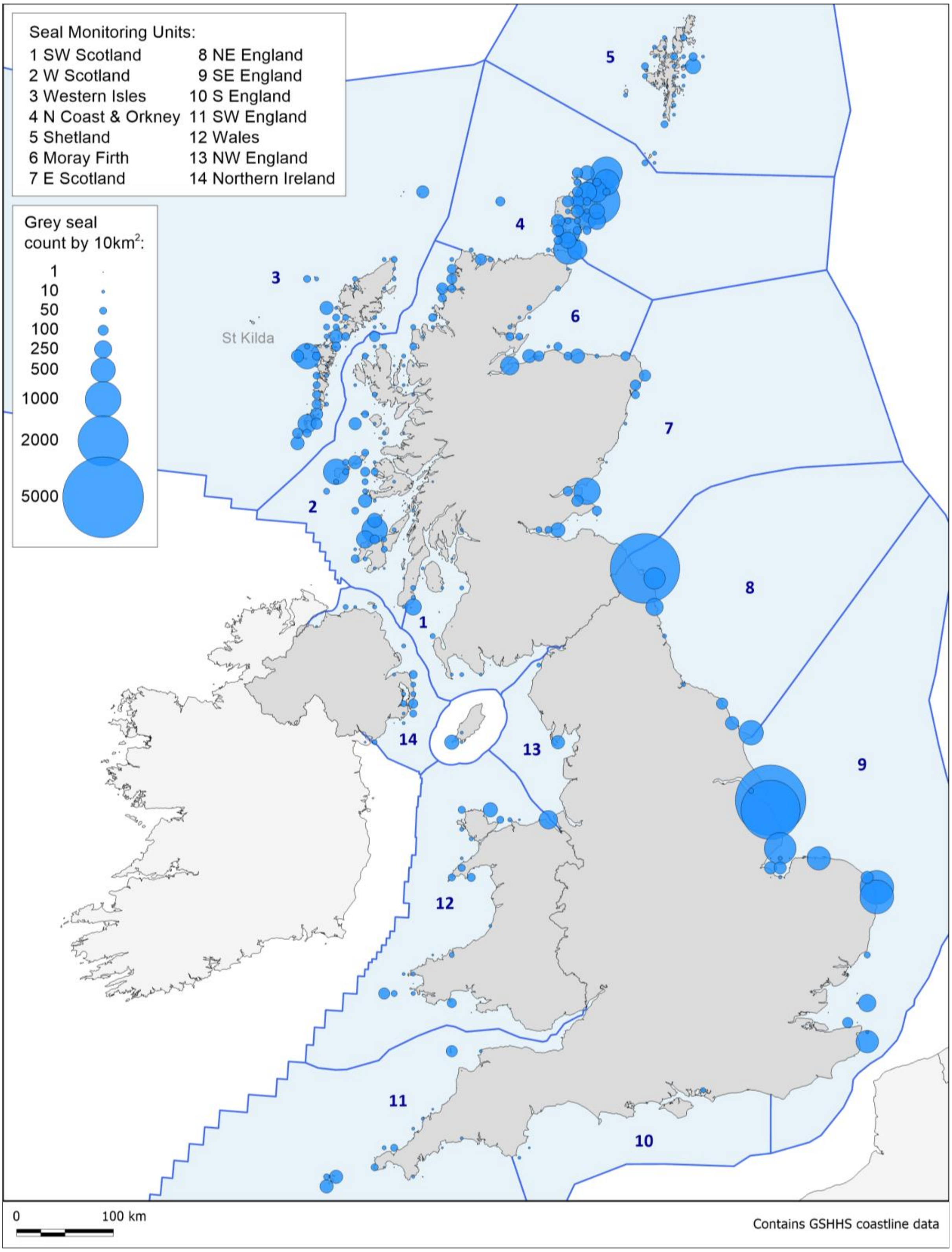


**Figure 8**. *Map of August haulout density of harbour seals around the UK per 10 km$^2$ based on the most recent available count data collected up until 2023 (coastline from GSHHS).* . Tees data from the INCA Tees Seal Research Programme. Some of the counts/estimates for Seal Monitoring Units 10 - 13 are based on counts by: Langstone Harbour Board & Chichester Harbour Conservancy, Cornwall Seal Group Research Trust, The Lundy Company, Cumbria Wildlife Trust, and Yorkshire Wildlife Trust.All other data from SMRU aerial surveys. No data available for St.Kilda.

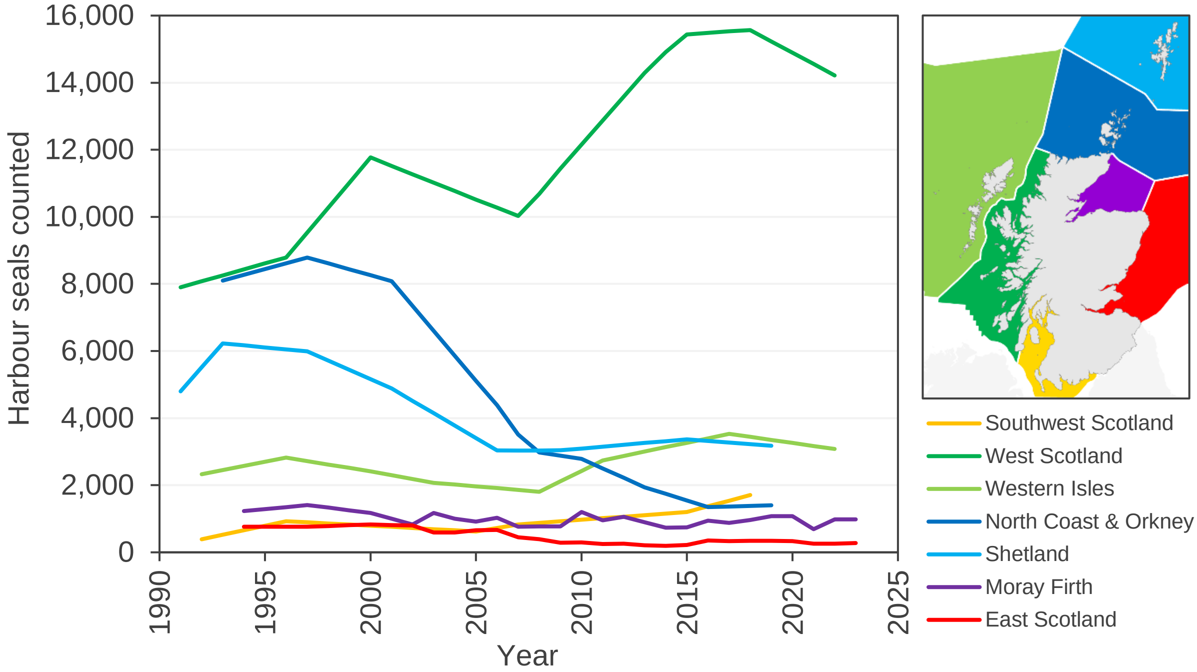


**Figure 3**. Comparison of August harbour seal counts in Scottish Seal Monitoring Units (SMUs) since 1991. Because SMU totals represent counts of seals distributed over large areas, individual data points may contain counts made in more than one year. For example, the 2022 data point for West Scotland contains a significant amount of data from a survey carried out in 2018 (south of Skye). Interpolated values are used for years with incomplete coverage.

# Most recent grey seal pup production estimates for UK breeding colonies

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**Abstract**

In 2022, SMRU surveyed around 60 grey seal breeding colonies in western and northern Scotland by plane using vertical photography.

Using the standard pup production model run (0.9 for proportion of moulters correctly classified, 23.0 days for mean time to fully moulted and 31.5 days for mean time to leave), pup production at the Inner Hebrides colonies (West Scotland SMU) was estimated to be approx. **4,900**, the highest estimate recorded so far. Pup production at colonies in the Outer Hebrides (Western Isles SMU) increased even more significantly (compared to 2019), reaching approx. **18,300**. In contrast, the total production estimate for Orkney dropped to **20,500**, the lowest estimate in over 10 years.

In 2018, 2021 and 2023, SMRU surveyed the key colonies in East Scotland, Northeast and Southeast England SMUs. In previous SCOS reports, estimates from eastern England have been based on ground-surveys. Here we report on aerial-based pup production estimates for 2018 and 2021. The 2023 data are still being processed and will be provided in the 2025 SCOS report.

The pup production for 2021 in the Firth of Forth, East Scotland, was estimated to be approx. **7,400**. On the Farne Islands in Northeast England around 3,000 and **3,200** pups were estimated to have been born in 2018 and 2021, respectively; the latter is the highest number on record. In Southeast England, the total production estimate for the three big colonies continued to grow to around 10,100 in 2018, and over **14,150 in 2021**. There are now more pups born at these three colonies than on the Monach Isles in the Western Isles, where the estimate was approx. 13,500 for 2022.

Combining the 2021 and 2022 estimates to provide an estimate for Scottish colonies used in the UK population model produces a total of just over **51,000** pups.

At the four main English North Sea colonies, pup production in 2021 totalled over **17,300 (13,100 in 2018)**.

Around **4,650** pups are estimated to be born at other (less regularly monitored) colonies in Scotland and England. Combining these with an estimated **2,500** pups born in Wales and an estimated **500** pups born in Northern Ireland, and adding them to the regularly monitored colonies, produces a total grey seal pup production estimate for the UK of around **75,950** in 2021/2022. This is the highest total estimate on record.

## Introduction

Grey seals breed at traditional colonies, with females frequently returning to the same colony to breed in successive years (Pomeroy *et al*. 2001). Some females return to breed at the colony at which they were born. Habitual use by grey seals of specific breeding colonies, combined with knowledge of the location of those colonies, provides opportunity for the numbers of pups born at the colonies to be monitored. Pup production estimates can then be used to estimate total population size (SCOS BP 24/05).

While grey seals breed all around the UK coast, most (over 95%) breed at colonies in Scotland and in eastern England (Figure 1). Other significant breeding colonies are in Southwest England, Wales, and Northern Ireland. Most colonies in Scotland and Northeast England are on remote coasts or remote off-lying islands, while large colonies in Southeast England are on easily accessible mainland beaches. Breeding colonies in Southwest England and in Wales are generally either at the foot of steep cliffs or in caves and are therefore extremely difficult to monitor.

Up until 2010, SMRU conducted annual aerial surveys of the major grey seal breeding colonies in Scotland to determine the number of pups born. Reductions in funding, combined with increasing aerial survey costs, have resulted in SMRU reducing monitoring the main Scottish grey seal breeding colonies from an annual to a biennial and then, due to expansion of the programme to cover east England, a triennial regime. Historically, the number of pups born at colonies along the east coast of England has been monitored annually through ground counting by different organisations: National Trust staff have counted pups born at the Farne Islands (Northumberland) and at Blakeney Point (Norfolk); staff from Lincolnshire Wildlife Trust count pups born at Donna Nook and Friends of Horsey Seals count pups born at Horsey/Winterton, on the east Norfolk coast. Due to the increasing size of these colonies making ground counting more difficult, these colonies are now also regularly covered by SMRU aerial surveys since 2018 (see SCOS BP 24/09). NatureScot staff ground count grey seal pups born in Shetland when weather conditions and staff availability allow.

In 2012, SMRU replaced the film-based large-format Linhof AeroTechnika system used since 1985 with a digital camera system consisting of two Hasselblad H4D-40 cameras. The change in methodology led to an apparent step change (increase) in observed production. It wasn't possible to carry out comparison surveys using the two different camera systems, so it has taken several years of data collection to allow for a reliable scalar to be estimated. This is discussed in SCOS-BP 24/03 where trend analyses for Seal Monitoring Units (SMU) and Special Areas of Conservation (SAC) are presented, and pup production estimates have been adjusted to account for the different methods used.

After dealing with multiple camera and computer issues in 2021 and 2022, a NERC capital grant enabled the purchase of a new digital camera system in October 2023. The new Phase One Aerial System PAS150 consists of a 150 MP camera and uses a gyro-stabilised mount, automated camera triggering, and a pilot guidance system. The georeferenced images can be processed to create detailed orthomosaics of each colony surveyed. This system was used to survey the colonies in the North Sea region (Firth of Forth to Norfolk) between late October and mid-December 2023. During one of the survey rounds, a second plane was used to photograph each of the colonies with the Hasselblad camera system as soon as the first aircraft had completed a site. The pup production estimates from these surveys will be presented in SCOS BP 25/02.

This Briefing Paper (SCOS BP 24/02) reports on pup production estimates produced from SMRU aerial surveys carried out in 2021 and 2022 at the main grey seal breeding colonies in Scotland and in eastern England, together with the most recent estimates available from other sites around the UK.

**Materials and Methods**

SMRU has been aerially surveying the main grey seal breeding colonies around Scotland for over 40 years. NatureScot staff have been ground counting pups in Shetland when conditions allow. Colonies in eastern England were historically all counted from the ground by staff from the National Trust (Farne Islands and Blakeney Point), Lincolnshire Wildlife Trust (Donna Nook) and Friends of Horsey Seals (Horsey/Winterton). Following large increases in pup numbers at these North Sea sites in the 2010s, eastern English colonies have been included in SMRU's aerial survey programme since 2018.

The numbers of pups born at the aerially surveyed colonies are estimated from a series of 3 to 6 counts derived from near-vertical aerial images, using a model of the birth process and the development of pups (Russell *et al.*, 2019). The method used to obtain pup production estimates for colonies surveyed in 2021 and 2022 was identical to that used in previous years. A lognormal distribution was fitted to colonies surveyed four or more times and a normal distribution to colonies surveyed three times.

In 2018 and 2021, SMRU successfully surveyed most of the main Scottish and English grey seal breeding colonies in the central and southern North Sea (from the Firth of Forth to Norfolk) four or five times between the end of October and mid-December. In 2022, most of the other Scottish colonies regularly surveyed by plane were photographed four times between mid-September and the end of November.

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

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

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

Since 2012, the digital images have generally been of sufficient quality to reduce the probability of misclassification, so a proportion of 90% was used as standard for all production estimates since 2012 (SCOS BP 13/03). In line with previous years, the standard mean time to moult of 23.0 days and mean time to leave of 31.5 days were also incorporated into the pup production model.

**Results**

The locations of the main grey seal breeding colonies in the UK are shown in Figure 1. In 2021 (Firth of Forth) and 2022 (Inner & Outer Hebrides and Orkney), pup production at the main aerially monitored breeding colonies in Scotland was estimated to be **51,049** (Table 1). Note that the 2018 estimate for East Scotland and the 2019 estimate for the rest of Scotland has been updated from SCOS 2022.

In 2018 and 2021, pup production at the main colonies in eastern England was estimated to be 13,116 and **17,323, respectively** (Table 1). Total pup production estimates since 1960, for the four regions used in the grey seal population model, are given in Table 2. Note that for Southeast England, these differ from values used in previous SCOS reports; the ground- and aerial-based estimates for eastern England have been combined into a single time-series resulting in new historic estimates for some colonies (SCOS BP 24/09).

Including approx. **3,925** pups born at other colonies in Scotland (Table 3), an estimated **650** pups born at additional sites in England, an estimated **2,500** pups born in Wales, and an estimated **500** pups born in Northern Ireland, the most recent grey seal pup production estimate for the UK (90% of which were from colonies surveyed by SMRU 2021 or 2022) was estimated to be **75,947** (Table 1), the highest total on record.

Whereas total pup production estimates in western and eastern UK SMUs reached their highest levels in the most recent available survey years, the number of pups born in Orkney (within the most productive SMU) appear to be declining. See SCOS BP 24/03 for trend analyses by SMU.

Although the total pup production in an SMU may appear to be following a consistent trend, individual colonies or different groups of colonies within the same SMU may show very different trends. Figures 6 to 9 show pup production estimates in different Scottish regions/SMUs either grouped by location (Inner Hebrides, Figure 6), grouped based on location and when the colonies were established (Outer Hebrides, Figure 7), grouped only by when they were established (Orkney, Figure 8), or by individual colony (Firth of Forth, Figure 9). The plots show the pup production estimates previously reported and have not been adjusted to account for the step change introduced by the change in methods between 2010 and 2012. The average increase associated with this change has been estimated to be 22.5 % (95% CI: 14.3, 30.7; SCOS BP 24/03).

**References**

Baines, M., Earl, S., Pierpoint, C. & Poole, J. (1995) The west Wales grey seal census. CCW Contract Science Report, no. 131, 238 pp.

Büche, B. & Bond, S. 2023. Grey Seal Breeding Census Skomer Island 2023. NRW Evidence Report number 750 The Wildlife Trust of South and West Wales.

Lundy Field Society. (2023) Annual Report No. 72. ISSN 0143-8026. www.lundy.org.uk

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

Robinson GJ, Clarke LJ, Banga R, Griffin RA, Porter J, Morris CW, Lindenbaum CP, Stringell TB (2020). Grey Seal (Halichoerus grypus) Pup Production and Distribution in North Wales during 2017. NRW Evidence Report No. 293.

Russell, D.J.F., Duck, C.D., Morris, C.D., Thompson, D. & Hiby, L. 2019. Monitoring long-term changes in UK grey seal pup production. Aquatic Conservation: Marine and Freshwater Ecosystems 29(S1):24-39. http://dx.doi.org/10.1002/aqc.3100

Sayer S, Millward S, Witt M (2020). Monitoring grey seal (Halichoerus grypus) pupping sites in Cornwall 2019/2020. Natural England Commissioned Report (PO 10070016704)

Sayer, S., Witt M.J. (2017a) Monitoring grey seal (Halichoerus grypus) pupping sites in Cornwall 2016. Natural England commissioned report.

Sayer, S., Witt M.J. (2017b) Grey seals in the Isles of Scilly during the 2016 pupping season. Natural England commissioned report.

Stephens N (2023). Ramsey Island Breeding Grey Seal Report 2023. Royal Society for the Protection of Birds.

**Table 1**. Most recent pup production estimates for UK Seal Monitoring Units (SMU) and subdivisions, along with the percentage of pup production considered in the UK population model. Note that the values for other colonies are approximate.

| Seal Monitoring Unit (subdivision) | | Pup production (with year counted): Colonies used in population model | | Other colonies | | Total | % production included in UK population model |
|---|---|---|---|---|---|---|---|
| 1 SW Scotland | | 0 | | 5 | (2020) | 5 | |
| 2a W Scotland - South | | 4,893 | (2022) | 50 | (2005-2010) | 4,943 | |
| 2b W Scotland - Central | | 0 | | 365 | (2005-2019) | 365 | |
| 2c W Scotland - North | | 0 | | 40 | (2009-2010) | 40 | |
| 3 Western Isles | | 18,272 | (2022) | 300 | (2008) | 18,572 | |
| 4a North Coast | | 0 | | 635 | (2019) | 635 | |
| 4b Orkney | | 20,506 | (2022) | 20 | (2010-2019) | 20,526 | |
| 5 Shetland | | 0 | | 760 | (2012) | 760 | |
| 6 Moray Firth | | 0 | | 1,715 | (2022) | 1,715 | |
| 7 E Scotland | | 7,378 | (2021) | 35 | (2019-2023) | 7,413 | |
| SCOTLAND TOTAL | | 51,049 | | 3,925 | | 54,974 | 92.9% |
| 8 NE England | | 3,198 | (2021) | 40 | (2016-2018) | 3,238 | |
| 9 SE England | | 14,125 | (2021) | 140 | (2023) | 14,265 | |
| 10 S England | a | 0 | | 10 | | 10 | |
| 11 SW England | b | 0 | | 450 | (2016-2023) | 450 | |
| 13 NW England | c | 0 | | 10 | (2023) | 10 | |
| ENGLAND TOTAL | | 17,323 | | 650 | | 17,973 | 96.4% |
| 12 WALES | d | 0 | | 2,500 | (1994 - 2023) | 2,500 | 0.0% |
| 14 NORTHERN IRELAND | e | 0 | | 500 | (2001-2020) | 500 | 0.0% |
| UK TOTAL | | 68,372 | | 7,575 | | 75,947 | 90.0% |

SOURCES – Unless otherwise indicated most production estimates were derived from aerial surveys conducted by SMRU and were funded by the Natural Environment Research Council (NERC). **a-e** are estimates generated by SMRU on the basis of the resources listed below. **a** Chichester Harbour Conservancy, **b** Sayer & Witt (2017a&b), Sayer *et al.* (2020), Lundy Field Society (2023), **c** Cumbria Wildlife Trust **d** Natural Resources Wales, Wildlife Trust of South and West Wales, Pembrokeshire Coast National Park Authority, Royal Society for the Protection of Birds. Baines *et al.* (1995); Robinson *et al.* (2020), Stephens (2023), Büche & Bond (2023), **e** Northern Ireland Department of Agriculture, Environment and Rural Affairs.

**Table 2**. Grey seal pup production estimates at the regularly monitored breeding colonies in Scotland and East England used in the UK grey seal population model by Seal Monitoring Unit (subdivision), from 1960 to 2022.

All estimates in Scotland are from SMRU aerial surveys using analogue film cameras up until 2010 and digital cameras since 2012. All estimates in England are from ground counts up to 2017 and from SMRU aerial surveys from 2018 onwards, with the exception of Blakeney Point (SE England) where estimates were used for 2015-2017. All Donna Nook (SE England) ground count estimates have been scaled by 1.25 to fit to the higher aerial survey estimates. See SCOS BP 24/09 for more information on the analyses used to adjust for estimates derived from ground counts at English colonies. For aerially surveyed colonies in Scotland, a change in methodology from film to digital between 2010 and 2012 is likely to be responsible for an average step increase of 22.5 % (95% CI: 14.3, 30.7) in production estimates. Please see SCOS BP 24/03 for more details.

| | Region used in the grey seal population model | | | | | | |
|---|---|---|---|---|---|---|---|
| | Inner Hebrides | Outer Hebrides | Orkney | North Sea | | | |
| | Seal Monitoring Unit (subdivision) | | | | | | |
| **Year** | **W Scotland - South** | **Western Isles** | **Orkney** | **E Scotland** | **NE England** | **SE England** | **TOTAL** |
| 1960 | | | 2,048 | | 1,020 | | |
| 1961 | | 3,142 | 1,846 | | 1,141 | | |
| 1962 | | | | | 1,118 | | |
| 1963 | | | | | 1,259 | | |
| 1964 | | | 2,048 | | 1,439 | | |
| 1965 | | | 2,191 | | 1,404 | | |
| 1966 | | 3,311 | 2,287 | | 1,728 | | |
| 1967 | | 3,265 | 2,390 | | 1,779 | | |
| 1968 | | 3,421 | 2,570 | | 1,800 | | |
| 1969 | | | 2,316 | | 1,919 | | |
| 1970 | | 5,070 | 2,535 | | 1,987 | 19 | |
| 1971 | | | 2,766 | | 2,041 | | |
| 1972 | | 4,933 | | | 1,617 | | |
| 1973 | | | 2,581 | | 1,678 | | |
| 1974 | | 6,173 | 2,700 | | 1,668 | | |
| 1975 | | 6,946 | 2,679 | | 1,617 | | |
| 1976 | | 7,147 | 3,247 | | 1,426 | | |
| 1977 | | | 3,364 | | 1,243 | | |
| 1978 | | 6,243 | 3,778 | | 1,162 | | |
| 1979 | | 6,670 | 3,971 | | 1,320 | | |
| 1980 | | 8,026 | 4,476 | | 1,118 | | |
| 1981 | | 8,086 | 5,064 | | 992 | 43 | |
| 1982 | | 7,763 | 5,241 | | 991 | 54 | |
| 1983 | | | | | 902 | | |
| 1984 | 1,332 | 7,594 | 4,741 | 517 | 778 | 38 | 15,000 |
| 1985 | 1,190 | 8,165 | 5,199 | 810 | 848 | 66 | 16,278 |
| 1986 | 1,711 | 8,455 | 5,796 | 891 | 908 | 44 | 17,805 |
| 1987 | 2,002 | 8,777 | 6,389 | 865 | 930 | 90 | 19,053 |
| 1988 | 1,960 | 8,689 | 5,948 | 608 | 812 | 68 | 18,085 |
| 1989 | 1,956 | 9,275 | 6,773 | 936 | 892 | 118 | 19,950 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1990 | 2,032 | 9,801 | 6,982 | 1,122 | 1,004 | 190 | 21,131 |

*Continued on next page.*

**Table 2**. *(continued)*

| | Region used in the grey seal population model | | | | | | |
|---|---|---|---|---|---|---|---|
| | Inner Hebrides | Outer Hebrides | Orkney | North Sea | | | |
| | Seal Monitoring Unit (subdivision) | | | | | | |
| Year | W Scotland - South | Western Isles | Orkney | E Scotland | NE England | SE England | TOTAL |
| 1991 | 2,411 | 10,617 | 8,653 | 1,225 | 927 | 279 | 24,112 |
| 1992 | 2,816 | 12,215 | 9,854 | 1,251 | 985 | 250 | 27,371 |
| 1993 | 2,923 | 11,915 | 11,034 | 1,454 | 1,051 | 256 | 28,633 |
| 1994 | 2,719 | 12,054 | 11,851 | 1,325 | 1,025 | 378 | 29,352 |
| 1995 | 3,050 | 12,713 | 12,670 | 1,353 | 1,070 | 418 | 31,274 |
| 1996 | 3,117 | 13,176 | 14,531 | 1,567 | 1,061 | 388 | 33,840 |
| 1997 | 3,076 | 11,946 | 14,395 | 2,032 | 1,284 | 478 | 33,211 |
| 1998 | 3,087 | 12,434 | 16,625 | 2,241 | 1,309 | 549 | 36,245 |
| 1999 | 2,787 | 11,759 | 15,720 | 2,034 | 843 | 629 | 33,772 |
| 2000 | 3,223 | 13,472 | 16,546 | 2,514 | 1,171 | 773 | 37,699 |
| 2001 | 3,032 | 12,427 | 18,196 | 2,253 | 1,247 | 818 | 37,973 |
| 2002 | 3,096 | 11,248 | 17,952 | 2,509 | 1,200 | 988 | 36,993 |
| 2003 | 3,386 | 12,741 | 18,652 | 2,664 | 1,266 | 1,138 | 39,847 |
| 2004 | 3,385 | 12,319 | 19,123 | 2,706 | 1,133 | 1,426 | 40,092 |
| 2005 | 3,427 | 12,397 | 18,126 | 2,818 | 1,138 | 1,525 | 39,431 |
| 2006 | 3,501 | 11,719 | 19,335 | 2,793 | 1,254 | 1,684 | 40,286 |
| 2007 | 3,118 | 11,342 | 19,184 | 2,957 | 1,164 | 1,958 | 39,723 |
| 2008 | 3,317 | 12,279 | 17,813 | 3,230 | 1,318 | 2,283 | 40,240 |
| 2009 | | [1] 11,887 | 18,548 | 3,770 | 1,346 | 2,611 | |
| 2010 | 3,108 | 11,831 | 18,562 | 4,054 | 1,498 | 2,962 | 42,015 |
| 2011 | | | | | 1,555 | 3,271 | |
| 2012 | 4,088 | 14,134 | 22,920 | 5,217 | 1,603 | 3,766 | 51,728 |
| 2013 | | | | | 1,575 | 4,437 | |
| 2014 | 4,054 | 14,331 | 23,777 | 5,860 | 1,740 | 5,505 | 55,267 |
| 2015 | | | | | 1,876 | 6,420 | |
| 2016 | 4,541 | 15,732 | 23,849 | 6,426 | 2,295 | 7,500 | 60,343 |
| 2017 | | | | | 2,131 | 8,590 | |
| 2018 | | | | 7,325 | 3,011 | 10,105 | |
| 2019 | 4,694 | 16,931 | 23,321 | 7,641 | | | |
| 2020 | | | | | | | |
| 2021 | | | | 7,378 | 3,198 | 14,125 | |
| 2022 | 4,893 | 18,272 | 20,506 | | | | |
| 2023 | | | | processing | processing | processing | |

[1] 2008 production estimates were used as a proxy for seven colonies in the Outer Hebrides for which new production estimates could not be derived in 2009.

**Table 3**. Grey seal pup production estimates at UK breeding colonies that are ground counted and/or surveyed irregularly.

Abbreviations: CSGRT - Cornwall Seal Group Research Trust; DAERA - Department of Agriculture, Environment and Rural Affairs; GC - Ground counts; NRW - Natural Resources Wales; NTS - National Trust for Scotland; SMRU - Sea Mammal Research unit; W.T. - Wildlife Trust.

| Seal Monitoring Unit (subdivision) | Location | Surveyor and method | Last survey | Most recent estimate |
|---|---|---|---|---|
| Southwest Scotland | Ailsa Craig | Online photos | 2020 | 5 |
| West Scotland - South | Loch Tarbert, Jura | SMRU; aerial visual | 2007 | 4 |
| | Treshnish small isles & Dutchman's | SMRU; aerial photo | 2010 | ~20 |
| | Staffa | SMRU; aerial visual | 2008 | ~5 |
| | Little Colonsay, by Ulva | SMRU; aerial visual | 2008 | 6 |
| | Meisgeir, Mull | SMRU; aerial visual | 2008 | 1 |
| | Craig Inish, Tiree | SMRU; aerial photo | 2005 | 2 |
| | Cairns of Coll | SMRU; aerial photo | 2007 | 10 |
| West Scotland - Central | Muck | SMRU; aerial photo | 2005 | 18 |
| | Rum | NatureScot; GC | 2013 | 15 |
| | Canna | SMRU; aerial photo | 2005 | 25 |
| | Ascrib Islands, Skye | SMRU; aerial photo | 2008 | 64 |
| | Fladda Chuain, North Skye | SMRU; aerial photo | 2019 | 187 |
| | Trodday, NE Skye | SMRU; aerial photo | 2008 | 55 |
| West Scotland - North | Summer Isles | SMRU; aerial photo | 2010 | 29 |
| | Islands close to Handa | SMRU; aerial visual | 2009 | 10 |
| Western Isles | Sound of Harris islands | SMRU; aerial photo | 2008 | 296 |
| | St Kilda | NTS; GC | rare | ~5 |
| North Coast | Loch Eriboll & Whiten Head | SMRU; aerial photo | 2019 | 561 |
| | Eilean nan Ron, Tongue | SMRU; aerial photo | 2019 | 76 |
| Orkney | Fers Ness, Eday | SMRU; aerial photo | 2019 | 21 |
| Shetland | Various sites | NatureScot; GC | 2012 | 761 |
| Moray Firth | Duncansby Head to Helmsdale | SMRU; aerial photo | 2022 | 1,715 |
| East Scotland | Ythan Estuary | Ythan Seal Watch; GC | 2023 | 5 |
| | Inchcolm | Fife Seal Group; GC | 2019 | 17 |
| | small Forth islands | Fife Seal Group; GC | 2023 | 11 |
| **SCOTLAND** | **Total** | | **to 2023** | **~3,925** |
| Northeast England | Coquet Island | SMRU; aerial photo | 2018 | 25 |
| | Ravenscar | Yorkshire W.T.; GC | 2016 | 10 |
| Southeast England | Flamborough Head | Yorkshire W.T.; GC | 2023 | 6 |
| | Orford Ness | National Trust; GC | 2023 | 139 |
| South England | Isle of Wight | RSPB | 2023 | 2 |
| Southwest England | Lundy | Landmark Trust; GC | 2023 | 66 |
| | Isles of Scilly | CSGRT; boat & GC | 2016 | 230 |
| | Cornwall mainland | CSGRT; GC | 2019 | 150 |
| | Devon mainland | CSGRT; GC | 2016 | ~ 5 |
| Northwest England | South Walney | Cumbria W.T.; GC | 2023 | 10 |
| **ENGLAND** | **Total** | | **to 2023** | **~ 650** |
| **WALES**[1] | **Total** | NRW & RSPB; GC | **to 2023** | **~2,500** |
| **NORTHERN IRELAND** | **Total** | DAERA; boat | **to 2023** | **~ 500** |

[1] Multiplier derived from indicator colonies surveyed in 2004-2005 applied to other colonies last monitored in 1994.

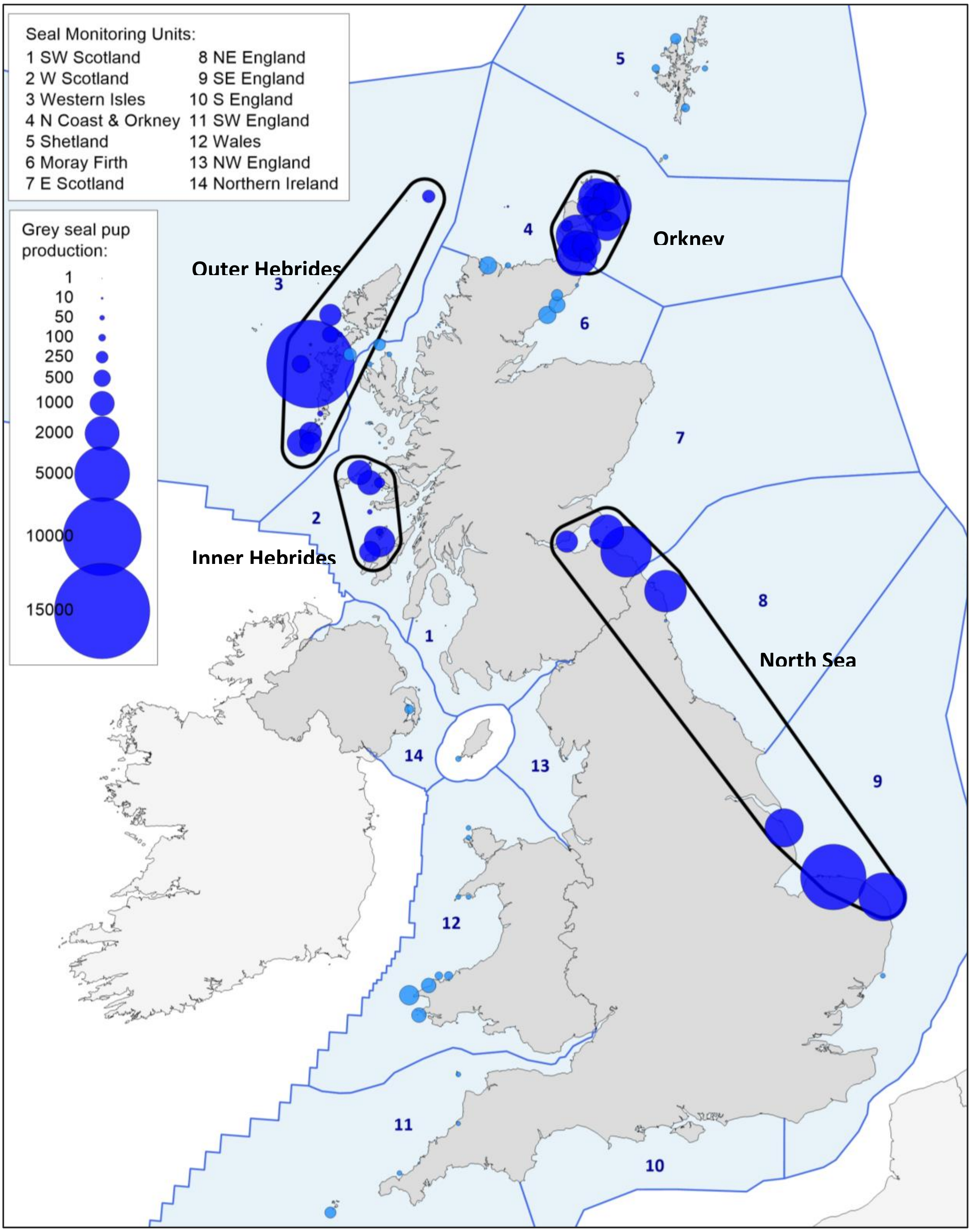


**Figure 1**. The most recent pup production estimates available for grey seal breeding colonies in the UK by 10 km grid squares. Smaller numbers of grey seals will breed at locations other than those indicated here, including in caves. The regions used for the UK grey seal population model are indicated by black polygons and labels. The breeding colonies included in the model are shown in dark blue, the other in light blue.

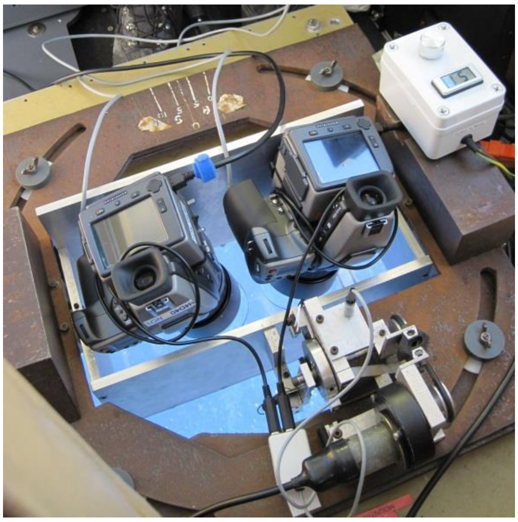

**Figure 2**. Two Hasselblad H4D-40 medium format cameras fitted in SMRU's Image Motion Compensation (IMC) mount. Each camera is set at an angle of 12 degrees to increase strip width. The cradle holding the cameras rocks backwards and forwards during photo runs. Rocking speed is set depending on the altitude and the ground speed of the aircraft. The camera shutters are automatically triggered and an image captured every time the cameras pass through the vertical position on each front-to-back pass. Images are saved directly to a computer as 60MB Hasselblad raw files and can be instantly viewed and checked using a small LED screen. The H4D-40 can take up to 40 frames per minute allowing for ground speeds of up to 130 kts at 1100 ft (providing 20% overlap between consecutive frames). The resulting ground sampling distance is approximately 2.5 cm/pixel.

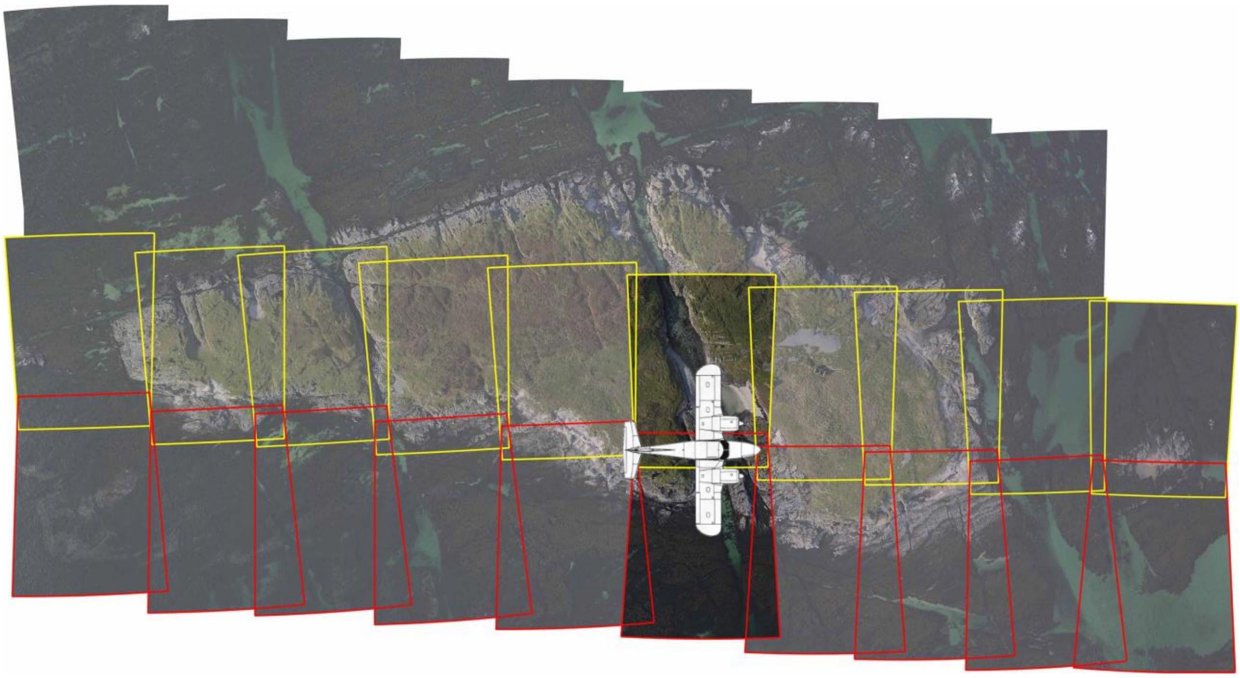

**Figure 3**. The individual footprints of each pair of photographs taken on a run over Eilean nan Ron, off Oronsay in the Inner Hebrides, flying at 1,100 ft (red: left-hand camera; yellow: right-hand camera).

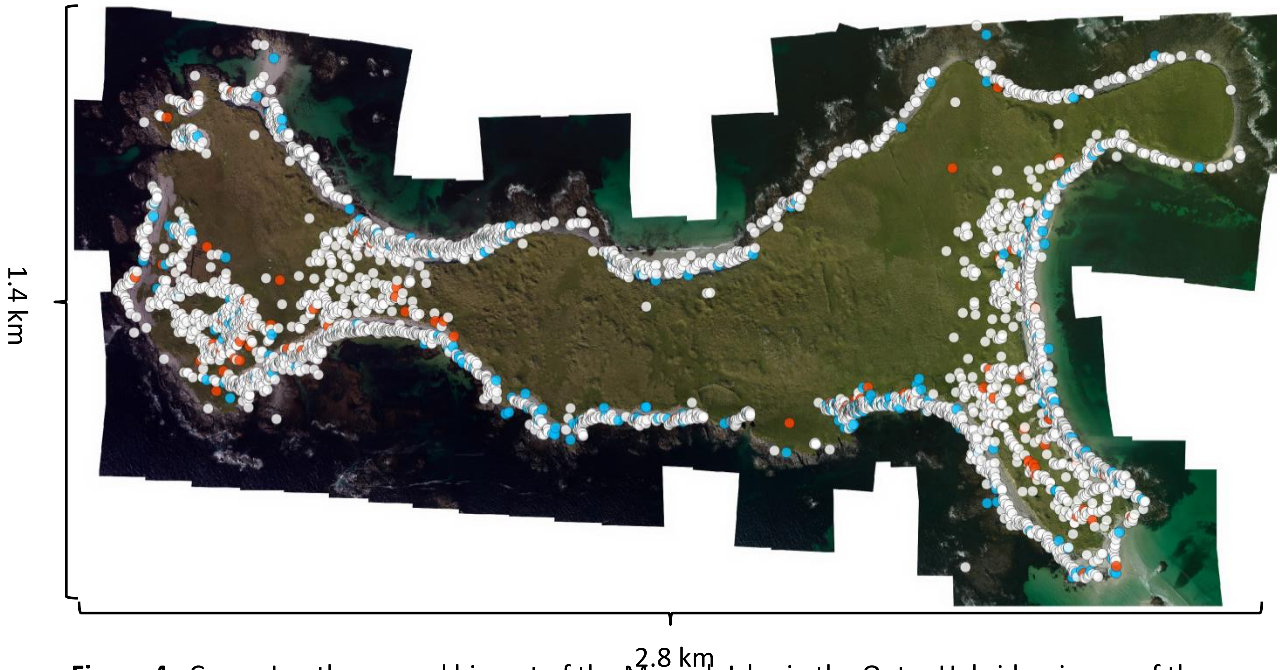


**Figure 4**. Ceann Iar, the second biggest of the Monach Isles in the Outer Hebrides, is one of the largest grey seal breeding colonies in Europe (approx. 7,000 pups were born here in 2022). This screenshot shows white-coated (white), moulted (blue) and dead pups (red) counted from approximately 200 stitched photographs taken on 7 October 2012. The composite image was stitched together and exported using Microsoft's Image Composite Editor v1.4.4®. The resulting 7.2 gigapixel PSB file (15 GB) was split into 30,000x30,000 pix TIFF tiles using Adobe Photoshop CS5®. These tiles were then imported into Manifold GIS 8.0® for counting.

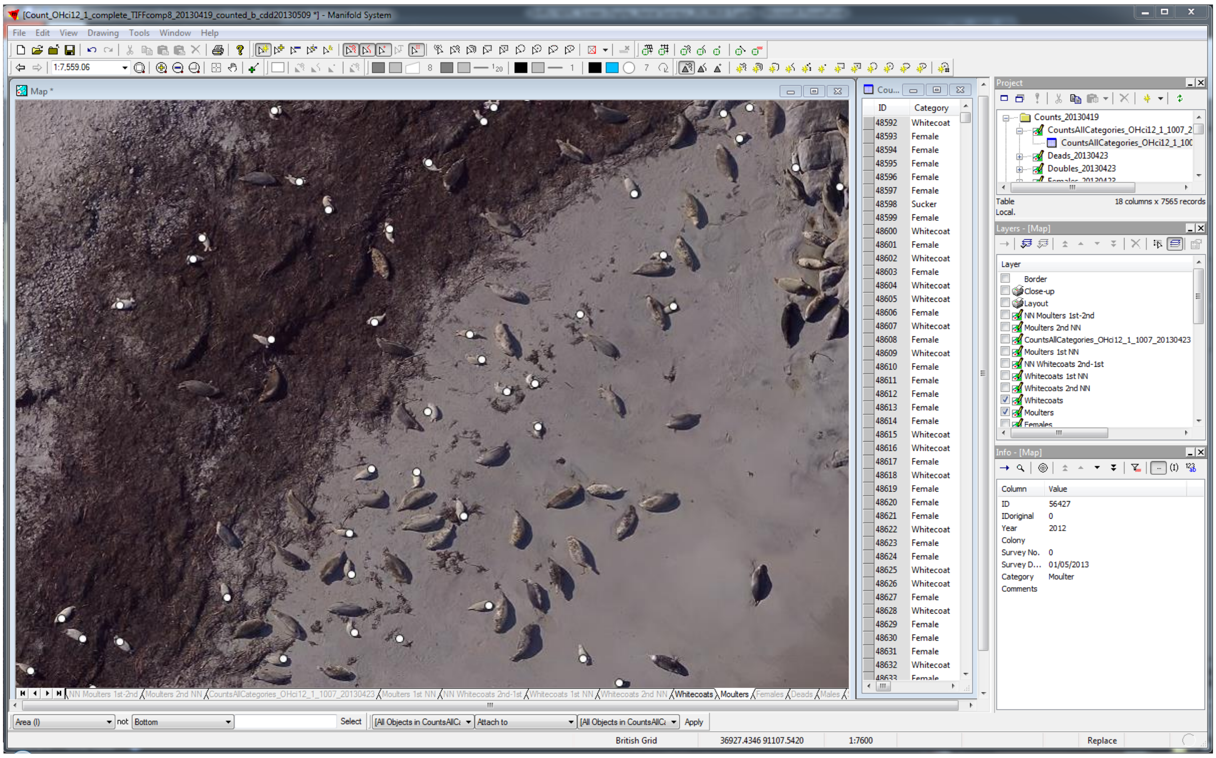

**Figure 5.** Manifold GIS 8.0® screenshot showing grey seal pups counted on Ceann Iar. Pups are marked and classified as whitecoats, moulted pups, or dead pups.

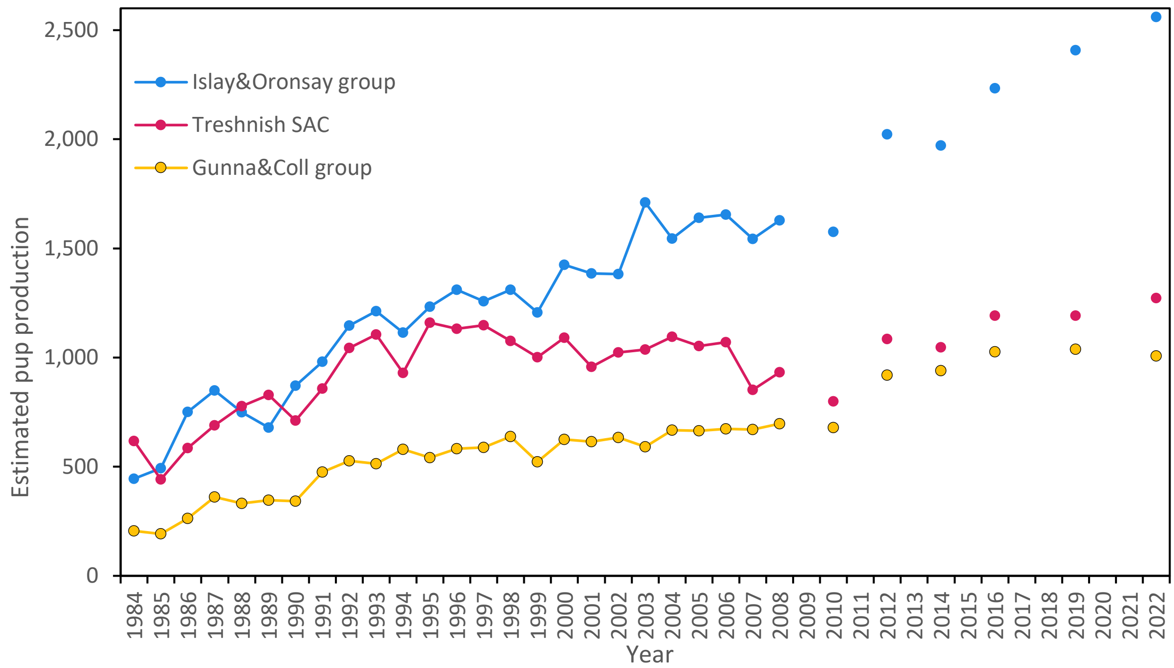


**Figure 6**. Grey seal pup production in the Inner Hebrides (SMU 2a, West Scotland – South), grouped by location. The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 24/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

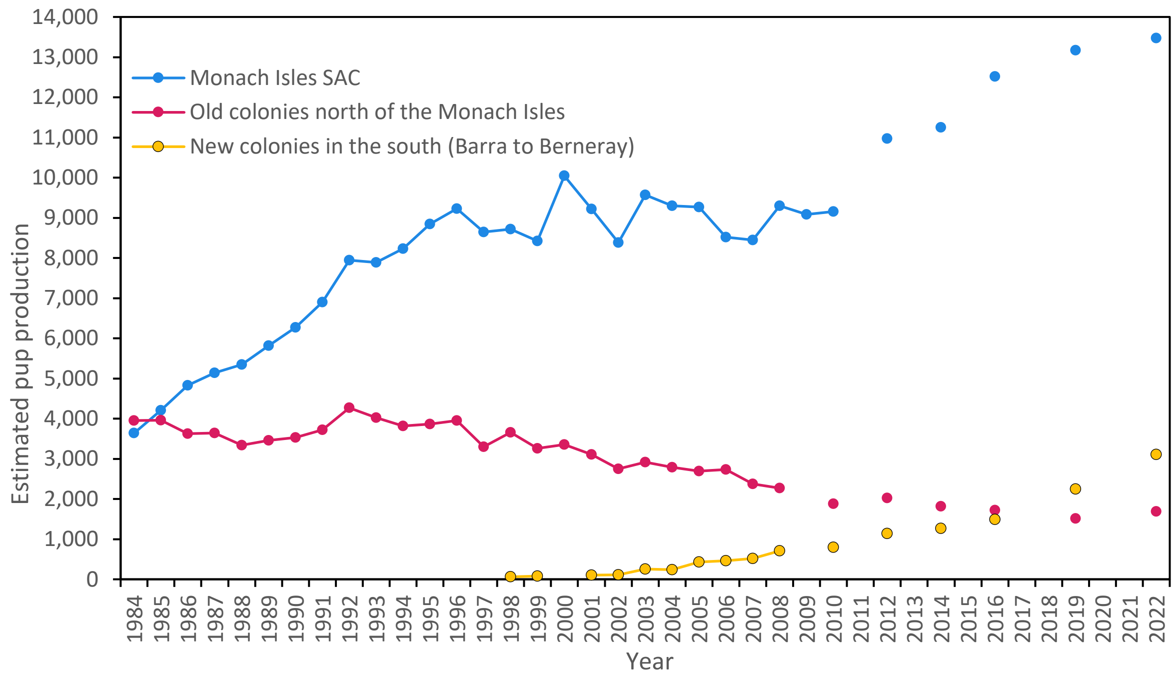


**Figure 7.** Grey seal pup production in the Outer Hebrides (SMU 3, Western Isles), comparing breeding colonies on the Monach Isles, long established (old) colonies to the north, and newly established colonies to the south of the Monachs. The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 24/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

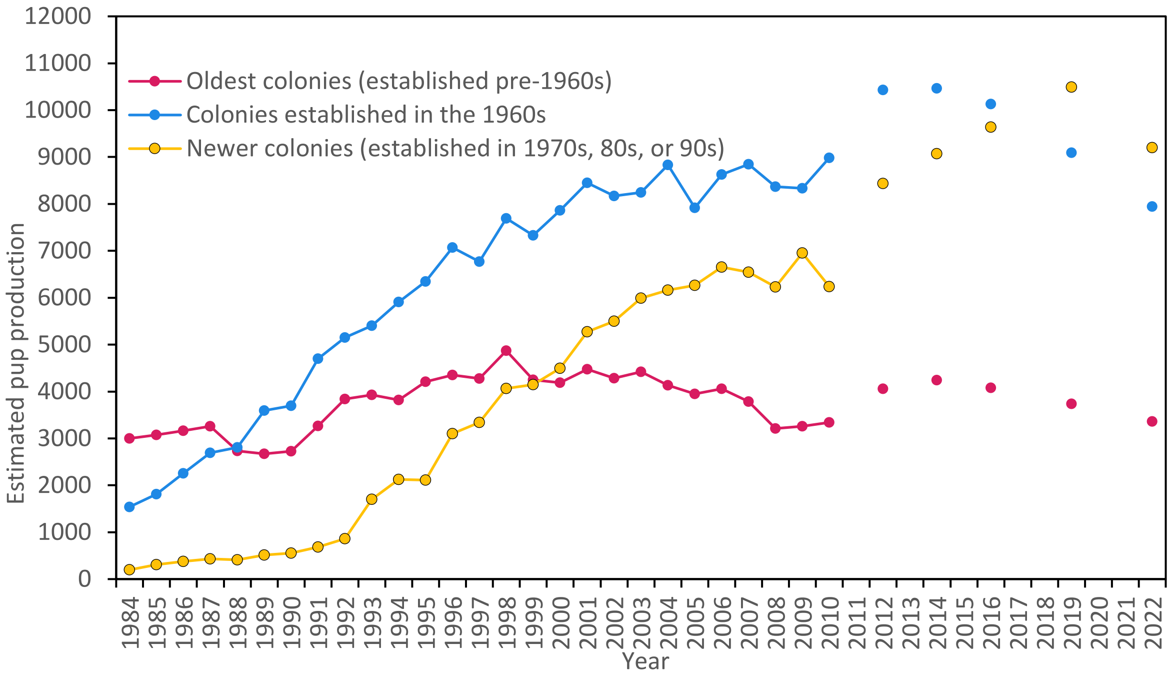


**Figure 8**. Grey seal pup production at colonies in Orkney (SMU 4b), comparing colonies well established before the 1960s, colonies established during the 1960s and colonies established more recently. The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 24/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

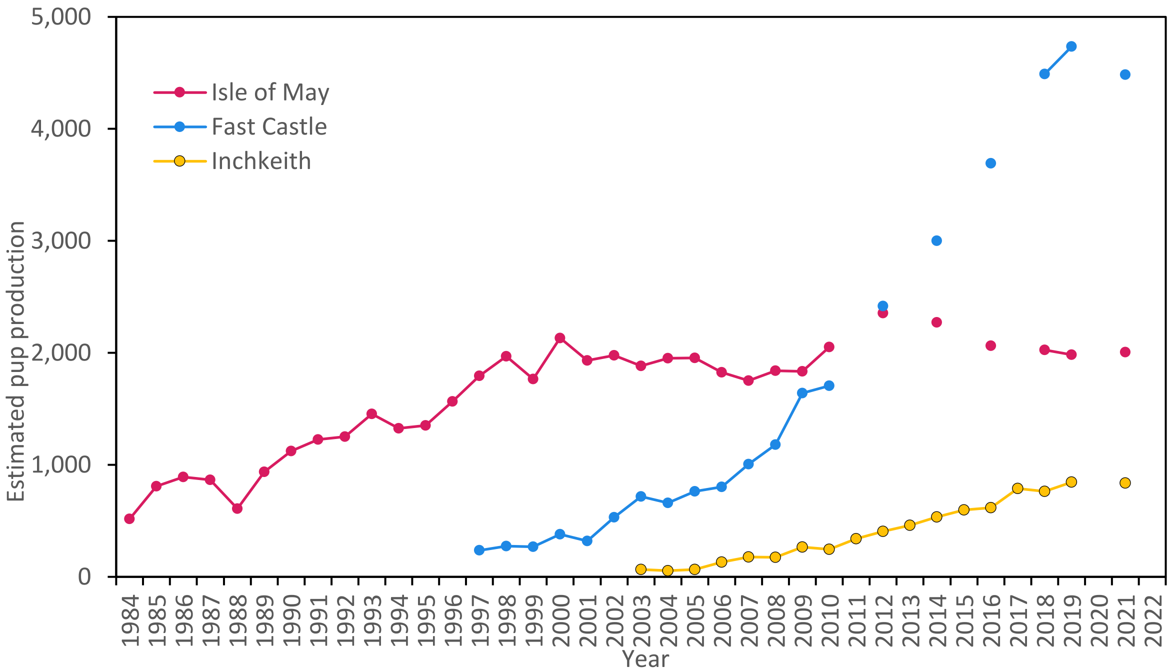


**Figure 9**. Grey seal pup production at the main colonies in the Firth of Forth (SMU 7, East Scotland). The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 24/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

**Trends in seal abundance and grey seal pup production**

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## Abstract

Scotland and eastern England (SMUs 1-9) hold the majority of the UK populations of grey and harbour seals (>95% of each species). The main method for monitoring harbour seal populations, both in the UK and elsewhere, is through surveys on land during their annual moult. UK grey seal abundance and trends are primarily monitored through a combination August haul out counts and pup production estimates. For both species, abundance levels and national trends, are assessed on the basis of the latest composite (multi-year) August counts (SCOS BP 24/01), and for grey seals pup production estimates (SCOS 24/02) and the output of a population model (SCOS BP 24/05). Estimates of trends in abundance for key SMUs, and their encompassed SACs, are essential for effective conservation and management. To assess trends on a SMU and SAC scale, counts/production estimates from individual surveys are used (rather than composite counts), maximising the use of data available; these counts are input into statistical models to generate trends. For grey seals, pup production and August should be considered in combination, as the former represents a powerful and consistent way to evaluate trend and the latter represents where seal acquire their resources.

For August count data, at least three models were considered; 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. In addition, for harbour seal counts in SMUs 4-9, step changes in abundance and trends around 2002 were offered. For grey seal pup production, a change in method (film to digital surveys) in Scottish SMUs was quantified. A consistent time-series of pup production estimates for Northeast and Southeast England was used (SCOS BP 24/08). Trends were assessed using four metrics of percentage change compared to the latest year of data available for a given SMU/SAC. There were two short-term metrics: 1 year (ST1) and 6 year (ST6; as for OSPAR). In addition, two long-term (LT) metrics: since 1992 or the earliest year thereafter (as for OSPAR), and since any historic high in the time series. Trends were deemed significant if the 95% confidence intervals did not encompass 0.

For both species, SAC trends were generally less favourable than for the SMU that encompassed them. Harbour seal abundance in Southwest Scotland and the subunits of West Scotland SMU are all showing stable or increasing trends. The current trend (one year) for Western Isles is of a slight decline but it is stable when looking at a slightly longer time frame (6 years). North Coast & Orkney and East Scotland SMUs are depleted and still declining, whereas Shetland and Moray Firth SMUs are depleted but stable. Southeast England SMU is depleted (since 2018) and showing no sign of recovery.

For grey seal pup production, the change from film (up to 2010) to digital (from 2012) aerial surveys in Scotland was associated with a c. 22.5% jump in pup production (over and above any underlying trend). Accounting for this jump, pup production in West Scotland and Western Isles is increasing and at an all-time high after a long period of stability. In Southwest Scotland (where < 10 pups are born annually) and West Scotland, summer abundance is also increasing. In contrast, August counts in the Western Isles are variable but show no apparent trend. Pup production and August counts in North Coast and Orkney are stable (since early 2000s). For Shetland, there is an indication of a decline in pup production but August counts show no trend. Production in all east coast SMUs (Moray Firth, East Scotland, Northeast England, Southeast England) is continuing to increase. However, the August counts are stable for the Moray Firth and East Scotland, but increasing in eastern England.

## Introduction

Scotland and eastern England (SMUs 1-9) hold the majority of the UK populations of grey and harbour seals (>95% of each species). The main method for assessing harbour seal populations, both in the UK and elsewhere, is through surveys on land during their annual moult when a high and stable proportion of the population are hauled out (Lonergan *et al.* 2013). UK grey seal abundance and trends are primarily assessed through a combination of August haul out counts and pup production estimates. For both species, abundance levels and national trends, are assessed on the basis of the latest composite (multi-year) August counts (SCOS BP 24/01), and for grey seals pup production estimates (SCOS 24/02) and the output of a population model (SCOS BP 24/05). Estimates of trends in abundance for key SMUs, and their encompassed SACs, are essential for effective conservation and management. To assess trends on a SMU and SAC scale, counts/production estimates from individual surveys are used (rather than composite counts), maximising the use of data available. For West Scotland, recognising the size of the SMU means there could be spatial variation in trends, and that coverage is often over multiple years, three subunits (south, central and north) are also considered for August surveys. The models used here broadly follow the approach taken in Thompson *et al.* (2019) and Russell *et al.* (2019). This BP represents an update from SCOS BP 22/02; the survey methods are briefly summarised, and changes are highlighted.

*Harbour seals*

The time series of August moult counts considered here started in the late 1980s. SMRU surveys cover SMUs 1-9 (Scotland and east coast of England). Key data are also provided by The Industry Nature Conservation Association (INCA; Tees; SMU 8) and Zoological Society of London (Thames; SMU 9). The length of the mainly rocky coastline around north and west Scotland (SMUs 1-5) means it is impractical to survey the whole coastline every year; SMRU aims to survey this entire coast every five years. 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 of the estuaries of the English and Scottish east coasts means that conventional photography in a fixed-wing aircraft can be used to survey there. Where there are indications of significant changes, and resource allows, the survey effort is higher, and some areas (Moray Firth SMU, Firth of Tay & Eden SAC in East Scotland SMU, parts of Southeast England SMU) are generally surveyed at least once each August (by fixed-wing).

*Grey Seals*

Pup production is focussed on a limited number of colonies and, once recruited, females often return to the same colony to breed year after year. Although this makes the pup production time-series incredibly useful for looking at change, the summer distribution, and changes therein, are also an important consideration as this represents where the UK population acquired the resources for pup production. It should be noted that the proportion of grey seals hauled out in August is relatively low (compared to harbour seals that are moulting), and is variable. Indeed, based on telemetry data, it is estimated that 25.15% (95% CI: 21.45-29.07%) of the population is hauled out during the specific survey window and thus available to be counted (SCOS BP 21/03, updated from Lonergan *et al.* 2011). As such, the power to detect trends is relatively low for the August counts, especially in SMUs that are not monitored annually.

The temporal extent of the grey seal breeding season means that any one pup count represents an unknown proportion of the number of pups produced. Thus, SMRU conduct multiple aerial surveys through a season (usually 4 or 5), and pups counts are classed into whitecoat and moulted classes. Pup production from aerial-surveyed colonies is estimated by combining count data (split into white coat and moulted) with life history and observation parameters (see Russell *et al.* (2019) for details). Estimates for Shetland are from ground-surveys, conducted by NatureScot. For most SMUs, the current time-series of pup production estimates is from 1984. Up until 2010, these surveys were conducted annually at regularly monitored colonies in Scotland. However, from 2012, the surveys were conducted biennially. With the recent inclusion of eastern England (see below), major grey seal colonies in Scotland and on the east coast of England are now currently surveyed every two or three years.

Interpretation of the trends in pup production over the entire time series is complicated by a change in survey methodology from ground to aerial (digital) surveys for eastern England (see Changes below), and from film (up to 2010) to digital (aerial) surveys for most Scottish SMUs. For logistical and technical reasons, it was not possible to directly cross-calibrate the film and digital aerial surveys. In all SMUs where the pup production time-series is entirely derived from aerial survey counts, there was an apparent step change (increase) in observed production associated with the change in methods. This apparent jump is estimated in the models (see Methods), allowing assessment of trends robust to this jump.

*Changes compared to SCOS 2022*

August counts

The new August count data available for this BP are from 2022 and 2023 (SCOS BP 24/01). In 2022, helicopter surveys were conducted in Western Isles and West Scotland SMUs (mainly central and northern subunits). In 2022 and 2023, fixed wing surveys covered the Moray Firth SMU, Tay & Eden SAC (East Scotland SMU), and Donna Nook to Scroby Sands (Southeast England SMU; in 2022 the whole SMU was covered). Note the indicator area for the Moray Firth has been changed and is now Helmsdale to Findhorn (which encompasses the previous area of Loch Fleet to Findhorn).

Grey Seal Pup Production

In SCOS BP 22/02, pup production estimates up to 2019 were considered for Scotland. Here, the 2019 estimates for Scotland have been updated, and estimates for 2022 included (except East Scotland for which the estimates are from 2021; SCOS BP 24/02). For eastern England, the estimates were exclusively based on ground surveys; a single time series incorporating ground and aerial surveys has been generated for Northeast and Southeast England SMUs (see SCOS BP 24/08), and has been updated to 2021.

Assessment Metrics

The time scales on which trend assessments are made has also been changed (see below). In SCOS BP 22/02, only the current trend (ST1 below) and the depletion from a historic high was considered.

Appropriate baselines for assessing the status of wildlife populations is a complex issue because the true “normal” levels of abundance is simply not known. For seals, there is added complexity associated with recovery following the end of hunting and culling, and also the Phocine Distemper Virus Outbreaks (1988 and 2002) which caused reductions in the populations. For the OSPAR Quality Status Report (QSR) 2023 (Banga *et al.* 2023), OSPAR considered a set Assessment Year (2019) against which changes were assessed on a short- (since 2013) and long- (since 1992) term basis. This maximised comparability spatially, but was relaxed for areas when dictated by a limited temporal extent of data. Indeed, for many Assessment Units, the time series did not go back as far as 1992 so in reality, the long-term assessment was based on differing time periods.

Due to the spatial extent of seal haulouts and colonies in the UK, key haulouts and colonies are surveyed across multiple years. This means that choosing a single Assessment Year would lead to delayed and outdated assessments for some SMUs. Thus, here we use the most recent survey year for each SMU/SAC. Given the natural variability in the proportion of seals hauled out during surveys, and the differing frequency of surveys across SMUs, the change in abundance is estimated from a model fitted to the count/production data rather than directly from the raw data.

Given the difficulties in selecting a long-term (LT) baseline, here 1992 is considered (or the earliest year thereafter if the time-series began after 1992) following OSPAR. However, in addition, depletion from the highest point in the time series is also estimated (historic high; HH year), recognising that populations may have increased to a higher level than in 1992, and since declined. Finally, an additional short-term (ST) trend was estimated (one year leading up to the latest survey year; ST1), recognising the importance of rapidly detecting declines. This is particularly relevant for SMUs/SACs monitored on an annual basis. So in total, four metrics of percentage change compared to the Assessment Year were considered: 1 year (ST1); 6 year (ST6); since 1992 (LT); and since any historic high (HH) in the time series. Changes in metrics were deemed significant if the 95% confidence intervals do not encompass 0. It should be noted this differs from 80% confidence intervals considered in OSPAR QSR 2023.

**Methods**

All analyses were conducted in R (R Core Team 2023).

*August surveys*

Counts were generally assigned to the year in which they were conducted. However, in some cases that was not possible (e.g. SMUs covered over a 2-year period) 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 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. Indeed, the latest August counts, and for indicator areas the percentage of the SMU they represent are shown in Tables 1a (harbour seals) and 1b (grey seals).

Counts were modelled as a function of year assuming negative binomial errors broadly following methods described in Thompson *et al.* 2019. 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 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 seal pup production*

Pup production estimates (SCOS-BP 24/02 and SCOS BP 24/08) were used for SMUs 2-9, with the exception of SMU 5, Shetland, for which peak counts from NatureScot ground surveys were used. Note pup production in SMU 1 (Southwest Scotland) is thought to be < 10, and thus not considered here. For Scottish SMUs, the estimates were derived from aerial survey counts (SCOS BP 24/02). Some historic estimates for East Scotland SMU were derived from ground-surveys and provided by Fife Seal Group. For most SMUs, a regularly monitored large subset is used as a proxy for the SMU as a whole. 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; SCOS BP 24/05), and represent the majority of production in those SMUs (see Table 1c). The latest estimates for East Scotland, Northeast England and Southeast England sum to the totals used for the North Sea region (SCOS-BP 24/05). Shetland and Moray Firth SMU data are not incorporated in the population model.

Pup production (peak count for Shetland) 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. 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 data being considered twice (SACs individually and as part of the SMU totals) 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 Shetland, 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). The trend data for Northeast and Southeast England comprised a mixture of ground (provided by National Trust, Lincolnshire Wildlife Trust and Friends of Horsey Seals) and SMU aerial-based estimates. Essentially, for Northeast England, a GAM was used across the time-series (ground and aerial-based estimates). For Southeast England, the trends were evaluated using the combined predictions from the colony specific trends (SCOS BP 24/08).

*Change metrics*

To calculate the metrics of change, 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.

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

t1 represented the count in different years depending on the metric considered: for ST1 it was the year preceding the latest survey, for ST6 if was the year 6 years prior to the latest survey, for LT it was 1992 or the earliest year thereafter (if the time-series began after 1992); for HH , it 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, HH is given as 0 (Table 1).

**Results & Discussion**

The changes discussed below are significant unless otherwise stated. Note the magnitude of increases is not discussed, and the estimates of percentage change (Table 1) should be considered in the context of the abundance in the SMU/SACs.

*Harbour seals*

The trends for SMUs 1-9, and their encompassed SACs, are as presented in Figures (a) below (numbered as per SMU) and Table 1a. There are ten harbour seal SACs in Scotland and England, all within SMUs 1-9; harbour seals are the primary reason for designation in all except Sound of Barra. Below, for each SMU and SAC the trends are described. 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.

Southwest Scotland (~6% of UK count) have increased on short- and long-time scales, and are at highest levels of the time-series.

The West Scotland SMU represent almost half of the UK harbour seal count. The SMU approximately has equal abundances in the south and central subunits, with only around 6% in the northern subunit. The SMU, and central subunit, has increased on short- and long-time scales, and is at time-series high levels. No trend was evident for the time-series of the southern subunit of West Scotland SMU. For the northern subunit, the only significant change was a LT increase in abundance (since 1992). The SACs in the southern part show differing trends; estimated abundance in the Eileanan agus Sgeiran Lios mor SAC is stable on all time scales (no trend) whereas abundance increased in the Southeast Islay Skerries SAC (ST1, ST6, LT up to Assessment Year 2018), and is at a high for the time-series. Estimated abundance in the Ascrib, Isay and Dunvegan SAC (central subunit) has decreased but not significantly so (ST1, ST6, LT). It is, however, significantly depleted (HH 2003). It should be noted that the latter SAC was surveyed in 2022, but that the latest data available for the central West Scotland, as a whole, is 2017, and thus the trends are not directly comparable.

The current trend for Western Isles (~11% of UK count) is of a slight decline (ST1) but it is stable when looking at a slightly longer time frame (ST6). This follows what was a time-series high (2017), and thus the abundance is still higher than at the start of the time series (LT). In contrast, there is currently no significant trend in abundance in the Sound of Barra SAC, and abundance is severely depleted compared to the start of the time series (LT). The last count (2017) represents around 3% of the SMU total compared to around 38% in 1992 (start of the time series).

North Coast & Orkney SMU (~5% of UK count) and its encompassed SAC (Sanday) are severely depleted (HH 1993) and are still in decline (ST1, ST6). The current rate of decline and level of depletion are 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% at the start of the time series.

Abundance in Shetland (~11% of the UK count), although depleted compared to the start of the time series (1992; by ~40%), is currently stable. This is also the case for the Yell Sound SAC. In contrast the Mousa SAC is almost completely depleted (~98% compared to 1992), and is still in decline, with a count of 7 in the last survey (2019).

Abundance in the Moray Firth SMU (~3% of the UK count) is depleted by ~ a third (HH 1994) tbut is currently stable (ST1, ST6). The Dornoch Firth and Morrich More SAC is more severely depleted (~90%) and still in decline (ST1, ST6); the SAC now represents 5% of the SMU count in 2023 compared to around 50% in the early 1990s.

The East Scotland SMU (~1% of the UK count) is severely depleted since the start of the time series (1997; by ~ 70%), and still in decline (ST1, ST6). The Firth of Tay and Eden Estuary SAC was last surveyed in 2023, and although it is ~95 % depleted compared to the 1990s, it is no longer significantly declining (ST1, ST6). Indeed, there has been a slight increase recently (significant for ST1). In the last count (2021) for the SMU as a whole, the SAC represented around 16% of the SMU total compared to around 83% in the first SMU-wide survey (1997).

The Northeast SMU hosts a small number of harbour seals (<150), the vast majority of which are within the Tees estuary. After drops associated with the last PDV epidemic (2002) and the most recent decline in eastern England (2019; see below), abundance has started to increase again. It is now at the highest level in the times series and has increased on all time scales (ST1, ST6, LT).

The Southeast England SMU hosts ~11% of the UK count. It's SAC, The Wash & North Norfolk Coast, accounts for around two thirds of the SMU abundance. With the exception of the Phocine Distemper Virus (PDV) outbreaks in 1988 and 2002, the SMU and encompassed SAC increased until levelling off around 2015. However, since 2019, the count was markedly lower than in the preceding years. There is no evidence of a continued decline within the SMU or SAC (ST1 non significant). The decrease, since the high in 2015, is ~20% for the SMU, and ~26% for SAC. The cause of this decline, and its implications, are the focus of a SMRU research project. Pup counts, and trends therein, are reported for the Wash in SCOS BP 24/07.

*Grey seals*

The trends for August counts (Table 1b) and pup production (Table 1c) for SMUs 1-9, and their encompassed SACs, are as presented in Figures below (numbered as per SMU). The majority of grey seal SACs were designated on the basis of the number of breeding seals they host, rather than foraging seals (August counts).

The final model estimating trends in grey seal pup production for aerially surveyed SMUs (excluding Moray Firth) included an estimated 22.5 % jump (95% CI: 14.3, 30.7) in pup production associated with the change from film to digital (delta AIC of -29.5 compared to a model without the jump). The plots and Table 1c show the pup production trends (and associated confidence intervals) for each SMU as 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 estimates derived from film surveys shows the same trend but at the lower level than for the estimates derived from digital surveys.

Southwest Scotland hosts a negligible proportion of UK pup production (< 10 pups), but hosts around 1% of UK grey seals in August. As for harbour seals, the abundance in August has increased on all time scales (ST1, ST6, LT) , and are at time-series high levels.

Pup production for West Scotland (~7% of UK production) appears to be increasing, after a long period of stability, and is now at a time-series high. Although not significant, there is an indication of an increase in Treshnish Isles SAC (ST1 & ST6), and it is no longer significantly depleted compared to the historic highs in the late 1990s (when the SMU trend first levelled off). The Treshnish Isles SAC accounts for around ~25% of pup production in the SMU, but is not a key haulout accounting for less than 5% of the SMU count. As for harbour seal counts, August grey seal counts in West Scotland SMU (host ~ 11% of UK count) has increased on all time scales (ST1, ST6, LT) s, and is at time-series high levels. However, in contrast to harbour seals, the increase was driven by increases in southern subunit (ST1, ST6, LT) which hosts the majority (>65%) of grey seals in the SMU. Such increases were also evident in the northern subunit (ST1, ST6, LT) which holds around 15% of the SMU total but not in the central subunit for which no trend was evident across the time series.

The Western Isles host a much larger proportion of UK pup production (~25%) than August count (~9%). Pup production in the Western Isles is increasing (ST1 & ST6), after a long period of stability, and is now at a time-series high. The Monach Isles SAC is also at its highest recorded level of production accounting for ~75% of the SMU's production, and although there is an indication of a recent increase, it is not significant (ST1 and ST6). 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 grey seals count have been variable for the Western Isles, and the encompassed Monach Isles SAC (~40% of the SMU count), with no trend evident in the time series; There was two periods of increasing counts followed by a particularly low count in 2022. The North Rona SAC is a small haul out (~5% of the SMU).

The North Coast & Orkney hosts the largest proportion of UK pup production of any SMU (~28%) and appears to have reached carrying capacity in the early 2000s. Since the peak in the late 1990s, pup production in Faray & Holm of Faray SAC has been declining (ST1, ST6). It is now significantly depleted to around half historic levels (HH 1992), now accounting for ~10% of the SMU production. The SMU accounts for ~22% of the August count, and increased to a stable level around 2000. Counts for the SAC are generally < 500 (~3% of SMU count) and have been variable. Although the count is still higher than 1992 (LT), the number of are ~50% of a high in 2007, with significant short-term declines (ST6).

Shetland accounts for a small proportion of UK pup production (~1%) and August count (~3%). Peak counts (supplied by NatureScot) for a subset of colonies (representing ~50% of Shetland production) were used to investigate the trend. Although, the trend (GLM) indicates a decreasing trend (ST1, ST6, LT), these should be treated with caution due to the use of a subset of colonies and the sensitivity of peak counts to variation in survey effort. For August counts, an exceptionally low count at the start of the time series precludes the fitting of a robust trend to current data; no trend was selected.

The Moray Firth accounts for around 2% of UK pup production, and 3% of the August count. Pup production has increased (ST1, ST6, LT) whereas August counts are variable with no clear trend.

East Scotland accounts for ~10% of pup production but only 4% of the August count. Pup production in East Scotland is at a time-series high (LT) and continues to increase (ST1, ST6). Production on the Isle of May SAC is ~20% lower than the historic high (HH 2004), and appears to still be declining (ST1, ST6). The 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. Around 60% of the pups born at the Fast Castle colony are within the Berwickshire and North Northumberland Coast SAC. In the 6 years leading up to the last estimate (2021), the increase in the SAC was more marked than in the colony as a whole (~54 vs 46% increase). However, likely due to the expanding nature of the colony, the current trend (ST1; 2000-2021) shows a significant increase for the colony as a whole, but not for production within the SAC. August counts are variable for East Scotland SMU with no trend evident. Neither SACs represent key haul out areas for grey seals during the August survey.

Northeast England accounts for around 4% of UK pup production but around 14% of the August count.  Pup production in the English portion of the Berwickshire and North Northumberland Coast for all intents and purposes represents all pup production in the SMU (>99%). Pup production and August counts are at record levels and are continuing to increase rapidly (ST1 and ST6). The SAC represents the vast majority of the August count (>90%) of the SMU.

Southeast England now accounts for almost 20% of UK pup production, and almost 27% of the August count. Pup production is the highest for the time-series and continues to increase rapidly (ST1, ST6). The Humber Estuary SAC (Donna Nook) represents a decreasing proportion of the pup production for the SMU as a whole. It accounted for 100% in pup production in 2000, but now accounts for less than 20%. The SAC appears to have recently reached a stable level with no significant increase leading up the last survey (ST1), but still a significant increase compared to 6 years previously (ST6). The trends for August show a similar pattern; Humber Estuary estimates (2023) are significantly higher than 6 years ago but are now stable accounting for ~65% of the SMU total. At the SMU level, the increase compared to 6 years ago is more marked and although the last count is the highest, the current trend (ST1) is not significant.

## References

Banga R, Russell DJF, Carter MID, Chaudry F, Gilles A, Abel C, Ahola M, Authier M, Bjørge, A, Brasseur S, Carlsson A, Carlstrom J, Christensen AH, Dinis A, Engene N, Galatius A, Geelhoed S, Granquist S, Haelters J, Jess A, Morris C, Murphy S, Ó Cadhla O, Persson S, Pierce G, Poncet S, Rosing-Asvid A, Saavedra C, Taylor N, Teixeira A, van Neer A, Vasconcelos R. and Vincent C. 2022. Seal Abundance and Distribution. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/seal-abundance-and-distribution

Cox T, Barker J, Bramley J, Debney A, Thompson D, & Cucknell AC. (2020). Population trends of harbour and grey seals in the Greater Thames Estuary. *Mammal Communications*, *6*, 42–51.

Lonergan M, Duck CD, Moss S, Morris C & Thompson D. (2013). Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 23, 135–144.

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

Morris CD, Duck CD & Thompson D (2021). Aerial surveys of seals in Scotland during the harbour seal moult, 2016-2019. NatureScot Research Report 1256.

R Core Team (2023). R: A Language and Environment for Statistical Computing. RvFoundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Russell DJF, Morris CD, Duck CD, Thompson D, Hiby L. (2019). Monitoring long-term changes in UK grey seal pup production. *Aquatic Conservation: Marine and Freshwater Ecosystem*;29(S1):24–39.

Thompson D, Duck CD, Morris CD, Russell DJF (2019). The status of harbour seals (*Phoca vitulina*) in the UK. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29(S1):40–60.

**Table 1a.** Trends in harbour seal August counts for all SMUs (1-9) and SACs in Scotland & eastern England. The latest counts and associated year is given. For proxy areas, the percentage of the SMU total in the last SMU survey is given. N indicates the number of data points used to fit the trend. The percentage change (and associated 95% confidence intervals) to the latest survey year for four metrics are shown (see text). Changes in bold indicate significant change (95% CIs do not overlap 0); negative in red. Values of 0 indicate no trend.

| SMU/ subdivision | SAC/Area | Last survey | | N | Change (%; 95% CI) | | | |
|---|---|---|---|---|---|---|---|---|
| | | Year | Count | | ST1 | ST6 | LT | HH (year) |
| 1. Southwest Scotland | | 2018 | 1709 | 6 | **3.9 (1.9, 6)** | **25.8 (11.6, 41.8)** | **169.9 (61.1, 354.3; 1992)** | - |
| 2. West Scotland | | 2018 | 15600 | 6 | **2.5 (1.6, 3.3)** | **15.8 (10.2, 21.6)** | **88.8 (53.2, 133.9; 1992)** | - |
| 2a. West Scotland - south | | 2018 | 7069 | 6 | 0 | 0 | 0 | - |
| | South-East Islay Skerries SAC | 2018 | 706 | 7 | **1.9 (0.5, 3.2)** | **11.8 (3, 21.1)** | **62.3 (13.1, 129.5; 1992)** | - |
| | Eileanan agus Sgeiran Lios mor SAC | 2018 | 238 | 10 | 0 | 0 | 0 | - |
| 2b. West Scotland - central | | 2017 | 7447 | 7 | **4.3 (3.5, 5)** | **28.5 (23, 34.1)** | **184.1 (136.3, 239.5; 1992)** | - |
| | Ascrib, Isay and Dunvegan SAC | 2022 | 340 | 12 | -5.2 (-13.4, 3.7) | -26.2 (-53.2, 16.8) | -6.1 (-46.1, 61.6; 1992) | **-46.4 (-69.8, -5.9; 2003)** |
| 2c. West Scotland - north | | 2022 | 919 | 7 | -0.9 (-4.9, 3.4) | -1.4 (-19.9, 21) | **183.2 (111.1, 280.4; 1992)** | -2.4 (-16.3, 13.9; 2018) |
| 3. Western Isles | | 2022 | 3080 | 9 | **-5.3 (-9.3, -0.9)** | -12.9 (-28.1, 6.3) | **28.4 (4.2, 58.4; 1992)** | -15 (-28.9, 2.2; 2017) |
| | Sound of Barra SAC | 2022 | 91 | 10 | -2.4 (-9.2, 5) | -11.2 (-36.9, 24.8) | **-89 (-93, -83; 1992)** | **-89 (-92.9, -83.1; 1992)** |
| 4. North Coast & Orkney | | 2019 | 1405 | 10 | **-8.6 (-10, -7.3)** | **-41.8 (-46.7, -36.5)** | **-85.5 (-87.6, -82.9; 1993)** | **-85.5 (-87.6, -82.8; 2002)** |
| | Sanday SAC | 2019 | 77 | 12 | **-14.2 (-18, -10.5)** | **-60.2 (-69.7, -48.5)** | **-96 (-97.6, -93.5; 1993)** | **-96 (-97.6, -93.5; 2002)** |
| 5. Shetland | | 2019 | 3180 | 8 | 0 | 0 | **-42.2 (-49, -34.7; 1992)** | **-42.2 (-48.9, -34.4; 2002)** |
| | Mousa SAC | 2019 | 7 | 8 | **-21.6 (-30.8, -11.2)** | **-74.6 (-85.6, -55.1)** | **-98 (-99, -96; 1992)** | **-98.1 (-99.1, -96.1; 1991)** |
| | Yell Sound Coast SAC | 2019 | 209 | 8 | 0 | 0 | **-39.3 (-57.5, -14.4; 1992)** | **-39.3 (-57.2, -14; 2002)** |

| SMU/ subdivision | SAC/Area | Last survey | | N | Change (%; 95% CI) | | | |
|---|---|---|---|---|---|---|---|---|
| | | Year | Count | | ST1 | ST6 | LT | HH (year) |
| 6. Moray Firth | | 2019 | 1077 | | | | | |
| | Helmsdale to Findhorn | 2023 | 926 (95%) | 23 | 0 | 0 | **-33.4 (-47.9, -15.4; 1994)** | **-33.4 (-47.7, -15.1; 2002)** |
| | Dornoch Firth and Morrich More SAC | 2023 | 55 | 31 | **-7.5 (-8.8, -6.3)** | **-37.6 (-42.4, -32.4)** | **-91.2 (-94.1, -86.8; 1992)** | **-91.2 (-94.2, -86.8; 1992)** |
| 7. East Scotland | | 2021 | 261 | 6 | **-4.9 (-7.1, -2.7)** | **-26.2 (-35.9, -15.3)** | **-70.3 (-82.9, -48.2; 1997)** | **-70.3 (-83.1, -48.6; 1997)** |
| | Firth of Tay and Eden Estuary SAC | 2023 | 55 | 31 | **6.9 (0.4, 13.9)** | 21.9 (-10.3, 66.1) | **-92.6 (-94.6, -89.8; 1992)** | **-93.5 (-95.4, -90.9; 1997)** |
| 8. Northeast England | | 2018 | 79 | | | | | |
| | The Tees | 2023 | 106 (96%) | 35 | **7.9 (1.6, 14.5)** | **32.1 (8.5, 60.6)** | **313.8 (239.6, 408.2; 1992)** | - |
| 9. Southeast England | | 2022 | 4039 | 11 | -4.2 (-9.4, 1.2) | **-18.9 (-32.9, -2.5)** | 14.9 (-11.1, 48.6; 2003) | **-19.5 (-33.6, -2.9; 2015)** |
| | The Wash and North Norfolk Coast SAC | 2023 | 2675 | 44 | -3.7 (-7.9, 0.7) | **-22.1 (-32.8, -9.7)** | **35.7 (15.7, 59.4; 1992)** | **-25.8 (-35.1, -14.8; 2015)** |

**Table 1b.** Trends in grey seal August counts for all SMUs (1-9) and SACs in Scotland & eastern England. The latest counts and associated year is given. For proxy areas, the percentage of the SMU total in the last SMU survey is given. N indicates the number of data points used to fit the trend. The percentage change (and associated 95% confidence intervals) to the latest survey year for four metrics are shown (see text). Changes in bold indicate significant change (95% CIs do not overlap 0); negative in red. Values of 0 indicate no trend.

| SMU/subdivision | SAC/Area | Last survey | | N | Change (%; 95% CI) | | | |
|---|---|---|---|---|---|---|---|---|
| | | Year | Count | | ST1 | ST6 | LT | HH (year) |
| 1. Southwest Scotland | | 2018 | 517 | 6 | **5.9 (3.4, 8.5)** | **41.2 (22.5, 63)** | **346.1 (140.8, 730.5; 1992)** | - |
| 2. West Scotland | | 2018 | 4174 | 5 | **2.8 (0.7, 5)** | **18.3 (4.1, 34.2)** | **107 (20.2, 261.2; 1992)** | - |
| 2a. West Scotland - south | | 2018 | 2922 | 6 | **3.3 (1.5, 5)** | **21.2 (9.3, 34.4)** | **130 (48, 262.5; 1992)** | - |
| | Treshnish Isles SAC | 2018 | 160 | 6 | 0 | 0 | 0 | - |
| 2b. West Scotland - central | | 2017 | 773 | 6 | 0 | 0 | 0 | - |
| 2c. West Scotland - north | | 2022 | 708 | 7 | **3.2 (0.9, 5.6)** | **21.1 (5.6, 38.4)** | **160.9 (30.5, 418.8; 1992)** | - |
| 3. Western Isles | | 2022 | 3527 | | | | | |
| | excluding offshore islands | 2022 | 3232 (92%) | 9 | 0 | 0 | 0 | - |
| | Monach Islands SAC | 2022 | 614 | 9 | 0 | 0 | 0 | - |
| | North Rona SAC | 2023 | 147 | | | | | |
| 4. North Coast & Orkney | | 2019 | 8599 | 10 | -0.4 (-6, 5.6) | -0.5 (-22, 26.9) | **57.4 (23.3, 101.5; 1992)** | -12.8 (-31.9, 11.5; 2000) |
| | Faray and Holm of Faray SAC | 2019 | 228 | 13 | -7.9 (-15.6, 0.5) | **-38.2 (-58.7, -8.2)** | **109 (29.8, 237.5; 1992)** | **-51.7 (-69.3, -25; 2007)** |
| 5. Shetland | | 2019 | 1009 | 8 | 0 | 0 | 0 | - |
| 6. Moray Firth | | 2019 | 1657 | | | | | |
| | Helmsdale to Findhorn | 2023 | 820 (94%) | 22 | 0 | 0 | **0** | - |
| 7. East Scotland | | 2021 | 2707 | 6 | 0 | 0 | **0** | - |
| | Firth of Tay and Eden Estuary | 2023 | 812 (72%) | 30 | 0 | 0 | **0** | - |
| | Isle of May SAC | 2021 | 97 | 6 | 0 | 0 | **0** | - |
| 8. Northeast England | | 2020 | 4668 | 7 | **11.7 (8.7, 14.9)** | **94.1 (65, 129.5)** | **1171.7 (576.7, 2307.7; 1997)** | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | English component, BNNC SAC | 2020 | 4251 | 7 | **11.5 (8.4, 14.8)** | **91.9 (61.8, 128.5)** | **1116.8 (529.9, 2254.2; 1997)** | - |
| 9. Southeast England | | 2022 | 8658 | | | | | |
| | Donna Nook to Scroby Sands | 2023 | 9793 (90%) | 42 | 4.1 (-1.6, 10.2) | **35.4 (1.3, 80.7)** | **5406.4 (3727.3, 7799.3; 1992)** | - |
| | Humber Estuary SAC | 2023 | 6008 | 51 | -0.5 (-9.1, 8.6) | 5.7 (-33.5, 65.4) | **5166.2 (2859, 9193.1; 1992)** | -0.7 (-17.1, 17.8; 2021) |

**Table 1c.** Trends in grey seal pup production for all SMUs (1-9) and SACs in Scotland & eastern England. The latest year & estimate is given. The percentage of the SMU total in the analyses is indicated if not 100%. N indicates the number of years used to fit the trend. The percentage change (and associated 95% confidence intervals) to the latest survey year for four metrics are shown (see text). Changes in bold indicate significant change (95% CIs do not overlap 0); negative in red. Values of 0 indicate no trend. For Shetland, the value shown is a peak pup count rather than production.

| SMU | SAC/Area | Last survey | | N | Change (%; 95% CI) | | | |
|---|---|---|---|---|---|---|---|---|
| | | Year | Estimate | | ST1 | ST6 | LT | HH (year) |
| 2. West Scotland | | 2022 | 4893 (90%) | 31 | 1.5 (-0.7, 3.7) | 9.4 (-2.4, 22.2) | **51.4 (28.7, 78.1; 1992)** | - |
| | Treshnish Isles SAC | 2022 | 1272 | 31 | 2.2 (-0.2, 4.7) | 12.3 (-0.9, 27.4) | 6.9 (-8.2, 24.1; 1992) | -8.8 (-20.4, 4.8; 1998) |
| 3. Western Isles | | 2022 | 18272 (98%) | 32 | **2.7 (0.6, 4.7)** | **15.7 (3.9, 28.6)** | **29.4 (10.7, 51.1; 1992)** | - |
| | Monach Islands SAC | 2022 | 13475 | 32 | 2 (-0.2, 4.2) | 12 (0, 25.6) | **46.8 (27.6, 69.3; 1992)** | - |
| | North Rona SAC | 2019 | 301 | 31 | **-8.5 (-11.4, -5.4)** | **-42.6 (-50.3, -33.2)** | **-81.8 (-84.6, -78.5; 1992)** | **-83.4 (-86.1, -80.2; 1984)** |
| 4. North Coast & Orkney | | 2022 | 20506 (97%) | 32 | -0.1 (-2.1, 1.9) | -1.7 (-11.6, 9.4) | **81.6 (55.5, 113.5; 1992)** | -8.1 (-21.2, 7.4; 2007) |
| | Faray & Holm of Faray SAC | 2022 | 1915 | 32 | **-5.9 (-8, -3.6)** | **-28.9 (-37, -19.5)** | **-46.3 (-53.8, -37.5; 1992)** | **-56.5 (-61.9, -50.1; 1998)** |
| 5. Shetland | | 2018 | 257 | 10 | **-2.7 (-4, -1.5)** | **-15.4 (-21.6, -8.6)** | **-32.3 (-43.4, -19; 2004)** | **-32.3 (-43.4, -19; 2004)** |
| 6. Moray Firth | | 2022 | 1715 | 9 | **1.8 (0.7, 2.8)** | **11.1 (4.3, 18.2)** | **32.4 (11.8, 56.1; 2006)** | - |
| 7. East Scotland | | 2021 | 7378 (99%) | 33 | **4.9 (3.1, 6.8)** | **33.3 (21.8, 46.2)** | **417.5 (349.4, 497.7; 1992)** | - |
| | Isle of May SAC | 2021 | 2005 | 33 | -1.2 (-3.5, 1.1) | -7.8 (-18, 3.7) | **26.7 (10.8, 44.9; 1992)** | **-19.5 (-29.1, -8.7; 2004)** |
| | BNNC SAC | 2021 | 2668 | 6 | 1.1 (-4.6, 7.1) | **54.1 (25.6, 89.3)** | **231 (170.5, 304.7; 2012)** | - |
| | Fast Castle | 2021 | 4483 | 20 | **5.4 (2.5, 8.4)** | **45.8 (27.9, 66.1)** | **>1000 (1997)** | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8. Northeast England | Farne Islands (BNNC SAC) | 2021 | 3198 (99%) | 36 | **9.8 (7.3, 12.2)** | **70.7 (51.7, 91.8)** | **233.7 (188.6, 284.5; 1992)** | - |
| 9. Southeast England | | 2021 | 14125 (99%) | | **13.4 (10.7, 16.2)** | **125.9 (108.9, 144.7)** | **>1000 (2001)** | - |
| | Humber Estuary SAC | 2021 | 2632 | 42 | 1.3 (-0.2, 2.8) | **14.5 (7.1, 22)** | **>1000 (1992)** | - |

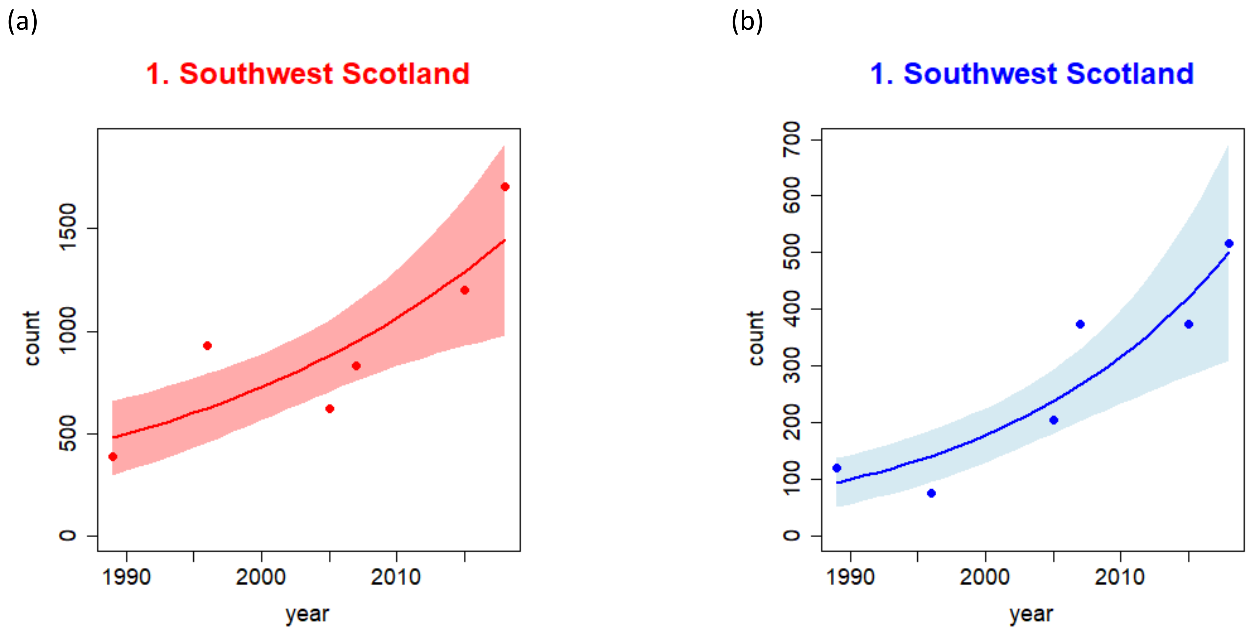


**Figure 1.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the Southwest Scotland SMU. The *filled circle* points represent the values used to fit the trends.

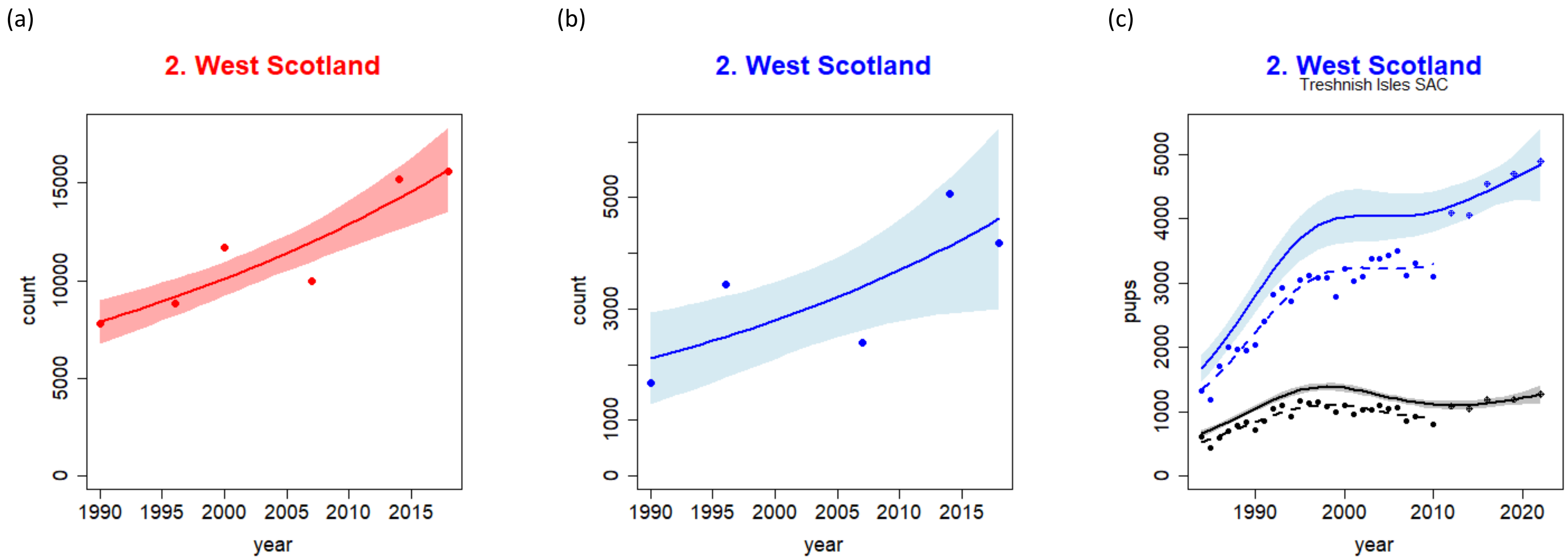


**Figure 2i.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the West Scotland SMU and encompassed SACs (c only). The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for film survey estimate (*circle plus indicate digital surveys; 2012 onwards*).

(a) (b)

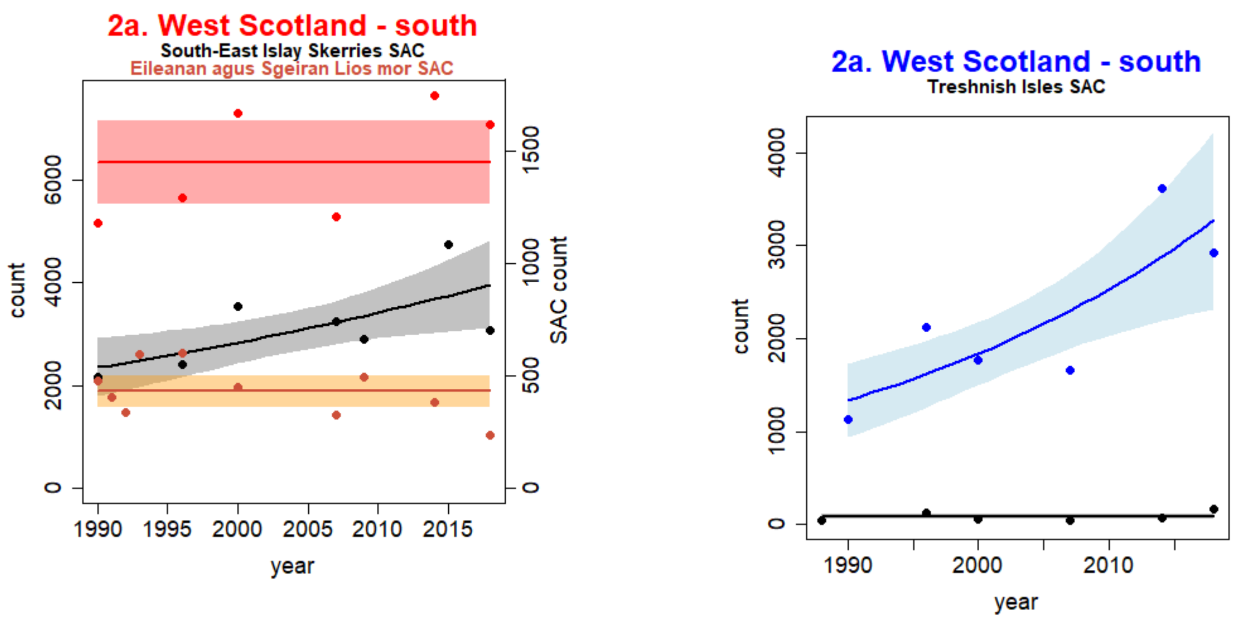


**Figure 2ii.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the southern part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

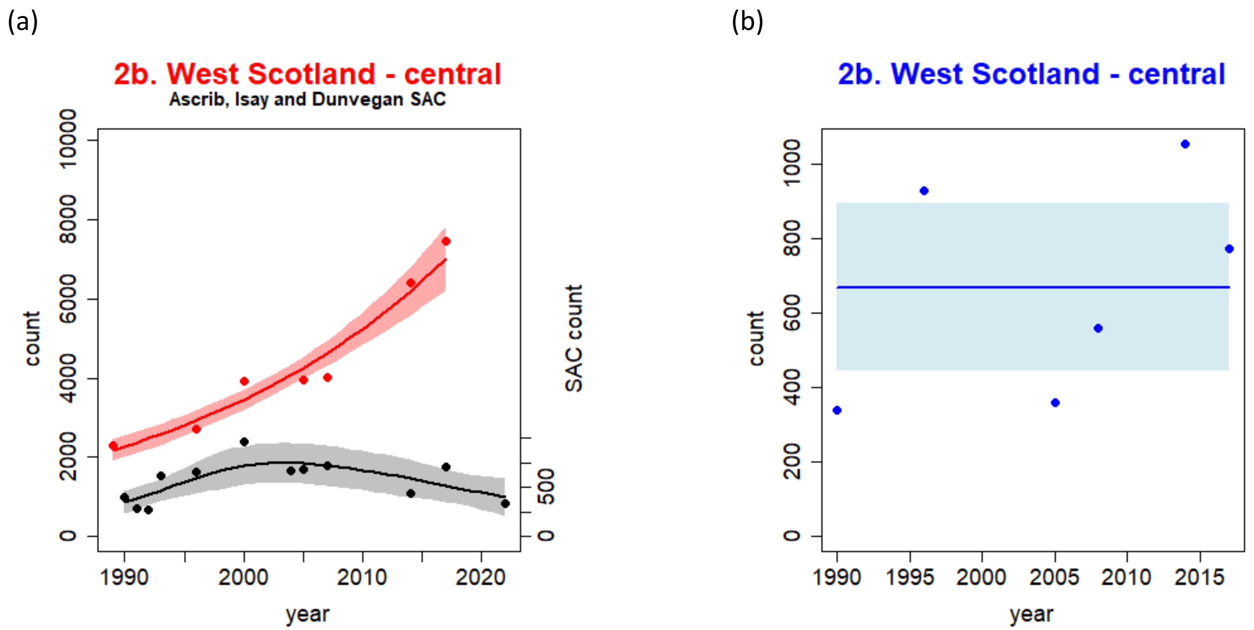


**Figure 2iii.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the central part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

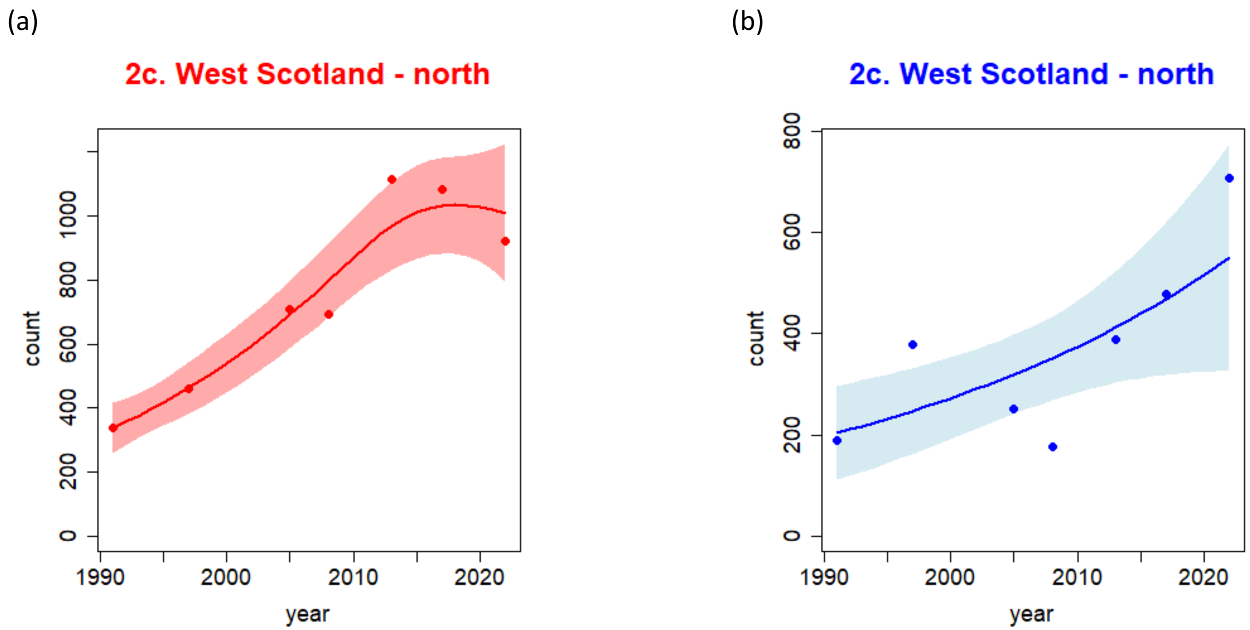


**Figure2iv.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the northern part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends.

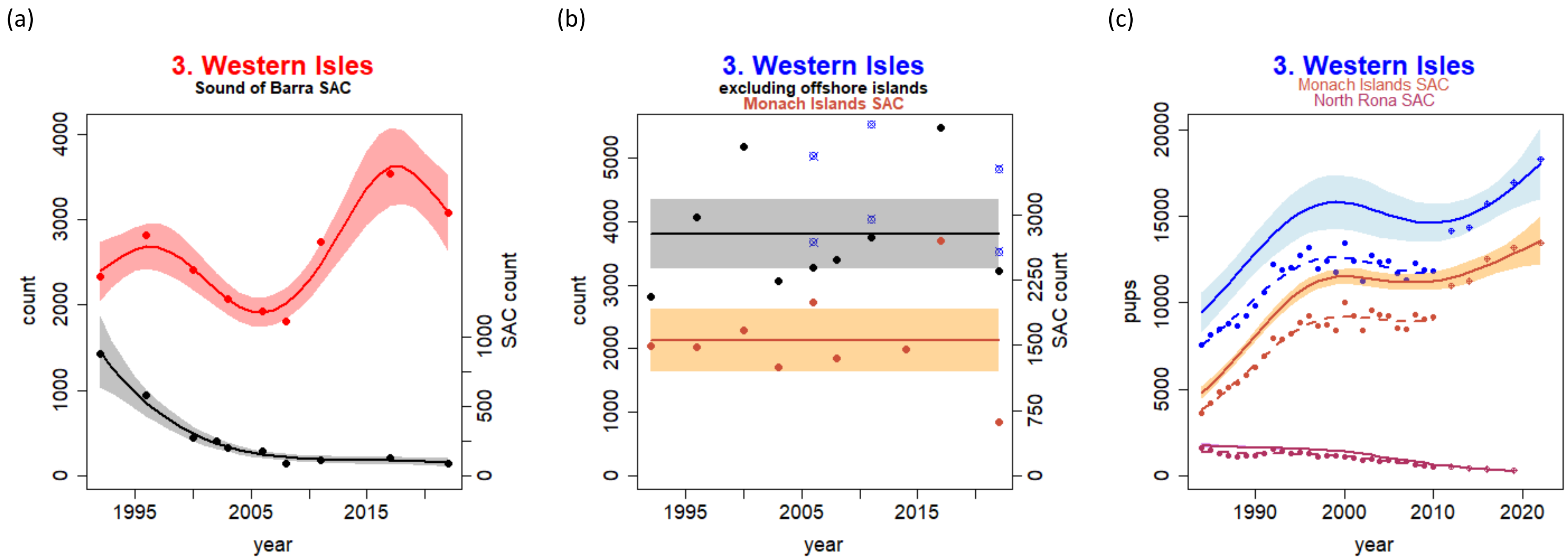


**Figure 3.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the West Scotland SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The *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 film survey estimate (circle plus indicate digital surveys; 2012 onwards). North Rona SAC is not a notable haul out for grey seals and thus August counts are not shown (b). Note the different axes for the SACs (a, b).

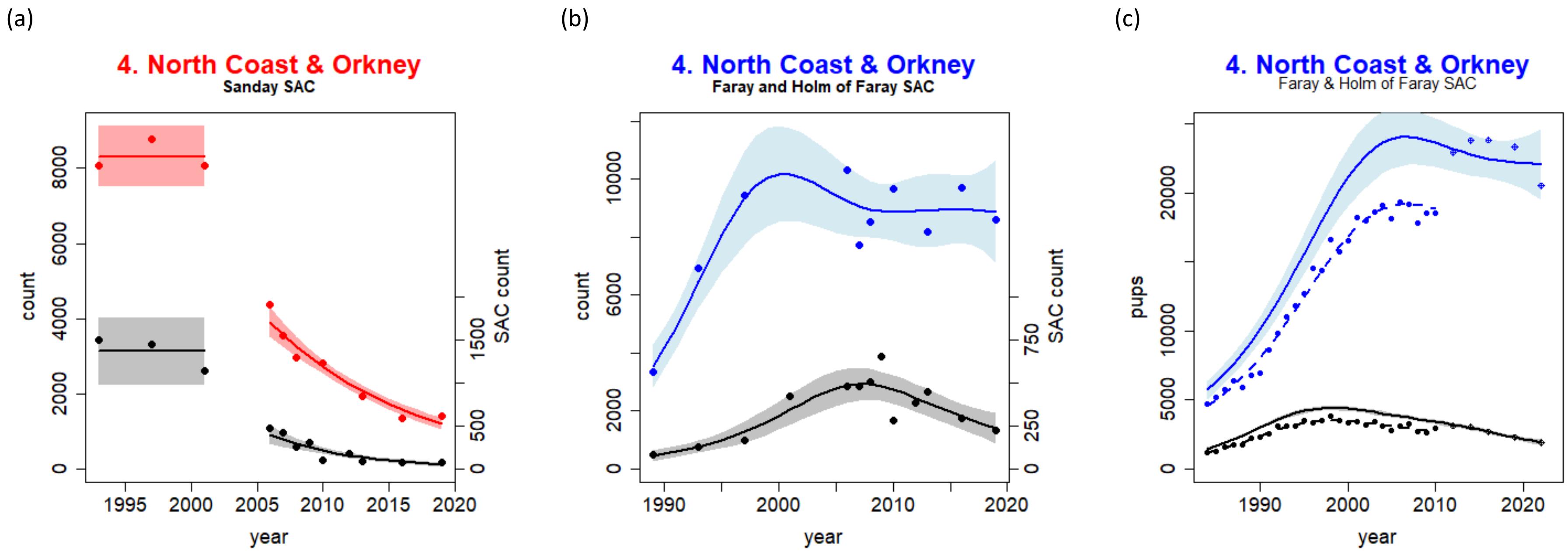


**Figure 4.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the North Coast & Orkney SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for film survey estimate (circle plus indicate digital surveys; 2012 onwards). Note the different axes for the SACs (a, b).

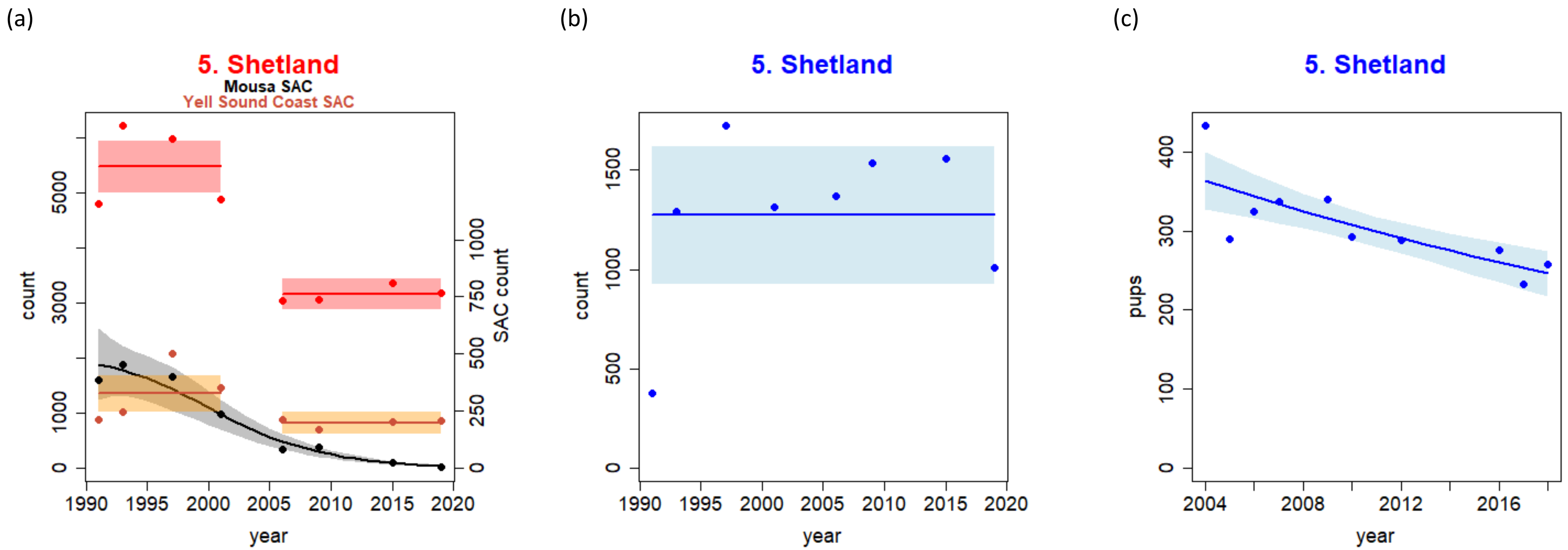


**Figure 5.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal peak counts (c) in the Shetland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs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

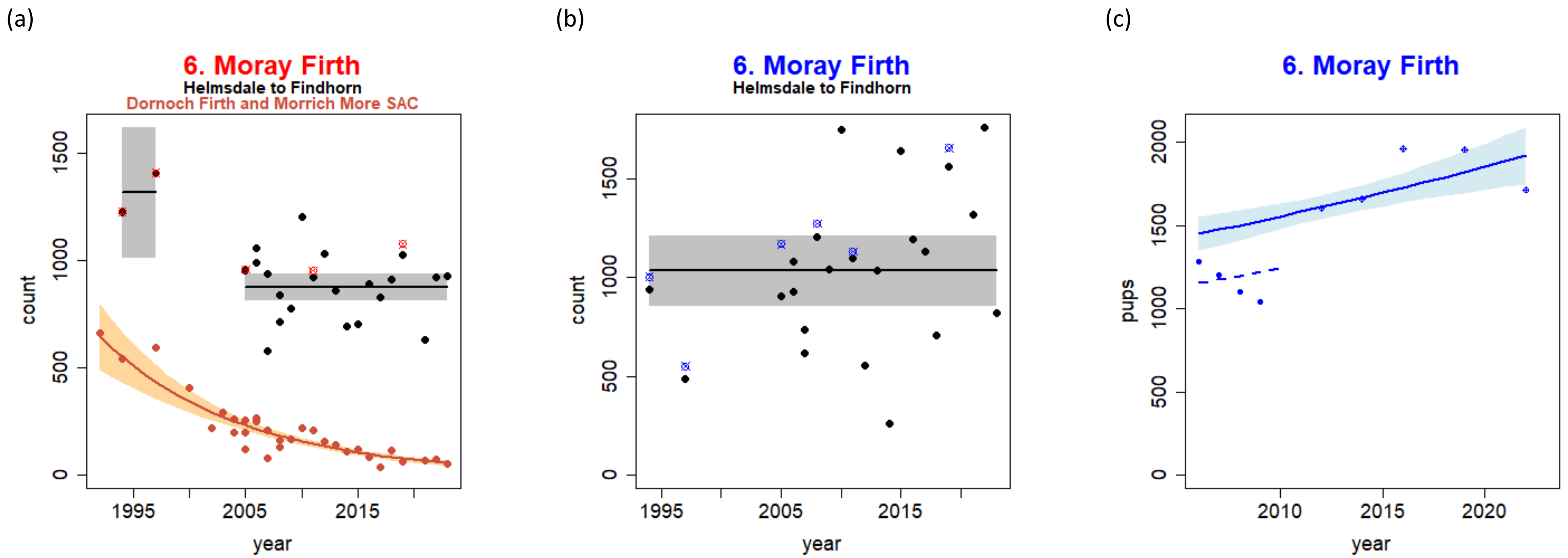


**Figure 6.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Moray Firth SMU (subset for a) and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit 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 film survey estimate (circle plus indicate digital surveys; 2012 onwards).

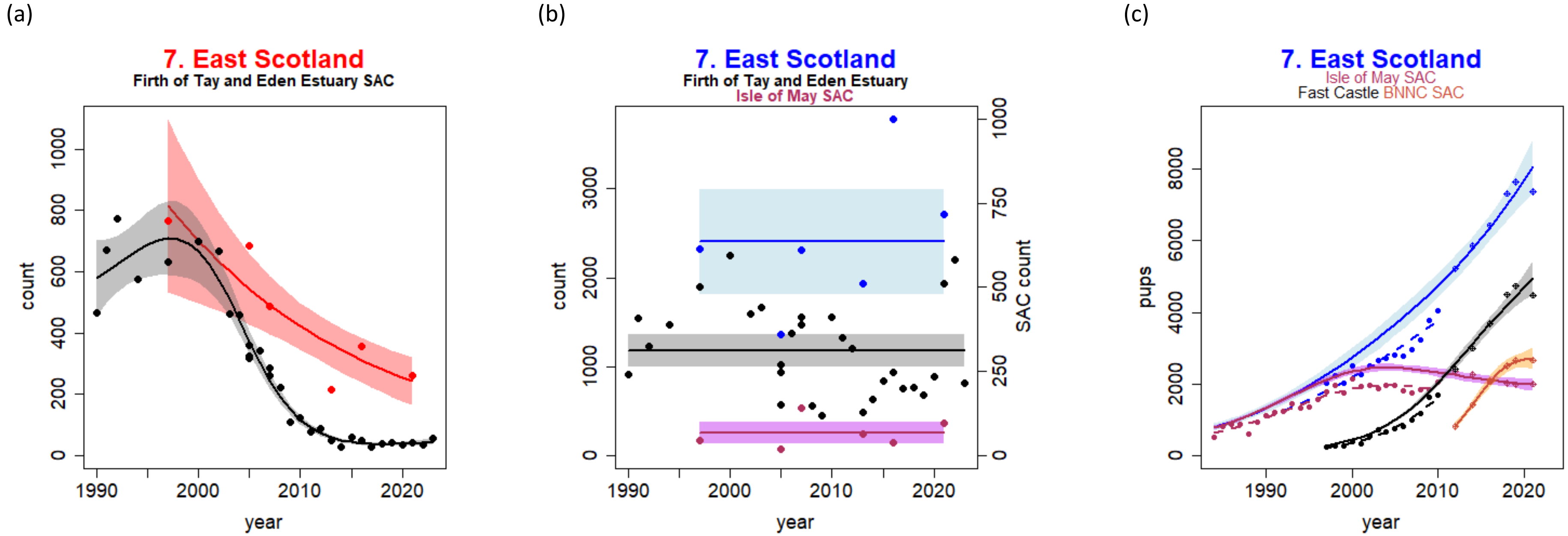


**Figure 7.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the East Scotland SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed line in (c) shows the same trend as the solid line but at the level of pup production predicted for film survey estimate (circle plus indicate digital surveys; 2012 onwards). Note the different axes for the SACs (b). For (c), the black point and line represent the Fast Castle colony as a whole, whereas the orange points and line indicate the production with the SAC proportion of the colony (only considered separately from 2012 onwards).

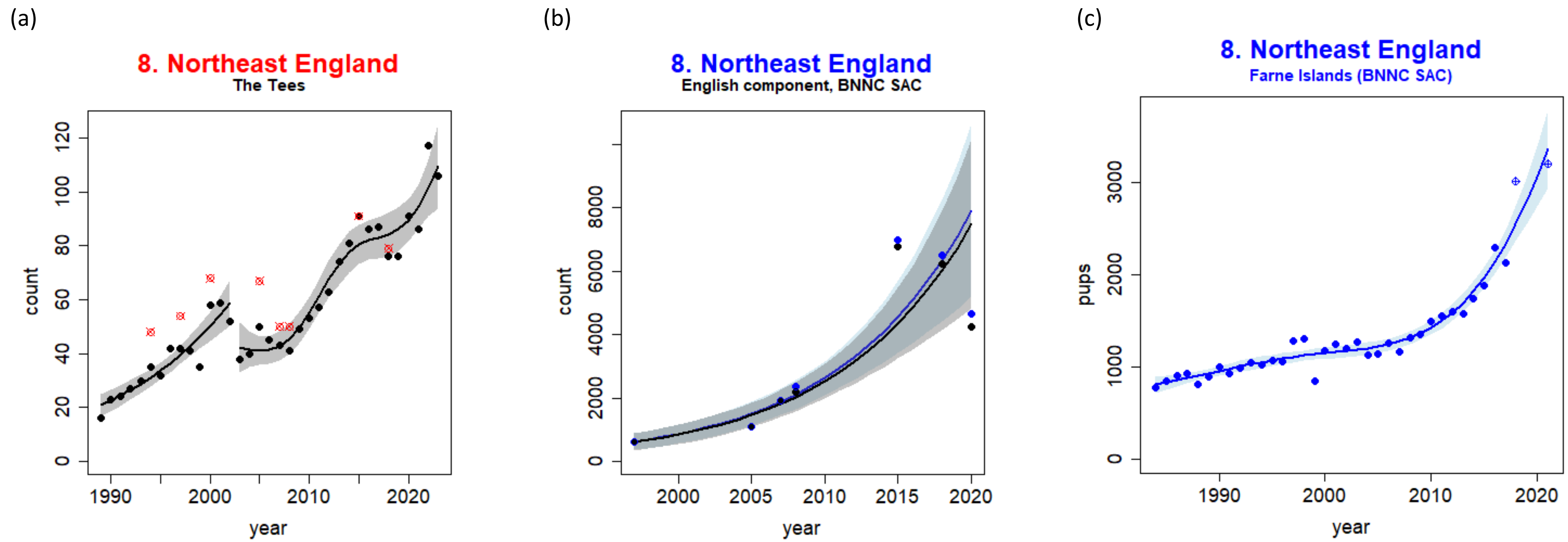


**Figure 8.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Northeast England SMU and encompassed SAC(s). The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. 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). The filled circles in (c) represent ground-based estimates, and the crossed circles represent estimates aerial-based estimates (digital).

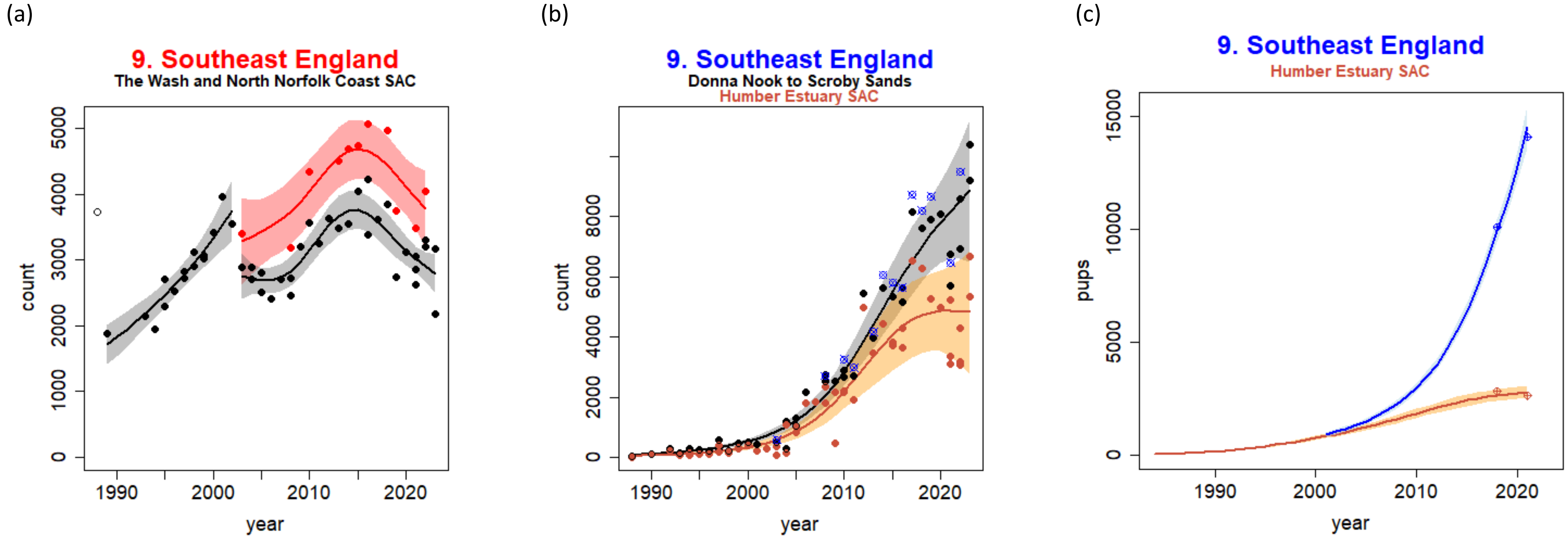


**Figure 9.** The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Southeast SMU and encompassed SACs. The *filled circle* points (a and b) represent the values used to fit the trends. The *circle* point (a) 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. For (c), the crossed circles represent estimates derived from aerial surveys (digital). Ground-based estimates (not shown) were also used to fit the trend prior to 2018; the trend was scaled up to level of production estimated from aerial survey data (SCOS BP 24/07).

# Annual review of priors for grey seal population model 2024

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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 $\phi_a$, maximum pup survival $\phi_{p\max}$, fecundity $\alpha$, shape of density dependence acting on pup survival $\rho$, region-specific carrying capacity (in terms of pup production) $\chi_{1-4}$, number of adults per female $\omega$, and precision of the pup production estimates $\psi$. 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 $\phi_a$** | 0.8+0.18*Be(1.79,1.53) | **0.90 (0.04)** |
| **pup survival $\phi_{p\max}$** | Be(2.87,1.78) | **0.62 (0.20)** |
| **fecundity $\alpha$** | 0.6+0.4*Be(2,1.5) | **0.83 (0.09)** |
| **dens. dep. shape $\rho$** | Ga(4,2.5) | **10 (5)** |
| **carrying capacity $\chi_1$** | Ga(4,5000) | **20000 (10000)** |
| **carrying capacity $\chi_2$** | Ga(4,1250) | **5000 (2500)** |
| **carrying capacity $\chi_3$** | Ga(4,3750) | **15000 (7500)** |
| **carrying capacity $\chi_4$** | Ga(4,10000) | **40000 (20000)** |
| **observation precision $\psi$** | Ga(2.1,66.67) | **140 (96.61)** |
| **sex ratio $\omega$** | **1.6+Ga(28.08, 3.70E-3)** | **1.7 (0.02)** |

## Parameters

### *Adult female survival* $\boldsymbol{\phi_a}$

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.

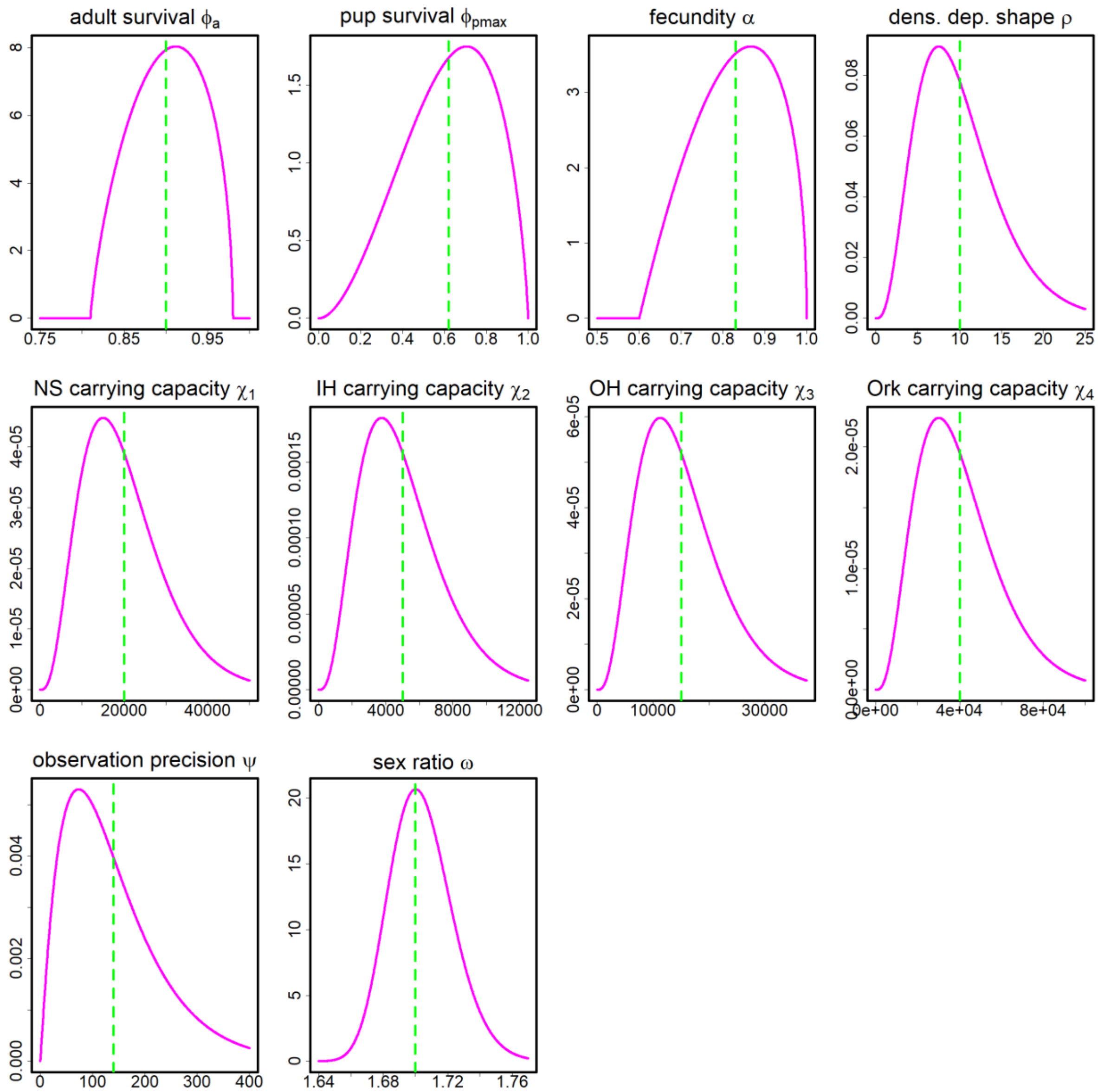


**Figure 1.** Prior probability density functions for each model parameter input in Thomas (2020), drawn from the distributions specified in Table 1. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions, respectively. Prior means are shown as green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

Rossi *et al*. (2021) developed an integrated population model (IPM) for Canadian grey seals that incorporated a demographic model describing sex-specific maturity-at-age, a population dynamics model structured by age, sex, and population (Scotian Shelf and Gulf), and a mark-recapture model describing the sighting and survival probabilities. The IPM was fitted to a time series of pup production estimates from 1960 to 2021, a time series of late pregnancy rate estimates from shot samples, resighting records of 2313 marked seals, and an index of density independent ice-related pup mortality (Hammil *et al*., 2023). The IPM produced similar female survival estimates to those from the standalone mark recapture analyses (den Heyer & Bowen, 2017; Hammil *et al*., 2023).

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

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

*Fecundity* $\boldsymbol{\alpha}$

Relevant studies are summarized in Table 3. For the purposes of this model, fecundity refers to the proportion of breeding-age females (aged 6 and over) that give birth to a pup in a year (natality or birth rate). For the most part, studies have measured pregnancy rather than natality rates. The resulting estimates are thus maxima in terms of fecundity as abortions will cause pregnancy rates to exceed birth rates. Mean estimated adult female pregnancy rates from examination of shot animals were between 0.83 and 0.94 in the UK (Boyd, 1985; Hewer, 1964), and between 0.88 and 1 at Sable Island, Canada (Hammill & Gosselin, 1995). A recent study in Finland (Kauhala *et al.* 2019; 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.

A number of studies have investigated the potential effects of environmental conditions on fecundity of grey seals which indicate relationships between fecundity and prey biomass, female body mass, and seal population density (Badger *et al.* (2020); Kauhala *et al.* (2019); Smout *et al.* (2019)). However, these results do not alter the choice of prior for fecundity.

*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 $\rho$ 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 $\psi$ (Ga(2.1,66.67), implying a prior on CV of pup production (which is $1/\psi$) of 10% with SD 5 (i.e., with 90% of the prior probability density between 5% and 20%).

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

| Age class | females | | | males | | | Total n | Time period | Data | Location | Considerations | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mean | uncertainty | n | mean | uncertainty | n | | | | | | |
| **Pup** | 0.66 | | 1036 | 0.66 | | 294 | | 1972, 1975 | Aged shot individuals | Farne Islands, UK | Accounted for effect of previous culls on sample structure. Based on life tables. | Harwood & Prime 1978 |
| **Pup** | 0.65 | 95% CIs: 0.39 - 0.85 | 180 | 0.50 | 95% CIs: 0.25 – 0.75 | 182 | | 1997 - 1999 | CMR (hat tag) | Isle of May and Farne Islands, UK | Tag loss accounted for. Telemetry data used to inform re-sighting probability | Reanalysis of data from Hall, McConnell & Barker 2001; Hall, McConnell & Barker 2002; grey pup seal telemetry data (Carter et al., 2017) |
| **Pup** | 0.54 | 95% CIs: 0.18 - 0.86 | 27 | 0.43 | 95% CIs: 0.11 – 0.82 | 28 | | 2002 | CMR (telemetry data) | Isle of May, UK | Tag loss accounted for | Reanalysis of data from Hall, Thomas & McConnell 2009 |
| **Pup** | 0.76<br>0.55 | | | 0.38<br>0.53 | | | 1185<br>2295 | 2000 - 2004<br>2005 - 2009 | Aged shot individuals | Baltic | Samples assumed representative. Based on life tables | Kauhala, Ahola & Kunnasranta 2012 |
| **≤ 4** | 0.735<br>0.331 | SE = 0.016<br>SE = 0.024 | 1700<br>1182 | | | | | 1985 - 1989<br>1998 - 2002 | CMR (brand) | Sable Island, Canada | Includes the data from Schwarz & Stobo (2000) | den Heyer, Bowen & Mcmillan 2014 |
| **Adult** | 0.95 | | 239 | | | | | 1956 - 1966 | Aged shot individuals | UK | Samples assumed representative. Based on life tables | Data from Hewer 1974, analysed by Lonergan 2012 |
| **≥ 10** | | | | 0.80 | | 294 | | 1972, 1975 | Aged shot individuals | Farne Islands, UK | Accounted for population trajectory. Assumed samples are representative within | Harwood & Prime 1978 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 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: 0.89 - 0.97 | 140 | 1979 - 1981 | Shot samples | Farne Islands, UK | | Boyd 1985 |
| **Pregnancy** | 0.83 | 95% CIs: 0.74 - 0.89 | 88 | 1978 | Shot samples | Outer Hebrides, UK | | Boyd 1985 |
| **Pregnancy** | 0.88-1 | | 526 | 1968 - 1992 | Shot samples | Canada | Aged ≥ 6 years old | Hammill & Gosselin 1995 |
| **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 |

## References


Badger, J. J., Bowen, W. D, den Heyer, C. E., & Breed, G. A. (2020). Variation in individual reproductive performance amplified with population size in a long-lived carnivore. *Ecology, 101 (6), e03024*

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

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

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

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

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

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

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

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

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

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

Hammill, M. O., & Gosselin, J. (1995). Grey seal (Halichoerus grypus) from the Northwest Atlantic:

Female reproductive rates, age at first birth, and age of maturity in males. *Canadian Journal of Fisheries and Aquatic Sciences*, *52*(12), 2757–2761.

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

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

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

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

Kauhala, K., Korpinen, S., Lehtiniemi M & Raitaniemi, J. (2019 Reproductive rate of a top predator, the grey seal, as an indicator of the changes in the Baltic food web. *Ecological Indicators* 102: 693 -703.

Kauhala, K and Kurkilahti, M. (2020) Delayed effects of prey fish quality and winter temperature

during the birth year on adult size and reproductive rate of Baltic grey seals. Mammal Research 65, 117 -126. https://doi.org/10.1007/s13364-019-00454-1

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

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

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

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

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

Schwarz, C. J., & Stobo, W. T. (2000). Estimation of juvenile survival, adult survival, and age-specific pupping probabilities for the female grey seal (Halichoerus gryprus) on Sable Island from capture – recapture data, *253*(1994), 247–253.

Smout, S., King, R., & Pomeroy, P. (2019). Environment-sensitive mass changes influence breeding frequency in a capital breeding marine top predator. *Journal of Animal Ecology*. 89, 384–396. DOI: 10.1111/1365-2656.13128

Thomas, L. (2018) *Estimating the Size of the UK Grey Seal Population between 1984 and 2017.* SCOS

Briefing Paper 18/04. Sea Mammal Research Unit, University of St Andrews.

Thomas, L. (2020) *Estimating the Size of the UK Grey Seal Population between 1984 and 2018.* SCOS Briefing Paper 19/01. Sea Mammal Research Unit, University of St Andrews.

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

# Estimating the size of the UK grey seal population between 1984 and 2023.

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**Abstract**

We fitted a Bayesian state-space model of British grey seal population dynamics to two sources of data: (1) regional estimates of pup production from 1984-2022 and (2) independent estimates assumed to be of total population size just before the breeding season in 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 model and prior distributions are identical to those used to provide advice in 2022 (the last year for which this briefing paper was produced); the data include new pup production estimates for the North Sea region from 2021 and other regions from 2022.

Pup production estimates are largely derived from aerial photographs taken at breeding colonies. The method for obtaining photographs changed (from film to digital, accompanied by a change in survey altitude) after 2010 and this has led to a jump (i.e., an increase) in estimated pup production. To evaluate the effect of this jump, three runs of the model were undertaken, each with different pup production estimates: uncorrected (raw pup production estimates not accounting for the jump), low (with pup production estimates after 2010 decreased to match the 1984-2010 trajectory) and high (with pup production estimates from 1984-2010 increased to match the post-2010 trajectory).

Estimated population size in regularly monitored colonies in 2023 was 151,400 (95% CI 134,400-168,700) using uncorrected pup production estimates, 150,000 (95% CI 124,000-176,600) using the “low” estimates, and 152,400 (95% CI 129,000-178,200) using the “high” estimates. The estimated rate of population increase is estimated to be 1.5% per year in the uncorrected scenario and 0.7% in both low and high scenarios.

Two aspects of the pup production time series were not accounted for by the population dynamics model: the near-exponential increase in pup production in the North Sea region and the recent increase in pup production in the Hebrides regions after a period of stability. Possible model alterations are discussed. In addition, there are ongoing efforts to update the estimation algorithm used to fit the population dynamics model and to examine alternatives to the assumption of independence between the 2008, 2014 and 2017 total population size estimates.

## Introduction

This paper presents estimates of British grey seal population size and related demographic parameters, obtained using a Bayesian state-space model of population dynamics fitted to pup production estimates (largely from aerial surveys of breeding colonies) and independent estimates of total population size (from August haul-out counts). The model and fitting methods are the same as those employed in recent years and are described in detail in Thomas et al. (2019); the prior distributions on model parameters are the same as those used for the last four years (see Russell et al. (2024c) for justification). The data are a time series of regional pup production estimates (1984-2022) of which the 2021/2022 estimates are new for this briefing paper, and independent estimates of total population size (2008, 2014 and 2017) in previous briefing papers. Three runs of the model are undertaken, each with a different input dataset reflecting different assumptions about how pup production estimates were affected by a change in survey methodology after 2010.

We present estimates of population size at the start of the 2023 breeding system (i.e., projected forward one year from the last pup production estimates). Note that all estimates of population size relate to seals associated with the regularly monitored colonies. A multiplier is required to account for the 6-8% of seals that breed outside these colonies.

**Methods**

Full details of the population dynamics model, data and fitting methods are given in Thomas et al. (2019). In summary, an age-structured population dynamics model is specified for each of four regions (North Sea, Inner Hebrides, Outer Hebrides and Orkney), with 7 ages included in the model: pups, age 1-5 females (assumed not to reproduce) and age 6+ females (which may breed). The model assumes constant adult (age 1+) survival (indexed by a parameter $\phi_a$), constant fecundity (probability that an age 6+ female will birth a pup, $\alpha$) and density-dependent pup survival with separate carrying capacity in each region (carrying capacity parameters $\chi_1 - \chi_4$ and common parameters for maximum pup survival $\phi_{p\max}$ and shape of the density dependence function $\rho$). The modelled pup production is linked to the data by assuming the data follow a normal distribution centred on true pup production and with precision parameter $\psi$. Adult males are not tracked explicitly in the population model, but instead, the total population size (of males and females) is derived by multiplying estimated adult females by a parameter $\omega$ that represents the ratio of total adults to adult females (sometimes called “sex ratio” as shorthand, although sex ratio is actually given by $\omega - 1$). The modelled total population size (age 1+ animals) is linked to the independent estimates using the empirically derived uncertainty on the independent estimates. Informative prior distributions are used on model parameters, as justified in Russell et al. (2024c) and summarised in Table 1 (detailed justification for prior distributions is given in Supporting Information of Thomas et al. 2019).

One source of input data was pup production estimates for 1984-2022 (Morris et al. 2024). These are derived largely from aerial photographic surveys of breeding colonies or, for North Sea region colonies in England, from ground-based estimates. Here, new estimates for 2021 (North Sea region) and 2022 (other regions) are used for the first time (Morris et al. 2024); previous estimates for colonies in England have also been revised based on both ground- and aerial-based surveys (Russell et al. 2024). In addition, three separate runs of the model were undertaken to explore the effect of a change in aerial survey methods that occurred after 2010. Up to 2010, photographs were recorded on film, while from 2012 (the next survey date) onwards, photographs were recorded digitally using different camera hardware and from a lower flight height. The change in methodology was associated with a jump (i.e., an increase) of 22.5% in pup production estimates from aerial surveys (Russel et. al 2014a). The three runs undertaken were: (1) “uncorrected”, i.e., raw pup production estimates not accounting for the jump), (2) “low”, i.e., with aerial pup production estimates after 2010 divided by 1.225, and (3) high, i.e., with aerial pup production estimates from 1984-2010 multiplied by 1.225.

The other source of data is three independent estimates of total population size in 2008, 2014 and 2017. These are derived from haul-out surveys undertaken in August scaled by estimates of proportion hauled out from tag data (Russell et al. 2024a). Note that the total population size estimates are assumed independent of one another, when in reality they are based on the same scaling factor (see Discussion).

Model fitting, as in previous reports, used a stochastic simulation-based procedure called a particle filter (Thomas et al. 2019). Reliability of reported results depends on the number of simulations. Here, 4 billion simulations were used, which gave results accurate to 2-3 significant figures.

## Results

The population model fitted to uncorrected pup production data estimates that the North Sea region is still growing, while the other regions are close to carrying capacity (Figure 1a). For both the “low” and “high” pup production runs, estimates for the North Sea trajectory are similar, but for the other regions the model estimates the populations overshot carrying capacity and have undergone a dampened oscillation in pup production (Figure 1b-c). However, the fit to the data in recent years is poor. For the North Sea region, pup production estimates have increased faster than the population model predicts for all three runs—there are increasingly positive residuals in each year of data since 2014, and 95% credible intervals (CIs) from the population model do not contain the most recent (2021) pup production estimate. For the other regions, in the uncorrected run fails to capture the levelling off that occurred in pup production in the decade starting 1995 and the recent apparent increase in pup production in the Hebrides, particularly Outer Hebrides. Instead it fits a smooth trajectory between these, resulting in a series of negative residuals for the Hebrides regions in the decade starting 1995 and positive residuals in the most recent decade. The dampened oscillation estimated in the low and high runs fits the Outer Hebrides data better, but fails to capture the most recent increase in pup production there or in the Inner Hebrides, and does not match the relatively flat recent trajectory in Orkney.

Total population size estimated using pup production data alone (Figure 2, blue lines) is larger for the high scenario than uncorrected or low (e.g., posterior mean estimates for 2023 are 198,400, 184,100 and 167,900 respectively). However, the three runs produce very similar estimates of recent population size once the independent estimates are added (Figure 2, red lines; see also below). For all three runs, population size is estimated to have been larger than the independent estimate from 2008 and smaller than that from 2014 and 2017. Posterior mean population size in regularly monitored colonies in 2023 was 151,400 with 95% CI 134,400-168,700 from the uncorrected run; it was 150,000 (95% CI 124,000-176,600) from the low run and 152,400 (95% CI 129,000-178,200) from the high run. Estimates by region are given in Table 2 and estimates for all years 1984-2023 are given in Appendix 1 (Tables A1-A3). The estimated growth in population size between 2022 and 2023 is 1.5% in the uncorrected run and 0.7% in both the low and high run—the dampened oscillation in growth of total population size for these runs is evident in Figure 2.

Posterior parameter distributions are shown in Figure 3, with numerical summaries in Table 1. One notable difference between the three runs is in the density dependent shape parameter, which is lower in the uncorrected run (posterior mean 2.9) than the low and high runs (6.9 and 7.6 respectively). The high values of this parameter in the latter two runs enable delayed density dependence to occur, with the damped oscillations noted above.

## Discussion

The population model gave surprisingly similar total population estimates for 2023 for the pup production scenarios, with the “high” run being <1% higher than the “uncorrected” run, which in turn was <1% higher than the “low” run. This is partly explained by the influence of the independent estimates of total population size, which were the same for all three scenarios and exert a lot of influence on the final estimates (see Figure 2). Without those estimates, the three scenarios differ by over 7%. Another contributing factor is the common assumptions between about grey seal population biology in the form of the population model and informative parameter priors.

With the addition of the most recent pup production estimates, the population model is no longer producing a good fit to the data. The estimated trajectory fails to keep up with growth in pup production in the North Sea. This may be rectified by increasing the prior mean carrying capacity for this region, which was set at double the current pup production over a decade ago. A higher carrying capacity would enable this region to continue growing in a near-exponential manner, closer to the observed trajectory. It may also be appropriate to broaden the prior distributions on carrying capacity across all regions (they currently are set such that the prior coefficient of variation is 0.5). The recent increase in pup production in the Hebrides, coming after a long period of stability, is more difficult to address with the current model which assumes carrying capacity is constant over time. One aspect of the model we plan to examine is the current assumption of no recruitment of breeding females between regions—previous iterations have allowed for density-dependent movement. We welcome feedback from SCOS on other possible biological mechanisms for the observed patterns, which may then be incorporated into future iterations of the population model.

Several other improvements to the input data and model fitting have been the subject of recent research and may be included in future. First, the modelling process that takes colony-level pup counts and estimates pup production is the subject of a current PhD; one expected outcome is estimates of uncertainty in region-level pup production that can be incorporated into the state-space model used here in preference to the current process of estimating this uncertainty from model lack-of-fit. Second, the current assumption that the total population estimates from 2008, 2014 and 2017 are mutually independent is known to be incorrect since all three use the same estimate of haul-out probability. One alternative approach has been examined (Thomas 2021), but further research is required here. Third, the particle filtering algorithm used in model fitting has recently been the subject of two PhDs (Empacher 2023, Fagard-Jenkin In revision). The former has developed a new algorithm that gives more reliable parameter estimates; there is also the potential to extend the model to allow random effects, for example on fecundity. The latter has developed and published (Fagard-Jenkin and Thomas 2024) a greatly accelerated GPU-based implementation of the model used by Thomas et al. (2019), although making any alterations will require a high level of technical knowledge of GPU programming. Progress on including these improvements into the workflow used to produce SCOS advice is constrained by lack of human resources.

**References**

Empacher, F. 2023. Ecient Methods for Fitting Nonlinear Non-Gaussian StateSpace Models of Wildlife Population Dynamics. PhD thesis, University of St Andrews.

Fagard-Jenkin, C.T.L. In revision. GPU-accelerated Computational Statistics in Ecology. PhD thesis, University of St Andrews.

Fagard-Jenkin, C.T.L. and L. Thomas. 2024b Faster inference from state space models via GPU computing. Ecological Informatics 80: 102486.

Morris, C.D., N.G. Riddoch, C.D. Duck, and D.J.F. Russell. 2024. Most recent grey seal pup production estimates for UK breeding colonies. SCOS Briefing Paper 24/02.

Newman, K.B., S.T. Buckland, S.T. Lindley, L. Thomas and C Fernández. 2006. Hidden process models for animal population dynamics. Ecological Applications 16: 74-86.

Russell, D.J.F. and M.I.D Carter. 2021. Grey seal independent estimate scalar: converting counts to population estimates. SCOS Briefing Paper 21/02.

Russell, D.J.F., C.D. Duck, C.D. Morris, N.G. Riddoch and D. Thompson. 2024a. Trends in seal abundance and grey seal pup production. SCOS Briefing Paper 24/03.

Russell, D.J.F, C.D. Morris, C.D. Duck and N.G. Riddoch. 2024b. Time series of grey seal pup estimates: east England. SCOC Briefing Paper 2024/09.

Russell, D.J.F., D. Thompson and L. Thomas. 2024c. Annual review of priors for grey seal population model 2021. SCOS Briefing Paper 24/04.

Thomas, L., D.J.F. Russell, C. Duck, C.D. Morris, M. Lonergan, F. Empacher, D. Thompson and J. Harwood. 2019. Modelling the population size and dynamics of the British grey seal. Aquatic Conservation 29(S1: 6-23. DOI: 10.1002/aqc.3134

Thomas, L. 2021. Estimating the size of the UK grey seal population between 1984 and 2020. SCOS Briefing Paper 21/05.

**Table 1.** Prior parameter distributions and summary of posterior distributions after fitting to pup production estimates from 1984-2022 and total population estimates from 2008, 2014 and 2017. Be denotes beta distribution, Ga Gamma distribution (with parameters shape and scale, respectively). Posterior estimates are shown for three runs: uncorrected (raw pup production estimates), low (post-2010 aerial pup production estimates divided by 1.225) and high (1984-2010 aerial pup production estimates multiplied by 1.225).

| Parameter | Prior distribution | Prior mean (SD) | Posterior mean (SD) | | |
|---|---|---|---|---|---|
| | | | Uncorrected | Low | High |
| adult survival $\phi_a$ | 0.8+0.17*Be(1.79,1.53) | 0.90 (0.04) | 0.96 (0.01) | 0.94 (0.01) | 0.96 (0.01) |
| pup survival $\phi_{pmax}$ | Be(2.87,1.78) | 0.62 (0.20) | 0.44 (0.07) | 0.56 (0.07) | 0.44 (0.05) |
| fecundity $\alpha$ | 0.6+0.4*Be(2,1.5) | 0.83 (0.09) | 0.91 (0.05) | 0.90 (0.06) | 0.94 (0.04) |
| dens. dep. $\rho$ | Ga(4,2.5) | 10 (5) | 2.90 (0.97) | 6.91 (2.11) | 7.61 (2.25) |
| NS carrying cap. $\chi_1$ | Ga(4,5000) | 20000 (10000) | 34800 (10100) | 26100 (10000) | 37800 (10800) |
| IH carrying cap. $\chi_2$ | Ga(4,1250) | 5000 (2500) | 4490 (808) | 3340 (202) | 4040 (227) |
| OH carrying cap. $\chi_3$ | Ga(4,3750) | 15000 (7500) | 14800 (1480) | 12300 (562) | 14900 (1190) |
| Ork carrying cap. $\chi_4$ | Ga(4,10000) | 40000 (20000) | 23900 (4250) | 17400 (1040) | 21000 (2350) |
| observation prec. $\psi$ | Ga(2.1,66.67) | 140 (96.6) | 57.7 (14.3) | 74.1 (20.0) | 78.0 (19.0) |
| sex ratio $\omega$ | 1.6+Ga(28.08, 3.70E-3) | 1.7 (0.02) | 1.7 (0.02) | 1.7 (0.02) | 1.7 (0.02) |

**Table 2.** Estimated size, in thousands, of the British grey seal population at the start of the 2023 breeding season, derived from a model fitted to pup production data from 1984-2022, and additional total population estimates from 2008, 2014 and 2017. Estimates from three runs are shown: uncorrected (raw pup production estimates), low (post-2010 aerial pup production estimates divided by 1.225) and high (1984-2010 aerial pup production estimates multiplied by 1.225). Values in the table are posterior means with 95% credible intervals in brackets.

| | Estimated population size in thousands (95% CI) | | |
|---|---|---|---|
| | Uncorrected | Low | High |
| North Sea | 56.8 (40.2 74.9) | 64.0 (39.6 89.2) | 60.9 (38.5 86.6) |
| Inner Hebrides | 9.8 (8 13.5) | 8.5 (7.1 10) | 9.1 (8 10.5) |
| Outer Hebrides | 33.1 (28.3 39.3) | 30.7 (26.5 35.1) | 33 (29.6 37.5) |
| Orkney | 51.8 (43.9 63.4) | 46.3 (39.7 53.6) | 49.3 (43.2 55.7) |
| Total | 151.4 (134.4 168.7) | 150 (124 176.6) | 152.4 (129 178.2) |

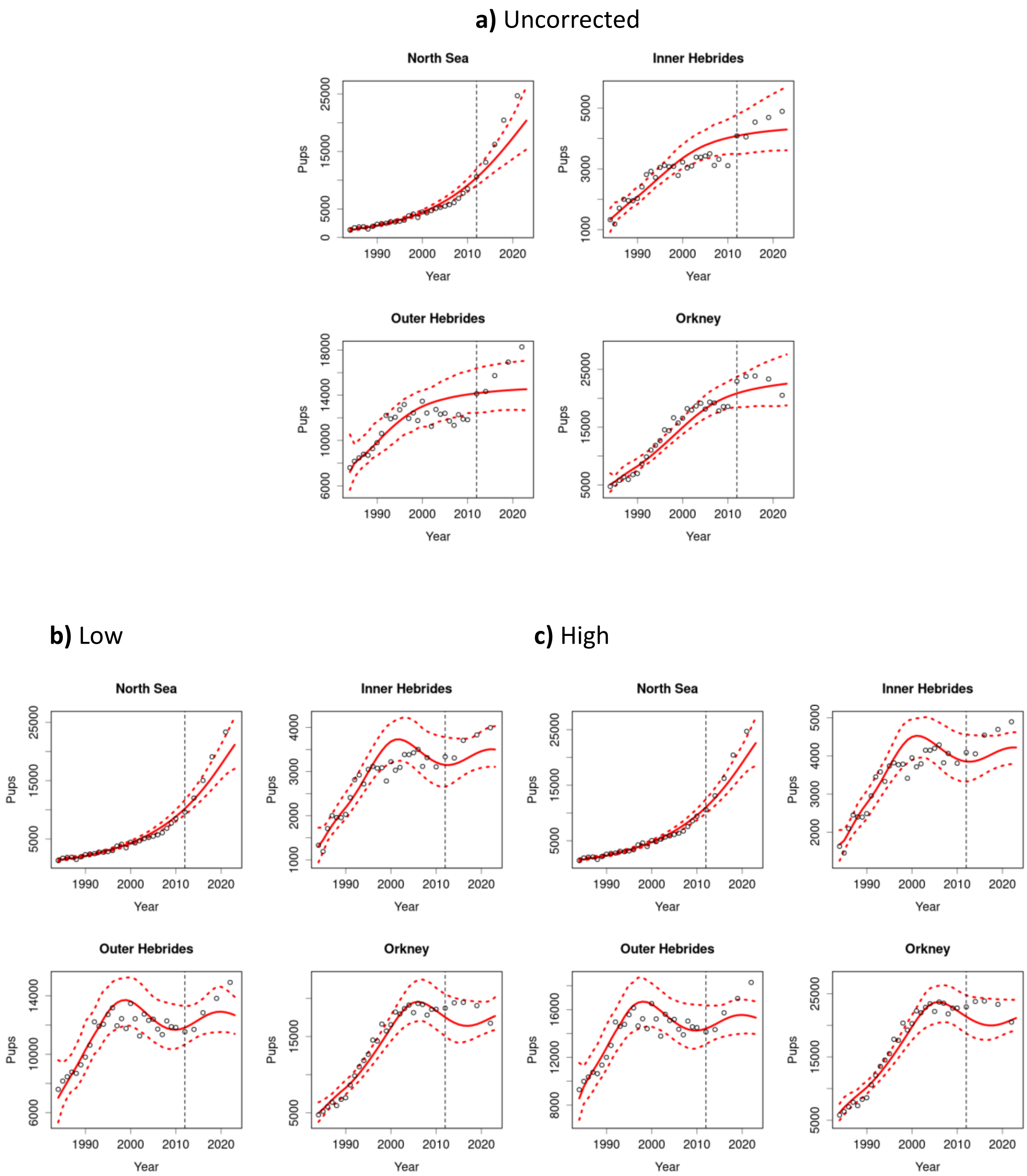
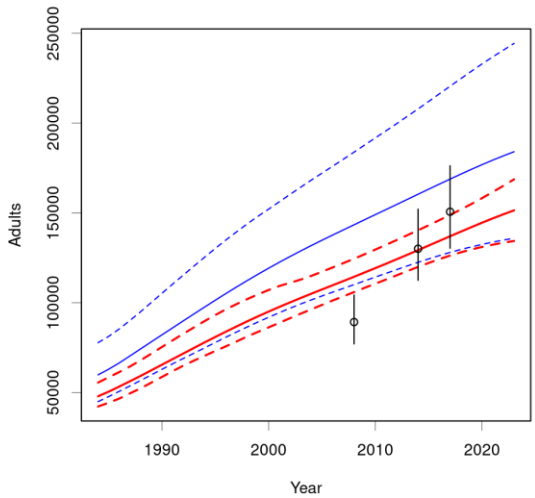
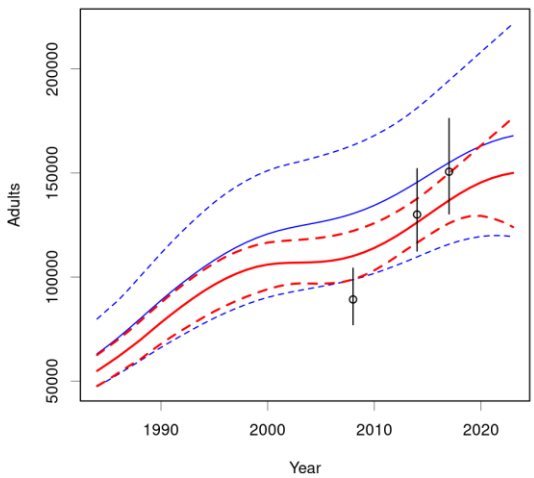



**Figure 1.** Posterior mean estimates of pup production (solid lines) and 95%CI (red dashed lines) in 1984-2023 from the model of grey seal population dynamics, fitted to pup production estimates from 1984-2022 and the total population estimates from 2008, 2014 and 2017. Vertical dashed line marks first year of digital surveys, in 2012. Estimates from three runs are shown: (a) uncorrected (raw pup production estimates), (b) low (post-2010 aerial pup production estimates divided by 1.225) and (c) high (1984-2010 aerial pup production estimates multiplied by 1.225).

**a)** Uncorrected




**b)** Low




**c)** High

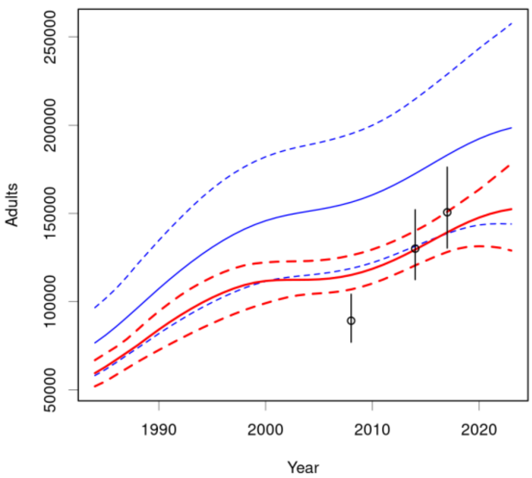
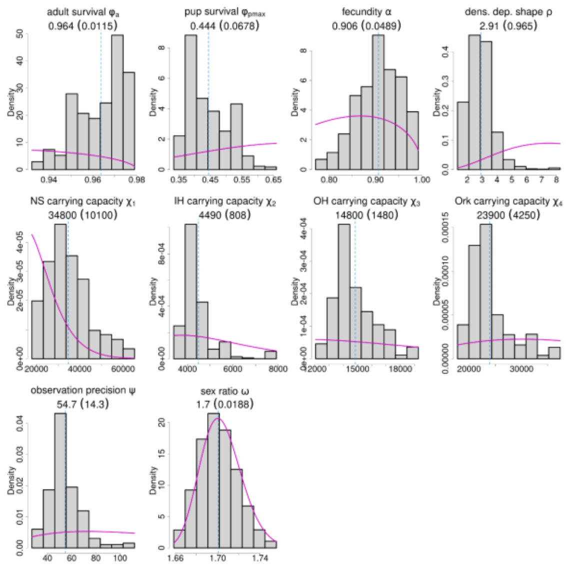
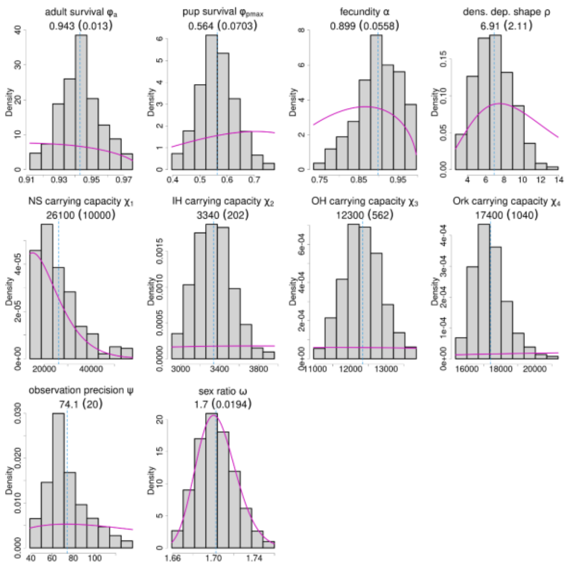



**Figure 2.** Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2023 from the model of grey seal population dynamics, fit to pup production estimates from 1984-202 and total population estimates from 2008, 2014 and 2017 (circles, with vertical lines indicating 95% confidence interval on the estimates). Blue lines show fit to pup production data alone, red lines show fit to pup production data and independent estimates. Estimates from three runs are shown: (a) uncorrected (raw pup production estimates), (b) low (post-2010 aerial pup production estimates divided by 1.225) and (c) high (1984-2010 aerial pup production estimates multiplied by 1.225).

**a)** Uncorrected




**b)** Low




**c)** High

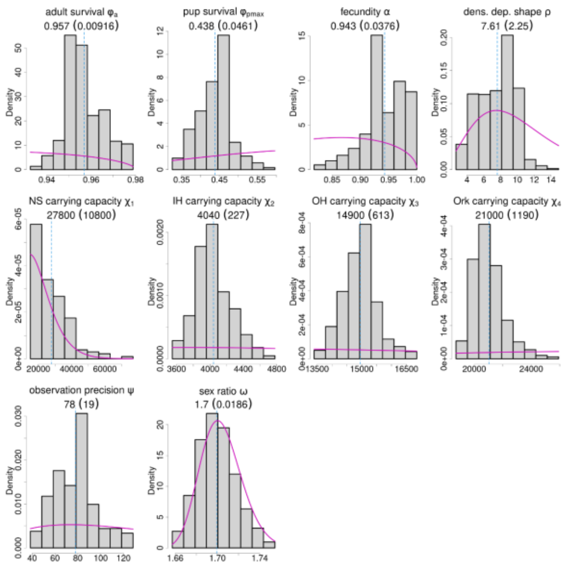



**Figure 3.** Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fitted to pup production estimates from 1984-2022, and total populations estimate from 2008, 2014 and 2017. The vertical dashed line shows the posterior mean; its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses. Estimates from three runs are shown: (a) uncorrected (raw pup production estimates), (b) low (post-2010 aerial pup production estimates divided by 1.225) and (c) high (1984-2010 aerial pup production estimates multiplied by 1.225).

**Appendix 1**

**Table A1.** With "uncorrected" pup production estimates.
Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2023, made using the model of British grey seal population dynamics fitted to pup production estimates from 1984-2022 under the "uncorrected" scenario and total population estimates from 2008, 2014 and 2017. Numbers are posterior means followed by 95% credible intervals in brackets.

| Year | North Sea | Inner Hebrides | Outer Hebrides | Orkney | Total |
|---|---|---|---|---|---|
| 1984 | 4.4 (3.9 5.2) | 4.5 (3.9 5.4) | 21.4 (18.4 25.5) | 17.6 (15.3 21.2) | 47.8 (42.2 55.5) |
| 1985 | 4.7 (4.2 5.5) | 4.7 (4.1 5.7) | 22.3 (18.7 26.9) | 18.7 (16.4 22.4) | 50.4 (44.3 58.5) |
| 1986 | 5.1 (4.6 5.9) | 5 (4.4 6) | 23.3 (19.4 28) | 19.9 (17.5 23.6) | 53.3 (46.6 61.4) |
| 1987 | 5.5 (5 6.4) | 5.3 (4.7 6.3) | 24.2 (20 28.9) | 21.3 (18.8 24.9) | 56.3 (49.5 64.5) |
| 1988 | 5.9 (5.4 6.8) | 5.6 (4.9 6.7) | 25 (20.6 30.1) | 22.7 (20.1 26.4) | 59.2 (52.3 67.9) |
| 1989 | 6.4 (5.8 7.3) | 5.9 (5.2 7) | 25.8 (21.4 31.1) | 24.2 (21.5 28.1) | 62.4 (55.5 71.6) |
| 1990 | 6.9 (6.3 7.9) | 6.2 (5.6 7.4) | 26.6 (22.3 32.1) | 25.7 (23 29.9) | 65.5 (58.7 75.4) |
| 1991 | 7.4 (6.7 8.5) | 6.5 (5.8 7.7) | 27.3 (23.1 32.9) | 27.3 (24.5 31.7) | 68.6 (61.9 79) |
| 1992 | 8 (7.3 9.1) | 6.8 (6.1 8.1) | 28 (23.7 33.6) | 28.9 (26 33.6) | 71.7 (64.9 82.7) |
| 1993 | 8.6 (7.8 9.8) | 7.1 (6.3 8.4) | 28.5 (24.2 34.1) | 30.6 (27.5 35.6) | 74.8 (67.8 86.3) |
| 1994 | 9.3 (8.4 10.6) | 7.4 (6.5 8.8) | 29 (24.6 34.6) | 32.2 (29.1 37.6) | 77.9 (70.4 89.8) |
| 1995 | 10 (9 11.4) | 7.6 (6.7 9.1) | 29.5 (25 34.9) | 33.9 (30.6 39.6) | 80.9 (73.1 93.1) |
| 1996 | 10.7 (9.7 12.2) | 7.8 (6.9 9.4) | 29.9 (25.3 35) | 35.5 (31.9 41.4) | 83.9 (75.7 96.3) |
| 1997 | 11.5 (10.5 13.2) | 8 (7 9.6) | 30.2 (25.6 35.2) | 37 (33.2 43.1) | 86.8 (78.4 99.3) |
| 1998 | 12.4 (11.2 14.2) | 8.2 (7.1 9.8) | 30.5 (25.8 35.3) | 38.5 (34.3 44.8) | 89.6 (81.2 102) |
| 1999 | 13.4 (12.1 15.3) | 8.4 (7.3 10) | 30.8 (26.1 35.5) | 39.8 (35.4 46.5) | 92.4 (83.7 104.6) |
| 2000 | 14.4 (13 16.5) | 8.6 (7.4 10.1) | 31 (26.3 35.7) | 41.1 (36.3 47.9) | 95.1 (86.3 107.1) |
| 2001 | 15.5 (13.9 17.7) | 8.7 (7.4 10.2) | 31.2 (26.5 36) | 42.3 (37.4 49) | 97.6 (88.8 109.3) |
| 2002 | 16.6 (14.9 19.1) | 8.8 (7.5 10.3) | 31.4 (26.8 36.3) | 43.4 (38.3 50.1) | 100.2 (91.3 111.1) |
| 2003 | 17.8 (16 20.5) | 8.9 (7.6 10.4) | 31.6 (27 36.5) | 44.3 (39.2 50.9) | 102.6 (93.9 112.9) |
| 2004 | 19.2 (17.1 22.1) | 9 (7.7 10.5) | 31.7 (27.2 36.7) | 45.1 (40.1 51.5) | 105 (96.3 114.9) |
| 2005 | 20.6 (18.3 23.8) | 9.1 (7.7 10.5) | 31.8 (27.4 36.9) | 45.9 (40.8 52.1) | 107.4 (98.8 117.3) |
| 2006 | 22 (19.5 25.5) | 9.2 (7.8 10.6) | 32 (27.6 37.1) | 46.5 (41.3 52.8) | 109.7 (101.2 119.6) |
| 2007 | 23.6 (20.8 27.5) | 9.2 (7.8 10.8) | 32.1 (27.8 37.3) | 47.1 (41.8 53.5) | 112.1 (103.5 122) |
| 2008 | 25.3 (22.2 29.6) | 9.3 (7.9 10.9) | 32.2 (28 37.5) | 47.7 (42 54.3) | 114.4 (105.9 124.5) |
| 2009 | 27 (23.6 31.9) | 9.4 (7.9 11.1) | 32.3 (28.1 37.7) | 48.1 (42.2 55) | 116.8 (108.3 127) |
| 2010 | 28.9 (25 34.2) | 9.4 (7.9 11.3) | 32.4 (28.2 37.8) | 48.6 (42.3 55.7) | 119.3 (110.6 129.6) |
| 2011 | 30.8 (26.5 36.7) | 9.5 (7.9 11.5) | 32.5 (28.2 38) | 48.9 (42.4 56.3) | 121.7 (112.9 132.2) |
| 2012 | 32.8 (27.9 39.4) | 9.5 (8 11.7) | 32.6 (28.3 38.1) | 49.3 (42.5 57) | 124.2 (115.3 134.9) |
| 2013 | 34.9 (29.4 42.2) | 9.6 (8 11.9) | 32.6 (28.3 38.3) | 49.6 (42.7 57.6) | 126.7 (117.6 137.6) |
| 2014 | 37.1 (30.8 45.1) | 9.6 (8 12.1) | 32.7 (28.3 38.4) | 49.9 (42.9 58.3) | 129.3 (119.9 140.3) |
| 2015 | 39.3 (32.1 48.1) | 9.6 (8 12.2) | 32.8 (28.3 38.5) | 50.2 (43.1 58.9) | 131.8 (122.1 143.1) |
| 2016 | 41.5 (33.4 51.1) | 9.7 (8 12.4) | 32.8 (28.3 38.7) | 50.4 (43.3 59.5) | 134.4 (124.3 146) |
| 2017 | 43.8 (34.6 54.1) | 9.7 (8 12.6) | 32.9 (28.3 38.8) | 50.7 (43.5 60.1) | 137 (126.2 148.9) |
| 2018 | 46 (35.7 57.2) | 9.7 (8 12.8) | 32.9 (28.3 38.9) | 50.9 (43.6 60.7) | 139.5 (128 151.9) |
| 2019 | 48.3 (36.8 60.2) | 9.7 (8 12.9) | 32.9 (28.3 38.9) | 51.1 (43.6 61.2) | 142.1 (129.6 155) |
| 2020 | 50.5 (37.8 63.4) | 9.8 (8 13.1) | 33 (28.3 39) | 51.3 (43.7 61.8) | 144.5 (131 158.2) |
| 2021 | 52.7 (38.7 67) | 9.8 (8 13.2) | 33 (28.3 39.1) | 51.5 (43.8 62.3) | 146.9 (132.3 161.6) |
| 2022 | 54.8 (39.5 71) | 9.8 (8 13.4) | 33 (28.3 39.2) | 51.6 (43.8 62.9) | 149.2 (133.4 165.1) |
| 2023 | 56.8 (40.2 74.9) | 9.8 (8 13.5) | 33.1 (28.3 39.3) | 51.8 (43.9 63.4) | 151.4 (134.4 168.7) |

**Table A2.** With “low” pup production estimates.
Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2023, made using the model of British grey seal population dynamics fitted to pup production estimates from 1984-2022 under the “low” scenario and total population estimates from 2008, 2014 and 2017. Numbers are posterior means followed by 95% credible intervals in brackets.

| Year | North Sea | Inner Hebrides | Outer Hebrides | Orkney | Total |
|---|---|---|---|---|---|
| 1984 | 5 (4.2 5.9) | 5.3 (4.4 6.3) | 24.7 (20.3 29.5) | 19.9 (16.7 23) | 54.9 (47.6 62.5) |
| 1985 | 5.4 (4.6 6.3) | 5.6 (4.7 6.7) | 26.2 (21.6 31.4) | 21.1 (18.1 24.4) | 58.3 (50.5 66.2) |
| 1986 | 5.8 (5 6.7) | 5.9 (5.1 7.1) | 27.6 (23 32.6) | 22.5 (19.5 25.8) | 61.8 (53.9 70) |
| 1987 | 6.2 (5.4 7.2) | 6.3 (5.4 7.4) | 29 (24.4 34.2) | 24.1 (20.9 27.6) | 65.6 (57.2 74.1) |
| 1988 | 6.7 (5.8 7.7) | 6.7 (5.7 7.9) | 30.2 (24.9 36) | 25.9 (22.5 29.6) | 69.5 (60.2 78.6) |
| 1989 | 7.2 (6.3 8.2) | 7.2 (6.1 8.4) | 31.6 (26.2 37.4) | 27.8 (24.1 31.7) | 73.8 (64.2 83.2) |
| 1990 | 7.7 (6.7 8.8) | 7.6 (6.5 8.9) | 32.9 (27.2 38.5) | 29.9 (25.9 33.9) | 78.1 (67.9 87.7) |
| 1991 | 8.3 (7.2 9.4) | 8.1 (6.8 9.4) | 33.8 (28 39.4) | 32 (27.7 36.3) | 82.2 (71.3 92) |
| 1992 | 8.9 (7.8 10.1) | 8.5 (7.1 9.9) | 34.5 (28.5 40) | 34.2 (29.7 38.7) | 86.1 (74.5 96) |
| 1993 | 9.6 (8.4 10.8) | 8.9 (7.4 10.3) | 34.9 (28.8 40.2) | 36.5 (31.6 41.2) | 89.8 (77.7 99.9) |
| 1994 | 10.3 (9.1 11.6) | 9.2 (7.6 10.5) | 35 (29.1 40.2) | 38.8 (33.5 43.9) | 93.2 (80.7 103.4) |
| 1995 | 11 (9.8 12.4) | 9.4 (7.7 10.8) | 34.7 (29.1 39.9) | 41.2 (35.2 46.5) | 96.4 (83.5 106.7) |
| 1996 | 11.9 (10.5 13.3) | 9.5 (7.8 10.9) | 34.3 (29 39.4) | 43.5 (36.8 49.1) | 99.1 (86 109.6) |
| 1997 | 12.7 (11.4 14.3) | 9.5 (7.9 11) | 33.6 (28.6 38.6) | 45.6 (38.2 51.5) | 101.5 (88.4 111.9) |
| 1998 | 13.7 (12.2 15.3) | 9.4 (7.9 11) | 32.9 (28.1 37.7) | 47.4 (39.4 53.7) | 103.5 (90.5 113.9) |
| 1999 | 14.7 (13.2 16.4) | 9.3 (7.8 11) | 32.2 (27.5 36.9) | 48.7 (40.4 55.4) | 105 (92.4 115.4) |
| 2000 | 15.8 (14.1 17.7) | 9.1 (7.7 10.9) | 31.5 (27 36.2) | 49.6 (41.2 56.7) | 106 (94.1 116.5) |
| 2001 | 16.9 (15.2 19) | 8.9 (7.5 10.6) | 30.9 (26.5 35.6) | 49.8 (41.7 57.4) | 106.6 (95.5 117.2) |
| 2002 | 18.2 (16.3 20.4) | 8.7 (7.2 10.4) | 30.4 (26.1 35.1) | 49.5 (41.9 57.5) | 106.8 (96.5 117.6) |
| 2003 | 19.5 (17.5 21.9) | 8.5 (7 10.2) | 30 (25.9 34.7) | 48.9 (41.8 57) | 106.9 (96.9 117.9) |
| 2004 | 21 (18.8 23.6) | 8.3 (6.8 10.1) | 29.8 (25.7 34.5) | 47.9 (41.2 56.1) | 107 (96.9 118.3) |
| 2005 | 22.5 (20.1 25.4) | 8.2 (6.6 10) | 29.7 (25.6 34.4) | 46.8 (40.2 54.9) | 107.3 (96.8 118.9) |
| 2006 | 24.2 (21.6 27.4) | 8.1 (6.5 9.9) | 29.9 (25.6 34.4) | 45.7 (39.1 53.7) | 107.9 (97 119.7) |
| 2007 | 26 (23.1 29.4) | 8 (6.5 9.8) | 30.1 (26 34.5) | 44.6 (38.1 52.5) | 108.8 (97.6 120.8) |
| 2008 | 27.9 (24.7 31.7) | 8 (6.6 9.7) | 30.5 (26.5 34.8) | 43.6 (37.2 51.5) | 110.1 (98.8 122.2) |
| 2009 | 30 (26.4 34.1) | 8.1 (6.8 9.7) | 31 (27.1 35.3) | 42.8 (36.3 50.7) | 111.8 (100.7 123.9) |
| 2010 | 32.2 (28.3 36.7) | 8.2 (7 9.7) | 31.5 (27.4 35.9) | 42.2 (36 50.2) | 114 (103.2 125.9) |
| 2011 | 34.5 (30.2 39.5) | 8.3 (7.1 9.7) | 32 (27.7 36.4) | 41.8 (35.9 49.7) | 116.6 (106.2 128.3) |
| 2012 | 37 (32.3 42.5) | 8.4 (7.2 9.8) | 32.4 (27.8 37) | 41.7 (36.2 49.4) | 119.5 (109.6 131.1) |
| 2013 | 39.6 (34.5 45.6) | 8.6 (7.4 9.9) | 32.7 (27.9 37.5) | 41.9 (36.7 49.2) | 122.8 (113.1 134.2) |
| 2014 | 42.3 (36.8 48.9) | 8.7 (7.5 10) | 32.9 (28 37.8) | 42.3 (37.1 49.2) | 126.2 (116.5 137.6) |
| 2015 | 45.2 (39.1 52.5) | 8.8 (7.5 10.2) | 32.9 (28.1 37.8) | 42.9 (37.6 49.3) | 129.8 (119.8 141.4) |
| 2016 | 48.1 (41.2 56.3) | 8.9 (7.6 10.3) | 32.8 (28.1 37.6) | 43.6 (38.1 49.7) | 133.4 (123 145.6) |
| 2017 | 51 (42.9 60.3) | 8.9 (7.6 10.4) | 32.6 (28.1 37.2) | 44.3 (38.5 50.5) | 136.8 (125.8 149.9) |
| 2018 | 53.8 (43.9 64.6) | 8.9 (7.6 10.5) | 32.3 (28 36.6) | 45.1 (38.9 51.5) | 140.1 (128.1 154.3) |
| 2019 | 56.5 (44 69) | 8.9 (7.6 10.4) | 32 (27.8 36.1) | 45.7 (39.2 52.5) | 143 (129.3 158.7) |
| 2020 | 59 (43.3 73.6) | 8.8 (7.5 10.4) | 31.6 (27.6 35.7) | 46.1 (39.4 53.2) | 145.5 (129.4 163.3) |
| 2021 | 61.2 (42.3 78.5) | 8.7 (7.4 10.2) | 31.3 (27.2 35.4) | 46.4 (39.6 53.7) | 147.5 (128.4 167.7) |
| 2022 | 63 (41 83.7) | 8.6 (7.3 10.1) | 31 (26.9 35.3) | 46.4 (39.7 53.8) | 149 (126.5 172.1) |
| 2023 | 64.6 (39.6 89.2) | 8.5 (7.1 10) | 30.7 (26.5 35.1) | 46.3 (39.7 53.6) | 150 (124 176.6) |

**Table A3.** With “high” pup production estimates.
Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2023, made using the model of British grey seal population dynamics fitted to pup production estimates from 1984-2022 under the “high” scenario and total population estimates from 2008, 2014 and 2017. Numbers are posterior means followed by 95% credible intervals in brackets.

| Year | North Sea | Inner Hebrides | Outer Hebrides | Orkney | Total |
|---|---|---|---|---|---|
| 1984 | 4.9 (4.2 5.7) | 5.8 (4.7 6.8) | 27.2 (22.6 31.9) | 21.5 (18.1 24.5) | 59.5 (52 66.9) |
| 1985 | 5.3 (4.5 6) | 6.2 (5 7.1) | 28.8 (23.9 33.6) | 22.9 (19.3 25.9) | 63.1 (54.9 70.6) |
| 1986 | 5.7 (4.9 6.4) | 6.6 (5.4 7.5) | 30.4 (25.5 35.4) | 24.5 (20.7 27.7) | 67.1 (58.6 74.4) |
| 1987 | 6.1 (5.3 6.9) | 7 (5.7 8) | 31.9 (27.1 36.9) | 26.3 (22.3 29.8) | 71.2 (62.2 78.8) |
| 1988 | 6.5 (5.8 7.4) | 7.4 (6.2 8.5) | 33.2 (28.1 38.4) | 28.2 (23.9 31.9) | 75.3 (65.9 84.2) |
| 1989 | 7 (6.2 7.9) | 7.9 (6.5 9.1) | 34.7 (28.9 40) | 30.2 (25.6 34.2) | 79.8 (69.3 89.6) |
| 1990 | 7.5 (6.7 8.4) | 8.4 (6.9 9.6) | 35.9 (29.7 41.4) | 32.4 (27.5 36.6) | 84.2 (72.6 94.6) |
| 1991 | 8.1 (7.2 9) | 8.9 (7.2 10.1) | 36.8 (30.2 42.4) | 34.6 (29.5 39.1) | 88.4 (75.9 99.2) |
| 1992 | 8.6 (7.7 9.6) | 9.3 (7.5 10.5) | 37.4 (30.6 43) | 37 (31.5 41.8) | 92.3 (79 103.6) |
| 1993 | 9.3 (8.3 10.3) | 9.7 (7.8 10.9) | 37.5 (30.8 43.3) | 39.5 (33.6 44.5) | 95.9 (82.1 107.5) |
| 1994 | 9.9 (8.9 11.1) | 10 (8 11.2) | 37.4 (31 43) | 42 (35.6 47.3) | 99.3 (85 110.9) |
| 1995 | 10.7 (9.6 11.9) | 10.1 (8.2 11.4) | 37 (31.1 42.3) | 44.5 (37.5 50.1) | 102.4 (87.8 113.9) |
| 1996 | 11.5 (10.3 12.7) | 10.2 (8.3 11.6) | 36.5 (31.1 41.6) | 47 (39.1 52.9) | 105.1 (90.4 116.6) |
| 1997 | 12.3 (11.1 13.7) | 10.2 (8.4 11.6) | 35.8 (31 40.7) | 49.2 (40.4 55.5) | 107.5 (92.9 118.9) |
| 1998 | 13.2 (12 14.7) | 10.1 (8.5 11.6) | 35.1 (30.9 39.9) | 51.1 (41.6 57.7) | 109.4 (95.2 120.6) |
| 1999 | 14.1 (12.9 15.7) | 9.9 (8.4 11.5) | 34.4 (30.5 39.2) | 52.4 (42.7 59.2) | 110.8 (97.3 121.6) |
| 2000 | 15.2 (13.8 16.9) | 9.7 (8.3 11.3) | 33.7 (30 38.4) | 53.2 (43.5 60.2) | 111.7 (99.2 122.2) |
| 2001 | 16.3 (14.8 18.2) | 9.5 (8.2 11.2) | 33.1 (29.5 37.8) | 53.3 (44.2 60.6) | 112.2 (100.9 122.6) |
| 2002 | 17.5 (15.9 19.5) | 9.3 (8.1 11) | 32.6 (29.1 37.3) | 53 (44.6 60.4) | 112.4 (102.4 122.8) |
| 2003 | 18.7 (17 21) | 9.1 (7.9 10.8) | 32.3 (28.7 37) | 52.2 (44.8 59.7) | 112.4 (103.6 122.9) |
| 2004 | 20.1 (18.2 22.5) | 8.9 (7.8 10.6) | 32.1 (28.6 36.7) | 51.3 (44.9 58.7) | 112.4 (104.3 123) |
| 2005 | 21.6 (19.5 24.2) | 8.8 (7.6 10.5) | 32 (28.6 36.5) | 50.2 (44.5 57.5) | 112.6 (104.7 123.4) |
| 2006 | 23.1 (20.8 26.1) | 8.7 (7.6 10.4) | 32.2 (28.8 36.5) | 49.1 (43.8 56.3) | 113.1 (105.1 124) |
| 2007 | 24.8 (22.3 28) | 8.7 (7.5 10.3) | 32.4 (29 36.5) | 48.1 (42.9 55.1) | 113.9 (105.8 125) |
| 2008 | 26.6 (23.8 30.1) | 8.7 (7.5 10.3) | 32.8 (29.2 36.6) | 47.1 (41.9 54.1) | 115.1 (106.9 126.2) |
| 2009 | 28.5 (25.5 32.4) | 8.7 (7.6 10.2) | 33.2 (29.5 36.9) | 46.3 (41.1 53.3) | 116.7 (108.4 127.7) |
| 2010 | 30.6 (27.2 34.8) | 8.8 (7.7 10.2) | 33.7 (29.6 37.5) | 45.6 (40.4 52.8) | 118.6 (110.3 129.6) |
| 2011 | 32.8 (29.1 37.4) | 8.9 (7.8 10.2) | 34.1 (29.8 38.2) | 45.1 (40.1 52.4) | 120.9 (112.6 131.8) |
| 2012 | 35.1 (31 40.2) | 9 (7.9 10.2) | 34.5 (29.9 38.9) | 44.9 (40 52.2) | 123.5 (115.2 134.3) |
| 2013 | 37.5 (33.1 43.1) | 9.1 (7.9 10.3) | 34.8 (30 39.5) | 44.9 (40.1 52) | 126.4 (117.7 137.1) |
| 2014 | 40.1 (35.2 46.1) | 9.3 (8 10.4) | 35 (30 39.8) | 45.2 (40.5 52) | 129.5 (120.6 140.1) |
| 2015 | 42.7 (37.3 49.4) | 9.4 (8.1 10.5) | 35 (30.1 39.7) | 45.6 (41.1 52) | 132.7 (123.2 143.3) |
| 2016 | 45.4 (39.2 52.9) | 9.5 (8.1 10.6) | 34.9 (30.2 39.5) | 46.2 (41.6 52.1) | 136 (125.8 147) |
| 2017 | 48.1 (40.5 56.8) | 9.5 (8.1 10.7) | 34.8 (30.2 39.1) | 46.9 (42.1 52.4) | 139.3 (128.1 151) |
| 2018 | 50.8 (41.1 60.7) | 9.5 (8.1 10.7) | 34.5 (30.2 38.6) | 47.6 (42.5 52.9) | 142.4 (130 155.1) |
| 2019 | 53.3 (41.3 65) | 9.5 (8.1 10.7) | 34.2 (30.2 38.2) | 48.2 (42.8 53.8) | 145.2 (131.2 159.3) |
| 2020 | 55.6 (40.9 69.8) | 9.4 (8.1 10.7) | 33.9 (30.1 37.9) | 48.8 (43 54.5) | 147.7 (131.4 163.6) |
| 2021 | 57.7 (40.3 75) | 9.3 (8.1 10.6) | 33.6 (30 37.6) | 49.2 (43.1 55.2) | 149.7 (131.2 168.4) |
| 2022 | 59.4 (39.4 80.6) | 9.2 (8.1 10.6) | 33.3 (29.7 37.4) | 49.4 (43.2 55.6) | 151.3 (130.5 173.2) |
| 2023 | 60.9 (38.5 86.6) | 9.1 (8 10.5) | 33 (29.6 37.3) | 49.3 (43.2 55.7) | 152.4 (129 178.2) |

# Provisional Regional PBR values for Scottish seals in 2025

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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.

Based on surveys carried out in 2022 and 2023, harbour seal PBRs have been reduced from 936 to 851 in the West Scotland SMU and from 105 to 92 in the Western Isles SMUs and increased from 4 to 5 in the Moray Firth SMU. Grey seal PBRs have been reduced from 1290 to 776 in the Western Isles SMU, from 414 to 302 in the Moray Firth SMU and from 605 to 354 in the East Scotland SMU, and have been increased from 933 to 981 in the West Scotland SMU and from 1922 to 1926 in the North Coast and Orkney SMU.

The recovery factor for harbour seals in the Southwest Scotland SMU has been increased from 0.7 to 1.0, with a resulting increase in PBR from 71 to 102. Recovery factors for harbour seals in all other SMUs, and for grey seals in all SMUs are unchanged from SCOS 2022.

## 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.

**$R_{max}$** 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 Nmin. (An alternative approach, closer to that suggested by Wade (1998), would be to rescale these counts into abundance estimates and take the 20th centile of the resulting distributions. Results of a recent telemetry study in Orkney (Lonergan et al., 2012) suggest that would increase the PBRs by between 8%, if the populations are predominantly female, and 37%, if most of the animals are male.)
- Grey seals: 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 25.2% (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 harbour seals, on the basis that the fastest recorded growth rate for a UK harbour seal population, in the Southeast England SMU, was <10% (Lonergan et al. 2007; SCOS-BP 24/03). However, it is not known to what extent density dependent factors may have influenced growth rates in different SMUs. The large population in the Wadden Sea consistently grew at slightly over 12% p.a. for long periods (Reijnders et al. 2010), so an $R_{max}$ of 12% p.a. has been used here.

Regional pup production estimates for the grey seal population in individual SMUs have had maximum growth rates in the range 5-10% p.a. with the exception of Southeast England SMU where average annual rates of increase have exceeded 14% p.a. over the last six years (Lonergan et al. 2011b; SCOS-BP 24/03). However, it is not known to what extent this increase is augmented by recruitment from other SMU populations. 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, followed by a rapid increase to a maximum around 2017. The latest count in 2022 was lower and the 6 year trend estimate is an annual decrease of 2.3% p.a. (SCOS-BP 24/03). 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. Due to the apparent recent decrease and the fact that there is an existing conservation order in place for the management unit, it is 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. Although the most recent SMU-wide estimate is the highest ever recorded and the overall population is apparently increasing, the fitted trend for West Scotland north indicates that part of the SMU population is stable and may be showing the start of a decline (SCOS-BP 24/03).

4) South West Scotland ($F_R$ = 1.0)
Although previously set to 0.7, the $F_R$ has been revised to 1.0 to bring it in line with West Scotland. The population is apparently stable, is effectively closed to the south and the large adjacent population to the north is apparently stable or increasing.

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 historically high levels with the exception of Orkney where pup production has declined slightly, at an average rate of 0.3% p.a. over the past six years. All grey seal populations are therefore either increasing or considered to be at or close to their carrying capacities (SCOS-BP 24/03). 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.

**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

**References**

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

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

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

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

Lonergan M, Duck C, Moss S, Morris C, Thompson D (2012) Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. Aquatic Conservation: Marine and Freshwater Ecosystems 23:135-144

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

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

Russell, D.J.F., Morris, C.D., Duck, C.D., Thompson, D., & Hiby, L. 2019. Monitoring long-term changes in UK grey seal pup production. *Aquatic Conservation: Marine Freshwater Ecosystems,* 29(S1): 24–39. https://doi.org/10.1002/aqc.3100

Thomas, L., Russell, D.J.F., Duck, C.D., Morris, C.D., Lonergan, M., Empacher, F., Thompson, D., & Harwood, J. 2019. Modelling the population size and dynamics of the British grey seal.

*Aquatic Conservation: Marine Freshwater Ecosystems*, 29(S1): 6–23. https://doi.org/10.1002/aqc.3134

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

**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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**Table 1.** Potential Biological Removal (PBR) values for harbour seals in Scotland by Seal Management Unit for the year 2024. Recommended $F_R$ values are highlighted in grey cells.

| Seal Management Area | | 2016-2023 count | $N_{min}$ | PBRs based on recovery factors $F_R$ ranging from 0.1 to 1.0: 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | selected $F_R$ | PBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Southwest Scotland | 1,709 | 1,709 | 10 | 20 | 30 | 41 | 51 | 61 | 71 | 82 | 92 | 102 | 1.0 | 102 |
| 2 | West Scotland | 14,189 | 14,189 | 85 | 170 | 255 | 340 | 425 | 510 | 595 | 681 | 766 | 851 | 1.0 | 851 |
| 3 | Western Isles | 3,080 | 3,080 | 18 | 36 | 55 | 73 | 92 | 110 | 129 | 147 | 166 | 184 | 0.5 | 92 |
| 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 | 983 | 983 | 5 | 11 | 17 | 23 | 29 | 35 | 41 | 47 | 53 | 58 | 0.1 | 5 |
| 7 | East Scotland | 276 | 276 | 1 | 3 | 4 | 6 | 8 | 9 | 11 | 13 | 14 | 16 | 0.1 | 1 |
| SCOTLAND TOTAL | | 24,822 | 24,822 | 146 | 294 | 443 | 592 | 742 | 889 | 1,039 | 1,189 | 1,337 | 1,485 | | 1,047 |

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

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

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

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

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

**Table 2.** Potential Biological Removal (PBR) values for grey seals in Scotland by Seal Management Unit for the year 2024. Recommended $F_R$ values are highlighted in grey cells.

| | | 2016-2023 | | 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 | 4,388 | 16,351 | 98 | 196 | 294 | 392 | 490 | 588 | 686 | 784 | 882 | 981 | 1.0 | 981 |
| 3 | Western Isles | 3,473 | 12,942 | 77 | 155 | 232 | 310 | 388 | 465 | 543 | 621 | 698 | 776 | 1.0 | 776 |
| 4 | North Coast & Orkney | 8,618 | 32,114 | 192 | 385 | 578 | 770 | 963 | 1,156 | 1,348 | 1,541 | 1,734 | 1,926 | 1.0 | 1,926 |
| 5 | Shetland | 1,009 | 3,760 | 22 | 45 | 67 | 90 | 112 | 135 | 157 | 180 | 203 | 225 | 1.0 | 225 |
| 6 | Moray Firth | 1,354 | 5,046 | 30 | 60 | 90 | 121 | 151 | 181 | 211 | 242 | 272 | 302 | 1.0 | 302 |
| 7 | East Scotland | 1,584 | 5,903 | 35 | 70 | 106 | 141 | 177 | 212 | 247 | 283 | 318 | 354 | 1.0 | 354 |
| SCOTLAND TOTAL | | 20,943 | 78,043 | 465 | 934 | 1,401 | 1,870 | 2,338 | 2,806 | 3,272 | 3,743 | 4,211 | 4,679 | | 4,679 |

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

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

**$N_{min}$** is a minimum population estimate. A revised analysis of GPS/GSM telemetry data from 60 grey seals, tagged between 2005 and 2018, allowed more accurate identification of haulout times (SCOS-BP 21/02). The revised estimate of proportion of seals hauled out during the survey window was 25.2% (95% CI: 21.5 – 29.1%), compared with the previous estimate of 23.9% (95% CI: 19.2 - 28.6%) (SCOS-BP 16/03). The 20th centile of the distribution of scalars from counts to abundances derived from the revised estimate is 3.73, approximately 3.5% lower than the previous scalar (3.86).

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

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

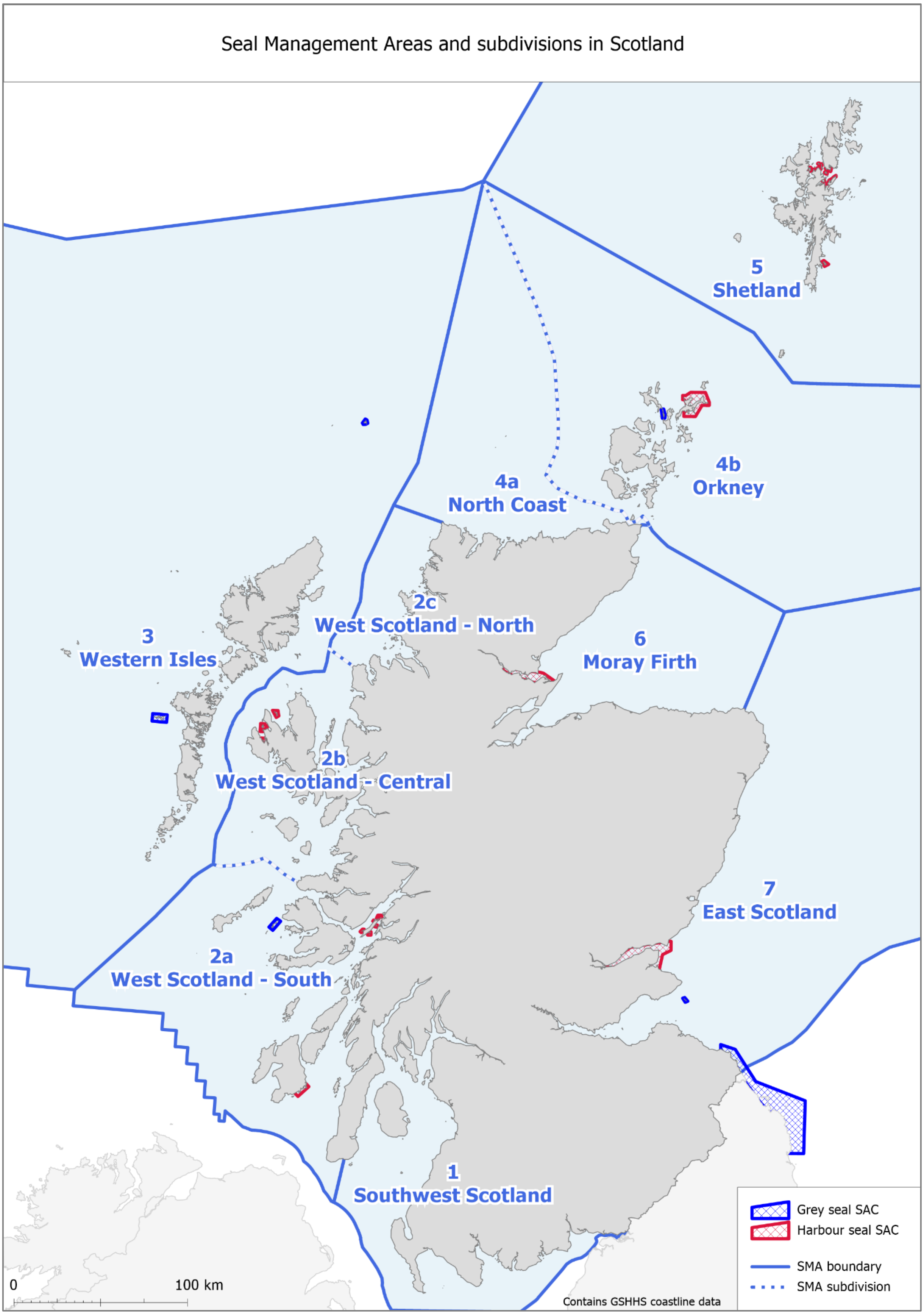


**Figure 1**. Seal Management Areas in Scotland.

# Preliminary report on the distribution and abundance of harbour seals (Phoca vitulina) during the 2023 breeding season in The Wash

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## Abstract

This report presents preliminary results of an aerial survey of the harbour and grey seal populations along the English east coast between The Wash in Lincolnshire and Blakeney Point in Norfolk on 1st July 2023 during the harbour seal breeding season. 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 underwent a marked decrease.

Results suggest that:

- The harbour seal pup count for The Wash on 1/7/2023 was 1417, which was 24% higher than the 2022 count, but similar to the mean of the seven peak counts during the preceding ten years (2013-2022).
- the peak counts and by implication the pup production had been increasing at an average rate of approximately 6% p.a. from 2004 to 2012 and reached a peak around 2015. Although there is a lot of inter-annual variability in the counts there is now clear evidence that the pup production has stopped increasing and has recently declined. 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, which is significantly higher than in early 2000s. The ratio was 2.7 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 has held the majority of the English harbour seal (*Phoca vitulina*) population since records began (Vaughan, 1978). This population has been monitored since the 1960s, using counts of animals hauled out during the annual moult 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. One survey was carried out in 1980 and a programme of annual surveys began in 1988 just prior to a major Phocine Distemper Virus (PDV) epizootic and has continued since.

***Historical harbour seal population trends in The Wash.***

In the summer of 1988, an epizootic 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 9). After the end of 1988, no more cases of the disease were observed until the summer of 2002, when another epizootic broke out (Harding *et al.*, 2002). Mortality in the European population during the 2002 epizootic was 47%, similar to that seen in 1988 (Harkonnen et al. 2006). However, on the English East coast the mortality rate estimated from pre and post epizootic air survey counts was much lower, approximately 22% (Thompson, Lonergan & Duck, 2005). The pre-epizootic population using the haulout sites between Donna Nook in Lincolnshire and Scroby Sands in Suffolk in 2002 was similar in size to the pre-epizootic 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 epizootic 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 9). The moult 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.

***Survey rationale***

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. Counts are carried out during the annual moult, when the highest and most stable numbers of seals haulout Thompson *et al*. (2005). 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.

Unfortunately, such counts do not provide a sensitive index of the current status of the population. 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. Therefore, in collaboration with Natural England, a programme of annual breeding season surveys was established in 2004 to obtain an annual index of pup production in The Wash and North Norfolk Special Area of Conservation (SAC)

**Methods**

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 were carried out of the coast from Donna Nook to Blakeney point from 2004 to 2018, and in 2022 and 2023. 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.

Based on the timing of breeding in The Wash in the 1960s and 1970s (Vaughan, 1978) it was initially assumed that that the peak number of pups would be encountered at the end of June or beginning of July. In 2008, 2010, 2015 and 2016 additional funds were provided to obtain multiple counts within single breeding seasons to estimate the parameters of the pupping curve. Surveys were carried out between 12th June and 13th July. 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 occurred between 26th June and 4th July. Because of military flying activities, surveys are restricted to weekends, and we have therefore surveyed the breeding population between 27th June and 4th July in each year from 2004 to 2018, and in 2022 and 2023.

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. All groups have been photographed with a handheld digital SLR camera and zoom lens since 2006. The equipment and techniques are described in detail in Hiby, Thompson & Ward (1986) and Thompson *et al*. (2005; 2019). 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.

The trend analyses for the peak pup counts followed the methods used in SCOS BP 24/03. In brief, peak counts were modelled as a function of year assuming negative binomial errors. 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). AIC was used to select the final model. All analyses were conducted in R (R Core Team 2023). Trends were assessed using four metrics of percentage change compared to the latest year of data available (2023). There were two short-term metrics: 1 year and 6 year. In addition, two long-term metrics: since the start of the time series (2001) and since any historic high in the time series. Trends were deemed significant if the 95% confidence intervals did not encompass 0 (see SCOS BP 24/03 for more details).

**Results**

***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 were counted in The Wash, 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 2893 which was 26% lower than the average of the peak counts during the previous five breeding season surveys (2014 – 2018) (Table 1).

***2023 survey results***

In 2023 a survey was carried out on 1st July, covering the entire coast between Donna Nook and Blakeney Point. A total of 1417 pups were counted in The Wash, 24% higher than the 2022 count, but was only higher than the mean of the of the peak counts for the preceding five surveys (2015-2022). The non-pup count was 3277 which was 13% higher than the 2022 count, but 11% lower than the average of the peak counts during the previous five breeding season surveys (2015 – 2022) (Table 1; Figure 10).

No pups were seen at Blakeney Point or at Donna Nook, in either 2022 or 2023, similar to previous years.

***Trends in pup counts***

A GAM was the model preferred through model selection, indicating a non-linear trend through time.

Figure 2 shows the trend in pup counts over the period 2001 to 2023. Pup production has significantly increased since the start of the time series (2001). Changes on a 1- and 6-year period leading up to 2023 are not significant. Since the high in 2015, there is an indication of a decline but it is not significant (-12%;

95% CIs: -31, 11). However, it should be noted that the mean max pup count since the start of the decline in the moult count (2022-2023: 1279) is substantially lower (~15%) than the mean in the 5 years preceding the decline (2014-2018: 1505).

There was no evidence of a decrease in pup production after the 2002 PDV epizootic; the 2004 count was 12% higher than the pre-epidemic count in 2001. The peak pup counts increased at around 9% p.a. during the 10 years following the PDV epizootic before reaching a peak around 2014-2015, which contrasts with the apparent decrease in the moult counts between 2003 and 2006 (Figures 1 & 2). The timing of the levelling off of the increase, and the possible recent decrease in pup counts is similar to the timing of the decline in the total population moult counts.

***Trends in apparent fecundity.***

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 (Figures 1 & 2). 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 epizootic means that the apparent productivity or apparent fecundity of The Wash harbour seal population changed over the early years of the time series (Figure 11). An index of fecundity, 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, and in 2022 the ratio was similar to the previous 10 years despite the significant drop in both the pup counts and the moult counts since 2018.

***Harbour seal pup distribution***

In 2023, harbour seal pups were recorded on 72 separate sites within The Wash and at Titchwell Marsh, on the North Norfolk coast just outside The Wash (Figure 12). Pups were widely distributed across those sites. The largest site contained 127 pups, 80% of pups were on the 27 largest sites. and 20 pupping sites each held five or fewer pups. As a consequence of the wide dispersion over a large number of occupied sites, only three sites had counts of more than 5% of the total pup count, and less than half of the sites had counts of more than 1% of the total.

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 allocating 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, 2022 and 2023 have been processed.

The relative importance of sites varies between years. Figure 5 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, 2018, 2022 and 2023. The maps represent the best estimates of the spatial extents of seal haulout sites observed during breeding season surveys and show 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. Although the fine scale distribution and relative sizes of groups varies between surveys there is no clear indication of a contraction or expansion in the distribution or number of pupping sites across The Wash.

***Grey seal distribution***

A total of 1294 grey seals were counted on sites within The Wash in the 1/7/2023 survey. A large majority (1130, equivalent to 87%) were counted on the outer banks at the northwest side of the mouth of The Wash, but groups of >10 grey seals are now appearing on the banks in the inner Wash (Figure 14). In 2023, approximately 30% of the harbour seal pups were found on sites with at least one grey seal (Figure 6). Figure 7 shows the differences in distribution of grey seals on haulout sites in The Wash between the 2017 and 2023 breeding season surveys. Until recently large groups of grey seals were only found on the Outer banks and there was little overlap between grey seal haulout locations and harbour seal pup sites. However, Figures 6 & 7 show that grey seals are spreading into the inner Wash and were present on at least eighteen of the harbour seal pup sites in the inner banks and tidal creeks in 2023 representing a dramatic increase in overlap since 2010.

## Discussion

The 2022 and 2023 breeding season survey counts for both pups and associated 1+ age classes at the estimated peak of the breeding season suggests that the apparent continuous increase in pup production since the first survey in 2001 has stopped and may be 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 around the time of the onset of the decrease in moult counts (Figures 1 & 2).

At present the causes of the decreases in pup and moult counts are unknown. A research program to investigate potential causes is underway, 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.

The change in the apparent fecundity index is interesting. Although there was a well-documented decline of over 20% in the population as a result of the 2002 PDV epizootic and a continued decline in the moult counts resulting in a total decline of >30% by 2006, there was no apparent decrease in pup production between the pre and post epizootic counts. Between 2014 to 2018 when the moult counts reached their peak, the numbers were similar to the 2001 pre-epizootic count. However, the estimated peak pup counts over the same period were more than double the 2001 pup count. 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 fecundity index shows no clear trend over the past 15 years. The fact that the index has remained high, despite the significant decreases in both moult and pup counts, may indicate that whatever is causing the decreases is not acting through changes in fecundity.

At present we do not have information on pregnancy rates from the SEE_SMU harbour seal population. The apparent fecundity rate reported here depends on the ratio between the moult population and the breeding population remaining constant. Changes in the index could therefore represent either changes in true fecundity or changes in the rates of short term immigration and emigration from the area. It is not currently possible to differentiate between these two mechanisms. 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.

Although we cannot differentiate clearly between these options, changes in either fecundity or immigration/emigration rates would represent a major change in harbour seal demographics and have implications for population management. 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 (Vaughan, 1978; SCOS, 2002). The 2004 and 2005 distributions were similar to the 2001 distribution, suggesting that there had been a real shift in distribution with a much higher proportion of pups being found in the southeastern corner of The Wash. At present we do not know why this distributional change is occurring but the results through to 2023 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 for harbour seal pups and breeding females (Brownlow *et al*. 2016).

## References

Brownlow, A., Onoufriou, J., Bishop, A., Davison, N., & Thompson, D. (2016). Corkscrew seals: grey seal (*Halichoerus grypus*) infanticide and cannibalism may indicate the cause of spiral lacerations in seals. PLoS One, 11(6), 1-14. Article e0156464. https://doi.org/10.1371/journal.pone.0156464

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

R Core Team (2023). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

SCOS (2002). Scientific Advice on Matters Related to the Management of Seal Populations: Report of the Natural Environment Research Council Special Committee on Seals:2002. 57 pp. https://www.smru.st-andrews.ac.uk/files/2016/08/SCOS-2002.pdf

SCOS (2021). Scientific Advice on Matters Related to the Management of Seal Populations: Report of the Natural Environment Research Council Special Committee on Seals:2021. 266 pp. https://www.smru.st-andrews.ac.uk/files/2022/08/SCOS-2021.pdf

SCOS (2022). Scientific Advice on Matters Related to the Management of Seal Populations: Report of the Natural Environment Research Council Special Committee on Seals:2021. 206 pp. https://www.smru.st-andrews.ac.uk/files/2022/08/SCOS-2022.pdf

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

Thompson, D., Onoufriou, J., & Patterson, W. ( 2016) Report on the distribution and abundance of harbour seals (*Phoca vitulina*) during the 2015 and 2016 breeding seasons in The Wash. Report number: SMRUC-DOW-2016-016, DECEMBER 2016 (UNPUBLISHED).

Thompson, D, Duck, CD, Morris, CD & Russell, DJF (2019), 'The status of harbour seals (Phoca vitulina) in the UK', Aquatic Conservation: Marine and Freshwater Ecosystems, vol. 29, no. S1, pp. 40-60. https://doi.org/10.1002/aqc.3110

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

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

| Year | 2001 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pups | 548 | 613 | 651 | 1054 | 984 | 994 | 1130 | 1432 | 1106 | 1469 | 1308 | 1802 | 1351 | 1586 | 1289 | 1498 | 1141 | 1417 |
| 1+ age classes | 1802 | 1766 | 1699 | 2381 | 2253 | 2009 | 2523 | 3702 | 3283 | 3561 | 3345 | 4020 | 4539 | 3905 | 3443 | 3747 | 2893 | 3277 |

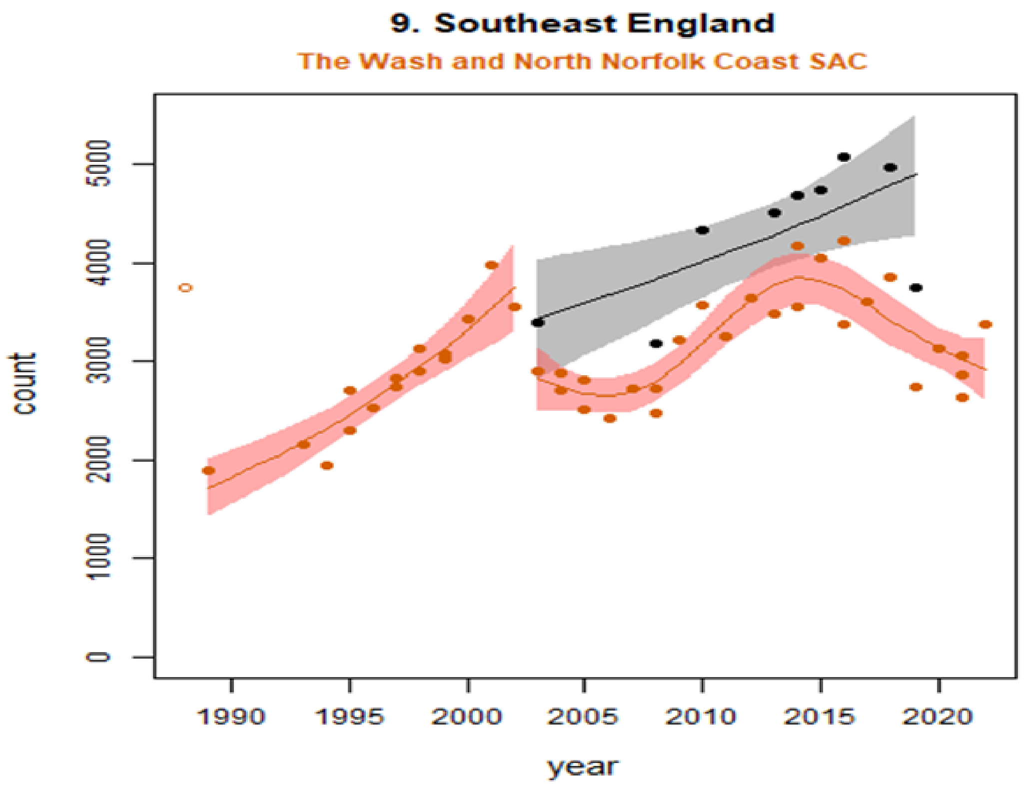


**Figure 9.** Counts of harbour seals in The Wash and North Norfolk SAC (red) and the total for the Southeast England SMU (grey) during the harbour seal moult in August, between 1988 and 2022, showing the changes in counts after the 1988 and 2002 PDV epizootics. Separate trend lines are fitted (see Russell et al. 2022 SCOP BP) to the 1989-2002 counts and post 2002 counts showing recoveries from the two PDV epizootics. 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).

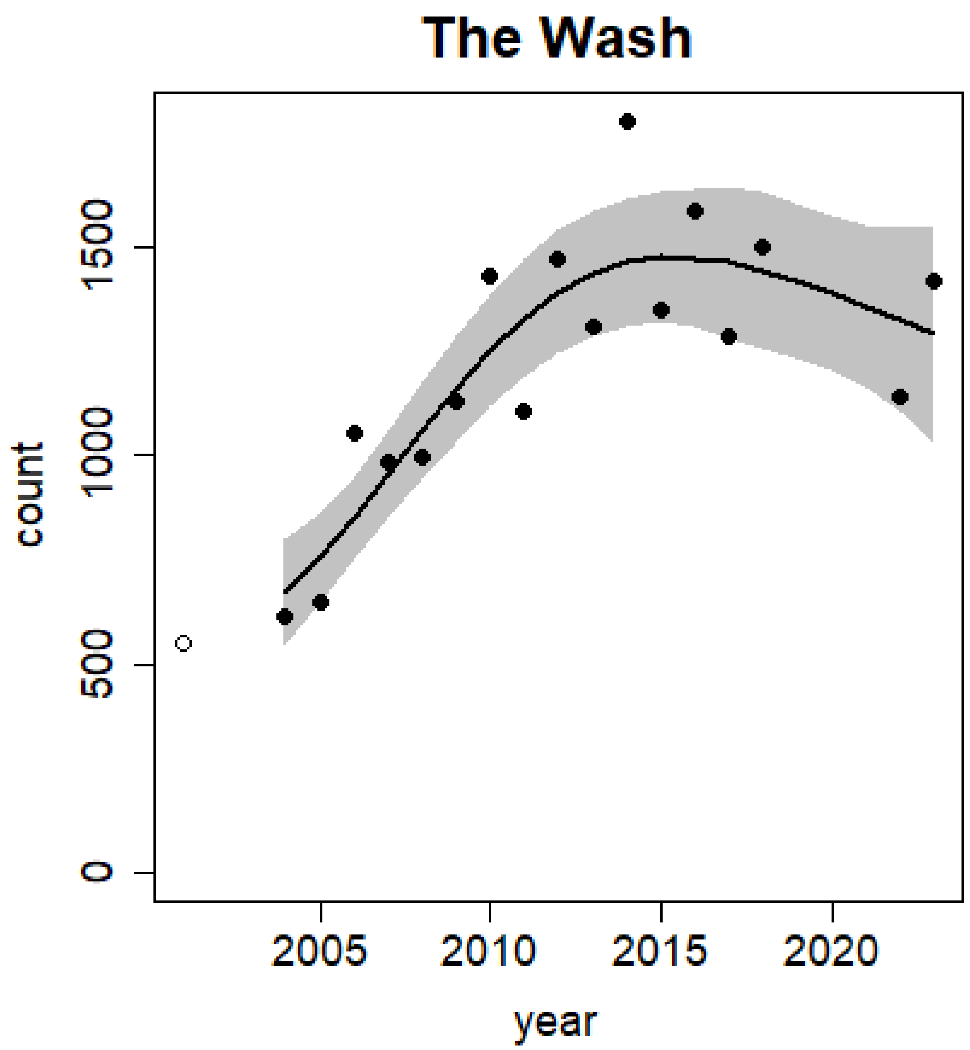


**Figure 10.** Maximum counts of pups in The Wash between 2001 and 2023. The fitted line is a GAM that illustrates the mean trend in harbour seal pup counts between 2004 and 2023 (with associated 95 % confidence intervals shown as the shaded area about the line) for The Wash and North Norfolk SAC. The pup counts increased rapidly after the 2002 PDV epizootic before reaching a peak around 2015. Since then, the pup counts have decreased significantly (see text for details).

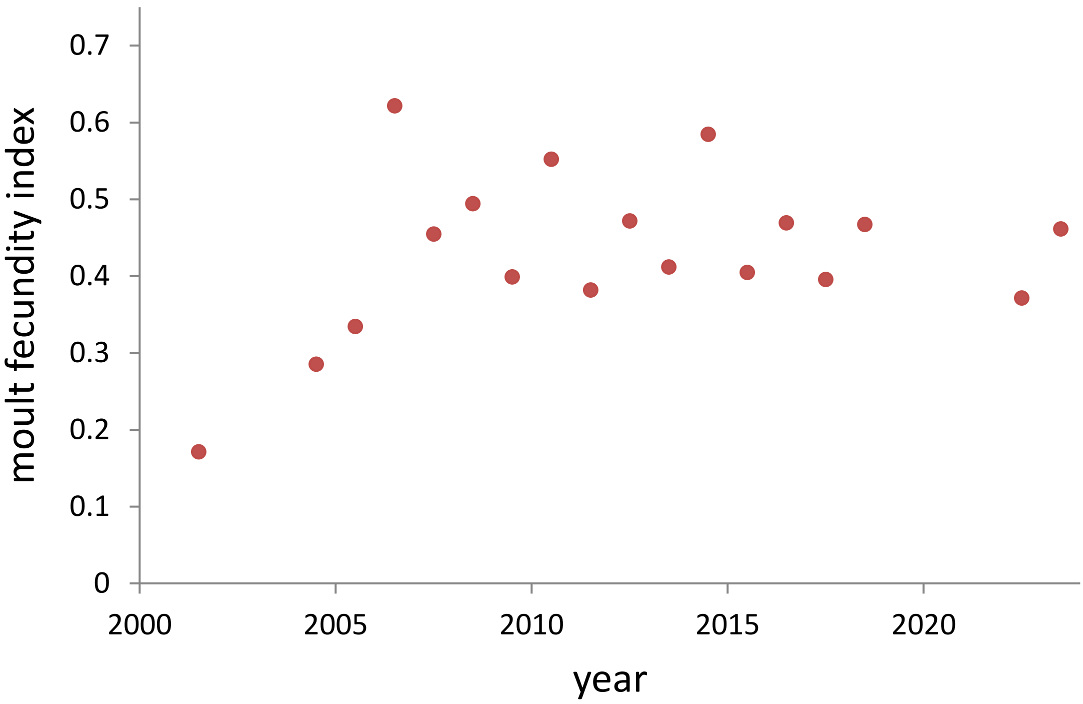


**Figure 11.** An index of fecundity, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size) increased between 2001 and around 2007 after which it appears relatively stable.

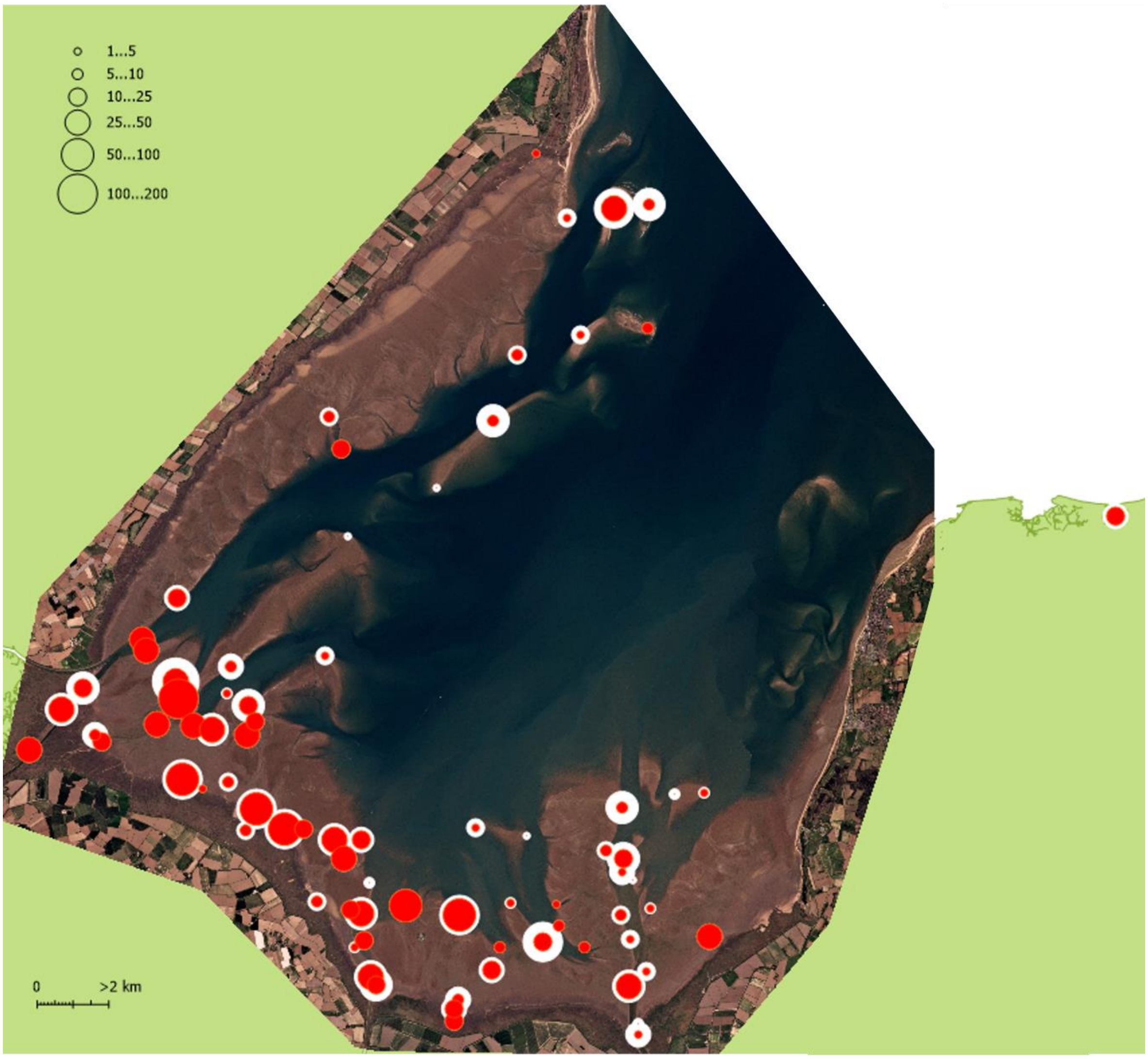


**Figure 12.** Distribution of pups (red circles) and 1+ age class harbour seals in The Wash on 1/07/2023. Numbers of seals are represented by the areas of the circles on each site. The majority of pups are found at haulout sites on the inner banks and tidal creeks in the southern part of The Wash. Red only dots indicate pup count equalled or exceeded 1+ age class count at that site.

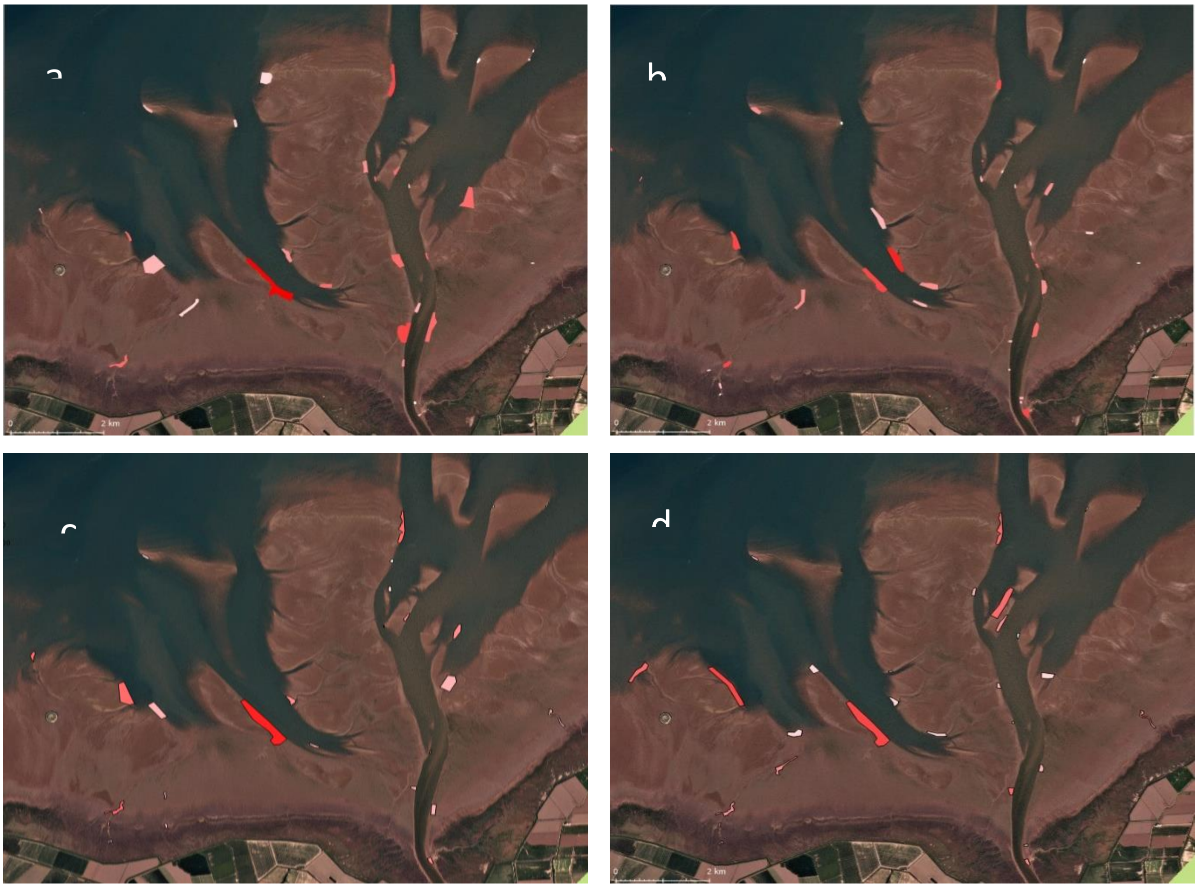

**Figure 13.** Example of the haulout extent maps for sites in the Great Ouse/Kings Lynn Channel during the breeding season in a)2017, b) 2018, c) 2022 & d) 2023. The maps represent the best estimates of the spatial extents of seal haulout sites observed during breeding season surveys and show changes in the fine scale distribution of harbour seals between surveys. Sites are colour coded according to the number of harbour seal pups counted.

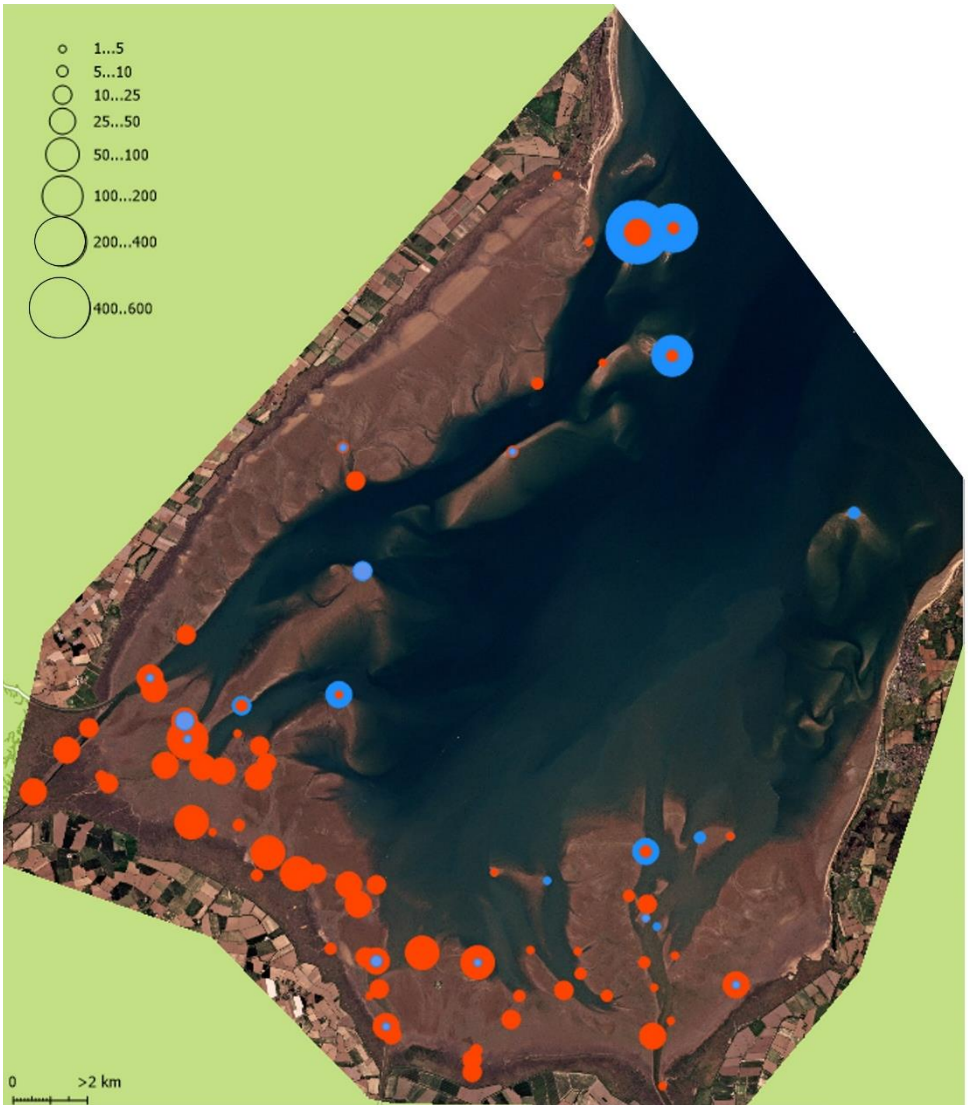


**Figure 14.** Distribution of harbour seal pups (RED) and grey seals ( BLUE) in The Wash on 1/7/2023. Numbers of seals are represented by the areas of the circles on each site. As in previous years, large groups of grey seals were present on the outer banks at the northwest side of the mouth of The Wash, but groups of >10 grey seals are now appearing on the banks in the inner Wash.

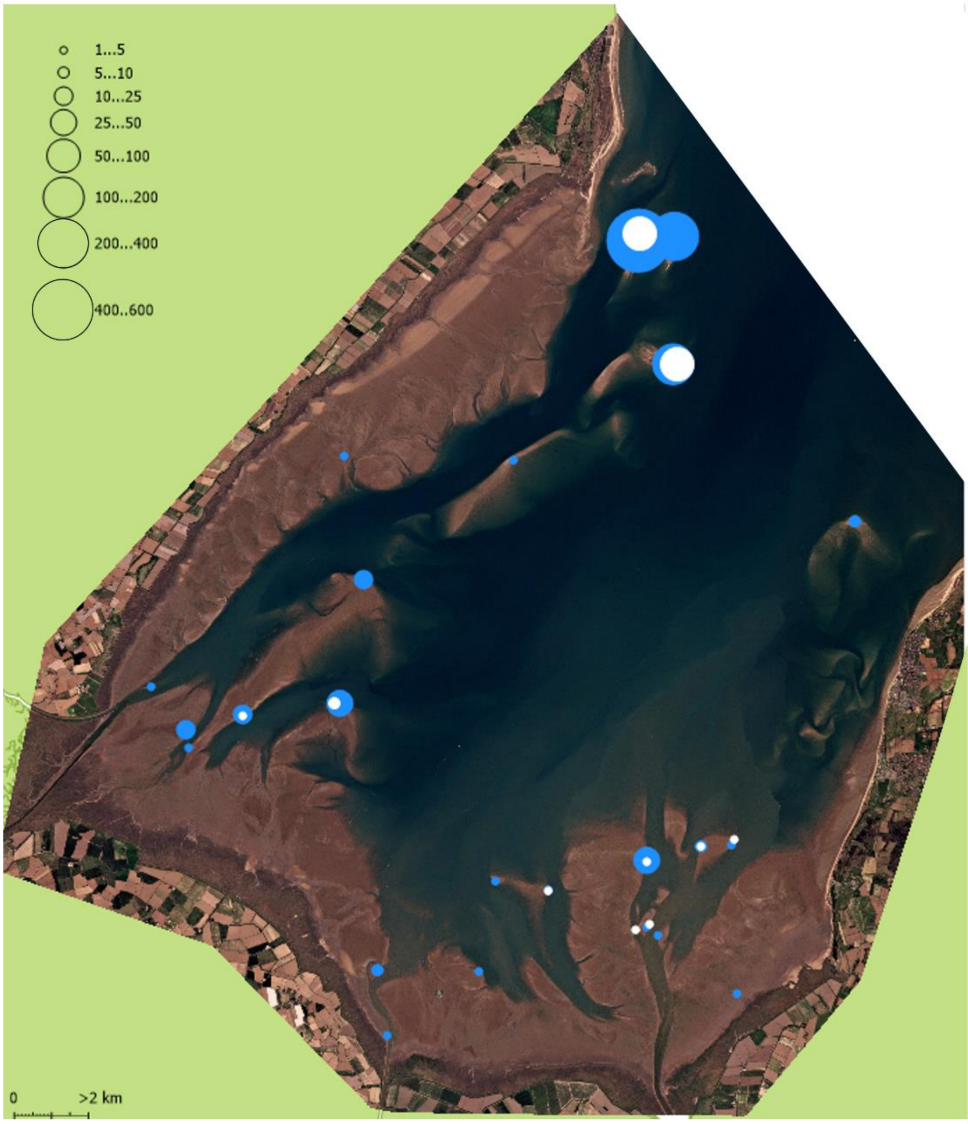


**Figure 7.** Distribution grey seals in The Wash on 1/7/2023 (BLUE) and on 4/7/2017 (WHITE). Numbers of seals are represented by the areas of the circles on each site. In both years the majority of grey seals were counted on the outer bank at the northwest side of the mouth of The Wash, but both the increase in numbers and the spread of grey seals into the inner Wash since 2017 are evident.

# Time series of grey seal pup estimates: east England

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## Abstract

Pup production estimates at grey seal colonies in Northeast (NEE; Farne islands) and Southeast England (SEE; Donna Nook, Blakeney and Horsey) Seal Monitoring Units (SMUs) have traditionally been generated from ground-based surveys (National Trust, Lincolnshire Wildlife Trust, and Friends of Horsey Seals). The method of pup estimation from these surveys differs between colonies. The increasing size of the colonies has made counting increasingly labour intensive, and in some cases, counting is hindered by risk of disturbance and safety concerns for counters. SMRU conducted a single aerial survey in 2014 and a full set in 2018. These aerial surveys indicated that, at least in some colonies, ground surveys were likely underestimating production. As a result of (1) preliminary comparison of the 2018 ground and aerial survey data; (2) the increasing proportion of the UK population eastern England represents; and (3) the cessation of ground-based pup production estimation for the Farne Islands and Blakeney, eastern England was incorporated into the SMRU aerial survey programme with surveys conducted in 2021 and 2023. This inclusion has ramifications for the frequency of aerial surveys of Scottish colonies, but it is possible that drone surveys may eventually replace the aerial surveys in eastern England.

Here we (1) compare the counts and associated pup production estimates from ground and aerial surveys in 2014, 2018 and 2021, and (2) use this information to integrate the ground and aerial survey production estimates into a single time series. Single time series are required for SMU-specific trend assessments (SCOS BP 24/03), and to feed into the population model (SCOS BP 24/05).

Comparisons between ground and aerial data (2014, 2018, 2021) indicated that for SEE-SMU, the ground counts, and likely the associated pup production estimates, were underestimates. For the Farne Islands, Blakeney and Horsey, ground-based production estimates, for comparison with aerial-based, were only available for 2018. For the Farne Islands, although the aerial counts were generally higher than the ground counts, the pup production estimates were more similar; ground-based estimates are based on spraying pups rather than counts.

Based on the findings, the ground- and aerial-based production estimates were integrated into a time-series in a colony-specific way. For the Farne islands and Horsey, the aerial-based production estimates were used to continue the time-series of ground-based estimates. For Donna Nook, a scalar (~25%) was derived to increase the ground-based estimates in line with the aerial. For Blakeney, ground-based production estimates up to 2014, and aerial-based estimates in 2018 and 2021, were used to generate a time-series. The generation of these time-series will be reviewed in light of new aerial-based estimates.

## Introduction

There are four large colonies on the east coast of England (Figure 1 in SCOS report), all of which were historically ground surveyed to produce pup production estimates: Farne Islands (1956-2019; part of Berwickshire and North Northumberland Coast SAC), Donna Nook (since 1970; Humber Estuary SAC), Blakeney Point (2001-2019) and Horsey (since 2002). Survey methods differed between the colonies, but have, for the most part, been 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 to as pup production. In each survey, all marked whitecoat pups as well as moulted pups are also counted. It was not possible to survey all islands in a single day. Indeed, the survey frequency was weather dependent but for the main pupping islands, they 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 a season's surveys; any pups born after the cessation of surveys will be missed. However, it is the survey method likely associated with the highest level of disturbance and associated safety concerns. This led the National Trust to start drone trials in 2017 resulting in high quality whole-island images for the 2021 season. For logistical reasons, these drone surveys were restricted to November, limiting the ability to use these for direct estimation of pup production. Although some ground counts were conducted in 2021, these were solely for comparison between ground and drone counts. The last ground-based production estimate for the Farne Islands was for the 2019 season.

The pups in SEE-SMU colonies - 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; FoHS) - were not routinely marked. At Donna Nook, pups are counted weekly with timing and frequency constrained by the RAF range. Pup production at Donna Nook 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 counted each week after the peak. At Blakeney Point, the method was similar, but the highest number of pups (1) used in the estimate was from mid-November (prior to the peak), and from that date in the season, surveys were conducted every 3-4 days with only pups thought to be born since the last survey being recorded (though occasionally full counts were conducted). Dead pups at Blakeney were marked to avoid repeat counting. For both colonies, the accuracy of the estimate is dependent on the degree to which pups are able to be delineated into those born prior to, and since, the last survey. Accuracy would also depend on the degree to which the highest count represents all pups born up to that point (i.e. pups have not yet left). 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 but least sensitive to pups leaving prior to the peak count. At Horsey, counts are conducted over two days, but for the purposes of comparison, we have assigned the counts to the second day. In 2021, a storm led to the cessation of counting for Horsey as a whole, with a subset (approx ~40% of the colony pup production) being surveyed thereafter (Somerton Gap to Winterton beach).

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. The length of coastline at Horsey, 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 single aerial survey in 2014, and a set of aerial surveys of the east coast of England in 2018. The preliminary findings from these surveys (SCOS BP 22/03); the rapid increase in pup production; and the cessation of ground-based estimates by the National Trust (Farne Islands and Blakeney), resulted in SMRU extending the aerial survey programme to include these colonies (2021, 2023). Due to limited capacity and resource, the inclusion of eastern England has resulted in lower frequency of surveys for most of Scotland (from biennial to triennial) but it is possible that drone surveys may eventually replace the aerial surveys in eastern England.

Here we (1) compare the counts, and associated pup production estimates, from ground and aerial surveys in 2014, 2018 and 2021, and (2) use this information to integrate the ground and aerial survey production estimates into a single time series. Single time series are required for SMU-specific trend assessments (SCOS BP 24/03), and to feed into the population model (SCOS 24/05). The aim was to minimise changes to the historic production estimates while maximising consistency across the time series.

**Methods**

All analyses were conducted in R (R Core Team 2023).

*Ground and aerial comparison*

SMRU conducted a single aerial survey of NEE and SEE colonies in 2014 (14/12/2014). During the 2018 season, five and four aerial surveys were carried out in NEE- and SEE-SMU, respectively. In 2021, five surveys were conducted of all colonies. Images from all surveys were stitched together to generate colony-wide images, and the number of whitecoat and moulted pups counted (see SCOS BP 24/02). The aerial counts in 2018 and 2021 were used to derive a birth curve and estimate pup production (see Russell *et al.* 2019 for details; Figure 1). It should be noted that the aerial-based pup production estimates for 2018 are ~5% higher than those reported in SCOS BP 22/03. The PCount value, the probability of counting a pup given it is expected to be present has been changed from 1 (SCOS BP 22/03) to 0.95 (see below).

For 2014, 2018 and 2021, ground-based pup production estimates and associated raw count data were sourced from the relevant organisations and people (see Acknowledgements).

Direct comparison of counts was only possible when aerial and ground surveys were conducted on the same day. Thus, for 2018 (for which there were ground survey data for all colonies), to aid comparison of methods, available ground counts were overlaid onto the pup production model input (aerial counts) and output. Furthermore, counts from both methods were compared against the expected count, for that day, predicted from the pup production model (fitted to aerial counts). Pup production estimates from ground and aerial surveys were compared in terms of both number of pups and percentage difference. Within the pup production model, the Farne Islands is considered a single colony to minimise the impact of movement of moulted pups between islands on production estimates. However, the frequency and dates of ground surveys vary by island, and thus for comparison purposes, the four key islands/groups were also considered individually in 2018 (Figure 1). Similarly, for Horsey, the 2021 ground surveyed subset of Horsey was also considered separately for the aerial survey data (Table 1).

To maximise the utility of the single aerial survey in 2014 (14$^{th}$ December), for SEE-SMU, the potential associated pup production values were estimated. Essentially, the mean scalar between the predicted count and pup production for the 14$^{th}$ of December for 2018 and 2021 was used to scale the 2014 count to generate the most likely pup production estimate. Recognising the potential changes in the birth curve from 2014, one week either side of the 14$^{th}$ of December for both 2018 and 2021 was used to derive a minimum and maximum scalar, and thus the potential range of pup production in 2014.

*Time-series to 2021*

The differences, between colonies, in the size, habitat, personnel and ground-survey methods necessitated colony-specific integration of the ground and aerial-based production estimates to generate time-series. This is in contrast to the single scalar estimated for the change from film to digital surveys in Scotland (SCOS BP 24/03). For each colony, pup production estimates were modelled as a function of year and survey method (ground vs aerial) in both a generalised additive (GAM) and generalised linear model (GLM) framework. Based on the comparisons between ground and aerial counts and production estimates (described above), and discussions with data providers, multiple options for inclusion and exclusion of data were explored (see Results). Model selection, via AIC, was used to choose between a GLM and GAM, and whether or not there was a jump between ground and aerial estimates. If survey method was not retained in the model, the model was refitted to exclude all ground-based estimates from 2018 onwards to ensure only one data point per year was included (see Results).

For SEE-SMU, the final model predictions from the three colonies were summed to produce a time-series for the SMU as a whole. The confidence intervals around the trend were generated by combining parametric bootstrapped estimates from the three colonies. The resulting trend was used to quantify changes over various time scales (reported in SCOS BP 24/03).

**Results and Discussion**

*Ground vs aerial comparisons*

The aerial survey pup production estimates are summarized in SCOS BP 24/02. Comparisons between counts and production estimates (from both aerial and ground surveys), and also the predicted counts from the pup production model (fitted with aerial data), are given in Table 1 (and Figure 1 for 2018).

For the Farne Islands, the production estimates were only available for 2018 (see Introduction). The 2018 estimate derived from ground surveys was ~9% (274 pups) lower than from aerial. Counts could only be compared on an individual island/group scale. For the two key pupping islands combined (~60% of Farne Islands production), the pup production was estimated to be 5% lower via ground- vs aerial based methods. However, the peak ground count was 15% lower than predicted by the model (the peak aerial count was 3% lower than predicted).

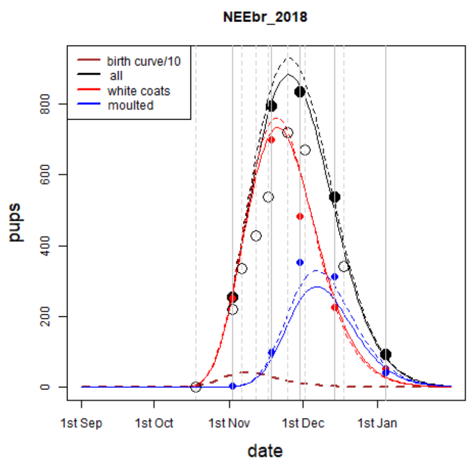
The Farnes ground counts themselves are not used to estimate pup production (rather it is the number sprayed), thus undercounting would not impact production estimates as long as the non-marked whitecoats were found and marked on a survey before they moulted. Indeed, there was more focus on spraying whitecoat pups than counting moulted pups (National Trust, pers comm.) which may explain some of the discrepancy between aerial and ground counts. 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, and thus only total counts were compared. In 2021, a limited number of ground counts were conducted but pup production was not estimated. Thus, the counts in 2021 did not provide any additional information to inform ground vs aerial based pup production estimates, and thus are not considered here.

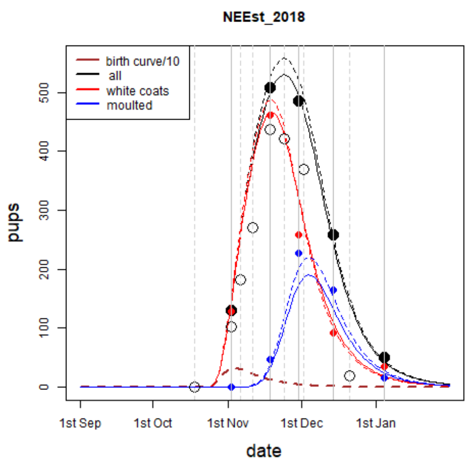
In 2018, compared to aerial-based estimates, the ground-based pup production estimates were 27, 40%, and 8% lower for Donna Nook, Blakeney Point and Horsey, respectively. In 2021, ground-based pup production estimates were only available for Donna Nook; the ground-based estimate was 19% lower than the aerial.

In both 2018 and 2021, the peak count at Donna Nook was from the same survey day for both methods. The ground count was 10% (209 pups) and 7% (109 pups) lower than the aerial in 2018 and 2021, respectively. In general, the ground counts for Donna Nook were lower than predicted from the pup production model (Figure 1). The greater 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 ground count (use to estimate pup production) is unlikely to represent 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. In 2021, the peak count was 6 weeks after the first count of 3 pups.

At Blakeney point, only newborn pups are counted from mid-November. However, to aid comparisons, National Trust conducted a full count in mid-December 2018, 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-based 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 surveys in 2018, there were considerable differences in the counts (Figure 1). Indeed, despite being conducted within a three-day window, the ground count was almost 20% (348 pups) lower than the aerial. 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. In 2021, peak counts could only be compared for a subsection of the colony; the ground count was 40% (558 pups lower than predicted).



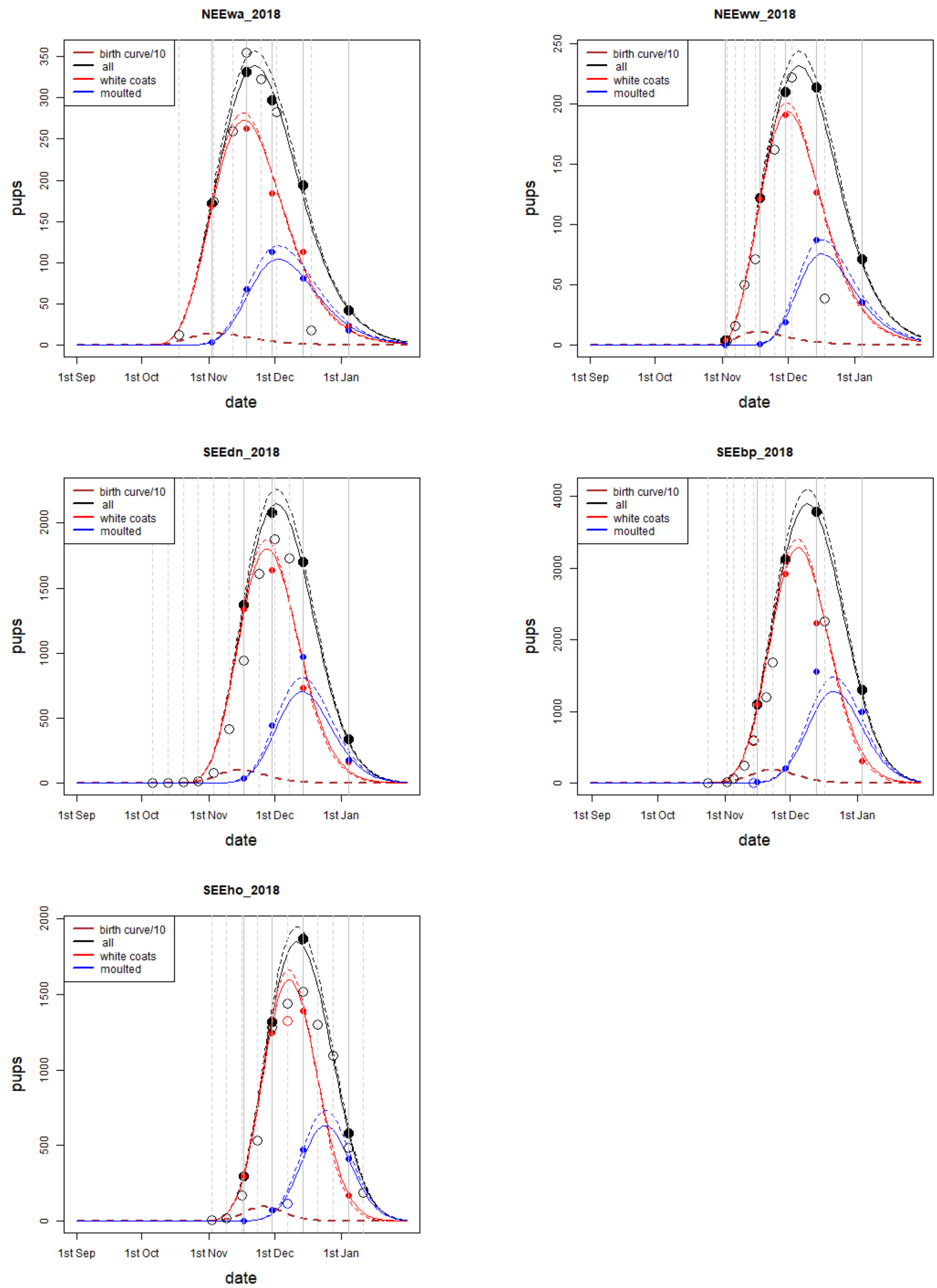



**Figure 1.** Grey seal pup counts and birth curve for eastern England in 2018. The four main Farne Islands islands/groups for grey seal pupping: Brownsman (NEEbr) and Staple (NEEst; top row); Wamses (NEEwa; second row) and West Wideopens (NEEww; second row). The other three colonies are Donna Nook (SEEdn), Blakeney Point (SEEbp), and Horsey (SEEho). Filled points represent the aerial survey counts, and the solid and dashed lines represent the numbers expected to be counted and present on the colony, respectively (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 vertical lines represent the dates of the surveys (solid for aerial and dotted for ground). The open circles represent the ground counts.

**Table 1.** The highest count for aerial and ground surveys, along with the predicted count, on the same day, from the pup production (fitted to aerial survey counts). The difference between the ground and aerial-based production estimates are also shown.

| Year | Group | Subset | Highest Count | | | | | | | | Pup Production | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Aerial | | | | Ground | | | | | | |
| | | | Date | Count | Predicted | Difference % (pups) | Date | Count | Predicted | Difference % (pups) | Aerial | Ground | Difference % (pups) |
| 2018 | Farnes Islands | Brownsman | 30/11 | 835 | 853 | -2.1 (-18) | 24/11 | 721 | 880 | -18.1 (-159) | 1211 | 1121 | -7.5 (-90) |
| | | Staple | 18/11 | 508 | 530 | -4.2 (-22) | 17/11 | 437 | 486 | -10.1 (-49) | 686 | 688 | 0.3 (2) |
| | | Wamses | 18/11 | 331 | 330 | 0.3 (1) | 17/11 | 355 | 325 | 9.1 (30) | 521 | 486 | -6.7 (-35) |
| | | W Wideopen | 14/12 | 214 | 209 | 2.2 (5) | 02/12 | 222 | 224 | -1.1 (-2) | 324 | 271 | -16.5 (-53) |
| | | Total | 30/11 | 1966 | 2022 | -2.8 (-56) | | | | | 3011 | 2737 | -9.1 (-274) |
| | Donna Nook | | 30/11 | 2083 | 2132 | -2.3 (-49) | 30/11 | 1874 | 2132 | -12.1 (-258) | 2824 | 2066 | -26.8 (-758) |
| | Blakeney | | 14/12 | 3795 | 3783 | 0.3 (12) | 18/12 | 2265 | 3465 | -34.6 (-1200) | 5036 | 3012 | -40.2 (-2024) |
| | Horsey | | 14/12 | 1866 | 1824 | 2.3(42) | 13/12 | 1518 | 1838 | -17.4 (-320) | 2245 | 2069 | -7.8 (-176) |
| 2021 | Donna Nook | | 03/12 | 2118 | 2151 | -1.5 (-33) | 03/12 | 2009 | 2151 | -6.6 (-142) | 2632 | 2134 | -18.9 (-498) |
| | Horsey | South | 11/12 | 1386 | 1410 | -1.7 (-24) | 09/12 | 832 | 1390 | -40.1 (-558) | | | |

*Time-series to 2021 (Figure 2)*

Farne Islands

Model selection favoured a model without survey method, and thus the production estimates from ground and aerial surveys was fitted as a single time series.

Donna Nook

A model with survey method was preferred with an increase of ~25% from ground to aerial-based production estimates. Although it is likely that accuracy of ground-based estimates is impacted by colony extent and density, there are various potential sources of inaccuracy (see above) and the potential range of estimated pup production for 2014 indicated that a step change of ~25% was not inappropriate at the lower level of production in 2014. Thus, in the absence of further data, the step change was applied through the time series.

Blakeney

The trend in ground-based estimates between 2015 and 2019 did not follow the trajectory of the earlier ground-based estimates and later aerial based estimates. Indeed, in 2014, the ground and aerial based estimates aligned well. These findings and the discussions with National Trust (see above) led to the exclusion of the ground counts between 2015 and 2019 from the analyses. A single model was then fitted to the ground- (up to 2014) and aerial-based (2018 and 2021) estimates.

Horsey

A model with survey method was only preferred if the ground-based estimate in 2022 was included. Given the lack of data to inform the potential mismatch beyond 2018 (there was no ground-based estimate in 2021), and the rapidly increasing colony size and extent (FoHS have indicated they do not cover the recent extensions to the colony), it was decided to exclude the 2022 estimate. The aerial based production range for 2014 indicated that the ground-based production estimate was too low. However, 2014 was not representative of the ground-based trend; indeed there was decreased survey effort that year due to illness (FoHS pers. comm). Model selection, via AIC, favoured a model without survey method. Thus, the model was refit without survey method using ground-based estimates up to 2017, and aerial-based thereafter.

SEE-SMU

The combined final trend for all three SEE-SMU colonies, the rates of change, are described in SCOS BP/03.

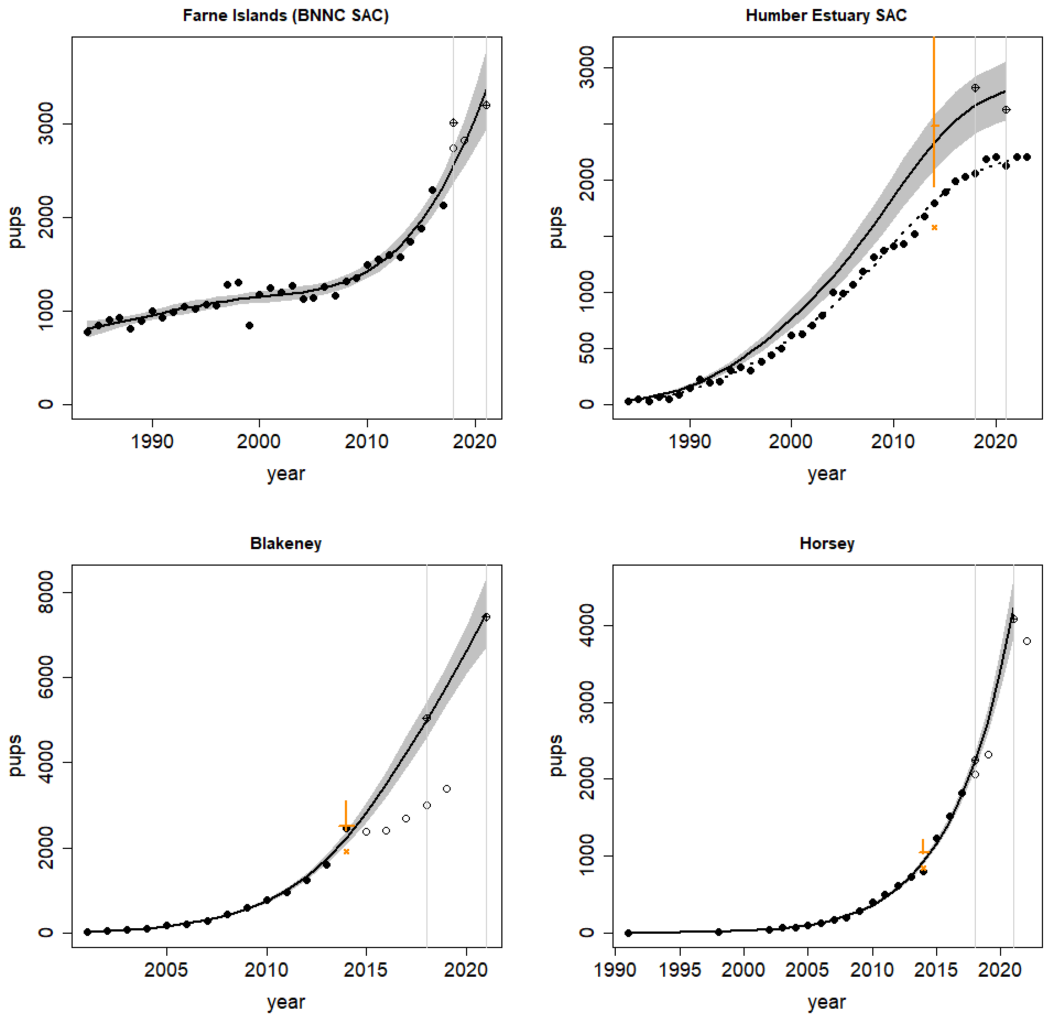



**Figure 2.** Time series for each of the main English east coast colonies. The generated trend used to generate a SMU-wide trends, and in all further analyses is represented by a solid black line, and the associated 95% CI are shown in grey. The ground-based estimates are shown as black circles (open circles indicate the data points were not used in the analyses). The crossed points represent the aerial-based estimates. The orange cross, vertical lines and horizontal line in 2014 indicates the single aerial survey count, the likely range of pup production estimates, and the most likely pup production estimate, respectively. Donna Nook is labelled as Humber Estuary SAC.

## Conclusions and ongoing research

The findings of this study highlight the difficulties in ground counting such large colonies and in the aging of pups (to classify them as born since last survey). The accuracy will likely depend on the experience of the counters, the availability of landmarks (e.g. groynes), 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 NT 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, including time pups spend in the water (and thus not available to be counted), and the decomposition of dead pups.

The ground and aerial comparisons also highlight the importance of a consistent monitoring method and the need for comparisons when methods change. The limited number of distinct colonies in eastern English colonies mean, in contrast to most Scottish colonies, they could all potentially be surveyed by drone in the future. This would have likely advantages in terms of image quality and 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, the utility of drone surveys for estimating pup production 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.* 2019). The continuation of the drone monitoring of the Farnes is uncertain (National Trust pers. comm). Natural England have trialed drone surveys of Horsey but the size of the Blakeney colony currently prohibits drone operators licenced 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.

The findings suggested that, in general, the aerial-based pup production estimates were higher than ground-based. However, this varied between colonies and, for the only colony for which we had two years of data (Donna Nook), also between years. These comparisons between ground and aerial survey data also have ramifications for the pup production model. Although the aerial-based pup production estimates were higher than ground-based, 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 ground method used (marking of pups), it seems unlikely that pup production could be overestimated. Thus, the fact for the two main pupping islands, aerial-based estimates were between 0 and 5% higher than the ground-based suggests that the higher pup production associated with the digital survey methods (compared to film) are 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 as part of a PhD project.

The time-series models will be reassessed as and when information (data and pup production model) become available. However, the generated trends represent a usable consistent time series for the NEE and SEE-SMUs for use in population models.

**Acknowledgements**

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**References**

Russell DJF, Morris CD, Duck CD, Thompson D, Hiby L. Monitoring long-term changes in UK grey seal pup production. Aquatic Conserv: Mar Freshw Ecosyst.2019;29(S1):24–39. https://doi.org/10.1002/aqc.3100

R Core Team (2023). R: A Language and Environment for Statistical Computing. RvFoundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

# 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

| | |
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