Scientific Advice on Matters Related to the Management of Seal Populations: 2025

Natural Environment Research Council Special Committee on Seals

This report has been compiled by Sea Mammal Research Unit staff: Carol Sparling, Debbie Russell and Dave Thompson with contributions from Chris Morris, Gordon Hastie, Joanna Kershaw and Simon Waitland.

Please cite as: SCOS (2025). Scientific advice on matters related to the management of seal populations: 2025. Natural Environment Research Council Special Committee on Seals.

Contents

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 (SMRU), University of St Andrews. NERC appointed a Special Committee on Seals (SCOS) to review and formally issue this advice.

What is new in SCOS 2025?

August surveys: In 2023 helicopter surveys of hauled out harbour and grey seals were conducted using a thermal imager of a large proportion of the Scottish west coast of Scotland from Loch Hourn to the border representing the south and central sections of the West Scotland Seal Monitoring Unit (SMU) (the north section of the West Scotland SMU was surveyed in 2022 and reported in SCOS 2024) and the entire Southwest Scotland SMU. The results from this survey are reported here for the first time. This provides updated harbour seal population abundance estimates for those SMUs and the whole of Scotland and the UK compared to those provided in SCOS (2024). The English and Welsh totals are from the 2023 fixed wing surveys previously reported in SCOS (2024).

Grey seal pup production: the results from the 2023 surveys of nine grey seal breeding colonies on the east coast of the UK are presented here for the first time. This includes the Firth of Forth colonies (East Scotland SMU), the Farne Islands (Northeast England SMU) and the colonies at Donna Nook, Blakeney and Horsey (Southeast England SMU).

Updated trend analyses for the relevant SMUs are presented using these new survey data.

Updated Potential Biological Removals estimates for 2025 are presented based on the latest survey data.

Updated bycatch estimates from the UK Bycatch Monitoring Programme are provided for UK fisheries in UK waters in 2022.

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 **36,956** (95% CI: 30,236-49,274). This represents a **decrease** of approximately **16%** (17%, 8% and 23% lower for Scotland, England and Northern Ireland, respectively) compared to the previous composite counts (covering the years 2011-2019).

It is concerning that all harbour seal Seal Monitoring Units (SMUs) anywhere in the UK with notable numbers (>250 individuals) are predicted to be declining and/or depleted ((estimated to be significantly lower than the highest point in the time series). Prior to the latest count, the western Scotland SMUs had been the only SMUs for which abundance was predicted to be increasing. The indication that this area could also be in decline is of particular concern given that the three western Scotland SMUs combined host over 60% of the UK total. North Coast & Orkney and East Scotland SMUs are depleted and predicted to be in decline, whereas Shetland and Moray Firth SMUs are depleted but appear stable. Southeast England SMU is depleted (since 2018) and showing no sign of recovery; it is not clear if it still declining. Northern Ireland SMU is in 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)	% of UK total
England	**3,548**	**4,928 (4,032-6,570)**	**13.3**
Wales	**1**	**1 (1-2)**	**0.0**
Scotland	**22,241**	**30,890 (25,274-41,187**	**83.6**
Northern Ireland	**818**	**1,136 (930-1,515)**	**3.1**
Total UK	**26,608**	**36,956 (30,236-49,274)**	

Grey Seals

UK grey seal abundance and trends are primarily assessed through a combination of estimates of pup production (number of pups born each year) and August haulout counts. Pup production is estimated using a series of pup counts across a breeding season. UK grey seal pup production has continued to increase, with that in 2022/2023 estimated to be ~2.5% higher than in 2019-2021. The most recent estimate of 79,122 pups is the highest total estimate on record; over 70% of these were produced in Scotland and 26% along the east coast of England. In Scotland, pup production in 2022/2023 was almost 3% lower than in 2019. In contrast, pup production in England (majority surveyed in 2023) was estimated to be ~18% higher than in 2021.

While pup production time-series provide the main index of population change at a UK level, August haulout counts (scaled using the proportion of grey seals hauled out during the aerial survey window, estimated from telemetry data), are also critical. Firstly, August counts provide estimates of total population that are independent from pup production. In addition, grey seal distribution during the main foraging season (represented by August counts) provides a broad-scale indication of 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 haulout counts are required for robust Potential Biological Removal estimates. The modelled trends across SMUs vary. Pup production in West Scotland and Western Isles SMUs is predicted to be increasing after a period of stability, to the highest level since pup surveys began. In Southwest Scotland (where very few pups are born annually) and West Scotland, August abundance is also predicted to be 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 have both been stable since the early 2000s. For Shetland, while there is an indication of a decline in pup production (latest data 2018), the August count (latest count 2019) shows no trend. Pup production in all east coast SMUs (Moray Firth, East Scotland, Northeast England, Southeast England) is predicted to be increasing, although the last three estimates (2018-2023) for East Scotland are all similar, indicating that the SMU may have reached carrying capacity. August counts are stable for the Moray Firth and East Scotland, but are predicted to be increasing in eastern England SMUs. Limited data are available to quantify trends in other SMUs. Based on these limited data, there are indications that pup production in Southwest England, Wales, and Northern Ireland is either stable or increasing. August haulout counts in Northern Ireland appear stable at the highest level observed throughout the entire time-series.

A NERC capital grant enabled the purchase of a new digital camera system in 2023 (Phase One, hereafter PAS) to replace the previously used H4D system. This system was used, for the first time, to survey the colonies East Scotland, Northeast England and Southeast England SMUs between late October and mid-December 2023. A side-by-side comparison of the new PAS system with the previous H4D system was conducted in Autumn 2023. This was necessary given the importance of observation parameters relating to the probability of counting whitecoated (whitecoats) and moulted pups in the model estimating pup production, and previous experience of an apparent step change when changing from film to digital survey methods in 2012 . The outcome of this comparison indicated that the change in system will likely be associated with only modest changes in the observation parameters, and that any bias (compared to H4D) in estimates from the current pup production model would likely be slightly upwards due to a higher detection rate, particularly of whitecoats.

Seal Conservation and Management

The most recent estimate of bycatch of harbour and grey seals in UK fisheries was 452 animals in 2022 (95% CI 352-820). The mean estimate is very similar to the previous year (458 Estimates of seal bycatch in recent years have been in the region of 400-600 seals per year, with no clear trend. 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. A recent study has highlighted a potential concern that the use of acoustic deterrents effective for reducing porpoise bycatch ('pingers') may be increasing rates of seal bycatch.

Concerns raised by fisheries organisations about the interactions between seals and fisheries remain. These are about the impact that seal predation is having on both river and sea fisheries. Depredation of catches and gear damage is also a concern. 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. Mitigation methods are a continuing focus of research with the development of startle signal based, targeted acoustic deterrent methods indicating promise.

There remain concerns about future disease outbreaks in UK seal populations. As it is now 23 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 coasts of the US and Canada and the potential for further outbreaks in UK seabird populations.

Climate change is already having a range of effects in the seas around the UK, but predicting the consequences of climate change for seal populations is difficult. There is currently little information on the relationships between environmental drivers and seal population dynamics, so it is unlikely that cause and effect can be reliably assigned to specific aspects of climate change. However, seal populations are influenced by a range of indirect (e.g. changes in prey availability) and direct impacts (e.g. loss of breeding/haulout sites). There is also the potential that the incidence of infectious disease outbreaks and exposure to toxins from harmful algal blooms could increase health impacts on UK seal populations. Long-term studies are required to be able to detect changes in body condition and reproductive output and investment, and to be able to link these with changes in environmental conditions. There is also a need for finer scale regular assessments of fish stocks at appropriate temporal and geographical scales (i.e. matching the scales for which data on seal abundance, distribution and vital rates exist), to be able to link prey availability with changes in environmental conditions and changes in seal condition and reproductive success.

Emerging techniques are reviewed and evaluated in terms of their current, and likely future, potential to augment or replace the current monitoring programme. The most promising emerging methods are associated with the survey platform and counting methods. The number and spatial extent of seal haulouts and breeding colonies in the UK means drones are not an appropriate platform for the majority of the SMRU survey programme. However, drone surveys can be the most appropriate platform for some study areas of a limited spatial extent, especially when additional information is required (e.g. animal condition and individual pelage recognition for mark-recapture estimation of population size). The potential use of satellite imagery as a replacement for existing SMRU surveys is limited by the relatively low temporal and spatial resolution of opportunistic observations, and issues with cost, image quality and cloud-cover.

While counting of seals in images is still typically conducted by researchers, Citizen Science and Artificial Intelligence (AI) are also being used in other projects, with mixed success. In particular, AI is a promising future avenue but there are no fully operational systems in use that involve the classification of seals (e.g., species, age) in images from manned aerial surveys. SCOS conclude that the SMRU aerial survey programme is currently the most appropriate solution for monitoring seal populations in the UK at the scale required. If and when future drone capabilities and legislation allow, SMRU will consider augmenting or replacing parts of the manned aerial surveys if funding is available. In the longer-term, AI-counting techniques would be advantageous, but the development and implementation of effective AI-counting techniques would require significant additional resources. Nevertheless, SMRU should continue to build a training set of annotated images to facilitate such development, and to allow retrospective application of AI techniques to historic images. SCOS highlight that the adoption of new techniques would need to be predicated on an ability to account for changes in methods to ensure continuity of time-series and to maximise comparability across the UK and Europe.

Additional questions received in 2025 included requests for information on patterns of grey seal use of Special Areas of Conservation (SACs) during and outwith the breeding season (Marine Directorate of the Scottish Government), an update on any research on harbour or grey seal interactions with tidal turbines (Natural Resources Wales) and a request for a synthesis and prioritisation of outstanding areas for seal research (Department of Food, Agriculture and Rural Affairs). It was agreed that this latter question would be added to the list of standing questions that would be addressed every year going forward.

SMRU's long-term funding has recently seen a substantial reduction, and further reduction is planned. 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 conduct critical research underpinning our understanding of changes in UK seal populations. Research and advisory activities continue to be reprioritised as necessary, and to respond to this, changes have been made to the way that SCOS advice is delivered with the adoption of standing questions covering the primary areas of seal conservation and management concern and a capped level of additional questions that can be submitted. It is likely that further reductions to the frequency and extent of survey activity will also be required in the coming years.

Summary of recommendations of SCOS in 2025

This section outlines the recommendations made by SCOS in 2025 including outstanding recommendations from previous SCOS meetings. As noted in the response to Q10 the level of priority of each will depend on the perspectives of different stakeholders and the different management and policy areas they cover. Priorities may also be informed by the resources, capacity and capability available to address them. Therefore, it would be challenging for SCOS to evaluate all relevant perspectives and prioritise accordingly. However, the abundance and distribution (and spatial and temporal variations therein) of seal populations underpins much of the SCOS advice. Indeed, knowledge of these are used to evaluate the potential impact of human activities (e.g. bycatch, renewable energy developments), the associated safe levels of "take" (Potential Biological Removals;), and top-down impacts on the ecosystem. As such the robust estimation of population size on appropriate temporal and spatial scales is considered by SCOS to be of the highest priority.

As also noted in Q10, and above, due to reductions in NERC National Capability funding to SMRU, additional resources would need to be made available to enable progress on these recommendations.

Seal population status and trends

Harbour seals

Specifically in relation to the observed harbour seal declines around the UK, SCOS recommends the following research is required:

- To investigate the potential role of changes in food availability, and/or competition between species for prey, a co-ordinated research effort is required to update knowledge on seal diet around the UK, there are now studies underway to update our estimates of grey and harbour seal diet in the southeast of England SMU and around Scotland and the work will enable a reassessment of the potential role that prey availability may have had in these declines.
- Routine health and disease surveillance through coordinated efforts involving strandings schemes, rescue and rehabilitation centres, and live captures for research is critical to better understand population health and ensure early detection and monitoring of infectious diseases in the UK, and to understand the potential for disease and health status to contribute to observed population trends.
- Considering recent advances in techniques including drone technology, SCOS recommends that, a scoping study should be carried out to assess the feasibility of developing additional studies of harbour seal survival, fecundity and indicators of condition at additional sites around the UK. This exercise should consider the resource requirements of collecting data at appropriate temporal and geographical scales and assess the cost/benefit of such studies in relation to other data requirements.

Grey seals

SCOS recommends the development of a grey seal UK metapopulation model incorporating seasonal movements and pup dispersal that is critical to our ability to reliably monitor and manage the UK grey seal population. Such a model could incorporate age and sex specific anthropogenic takes, taking account of seasonal movements and structure within the metapopulation. (Q1, Q2, Q3)

There are two key data gaps that would need addressed: (1) seasonal movements of adults between and within SMUs; (2) dispersal and survival of grey seal pups, and the spatial relationship between initial dispersal and recruitment into the breeding population. To fill these knowledge gaps SCOS recommends the following:

- SCOS recommends the development and subsequent large-scale deployment of small satellite flipper tags to investigate temporal and spatial patterns of pup mortality, dispersal of pups, the spatial relationship between initial dispersal and recruitment into the breeding population, and seasonal movements of adults. (Q1, Q2, & Q3)
- These tagging efforts should be accompanied by large scale genetic sampling that would provide movement data for the grey seal metapopulation model, identification of source populations and increased understanding of the population scale at which bycatch should be considered and provide data to facilitate estimation of population size through Close-kin mark-recapture models. (Q1, Q2, & Q3)
- 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. (Q1, Q2, & Q3)

Interactions with fisheries

Bycatch

- 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. SCOS recommends the inclusion of bycatch from non-UK vessels to improve total bycatch estimates and assess impacts to UK seals. This would require co-ordination with other countries to provide data for all fisheries impacting seals in UK and adjacent waters. (Q5)
- SCOS recommends further investigation of bycatch mitigation methods. With a particular need to investigate the finding that ADD (‘pinger’) use on static net fisheries to reduce bycatch of cetaceans has led to increased rates of seal bycatch, and adaptations and development of mitigation strategies may be required. (Q5)

Reducing impacts of seals in rivers

- SCOS recommends continued investigation of non-lethal control of seals in rivers to reduce impacts on recreational fisheries and the conservation of fish prey species. Triggered deterrents and modified physical barriers remain the most promising methods, but additional resources will be required to assess long-term effectiveness in a range of environments. (Q6)

Competition with commercial fisheries

- Research is required to provide information on the scale and extent of seal damage to catch and fishing gear in the UK. SCOS recommend that additional resources should be allocated to conduct a quantitative assessment of seal-damaged fish data from the UK Protected Species Bycatch Monitoring Scheme. (Q6)
- 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. Studies are

underway to update grey and harbour seal diet estimates in the southeast England SMU and around Scotland. A reassessment of the potential for competition with commercial fisheries should be undertaken once this work is complete. Diet data should be incorporated into multi-species ecosystem models. (Q6)

Health and disease

- There is a need for the coordinated development and adoption of Phocine Distemper Virus (PDV) and Avian Influenza response plans for seals, across all UK nations. Given the evolving situation with Highly Pathogenic Avian Influenza (HPAI) globally, SCOS encourages UK nations to build on the work done by Scottish Government and SMRU to develop response plans. (Q7)
- Routine disease and health surveillance of live captures, stranded animals and rescues is required to ensure the early detection and monitoring of infectious diseases in UK seals.
- Regular reporting and collection of carcasses in England is vital to address data gaps in causes of death, to contribute to disease and health surveillance. This is also required to contextualise background strandings numbers for the identification of spatial and temporal anomalies that warrant further investigation. (Q7)

Permits & Licences

- The delay between application and granting of authority to conduct studies requiring capture and/or sampling of seals precludes rapid response to the onset of disease events or other acute environmental perturbations. SCOS recommend that a mechanism to allow rapid permitting should be a priority to allow timely responses to unusual events. SCOS recognise that some progress in that regard has been made in Scotland; although there is no specific new mechanism (Q7)

Marine Renewables

- Development of methods is required to improve estimation of the number of individuals exposed to repeated anthropogenic stressor events (e.g. pile driving, collision with tidal turbines) over relevant time periods. At-sea density maps provide static snapshots, but existing telemetry data could provide estimates of the turnover of individuals to improve estimates of cumulative exposure risk. SCOS recommend that regulators and SMRU meet to discuss the current issues. (Q12)
- Additional research is required to understand seal behavioural responses to offshore wind farms. Data available for harbour seals has indicated significant responses to pile driving noise during construction but this is based on data collected on 24 seals during the construction of a relatively small wind farm. It is unclear how transferable these findings are to the wide range of sites and scales now under development and envisaged for future offshore wind. (Q12)
- Work is required to appropriately combine the estimates of avoidance of tidal turbines that exist at a range of spatial scales to derive an overall avoidance rate that can be used as a scalar to current collision risk model outputs. (Q12)

- SCOS recognise that the absence of information on grey seal interactions with tidal energy devices remains a key data gap with respect to understanding the potential risks of tidal turbines to this species. (Q12)
- Future work should explore the effects of operational arrays rather than a single turbine in isolation. It will be important to understand the trade-off between avoidance behaviour that effectively reduces acute impacts from collision risk and exclusion of animals from important habitats. It will be important to consider how seal responses to arrays might be monitored at a variety of spatial scales and the technologies that are available (or need to be developed) to measure this. (Q12)

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 UK Government and devolved administrations 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 2025. It begins with some general information on UK seals, provides information on their current status, and addresses specific questions raised by Scottish Government (SG), the Department of the Environment, Food and Rural Affairs (Defra) and Natural Resources Wales (NRW).

SMRU's long-term funding has recently seen a substantial reduction, and further reductions for the current round of NERC National Capability National Public Good funding (the source of the funding for ongoing seal monitoring and SCOS reporting activities) have been confirmed over the remainder of the grant (to FY 2028/29). This is having an impact on the frequency and types of advice that SMRU can deliver and also impacts SMRU's capacity to conduct underpinning research to understand changes in UK seal populations. Research and advisory activities continue to be reprioritised as necessary, and in response to this reduction in capacity and resource, it was agreed during SCOS (2024) that to mitigate continuing increases in the number and complexity of advice requests, a number of standing questions would be agreed that would form the basis of advice on topics that have formed the basis of questions repeatedly and consistently in recent SCOS Advice, allowing review and update on an annual basis. A total of nine standing questions were drafted and agreed with the government departments (ANNEX II). In addition, each government department was invited to submit up to five additional questions on topics not covered by the standing questions. In 2025, one of the questions submitted by Defra was subsequently adopted as a tenth standing question.

Although this provides a more streamlined mechanism for the delivery of annual SCOS advice, it must also be recognised that to respond to reductions in funding over the coming years, reductions in the frequency and extent of surveys may also be required.

Briefing papers (SCOS-BP 25/01-06) which provide additional scientific background for the advice are appended to the main report.

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 and Churchill, 2011). The population in European waters is the Atlantic subspecies (*Phoca vitulina vitulina*).

Grey seals only occur in the North Atlantic and Barents and Baltic Seas, 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 on the east coast of England is part of the continental European metapopulation (Lonergan et al., 2013; Carroll et al., 2020). 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 into 14 Seal Monitoring Units (SMUs;

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. Except for 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, considering knowledge on population structure where available.

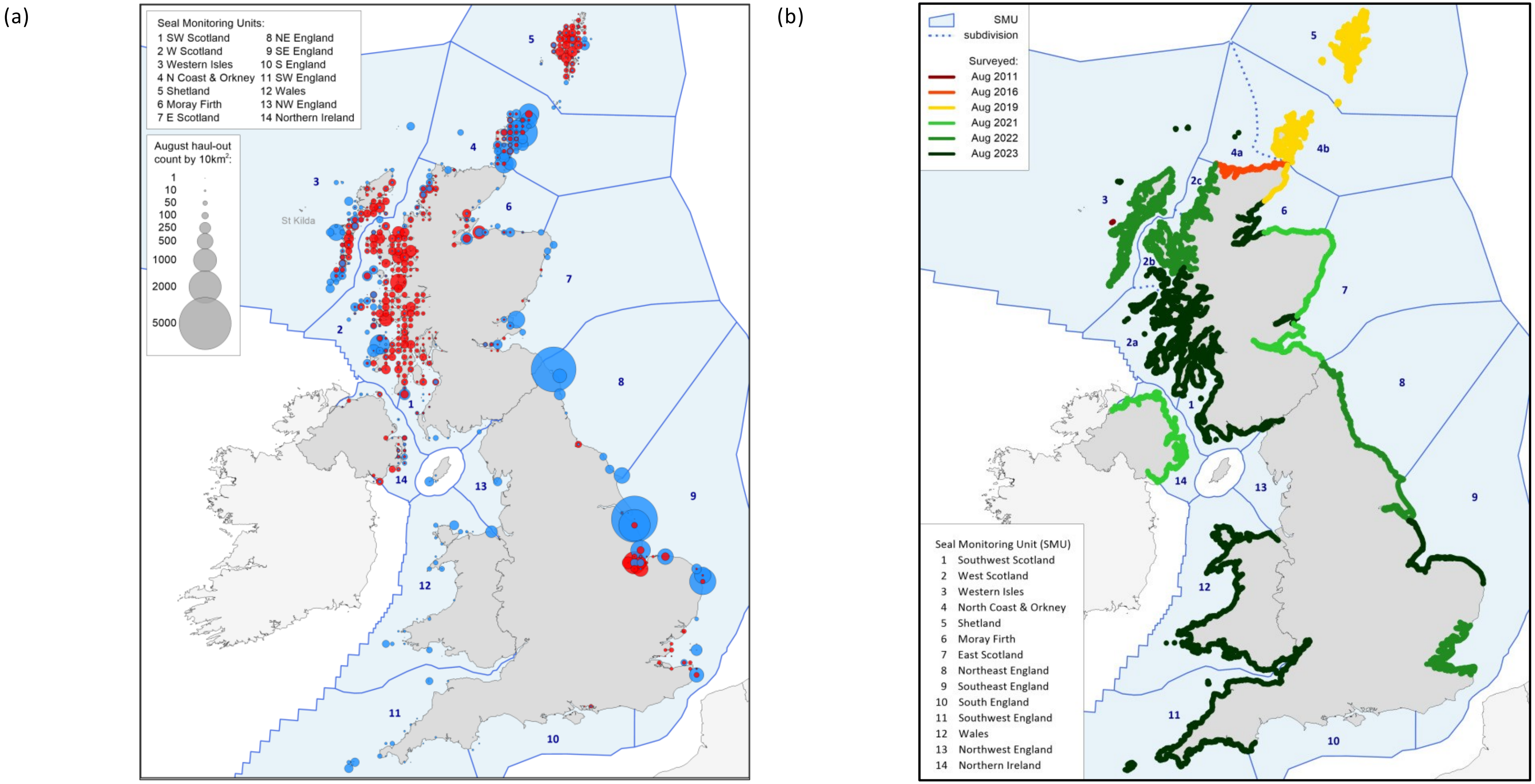

Figure 1. The 14 Seal Monitoring Units (SMUs) used for monitoring and reporting seal abundance and trends. August counts for harbour (red) and grey (blue) seals are shown on a 10 km^2 grid scale using data available from the latest survey year(a). The year pertaining to the most recent August aerial survey data available are shown in (b) aerial survey from year. Data are from aerial surveys conducted by SMRU (and ZSL for SMU 9) in the years shown in (b) and from other organisations (see **Table 1** and SCOS-BP 25/01).

Harbour seals

Adult harbour seals typically weigh 80-100 kg. Males are slightly larger than females. Like grey seals, harbour seals are long-lived with individuals living up to 20-30 years. Harbour seals are generally considered to be more sedentary than grey seals, with few long-range movements between distant haulout sites. Foraging ranges vary substantially both regionally and within sites. Some harbour seals forage >100 km 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 temporal 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 then remained relatively constant , 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 seals

Grey seals are the larger of the two resident UK seal species. Adult males can weigh over 300 kg 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 100 m, 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 and activity of the seal and energy and nutrient content quality 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 100 km 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 100 km 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 (Bergman and Olsen, 1986; Bergman, 1999) . 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, 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 southwest 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 (the 'whitecoat' stage), 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 in 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. Currently, seals in the UK 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 (1970) 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. 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 fisheries or aquaculture activities. These changes allows the UK to comply with the US Marine Mammal Protection Act Import Provision Rule.

In Scotland, it is also an offence to 'intentionally or recklessly harass' seals at designated haul-out sites. NERC (through SMRU) provide advice on haul out designations and are a statutory consultee in relation to seal licence applications.

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 SACs have been designated specifically for seals, and seals are considered 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 and an updated assessment is currently underway by JNCC.

Seal population status and trends

1. **What are the latest estimates and trends in the number of seals in the UK and by individual UK country?**

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 2023 (SCOS-BP 25/01). In 2023, helicopter surveys were conducted covering the whole of the Southwest Scotland SMU and part of the West Scotland SMU (the rest was surveyed in 2022). In 2024, fixed-wing pup surveys were conducted in The Wash (and reported here), and August surveys of parts of Moray Firth, East Scotland, and Southeast England SMUs (to be reported in SCOS 2026). In addition, counts from helicopter surveys of Northern Ireland in 2024 will be reported in SCOS 2026.

The current estimate of the UK harbour seal population is36,956 (95% CI: 30,236-49,274; Table 1). This is derived from the most recent composite count of 26,608 (based on surveys largely conducted between 2019 and 2023; SCOS 25/01), 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 30,890 in Scotland (95% CI: 25,274 - 41,187), 4,928 in England (4,032-6,570), 1,136 in Northern Ireland (930 - 1,515), and less than 5 in Wales.

The survey frequency varies by SMU, from once every five years to multiple times each survey season. Thus, to examine trajectories 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 (2019-2023) British harbour seal population is estimated to be around 21% lower than in the late 1990s; 25% 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. Indeed, compared to the composite count (2011-2015) prior to the recent decline in Southeast England, the latest estimate for England is 27% lower. In terms of the most recent trend, the current estimate for the UK is 16% lower than the previous composite count (2016-2019): 17%, 8%, and 23% lower for Scotland, England and Northern Ireland, respectively. It should be noted that the last survey of North Coast & Orkney and Shetland SMUs (2019) are used in the two most recent composite counts.

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 and thus power to detect trends (Figure 2; see SCOS-BP 25/03 for more details). No harbour seal SMUs with notable numbers (>250 individuals) are predicted to be still increasing; even for SMUs not depleted (i.e. estimated not to be significantly lower than the highest point in the time series) the latest count was lower than the previous one. With the potential exception of Western Isles, the western Scotland SMUs are still at high levels (compared to the start of the time series; early 1990s), but the most recent count for all three SMUs in western Scotland was lower (~20% across the three SMUs) than the previous count which, taken together, is concerning for this area which encompasses over 60% of the UK total. In terms of the estimated current trends, Southwest Scotland is stable whereas West

Scotland and Western Isles is in significant decline. North Coast & Orkney, East Scotland, Shetland and Moray Firth SMUs are depleted compared to the start of the time series (1990s). The North Coast and Orkney and East Scotland SMUs are still declining whereas Shetland and Moray Firth SMUs are depleted but stable. It should be noted that the latest survey for North Coast & Orkney and Shetland SMUs was in 2019. Southeast England SMU is depleted (since 2018) and showing no sign of recovery; it is not clear if it is still declining. 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 all 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 typically 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 Northern Ireland Department of Agriculture, Environment and Rural Affairs (DAERA; see Table 1). 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 (sources in Table 1); less than 100 harbour seals are counted in the other SMUs. 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 in August of a single year; 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; 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, and parts of Southeast England SMU are generally surveyed at least annually by fixed-wing aircraft. However, following reductions in funding, this frequency is unlikely to be maintained in future years.

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. 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 in 2009(Lonergan et al., 2013). The estimated variation in proportion of the population hauled out results in considerable uncertainty in the final population estimates (Table 1). 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. Ries et al., 1998; Huber et al., 2001; Simpkins et al., 2003; Harvey and Goley, 2011). 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 a lower 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 presented in this SCOS report are from surveys in 2023 (see SCOS-BP 25/01 for more details) and a 2024 pup survey of The Wash (see SCOS-BP 25/05). In 2023, helicopter surveys were conducted covering the whole of Southwest Scotland SMU and part of the West Scotland SMU (the rest was surveyed in 2022). In 2024, SMRU conducted helicopter surveys of Northern Ireland (to be reported in SCOS 2026) as well as conducting commissioned surveys of Republic of Ireland. Due to camera failure, surveys of North Coast & Orkney and Shetland SMUs were postponed to 2025. In 2024, fixed-wing August surveys of parts of Moray Firth, East Scotland, and Southeast England SMUs were also conducted (to be reported in SCOS 2026).

Based on the latest surveys, up to and including 2023 where available, the current best estimate of the UK harbour seal population in 2023 is **36,956 (95% CI: 30,236 - 49,274)**. This is derived from the most recent composite count of **26,608** (based on surveys largely conducted between 2019 and 2023**;** Table 1), divided by the estimated proportion of the population hauled out during the surveys (0.72; 95% CI: 0.54-0.88; Lonergan et al., 2013). By country, the total population estimate is 30,890 in Scotland (95% CI: 25,274 - 41,187), 4,928 in England (4,032 – 6,570), and 1,136 (930 - 1,515), in Northern Ireland, with less than five seals 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 trajectories, generally representing consecutive 5-year periods. The longest time-series is for Britain (i.e. UK excluding Northern Ireland); the current (2019-2023) British harbour seal population is estimated to be around 21% lower than in the late 1990s; 25% 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.

Table 1. The most recent August counts, up to 2023, of harbour seals at haul-out sites in the UK by Seal Monitoring Unit (SMU) and country compared with previous periods. The grey values given for SMUs 10-13 are estimates. The grey italic values in the most recent count column do not contain any new data compared to the 2016-2019 period. The latest population estimates use scalars derived from (Lonergan et al., 2013).

			Harbour seal counts							Latest population estimate		
Seal Monitoring Unit / Country			**1996-1997**	**2000-2006**	**2007-2009**	**2011-2015**	**2016-2019**	**Most recent count data to 2023**		**mean**	**95% CIs**	**% of UK total**
1	Southwest Scotland		929	623	923	1,200	1,709	1,563	(2023)	2,171	(1,776; 2,894)	5.9%
2	West Scotland	a	8,811	11,666	10,626	15,184	15,600	11,754	(2022; 2023)	16,325	(13,357; 21,767)	44.2%
3	Western Isles		2,820	1,920	1,804	2,739	3,532	3,080	(2022)	4,278	(3,500; 5,704)	11.6%
4	North Coast & Orkney		8,787	4,388	2,979	1,938	1,405	*1,405*	*(2016; 2019)*	1,951	(1,597; 2,602)	5.3%
5	Shetland		5,994	3,038	3,039	3,369	3,180	*3,180*	*(2019)*	4,417	(3,614; 5,889)	12.0%
6	Moray Firth		1,409	1,028	776	745	1,077	983	(2019; 2021; 2023)	1,365	(1,117; 1,820)	3.7%
7	East Scotland		764	667	283	224	343	276	(2021; 2023)	383	(314; 511)	1.0%
SCOTLAND total			29,514	23,330	20,430	25,399	26,846	22,241	(2016; 2018: 2019; 2021-2023)	30,890	(25,274; 41,187)	83.6%
8	Northeast England	b	54	62	58	91	79	106	(2020; 2022; 2023)	147	(120; 196)	0.4%
9	Southeast England	c	3,222	2,964	3,952	4,740	3,752	3,372	(2022; 2023)	4,683	(3,832; 6,244)	12.7%
10	South England	d	10	15	15	25	40	65	(estimate)	90	(74; 120)	0.2%
11	Southwest England	d	0	0	0	0	0	0	(2023)	0	(0; 0)	0.0%
13	Northwest England	d	2	5	5	5	5	5	(estimate)	7	(6; 9)	0.0%
ENGLAND total			3,288	3,046	4,030	4,861	3,876	3,548	(2020; 2022; 2023)	4,928	(4,032; 6,570)	13.3%
WALES		e	2	5	5	10	10	1	(2023)	1	(1; 2)	0.0%
BRITAIN total			32,804	26,381	24,465	30,270	30,732	25,790	(2016; 2018-2023)	35,819	(29,307; 47,759)	96.9%
NORTHERN IRELAND		f		1,176	1,101	948	1,062	818	(2021)	1,136	(930; 1,515)	3.1%
UK total				27,557	25,566	31,218	31,794	26,608	(2016; 2018-2023)	36,956	(30,236; 49,274)	

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, 2024). 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 (Westcott, 2002; Sayer, 2010, 2011; Boyle, 2012; Sayer et al., 2012; Hilbrebirdobs blogspot, n.d.). **e)** For Wales, counts 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).

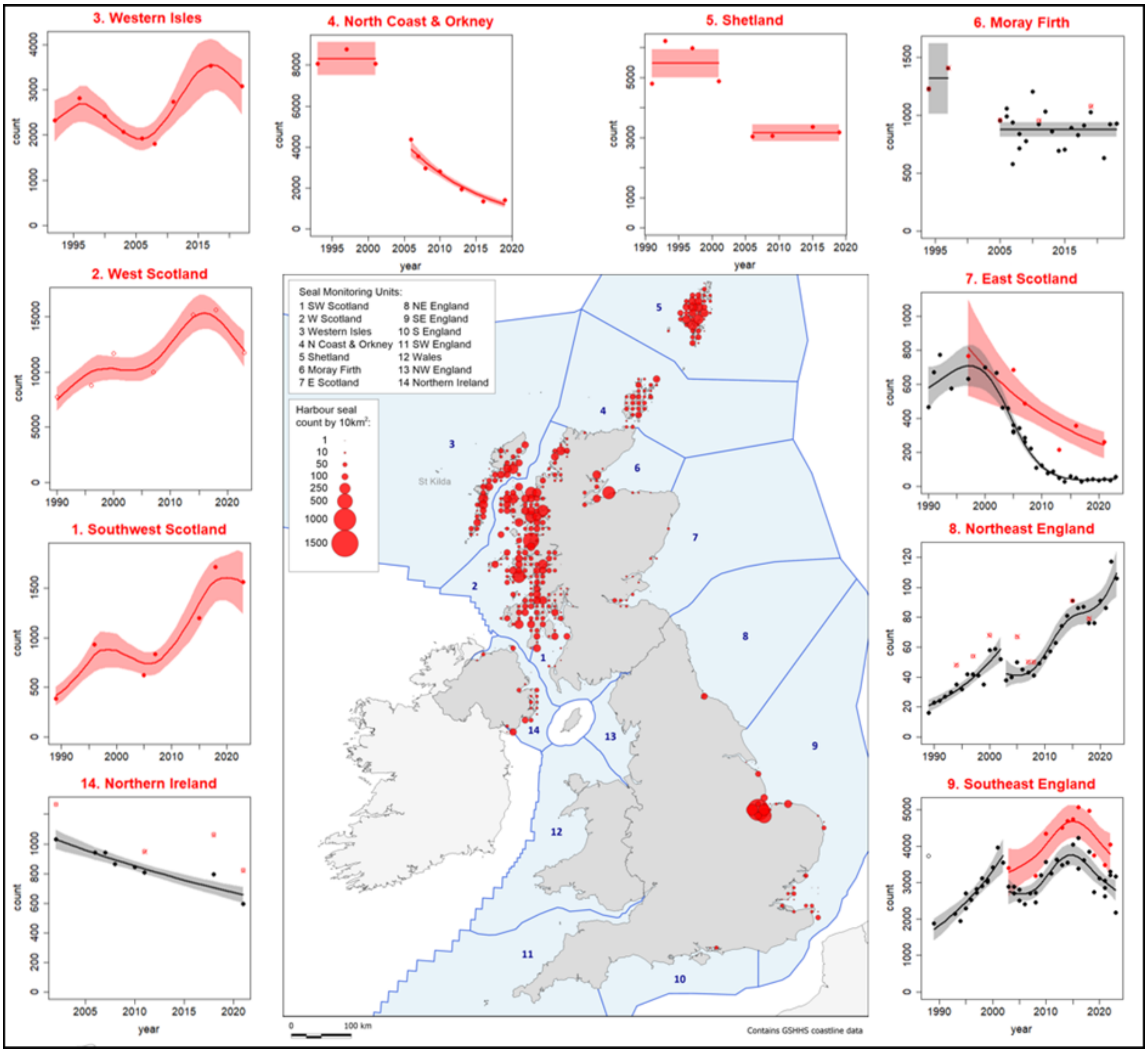

Figure 2. Map of August haulout density of harbour seals around the UK per 10 km^2 based on the most recent available count data collected up until 2023 (coastline from GSHHS). Less than 100 harbour seals are in SMUs 10-13. For SMUs 1-9 and 14, the counts by year, and trend lines and associated 95% confidence intervals are shown in red. The black lines indicate the use of a subset of the SMU. For more details see SCOS-BP 25/01 and 25/03. 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. 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). As in previous SCOS reports, additional models were fit allowing a step change around and/or differing trends before and after the 2002 Phocine Distemper Virus (PDV) outbreak. In addition, for SCOS 2025, additional models were fitted for western Scotland SMUs in response to the latest count data (2022/2023). See details below and in SCOS-BP 25/03.

Northeast and Southeast England SMU populations have generally shown increasing overall trends, interrupted by sudden, drastic declines caused by the 1988 and 2002 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 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 drivers 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. Surveys of the Wash & North Norfolk Coast SAC have a longer temporal extent than surveys of the Southeast SMU as a whole, are more frequent, and account for the majority of the harbour seals in this SMU.

For all three western Scotland SMUs, the latest count was lower than the count from the previous survey (and the one before that for West Scotland). West Scotland is the largest SMU, both geographically (length of coastline) and in terms of proportion of the UK total abundance for harbour seals, and is thus split into three subdivisions (2a-2c: South, Central, and North). The trend analyses were previously conducted separately for each SMU, subdivision and SAC, and the restricted frequency of surveys (every 4-6 years) means that the power to detect initial declines was very limited. Visual inspection of the data for the SMUs and subdivisions indicated similar patterns across western Scotland. As such, two additional GAMs were fitted considering five separate regions; SMU 1, the subdivisions of SMU 2 (but not SMU 2 as a whole), and SMU 3. All regions were modelled together, allowing their trends to be a combination of a shared and regional-level trend. Due to the increased robustness and power associated with this additional analysis, the results of this analysis, rather than the one conducted as for other SMUs, are presented here.

Except for Southwest Scotland (predicted to be stable), all SMUs which host notable numbers (> 250; SMUs 1-7, and 9) are predicted to be declining and/or depleted (estimated to be significantly lower than the highest point in the time series) at the latest survey (Table 1). It should be noted that the most recent survey data for North Coast & Orkney and Shetland SMUs are now over five years old (2019). Prior to the latest count, the western Scotland SMUs had been the only SMUs for which abundance was predicted to be increasing. The indication that this area could also be in decline is of particular concern given that the three western Scotland SMUs combined host over 60% of the UK total. North Coast & Orkney and East Scotland SMUs are depleted and predicted to be in decline, whereas Shetland and Moray Firth SMUs are depleted but appear stable. Southeast England SMU is depleted (since 2018) and showing no sign of recovery; it is not clear if it still declining. The cause of that decline is the subject of a current SMRU-led project (see Q7 for updates on health workpackage). 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 (funded by Natural England; SCOS-BP 25/05). 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 a season (most recently in 2015 and 2016; Thompson et al., 2016) indicate that the peak number of pups on the sandbanks occurs 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 2024, the pup count was 896, which is almost 37% lower than in 2023. The mean maximum pup count (2022-2024: 1150 pups) since the drop in the moult count (between 2018 and 2019) is substantially lower (~23.5%) than the mean maximum number of pups in the five years preceding the decline (2014-2018: 1505 pups). The particularly low 2024 pup count is of concern; it indicates the population is unlikely to be recovering and may decline further.

UK harbour seal populations in a European context

The UK is a key centre of abundance for harbour seals in Europe, hosting approximately 28% of the total (Table 2). This is a decreased percentage holdings compared to historically (2000) due to declines in Scotland (since early to mid 2000s), the recent decreases in Southeast England (2019), and the most recent decline in west Scotland.

Table 2. Latest estimates of the relative size of European populations of harbour seals up to 2023. Data are counts of seals hauled out during the moult. Counts are rounded to the nearest 50.

Region	Number of seals counted	Most recent survey years	Source
UK	26,600	2019-2023	SCOS-BP 25/01
Ireland	4,000	2017-18	Morris and Duck, 2019)
France	1,550	2023	Poncet et al., 2024
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
Limfjorden	1,400	2023	ICES, 2025
Kattegat	9,050	2023	ICES, 2025
Skagerrak	4,300	2023	ICES, 2025
Baltic – Kalmarsund	2,500	2023	ICES, 2025
Baltic – Southwestern	1,650	2023	ICES, 2025
Norway	7,900	2009-2010, 2016-2023	Nilssen et al., 2021; ICES, 2025
Svalbard	1,900	2010	Merkel et al., 2013
Iceland	10,300	2020	Granquist, 2022
Europe excluding UK	**68,700**		
Europe – total	**95,300**		

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 (see harbour seal section). Pup production from aerially-surveyed colonies (Scotland and eastern England excluding Shetland), is estimated by combining count data from 4 to 5 surveys with life history and observation parameters. Pup production estimates for Shetland, Southwest England, Wales, and Northwest England are generally from boat-/ground-surveys. While pup production time-series provide the main metric of the UK population changes, August haulout counts are also critical. Indeed, distribution during the foraging season (represented by August counts) indicates 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 consistent August surveys are required for robust Potential Biological Removal estimates. Here we report on the latest pup production estimates and August counts, with updates from 2023; pup production in East Scotland, Northeast England and Southeast England; and August counts mainly from Southwest and West Scotland (Table 3). Pup production estimates from SMRU 2022/2023 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 79,122: 55,095 in Scotland (~70%), 21,027 (~27%) in England, 2,500 in Wales, and 500 in Northern Ireland. The latest August counts were 21,306 in Scotland, 17,075 in England, 1,313 in Wales, and 549 in Northern Ireland.

At a national scale, current trajectories can be inferred through changes in pup production and composite August counts. Total UK pup production in 2022/2023 was estimated to be ~2.5% higher than in the last main survey period (2019-2021). In Scotland, pup production in 2022/2023 was almost 3% lower than in 2019, while in England (majority surveyed in 2023) pup production was estimated to be ~18% higher than in 2021. For a small proportion of colonies, the same estimates were used across the two periods. The latest UK (largely 2019-2023) composite August count was ~6% lower than the previous time period (2016-2019); 16% lower for Scotland, and 7% higher for England. It should be noted that counts from the last August surveys of North Coast & Orkney and Shetland SMUs (from 2019) are used in both periods. The total UK August count is ~55% higher than in the early 2000s, entirely due to the increase in England (346%). The differences in percentage of the UK total in each nation, and the trajectories therein, between seasons (breeding versus August) , indicates marked seasonal redistribution. Scotland hosts ~70% of UK pup production but just over half (53%) of total UK count in the summer. The UK hosts a higher proportion of the Northeast Atlantic grey seal metapopulation during breeding than during the summer. Grey seal pup production is used globally as an abundance metric; UK pup production represents approximately 38% of the global production (Table 4).

Trends in abundance at the SMU and SAC levels are assessed by fitting models to time-series of pup production estimates and August counts. It should be noted that the higher uncertainty around the mean proportion of the population hauled out in August means the power to detect trends is relatively low for these counts (compared to pup production) especially in SMUs that are not monitored annually. After an extended 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. In North Coast & Orkney, pup production and August counts (latest counts 2019) have both remained stable since the early 2000s. For Shetland, there is an indication of a decline in pup

production (latest comprehensive data 2018), but the August count (latest count 2019) shows no trend. Production in all east coast SMUs (Moray Firth, East Scotland, Northeast England, Southeast England) is estimated to be increasing, although the last three estimates (2018-2023) for East Scotland are all similar indicating that the subpopulation may have reached carrying capacity in that SMU. 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 the highest levels observed throughout the time-series.

A Bayesian model integrating information on life history and demographic parameters, pup production data, and scaled August haul out counts, was used to estimate population size and trajectories, as described in previous SCOS reports. In 2024, SCOS concluded that, due to the poor fit to recent data, the population model in its current form should no longer be used to generate population estimates. Instead pup production estimates and August counts should be used instead of modelled population estimates.

Pup Production

UK grey seal abundance and trends have been primarily assessed based on pup production estimates, though numbers counted during August were also considered. The temporal extent of the grey seal breeding season means that any one pup count represents an unknown proportion of the total number of pups produced. Thus, SMRU conduct multiple aerial surveys through a season (usually four or five), and pups are classified as either 'whitecoat' or 'moulted'. Pup production at aerial-surveyed colonies is estimated by combining these classed 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 considered here 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. From 2018, key colonies in eastern England (see below) were included in the aerial survey program. As a result of this increased spatial extent, and decreased funding, key colonies in Scotland and eastern England are surveyed every two to three years. The most recent available pup production estimates are from surveys carried out in 2023 for East Scotland, Northeast England and Southeast England SMUs. The results of these surveys are summarised below and covered in detail in SCOS-BP 25/02. The surveys in 2023 were the first surveys with a new camera system (Phase One).

Pup production estimates from the SMRU 2022/2023 surveys, combined with estimates up to 2023 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 79,122 (Table 3); 55,095 in Scotland, 21,027 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 (Hasselblad) aerial surveys for most Scottish SMUs (from 2012) and from ground to aerial surveys for eastern England (from 2018). It is not expected that the change from Hasselblad (2012-2022) to Phase One (2023 onwards) resulted in markedly different estimates (see SCOS 25/06). Nevertheless, to avoid Phase One-derived estimates impacting the estimation of changes in pup production associated with historic changes in method (film to digital and ground to digital aerial surveys), the previous estimated changes (SCOS 24/03 and 24/08) were applied to this time-series. These changes are described briefly below. The results of the trends analyses of both pup production and August counts are described in the Trends section.

For logistical and technical reasons, it was not possible to directly cross-calibrate the film and digital aerial surveys. In all SMUs in which the pup production time-series is derived from aerial survey counts, there was an apparent jump in observed production coinciding with the change in methods. Using production estimates up to 2022, 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 jump was applied to the latest trend analyses (SCOS-BP 25/03), to allow estimation 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 (SCOS-BP 24/08), indicates that true pup production is most likely nearer to the estimates associated with digital (compared to film) based estimates.

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 made counting increasingly labour intensive, and in some cases, counting was 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 breeding 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. It is hoped that drone surveys may eventually replace the aerial surveys in eastern England (see Q 9). Indeed, drone surveys were trialled at Horsey in 2023 (Natural England) and have been used to survey the Farne Islands (see SCOS-BP 25/06).

Using data up to and including 2021, ground- and aerial-based (from 2018) 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 (i.e. the ground-based estimates were used directly up to 2017). For Donna Nook, the aerial-based estimates were estimated to be ~25% higher than the ground-based, and thus the ground-based estimates (up to 2017) were scaled up to provide a consistent time-series. For Blakeney, ground-based production estimates up to 2014, and aerial-based estimates in 2018 and 2021, were used to generate a time-series (see SCOS-BP 24/08 for details). The new pup production estimates (2023) were used to extend the time-series described in SCOS-BP 24/08.

The map of the SMU boundaries and the distribution of grey seal pups born within them is presented in Figure 3. The results of the trend analyses are summarised at the end of this answer (see SCOS-BP 25/03 for more details).

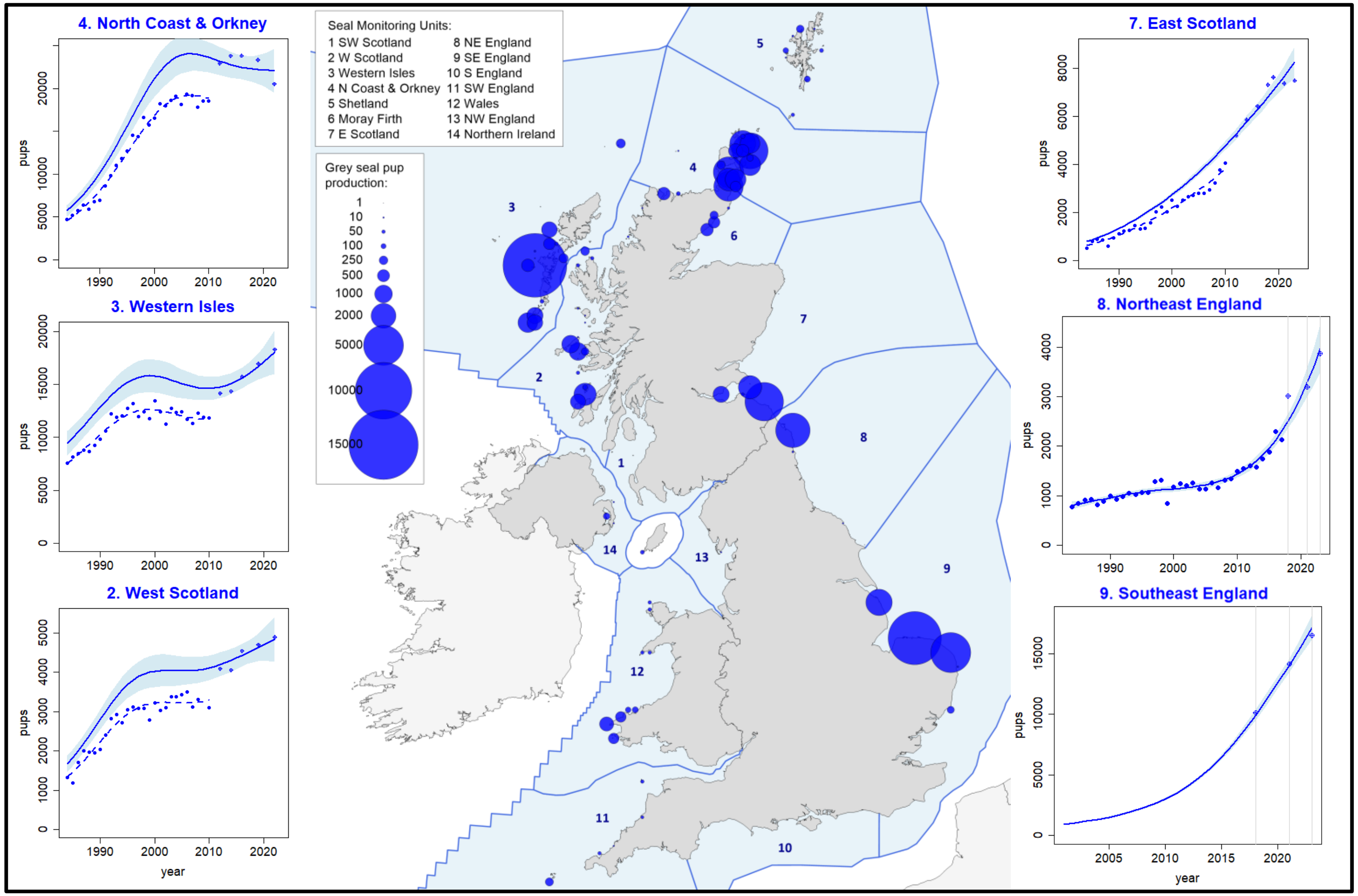

Figure 3. Distribution and estimated pup production of key UK grey seal breeding colonies; dark blue circles represent colonies included in trend analyses. SMU boundaries are shown in blue. Pup production estimates by year, and predicted trend and associated 95% confidence intervals, are shown (dotted 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. The grey lines indicate the three aerial surveys conducted in eastern England.

Table 3. The most recent August counts (and associated population-level estimates) and pup production estimates for grey seals by Seal Monitoring Unit and country, along with the percentage of UK holdings. For more details see SCOS-BP 25/01 and SCOS 25/02.

Seal Monitoring Unit / Country		Most recent August haulout counts to 2023	Latest population estimate: mean	95% CIs	% of UK total		Latest grey seal pup production estimates: Colonies regularly surveyed by plane	Other colonies	Total	% of UK total
1 Southwest Scotland		760 (2023)	3,022	(2,614; 3,543)	1.9%		0	5 (2020)	5	0.0%
2 West Scotland	a	4,508 (2022; 2023)	17,924	(15,507; 21,016)	11.2%		4,893 (2022)	450 (2005-2019)	5,343	6.8%
3 Western Isles		3,473 (2022; 2023)	13,809	(11,947; 16,191)	8.6%		18,272 (2022)	300 (2008)	18,572	23.5%
4 North Coast & Orkney		8,618 (2016; 2019; 2023)	34,266	(29,646; 40,177)	21.4%		21,143 (2019-2022)	20 (2010-2019)	21,163	26.7%
5 Shetland		1,009 (2019)	4,012	(3,471; 4,704)	2.5%		0	760 (2012)	760	1.0%
6 Moray Firth		1,354 (2019; 2021; 2023)	5,384	(4,658; 6,312)	3.4%		1,715 (2022)	0	1,715	2.2%
7 East Scotland		1,584 (2021; 2023)	6,298	(5,449; 7,385)	3.9%		7,502 (2023)	35 (2023)	7,537	9.5%
SCOTLAND total		21,306 (2016; 2018: 2019; 2021-2023)	84,716	(73,292; 99,329)	52.9%		53,525	1,570	55,095	69.6%
8 Northeast England	b	5,381 (2020; 2022; 2023)	21,396	(18,510; 25,086)	13.4%		3,997 (2023)	35 (2016-2018)	4,032	5.1%
9 Southeast England	c	10,735 (2022; 2023)	42,684	(36,928; 50,047)	26.7%		16,485 (2023)	5 (2023)	16,490	20.8%
10 South England	d	50 (estimate)	199	(172; 233)	0.1%	g	0	5 (2023)	5	0.0%
11 Southwest England	d	729 (2023)	2,899	(2,508; 3,399)	1.8%	h	0	490 (2016-2023)	490	0.6%
13 Northwest England	d	180 (2023)	716	(619; 839)	0.4%	i	0	10 (2023)	10	0.0%
ENGLAND total		17,075 (2020; 2022; 2023)	67,893	(58,738; 79,604)	42.4%		20,482 (2023)	545	21,027	26.6%
WALES	e	1,313 (2023)	5,221	(4,517; 6,121)	3.3%	j	0	2,500 (to 2023)	2,500	3.2%
BRITAIN total		39,694 (2016; 2018-2023)	157,829	(136,546; 185,054)	98.6%				78,622	99.4%
NORTHERN IRELAND	f	549 (2021)	2,183	(1,889; 2,559)	1.4%	k	0	500 (to 2020)	500	0.6%
UK total		40,243 (2016; 2018-2023)	160,012	(138,435; 187,613)	100.0%		74,007	5,115	79,122	

SOURCES - Most August data were obtained from aerial surveys conducted by SMRU and were funded by the Natural Environment Research Council (NERC) and NatureScot (for Scottish surveys). For August surveys (superscript letters **a-f**), refer to **Table 1**. Unless otherwise indicated most pup production estimates were derived from aerial surveys conducted by SMRU and were funded by NERC. For pup production, superscript letters **g-k** indicate estimates generated by SMRU on the basis of the resources listed here: **g)** Chichester Harbour Conservancy, **h)** (Sayer and Witt, 2017a, 2017b; Sayer et al., 2020; Lundy Field Society, 2023), **i)** Cumbria Wildlife Trust, **j)** 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; Büche and Bond, 2023; Stephens, 2023), **k)** Northern Ireland Department of Agriculture, Environment and Rural Affairs.

August Counts

SMRU also survey grey seals in August (SMUs 1-9). In 2023, SMRU also conducted a survey of Southwest England and Wales (funded by JNCC and NRW, 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). Indeed, based on telemetry data, it is estimated that 25.2% (95% CI: 21.5-29.1%) of the population is hauled out during the specific survey window and thus available to be counted (Russell and 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. Distributions 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.

The total composite count for grey seals around the UK (mainly from 2019-2023) is 40,243 (see SCOS-BP 25/02 for more details); a total population of ~160,012 (95% CI: 138,435-187,613; Table 3). The trends in August counts, and pup production, are presented in SCOS-BP 25/03 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.

Trends

At a UK and national level, changes in pup production and composite August counts can be used to infer trajectories. At the UK level estimated pup production in 2022/2023 was ~2.5% higher than in the last main survey period (2019-2021). In Scotland, estimated pup production in 2022/2023 was almost 3% lower in 2022/2023 than in 2019. In contrast, in England it was ~18% higher in 2023 compared to 2021. It should be noted, however, that for a small proportion of colonies, the same estimates were used across the two periods. The latest UK composite (largely 2019-2023) August count was ~6% lower than the previous time period (2016-2019). Specifically, it was 16% lower for Scotland, but 7% higher for England. It should be noted that the last surveys of Shetland and North Coast & Orkney SMUs (2019) are used in both these time periods. Some of the increase in England is due to the use of counts for the latest period rather than estimates (used for the previous period). In total, the UK count is ~55% higher than in the early 2000s, entirely due to the increase in England (346%). The differences in trajectories between breeding and summer metrics of abundance, are a result of seasonal movements.

Trends at 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, as well as August count data. Pup production in West Scotland and Western Isles was estimated to be at an all-time high (2022) 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 was also predicted to be increasing. In contrast, August counts in the Western Isles are variable and show no apparent trend. Pup production and August counts in North Coast & Orkney have remained stable since the early 2000s. For Shetland, the August counts show no trend; there is an indication of a decline in pup production in Shetland. Pup production for east coast SMUs was estimated to be increasing (2022: Moray Firth; 2023: East Scotland, Northeast England, Southeast England). It should be noted that the East Scotland pup production estimate was similar across the last three surveys (since 2018), indicating that SMU may be nearing carrying capacity. 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.

Ground surveys were conducted at some east coast colonies in 2024, a year for which no aerial surveys were conducted. These surveys indicated that pup production was lower than expected in 2024 for some colonies (NatureScot, Fife Seal Group, National Trust for Scotland, Lincolnshire Wildlife Trust, Friends of Horsey Seals; see (SMRU Press Release, 2025) for more details). It is not yet clear whether this apparent decline represents a decrease at a SMU level. Based on aerial survey data, 16,485 pups were estimated to have been born in Southeast England SMU in 2023. At Donna Nook, the Humber Estuary SAC, ground-based surveys indicated that numbers were ~25% lower in 2024 than in 2020-2023 (when ground-based estimates were constant ±100 pups). On a colony level, grey seal pup production is rarely stable, instead often increasing to a peak then falling, and estimates based on aerial surveys indicated that Donna Nook was already in decline in 2023. There was also a drop in ground-based estimates for Horsey between 2023 and 2024, but this may have been due to groyne construction activities on the beach. These apparent falls could have been completely offset by increases at Blakeney (not surveyed in 2024). Blakeney is now the biggest colony on the UK east coast; almost 9,000 pups were born there in 2023 (>50% of the Southeast England SMU total). Surveys conducted by the National Trust revealed that the recently established colony at Orford Ness continued to increase between 2023 and 2024, but the colony is still relatively small (~250 pups).

In Southwest England SMU, Seal Research Trust also reported a decrease in mainland Cornwall (~a third of total SMU pup production) pup production in 2024. The 2024 count, derived from ground-based surveys, was 171, compared to 191 in 2023. However, the pup count in the Lundy SAC continued to increase between 2023 and 2024 (Lundy Field Society).

UK grey seals in a world context

The UK grey seal population represents approximately 38% 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 global range.

Population size

In previous SCOS reports (including SCOS 2024), a population model was used to estimate total population size and trajectories. Specifically, the total grey seal population (1+ aged population, referred to as 'adult population') was estimated within a Bayesian state-space population dynamics model (Thomas et al., 2019) 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. The model also used three estimates of population size from scaled up August counts from years surrounding 2008, 2014 and 2017. These estimates were from composite counts and adjusted to represent the proportion of pup production in SMUs 1-9 included in the model. The model incorporated prior estimates of fecundity rates, survival rates (pup and 1+) and sex ratio. The inclusion of the summer estimates of population size indicated that density dependence was acting through pup survival rather than fecundity.

The fit of the model to the pup production estimates had been poor in some regions in recent years (SCOS 2022). Whilst the model accurately captured 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. For SCOS 2024, fit issues were 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 (i.e. stable conditions), and thus was 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 was 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%). In addition, there are indications of considerable movements outwith the area considered by the model; both in terms of temporary movements between breeding and summer seasons (Russell et al., 2013) and recruitment (Brasseur et al., 2015). The former is likely, in part, responsible for the mismatch between population estimates derived from the population model, and those estimated from scaling summer haulout counts. SCOS recommends that to enable robust estimation of both the grey seal breeding and summer populations, a metapopulation model needs to be developed. This would also allow explicit modelling of inter-seasonal movements, and thus the relationship between where resources are gained (e.g. during the summer), and where those resources are utilised (breeding season). As such, the impact of removals from components of the metapopulation could be modelled, and safe limits of removal estimated. However, additional funding would be required to develop such a model.

In 2024, SCOS concluded that, due to the poor fit to recent data, the population model, in its current form, should no longer be used to generate population estimates. Most countries in Europe use pup production or peak pup count as an index of grey seal abundance, and thus limited scalars to population size exist. Moreover, the true scalar will depend on the age-sex structure of the population, which itself will be impacted by drivers of population change (e.g. density dependence acting on pup survival).

Table 4. Relative sizes and status of grey seal populations using estimated pup production (to nearest 50; up to 2023) as an index of population size.

Region	Pup Production	Year	Trend	Source
UK	**79,100**	**2022/2023**	**Increasing**	**SCOS BP 25/02**
Isle of Man	**100**	**2023**	**Increasing**	**Manx Wildlife Trust (2023)**
Ireland	**2,100**	**2012**	**Increasing**	**Ó Cadhla et al. (2013)**
Wadden Sea & Helogoland	**2,550**	**2023**	**Increasing**	**Schop et al. (2024)**
Dutch Delta	**50**	**2021-2022**	**Increasing**	**Hoekstein et al. (2023)**
France	**100**	**2023**	**Increasing**	**Poncet et al. (2024)**
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	**24,550**			
Canada - Sable Island & coastal Nova Scotia	**81,300**	**2021**	**Possibly declining**	**de Heyer et al. (2024)**
Canada - Gulf of St Lawrence	**16,900**	**2021**	**Increasing**	**de Heyer et al. (2024)**
USA	**6,650**	**2021**	**Increasing**	**Wood et al. (2022)**
WORLD TOTAL	**208,500**		**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 are the latest available August counts/pup production estimates and trends for Special Areas of Conservation in Scotland and England in the context of their SMUs.

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 25/03 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) ; one long-term (LT) metric: since 1992 or the first year in time series that start after 1992 year thereafter; and finally, change since any historic high in the time series (HH year). Unless otherwise stated, changes in the metrics described below are considered significant if the 95% confidence intervals do not encompass 0. For the LT and HH metrics, SMUs/SAC with significant negative values are considered depleted.

For harbour seals, following the incorporation of the 2023 August surveys (West Scotland), all SACs are now either declining (ST1 and/or ST6) or depleted (LT and/or HH). The SACs are exhibiting similar or more marked declines/levels of depletion compared with the SMU in which they are encompassed. There are three SACs in the declining West Scotland SMU; the two (South-East Islay Skerries and Eileanan agus Sgeiran Lios mor) in the south subdivision are significantly declining and depleted (ST1, ST6, LT, HH). There is no significant current trend for Ascrib, Isay and Dunvegan SAC (surveyed in 2022; central subdivision), but it is depleted compared to a historic high (HH 2003). Recent harbour seal pup counts are only available for The Wash; the 2024 count indicated a continued decline.

For trend analyses of grey seal pup production, changes in production estimates associated with a change in methods – from aerial film to digital surveys in Scotland and from ground to digital aerial surveys in eastern England – were accounted for, and thus the estimated rates of change likely reflect the true trajectory. In general, the trends in pup production within SACs are less favourable than for the SMUs which encompass them. It should be noted that for grey seals, individual colony trajectories are often not representative of area-wide (e.g. SMU) trends. Grey seal 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 short-term scale (ST1 or ST6), pup production has increased only in two SACs (English component of Berwickshire & North Northumberland Coast and Lundy SACs). 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.

The derivation of 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., 2022), OSPAR considered a set Assessment Year (2019) against which changes were assessed on a short- (six year; ST6) or 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 OSPAR 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 years (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 did 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 the Seal Monitoring Unit (SMU) scale (SCOS-BP 25/03). Changes in the four metrics for all Scottish and English SACs are discussed. Note that any changes (increases, decreases)) described below are statistically significant changes (at 5% level) unless otherwise stated. Note that depletion is used to indicate significant negative changes for LT and HH metrics. 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 50 km 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 index of fecundity, and provide an indication of the condition of the local population. 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 integrating trends in pup counts into SAC Assessments would not be straightforward for the following reasons. 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. Harbour seals do show short-range movements between breeding and moult in some places. 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 a fecundity index.

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

Following the incorporation of the 2023 August surveys, abundance in West Scotland SMU appears to be in decline (ST1, and for south subdivision and West Scotland as a whole, ST6). The two SACs in the south subdivision (Eileanan agus Sgeiran Lios mor SAC, Southeast Islay Skerries SAC) are estimated to be declining (ST1, ST6) and depleted (LT, HH). Estimated abundance in the Ascrib, Isay and Dunvegan SAC (central subdivision) has decreased but not significantly (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, whereas the former two SACs were surveyed in 2023.

Western Isles SMU: Sound of Barra SAC

Abundance in the Western Isles SMU is estimated to have declined to the last survey in 2022, significantly so for ST1 but not on a longer time-scale (ST6, LT, HH). In contrast, there is currently no significant ST1 (or ST6) trend in abundance in the SAC but abundance is severely depleted compared to the start of the time-series (LT). The last count (2022) 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 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 (count of 55), and although it is over 90% depleted compared to the 1990s, it is no longer significantly declining. Indeed, it has shown a slight recent 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 has been markedly lower than 2015-2018. There is no significant continued decline within the SAC or SMU (ST1). The decrease, since the high in 2015, is ~20% for the SMU, and ~26% for the SAC.

The Wash accounts for the majority of harbour seal pup production in the Southeast England SMU. In 2024, the pup count was 896, which is almost 37% lower than in 2023. The mean maximum pup count (2022-2024: 1150 pups) since the drop in the moult count (between 2018 and 2019) is substantially lower (~23.5%) than the mean maximum number of pups in the 5 years preceding the decline (2014-2018: 1505 pups). In terms of the trend analyses, pup peak counts are significantly in decline for ST6 (-24.49%; 95% CIs: -40.96, -3.83) but not ST1 (-5.56; 95% CI: -11.35, 0.47). The current peak pup count is significantly higher than in 2004, the start of the time series, when The Wash population was depleted following the 2002 PDV epidemic (62.76%; 95% CI: 23.03, 115.81). However, the peak pup counts is significantly lower than the time-series peak in 2015 (HH -26.89 95% CIs: -42.52, -7.17)

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. However, it should be noted that for grey seals, individual colony trajectories are often not representative of area-wide (e.g. SMU) trends. For example, pup production in Orkney levelled off around year 2000 but the majority of individual colonies still exhibited increasing or decreasing trends thereafter (Russell et al. 2019). 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 25/03 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 & 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 (ST1, ST6, LT, HH 1998). It is now significantly depleted to around half of the historic levels, accounting for ~10% of the SMU production. Haulout counts in August are stable in the SMU (last surveyed in 2019). 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

The trend in pup production in East Scotland is predicted to still be increasing (2023) but the pup production estimates have been steady since 2018 (3 surveys). Production on the Isle of May SAC is estimated to be ~23.5% lower than the historic high in 2004, and there are indications it is in decline (but this is not significant; 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 57% of the pups at Fast Castle are within the Berwickshire and North Northumberland Coast SAC. Likely due to the expanding nature of the colony, there are increases at the colony level (ST1, ST6) but not within the SAC. Neither SACs in East Scotland 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 15%. There are no significant short-term trends in the SAC, but the last estimate was almost 12% lower than in 2021. In contrast, production in the SMU is still increasing rapidly by ~10.6% per annum. The trends for August show a similar pattern; Humber Estuary is no longer increasing (ST) but the SMU as a whole is increasing on the ST6 level.

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 and Witt, 2017b, 2017a), the majority of which were in the SACs (228 Isles of Scilly Complex SAC; 27 at Lundy SAC in 2015; (Lundy Field Society, 2023). 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).

3. **What update can SCOS provide on the most current information regarding the population structure/demography of grey and harbour seals in the UK as well as within England, Scotland, and Europe? SCOS will include any updated information on mortality, age and sex structure of both species, highlighting any changes that might impact their conservation.**

Population Structure and Demography: 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 (Moray Firth SMU). 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 at study sites in the North Coast & Orkney SMU, and West Scotland SMUs. These are updated from previous estimates presented in SCOS (2022).

An index of fecundity (max pup count divided by moult count) recently increased in both The Wash and Wadden Sea. This could be an indication that demographic rates have changed, or that the relationships between pup count and pup production, or the moult count and the total population have changed.

In light of recent advances in techniques including drone technology, SCOS recommends that, a scoping study should be carried out to assess the feasibility of developing additional studies of harbour seal survival, fecundity and indicators of condition at additional sites around the UK. This exercise should consider the resource requirements of collecting data at appropriate temporal and geographical scales, and assess the cost/benefit of such studies in relation to other data requirements

Genetic studies show that harbour seals in southeast England are part of the continental European metapopulation. A separate metapopulation is centred on Scotland, and this metapopulation can be further divided into three distinct genetic clusters; Western Scotland (comprising SMUS 1,2 & 3); Northern Scotland (comprising SMUs 4,5&6); and Eastern Scotland (SMU 7). Population trends are consistent within each cluster but differ between clusters.

Survival and fecundity rates

Most of the work on harbour seal life history parameters in the UK has been focussed on a limited number of sites where photo I.D. or direct visual observation studies are possible. The differences in estimates across populations with different trajectories provide a useful indicator of the potential range of parameters, and the role of such parameters in population trajectories. There has been a long-term study at Loch Fleet (Moray Firth SMU) led by University of Aberdeen (referred to as the Moray Firth study). Additional recent studies (2016 - 2022) were focussed on sites around the Isle of Skye in the West Scotland SMU (referred to as the Skye study) which was, at the time, thought to be increasing, and Burray in the North Coast & Orkney SMU (referred to as the Orkney study), which is severely depleted and still declining. It should be noted that the most recent surveys indicate a decline in West Scotland between 2017 and 2022/2023, but it not known when this decline started. Relatively high resolution (at least one survey per August) count data, and also pup counts, are available for The Wash (Southeast England SMU).

Pup/juvenile survival

A study investigating first year survival of female harbour seal pups, using telemetry tags was carried out in Orkney and on Lismore (West Scotland SMU) 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 six months was 0.39 (Hanson et al., 2013). (Harding et al., 2005) showed that overwinter survival in harbour seal young of the year in Sweden was positively related to body mass and to water temperature. Although the published estimates of pup survival from a mark recapture study in Tugidak Alaska were not directly comparable, pup survival to age six months was approximately double that seen in the Scottish study (Hastings *et al*., 2012). The timing of pup mortality was also different with maximum pup mortality during the pre-weaning period, primarily in the first three weeks. Conversely, mortality of the Scottish tagged pups was very low during the pre-weaning period but increased after weaning and then remained relatively constant to the end of the study (Hanson *et al*., 2013).

Adult survival

A long-term photo-ID study of harbour seals at Loch Fleet produced annual survival rate estimates of 0.95 (95% CI 0.91-0.97) for adult females and 0.92 (95% CI 0.83-0.96) for adult males (Cordes & Thompson, 2014). ; Mackey *et al*., (2008 produced adult female survival rates of 0.98 (approximate 95% CI's 0.92-1.00) from five models fitted to a four year mark recapture dataset from the nearby Cromarty Firth.

A recent study used mark-recapture models applied to photo-ID data collected during the breeding season at the Loch Fleet study sites to estimate sex-specific survival and fecundity rates.

Apparent adult survival rates were lower at the declining site of Burray in the North Coast and Orkney SMU (data 2016-2022; female survival = 0.844 (95%CI 0.803-0.878); male survival = 0.826 (95%CI 0.751-0.883), compared to sites in areas where numbers are stable (Loch Fleet, Moray Firth SMU, data 2006-2021: 0.941 (95%CI 0.922-0.956) for females and 0.919 (95%CI 0.888-0.942) for males; and Dunvegan, West Scotland SMU, data 2016-2022: 0.878 (95%CI 0.810-0.924) for females and 0.842 (95%CI 0.756-0.902) for males). The estimated rates inform current research into potential causes of the declines and are being incorporated into stage-structured population dynamics models to investigate if the hypothesized mechanisms for decline are supported by the data. 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 four years or since first pup for females, whereas in Orkney and 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 (Arso Civil *et al*. submitted).

It is interesting to note that although the Skye study site was chosen as representing an increasing population based on survey counts up to 2014, the survey counts since then suggest that the West Scotland SMU (including Skye) population may have reached a peak around the start of the study (2017), it was then significantly lower by the next survey (2022). It is not known when the decline started. The fact that Skye survival rates are intermediate between the low Orkney estimates and the higher Moray Firth estimates may indicate that the Skye population was already responding to the drivers of decline.

Available estimates of survival for harbour seals are otherwise scarce, especially those based on photo-ID data from live individuals. The estimated overall adult survival from 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 *et al*. (2012)). However, the Tugidak estimate was based on young adult seals up to 8 years. Not including older animals could have biased the adult survival estimates.

Fecundity

Fecundity rates, i.e. the average number of pups born per adult female per annum, were also estimated for harbour seals at sites in Orkney, Skye and Loch Fleet. Fecundity estimates were derived 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 declining trend also being supported (fecundity ranging 0.869 to 0.715 over 2016 to 2022 period). Skye and Loch Fleet females had slightly higher fecundity rates at 0.883 (95%CI 0.823-0.924) for Skye and 0.872 (95%CI 0.847-0.894) for Loch Fleet. A model with a negative temporal trend was also supported in Skye, with fecundity rate ranging from 0.921 to 0.785 between 2016 and 2022, again consistent with the observed decrease in the West Scotland SMU population

In Southeast England, there is evidence for recent changes in demographic parameters in harbour seals. A fecundity index, the peak count of pups (as an index of pup production) divided by the moult survey count from the previous moult (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 more than doubled between 2001 and 2006 and remained high until at least 2024.

Until recently the fecundity index in the larger population in the Wadden Sea (Galatius et al., 2023) (Galatius et al. 2023) was similar to the 2001 value in the Wash. However, since 2008 the Wadden Sea fecundity index has also increased (Galatius et al., 2023) and is now of a similar level to The Wash (SCOS-BP 25/05). This suggests that the observed increase in the early 2000s was not due to movement between breeding and moulting populations in the two areas. The fecundity index 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.

In light of recent advances in techniques including drone technology, SCOS recommends that, a scoping study should be carried out to assess the feasibility of developing additional studies of harbour seal survival, fecundity and indicators of condition at additional sites around the UK. This exercise should consider the resource requirements of collecting data at appropriate temporal and geographical scales, and assess the cost/benefit of such studies in relation to other data requirements

Age and sex structure

The absence of comprehensive 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 with a preponderance of males, a large proportion of young of the year, and a large proportion were not sexed. These data were not used to generate population age structures (Hall et al., 2019).

Growth rates

The observed declines in some harbour seal populations indicate that some combination of increased adult and juvenile mortality and/or a decrease in fecundity must have occurred. If the drivers of these changes are related to food resource limitations, e.g., reduced prey density or increased competition, the effects on individual seals would be expected to also result in slower growth and/or 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, 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 associated with population trends 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, p. 201). 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 extended (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 microsatellite 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.

Interestingly, the population trends in the three genetically identified clusters differ. Populations in the southern cluster show continual rapid increase punctuated by major declines associated with PDV epizootics in 1988 and 2002 (SCOS-BP 24/03). Populations in the north-eastern cluster are depleted and/or declining while populations in the north-western cluster were either stable or increasing until recently; recent survey results may indicate that the north-western cluster population may have begun to decline (SCOS-BP 25/03).

(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 & 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 decline.

(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 decreasing (North Coast & Orkney, East Scotland and Northern Ireland SMUs) or showing recent decreases after a protracted increase (Southeast England, West Scotland, and Western Isles SMUs) (SCOS-BP 25/03). In all cases the observed trajectories preclude estimation of robust carrying capacities.

A substantial increase in grey seal numbers in the Southeast England SMU region since the 2002 epidemic has likely reduced carrying capacity for the harbour seals due to increased competition for food. Grey seal August counts suggest a rise from around 2000 animals in 2000 to approximately 42000 by 2023 (SCOS-BP 24/01). This sharp increase may have significantly impacted harbour seal foraging success lowering their carrying capacity by an unknown, but potentially considerable amount.

Population Structure and demography: Grey seals

There is evidence for regional differences in grey seal demographics, 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.

The grey seal breeding population in Orkney appears to be close to carrying capacity. Recent increases in pup production in West Scotland and in the Western Isles indicate a possible increase in carrying capacity for those SMUs. The population in the East Scotland SMU has increased rapidly but recent estimates indicate it may be approaching carrying capacity, and the population in the Southeast England SMU is continuing to increase rapidly and shows no sign of density dependent constraint.

Grey seals in the UK are members of the Northeast Atlantic metapopulation. There are two recent grey seal genetics studies which are relevant to the UK. One centred in Europe 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, the relative population sizes in these areas do not support these conclusions. A range-wide study suggests that there is a split between the west and east of the UK; this conclusion is, in part, supported by tracking and population data.

Earlier studies indicated a degree of reproductive isolation between grey seals that breed in the southwest (Southwest England and Wales) and those breeding around Scotland, and within Scotland there were significant differences between the Isle of May and North Rona. However, these relationships may have changed due to increased recruitment into non-natal SMUs as potential source populations reached carrying capacity. There is therefore indication of sub-structure within the UK grey seal population.

Age and sex structure

While the pup production was growing at a constant (i.e. exponential) rate, it was assumed that the female population size was directly proportional to the pup production. However, the observed changes in the rate of increase in pup production will have changed the 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, which hampers efforts to estimate population size from pup production data. An indirect estimate of the age structure, at least in terms of pups, immature and mature (breeding age) females was previously generated within a population estimation model (SCOS-BP 24/05). The model fitted single global estimates for fecundity, maximum pup survival (i.e. for an unconstrained population), adult female survival, and individual carrying capacity estimates separately for each region to account for differing dynamics through density dependent pup survival. However, the model formulation precludes robust fitting of recent trends in the data. As such, outputs from the model using data up to 2014 (see Q1) are considered.

Recently (Bull et al., 2021) suggested that changes in timing of births on Skomer Island (pup production ~250) 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 these suggested mechanisms could have resulted in 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 2,768 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 (Western Isles SMU), and the Isle of May (East Scotland SMU). 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 feasible ranges of demographic parameters (SCOS-BP 24/04).

First year survival

First year survival is taken to mean the probability that a 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.

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. However, the model predictions underestimated the populations in the North Sea region and in the West Scotland and Western Isles SMUs, so these maximal (un-constrained) pup survival estimates should be treated with caution.

The current grey seal populations around Scotland are apparently constrained by density dependent factors that appear to be acting on pup survival (Thomas et al., 2019); SCOS-BP 24/05). Estimates of pup survival in UK SMU populations around Scotland are much lower than the maximal values. It is possible to derive current pup survival estimates from the model previously used to estimate population size from the pup production data time series. The posterior estimates of pup survival at current population sizes differ between regions. In the North Sea where density dependence is having little effect, the current pup survival estimate is 0.43, close to the maximum, unconstrained rate. In the other three regions where population growth has slowed or stopped the current estimate is much lower, being 0.11 in the Inner and Outer Hebrides and Orkney. This is close to what Thomas et al., (2019) estimated that pup survival for a population at carrying capacity will be, i.e. around 0.1-0.14.

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 et al., 2013; den Heyer and Bowen, 2017), 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.

Adult female survival

Relevant studies for estimating female survival of grey seals are shown in Table 5. Estimates of annual adult female survival in the UK, obtained by aging teeth from shot animals were between 0.93 and 0.96 (Hewer, 1964; Harwood and Prime, 1978); SCOS-BP 12/02). Capture-mark-recapture (CMR) of adult females on breeding colonies (Smout et al., 2020) 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, 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 and 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 and 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% for 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 estimates of pregnancy rate from shot samples close to full term, resighting records of 2313 marked seals, and an index of density independent ice-related pup mortality (Hammill 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 and Bowen, 2017; Hammill et al., 2023).

In the population model previously used to estimate total UK grey seal population, 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 and Bowen, 2017; Rossi et al., 2021).

Sex ratio

Although sex ratio at birth is 1:1, differential sex-linked mortality throughout the age structure leads to an uneven sex ratio with a higher proportion of females in the population. The size of the adult female population can be estimated from pup production and fecundity estimates, but information on sex ratio is required for scaling female population estimates up to the total population size.

Unfortunately, there is little information in the pup production data to allow estimation of the sex ratio. Three estimates of total grey seal population size (based on separate, summer haulout surveys) indicates that 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. Previous UK grey seal population estimates have been 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 (Thomas et al., 2019).

Relevant studies on sex-specific survival rates that provide information on sex ratio are summarized in **Table 5**.

- A sex ratio of 0.73:1 (♂ : ♀) was derived from shot samples (Harwood and 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 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 (SCOS-BP 14/04; **Table 5**). 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 (SCOS-BP 14/04).
- 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 estimate derived from shot samples for grey seals in UK waters. However, an IPM model fitted to an extended brand re-sightings data set, and accounting for the sustained rapid population growth, estimated a sex ratio of 0.93:1 for grey seals at Sable Island (Hammill et al., 2023).

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 et al., 2019). Fecundity in 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 and Bowen, 2017; Smout et al., 2020). 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 et al., 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 and enhance 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.

Fecundity

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). Available information on grey seal fecundity is summarised in Table 6.

Pregnancy rates estimated from samples of seals shot in the UK (Hewer, 1964; Boyd, 1985) and Canada (Hammill and 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.

Fecundity estimates based on direct observation of birth rates of marked animals produce lower estimates than from shot samples, 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 (Bowen et al., 2006; den Heyer and Bowen, 2017). 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 declining (North Rona) and increasing (Isle of May) populations, respectively (Smout et al., 2020, p. 20).

In the population model previously used to estimate total UK grey seal population (SCOS 2024), density dependence acts through pup survival only, so fecundity does not vary with time or between regions. The fitted posterior values for fecundity were 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:

Isle of May and North Rona (UK)

(Smout et al., 2020) reported a link between the likelihood of breeding and environmental conditions for marked grey seals at two sites in Scotland: a positive relationship with sandeel abundance during the preceding year at the Isle of May, and a negative relationship with a lagged North Atlantic Oscillation index at North Rona.

(Hanson et al., 2013) showed high levels of variation in individual postpartum maternal body composition. Although average composition was similar between the colonies, it increased through time at the Isle of May where pup production increased but declined at North Rona where pup production decreased.

Sable Island, Canada

(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. Individual known age seals were followed to estimate reproductive rate or histories, at higher population densities there was more variability in individual reproductive performance and while high-quality females maintained their reproductive output as population density increased, reproductive performance of low-quality females declined.

(Badger et al., 2021) 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 in 2024 were the lowest observed in the past 30 years (den Heyer, personal communication). Several factors could have contributed to this including unusual environmental conditions, exposure to diseases, an increase in predators and resource competition.

Finland

(Kauhala et al., 2019) used samples from shot seals to show that pregnancy rate can fluctuate significantly (between~0.6 and~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.

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.

Carrying capacity

Grey seal populations in West Scotland and the Western Isles had appeared to reach carrying capacities (Figure 3), with little or no increase in pup production since the mid-1990s. However, recent surveys indicate that pup production is increasing in these regions again, suggesting an increase in carrying capacity for these SMUs. The Orkney population appears to have reached carrying capacity in the early 2000s. The population in the East Scotland SMU has increased rapidly but recent estimates indicate it may have reached carrying capacity now showing signs of levelling off. The population in the Southeast England SMU is continuing to increase rapidly and shows no sign of density dependent constraint.

Genetics

Grey seals in the UK are members of the Northeast Atlantic metapopulation, and there have been various genetic studies examining its structure. 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 and 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). However, these relationships may have changed due to increased recruitment into non-natal SMUs as potential source populations reached carrying capacity.

(Steinmetz et al., 2024) 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 has a much smaller population of grey seals than Ireland. 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 earlier 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).

(McCarthy et al., 2025) present a range-wide genomic analysis of grey seals based on 188 samples from 17 distinct localities. Results support the existence of three main grey seal populations centred in the NW Atlantic, NE Atlantic and Baltic Sea, and some substructure within the NE Atlantic, e.g.

separation of seals in Iceland, Norway and Russia from the core NE Atlantic population. That analysis indicated genetic differentiation between Wales (Skomer Island) and East Scotland (Isle of May).

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, i.e. cannot exclude the possibility of the Northwest Atlantic population being fully mixed.

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.

To inform the scale at which population should be managed, both the genetic and ecological connectivity of areas must be considered (Carroll et al., 2020). This is particularly pertinent in the grey seal, a partial migrant, for which areas of breeding and foraging can be geographically distinct (Russell et al., 2013).

Table 5. Available survival data for grey seals. 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 and 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 et al., 2001, 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 et al., 2009
Pup	0.76 0.55			0.38 0.53			1185 2295	2000 - 2004 2005 - 2009	Aged shot individuals	Baltic	Samples assumed representative. Based on life tables	Kauhala et al., 2012
≤ 4	0.735 0.331	SE = 0.016 SE = 0.024	1700 1182					1985 - 1989 1998 - 2002	CMR (brand)	Sable Island, Canada	Includes the data from Schwarz & Stobo (2000)	den Heyer et al., 2013
Adult	0.95		239					1956 - 1966	Aged shot individuals	UK	Samples assumed representative. Based on life tables	Data from Hewer, 1974, analysed in SCOS-BP 12/02
≥ 10				0.80		294		1972, 1975	Aged shot individuals	Farne Islands, UK	Accounted for population trajectory. Assumed samples are representati	Harwood and Prime, 1978

										ve within focal age class.	
≥ 7	0.935 (0.90-0.96)		1036				1972, 1975	Aged shot individuals	Farne Islands, UK	As above	Harwood and Prime, 1978 (reanalysed in SCOS-BP 12/02)
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 et al., 2020
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 and 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 6. Available fecundity data for grey seals. 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 and 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., 2020
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 and 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

Potential Biological Removal

4. SCOS will provide the most current estimates of Potential Biological Removal (PBR) for both harbour and grey seals. Estimates will be provided for each Seal Monitoring Unit (SMU) in the UK.

In the UK, what is considered a 'safe level of anthropogenic takes' from defined populations is based on the Potential Biological Removals (PBR) method (Wade 1998: NOAA 2023). Here PBRs are calculated on a Seal Monitoring Unit (SMU) basis but it is recognised that, especially for grey seals, these do not represent closed populations. Thus, depending on the appropriate scale of the management question, PBRs should be combined across SMUs. However, this should be done with caution as larger area (e.g. western UK and Ireland) do not represent fully mixed populations.

PBR uses information on intrinsic rates of population increase for the species in question, recent conservative population estimates (N_{min}; 20th percentile of population estimate, 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 with notable numbers (> 250), 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 25/04. PBR values for the harbour and grey seals by SMU, based on suggested values for the recovery factor and the latest confirmed counts (up to 2023), are presented in

Table 7 **and Table 8. It should be noted that the PBR estimates are based on the latest August count data (some of which are over 5 years old). The PBR estimates, especially for declining SMUs should be considered in that context.**

Changes since previous SCOS report

Other than the extension to all UK SMUs with notable populations (previously only Scottish SMUs were considered), the other main change compared to SCOS 2024, is that instead of using the August count directly as N_{min} for harbour seals, the count is scaled. Specifically, the count is raised using the 20th percentile of the distribution of the scalar used to account for seals at sea during the survey windows. This aligns with the method used for grey seals and recommended by Wade (1998).

The latest counts have been updated for SMUs 1 and 2 (Southwest Scotland and West Scotland). Moreover, the harbour seals recovery factors have also been adjusted for these SMUs to reflect that abundance is no longer increasing. Indeed, harbour seal recovery factors across all considered SMUs are < 1. Grey seal recovery factors were all set to 1 on the basis of the stable or increasing trends. This is with the exception of SMUs 4 and 5 (North Coast & Orkney and Shetland) for which the recovery factor was set to 0.5 on the basis that the available data are > 5 years old.

See (see SCOS-BP 25/04) for more details.

Table 7. Potential Biological Removal (PBR) values for harbour seals in by SMU. The count data, estimates of Nmin and the recommended FR values are shown (see SCOS-BP 25/04).

SMU		2016-2023 count	Survey years	N_{min}	selected F_R	PBR
1	Southwest Scotland	1,563	(2023)	2,001	0.5	60
2	West Scotland	11,754	(2022; 2023)	15,050	0.5	451
3	Western Isles	3,080	(2022)	3,944	0.5	118
4	North Coast & Orkney	1,405	(2016; 2019)	1,799	0.1	10
5	Shetland	3,180	(2019)	4,072	0.1	24
6	Moray Firth	983	(2019; 2021; 2023)	1,259	0.1	7
7	East Scotland	276	(2021; 2023)	353	0.1	2
9	Southeast England	3,372	(2022; 2023)	4,318	0.1	25
14	Northern Ireland	818	(2021)	1,047	0.1	6

Table 8. Potential Biological Removal (PBR) values for **grey seals** by SMU. The most recent count data, estimates of N_{min} and the recommended FR values are shown (see SCOS-BP 25/04).

SMU		2016-2023 count	Survey years	N_{min}	selected F_R	PBR
1	Southwest Scotland	760	(2023)	2,832	1.0	169
2	West Scotland	4,508	(2022; 2023)	16,798	1.0	1,007
3	Western Isles	3,473	(2022; 2023)	12,942	1.0	776
4	North Coast & Orkney	8,618	(2016; 2019; 2023)	32,114	0.5	963
5	Shetland	1,009	(2019)	3,760	0.5	112
6	Moray Firth	1,354	(2019; 2021; 2023)	5,046	1.0	302
7	East Scotland	1,584	(2021; 2023)	5,903	1.0	354
8	Northeast England	5,381	(2020; 2022; 2023)	20,052	1.0	1,203
9	Southeast England	10,735	(2022; 2023)	40,003	1.0	2,400
11	Southwest England	729	(2023)	2,717	1.0	163
12	Wales	1,313	(2023)	4,893	1.0	293
13	Northwest England	180	(2023)	671	1.0	40
14	Northern Ireland	549	(2021)	2,046	1.0	122

Interactions with fisheries

5. **SCOS will provide the latest estimates of seal bycatch across both Scottish and UK fisheries. Where available, estimates will be provided by gear type and will provide any available information on the location of bycatch. Where there is insufficient information to provide bycatch estimates, SCOS will identify the key knowledge gaps (e.g., monitoring effort). SCOS will also provide advice regarding the impact of bycatch on seal populations and current technologies and approaches for mitigation (e.g., Acoustic Deterrent Devices, Acoustic Startle Devices).**

The most recent bycatch estimate for seals in UK fisheries is for 2022. The total estimate is 452 animals (95% CI 352-820). 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 2022 is similar to 2021 (458), 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 10.

Spatially, bycatch of seals in UK fisheries is mainly concentrated in ICES Divisions 7.d-f (English Channel and Bristol Channel) with 69 % of all estimated bycatch occurring there, with lower levels in the northern and southern North Sea (4.a, 4.c). The same pattern was evident in previous assessments although this is dependent on the spatial location of the sampling effort, much of which is focused in areas where bycatch is known to occur.

Most bycaught seals examined were young grey seals. Although species identification is uncertain where seals cannot be brought on deck, this bycatch is likey grey seals 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.

In terms of methods for monitoring bycatch, attention is being increasingly paid to the use of electronic monitoring (EM) on vessels. Work is currently ongoing under the UK Bycatch Monitoring Programme (BMP) to evaluate the potential of EM for accurate identification of a wide range of endangered, threatened and protected (ETP) species, including seals. If EM is used routinely as a bycatch monitoring tool in the future, careful consideration will need to be given to EM system deployment patterns to help minimise sampling biases that could affect the accuracy of mortality estimates.

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 (Tilzey et al., 2006; Hamilton and Baker, 2015; Lyle et al., 2016). Gear modification, alternative gears or acoustic deterrents are the available options.

SCOS are not aware of any published studies on modifications to gear that have been shown to reduce bycatch in large mesh tangle or trammel nets. Switching to seal safe pot/trap fishing rather

than netting could avoid or reduce seal bycatch. However, there are likely to be significant challenges with this, not least because pot/trap gears are unlikely to be effective for some of the species targeted with the gears associated with highest seal bycatch in the UK. Analysis by Cosgrove et al. (2016) suggested higher rates of seal bycatch in tangle nets were associated with larger mesh sizes. Therefore alterations (increase or decrease) in net mesh sizes could potentially be considered although this would need significant testing to evaluate effectiveness at reducing bycatch and any impacts on commercial catch.

Changes to fishing practices similar to those being trialled for reducing depredation may also reduce bycatch risk. For example, changing timing, location and/or duration of sets could help reduce bycatch, e.g., avoiding setting nets close to areas of high seal density (assuming bycatch rates are positively associated to density).

Use of acoustic deterrents is another possible mitigation method, but its widespread use on large numbers of nets may raise concerns about wider effects on non-target species. Trials of seal-specific acoustic deterrents, including the Targeted Acoustic Startle Technology (TAST, Genuswave Ltd.) do indicate some promise for reduction of bycatch, but further research is necessary to determine the practicality and cost-effectiveness of large-scale deployment in fisheries to reduce bycatch.

Bycatch

UK Bycatch Monitoring Programme seal bycatch estimates

It should be noted that the following discussion refers to the bycatch of seals by UK registered vessels, based primarily on data from the UK Bycatch Monitoring Programme (UKBMP) and official fishing effort statistics. Bycatch by UK and 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 comprehensive overall bycatch estimates (ICES, 2024; **Table 12**). This is because these data are provided at ICES Division level, which (apart from 7F (Bristol Channel)) contain both UK and non-UK waters. There is also the complication of different data collection protocols in different countries.

Seal bycatch estimates for the UK are made for both species (grey and harbour seals) combined (Kingston et al., 2025). A significant proportion of bycaught seals examined were young grey seals (based on length estimates), and most seals recorded in recent years were caught in the southwest UK 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 more historical bycatch was of 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 estimated.

The total seal bycatch estimate by UK vessels in UK waters in static net fisheries in 2022 is 452 animals (95% confidence limits 352-820). The mean estimate is very similar to the previous year (458 Estimates of seal bycatch in recent years have generally been in the region of 400-600 seals per year, with no clear trend (**Table 9**).

The calculation of bycatch rates uses sampling data over multiple years (Kingston et al. 2025). This allows more precise 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 suggests that bycatch estimates can be significantly biased by the distribution of sampling effort. Data for ICES Subarea 7 Divisions d-j (including UK and non-UK portions of these areas) for 2022 (ICES 2023) indicate that the total netting effort from UK fishing vessels was circa 15,500 days and the total for non-UK fishing effort was 23,000 days. While these totals include non-UK waters, this gives some indication of the relative amounts of UK vs non-UK netting effort in the region in this year. 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.

Table 9. 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
2022	452	351-820

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

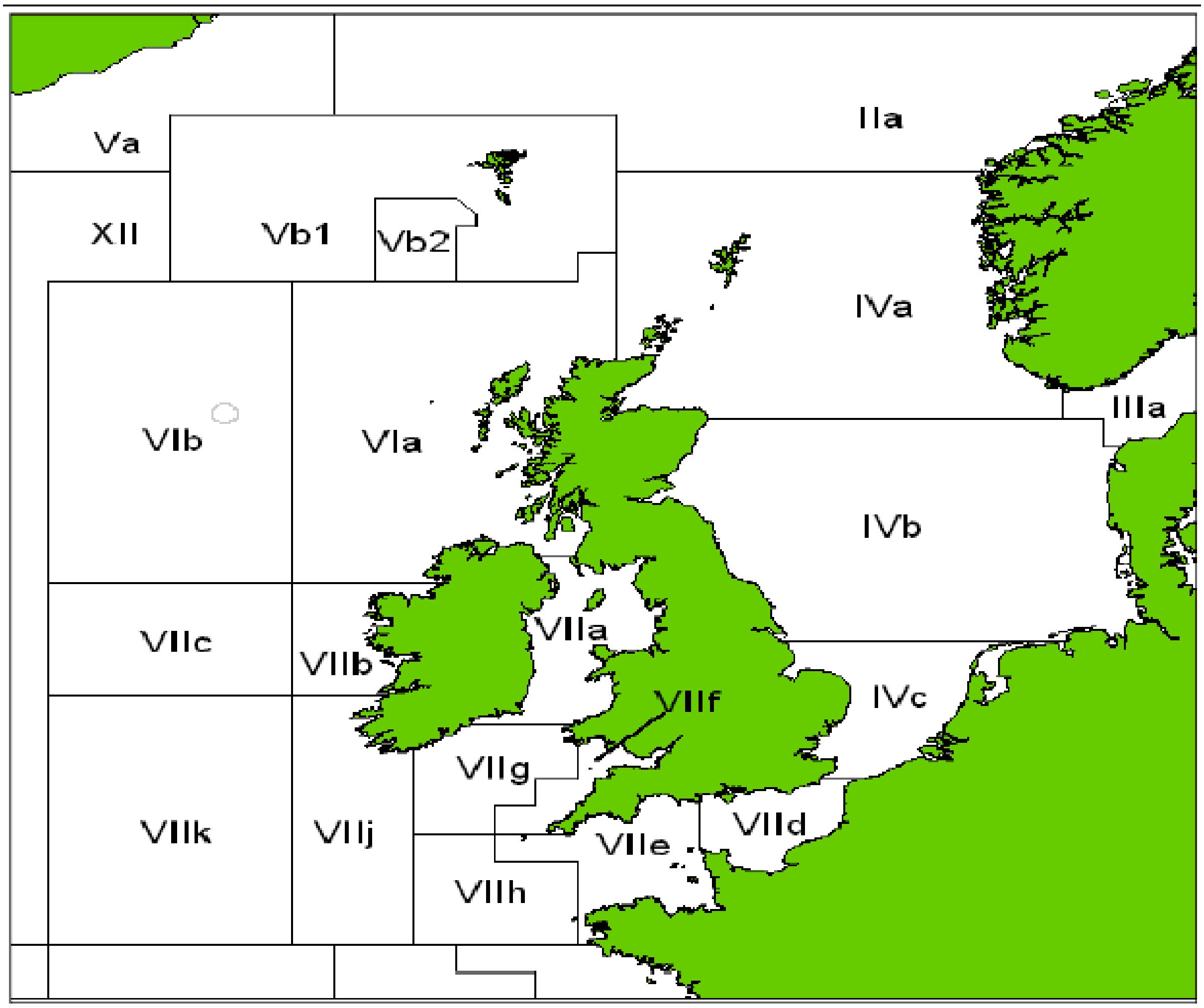

Figure 4. ICES Sub-areas and Divisions

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. A map of the ICES Divisions is provided in Figure 4.

Table 10 provides the UKBMP seal bycatch estimates for UK registered vessels by ICES Division and subareas. Approximately 69% of the bycatch (311 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 241 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 66 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 estimates for ICES Subarea 6 and Division 4.a in 2022 was 96 seals, representing around 21% of the UK total. It should be noted that estimates are not produced for Division 6a, although a row for that Division is included in Table 10. There is no record of static net effort in 6a in the official statistics. We have recently become aware of some low-level netting activity in the Western Isles carried out by polyvalent (multi-gear) vessels that predominantly use other gears and is not reported as distinct netting effort. Our current “best” estimate of effort in the area is in the region of 50-100 days at sea per annum in total across about 15 vessels. Gear soak time is typically a few days so actual soak effort will be higher than the days at sea estimate. For context, that is likely less than the annual effort of a single dedicated netter of similar size based on knowledge from other parts of the country. We have done a few days of data collection in these fisheries and have recorded 5 seal bycatches, but it is too early to generate (reliable) bycatch rates, and we will also need to find an appropriate way of quantifying and incorporating this fishing effort into the estimation procedure before producing estimates for 6a. Given the greater presence of harbour seals in Subareas 6 and 4 compared to the SW of the UK, it is possible that the current estimates include a proportion of harbour seals but the composition by species is currently not fully known.

Since the above bycatch estimate is based on UK registered vessels only, it represents an underestimate of the total bycatch, particularly in the Southwest. Bycatches (of largely unknown extent) by Irish, French, and Spanish vessels working the same areas will contribute to total mortality. 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 simply be added to the UK estimates 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, several French and Irish vessels fish in UK waters and will also likely experience seal bycatch but are not included in either (Luck et al. (2020) or Kingston et al. (2025) estimates. The extent of effort by non-UK registered vessels in UK waters is likely to have changed in recent years, and hence also the levels of seal bycatch by these vessels in UK waters. Generating comprehensive estimates of total bycatch in UK waters would require access to the raw data collected by each country’s bycatch monitoring programmes along with effort data from each fleet and split into UK and non-UK waters. One simpler, but less robust option would be to allocate effort within a Division equally across the relevant rectangles and then sum across just the rectangles that occur in UK waters. Differences in data collection protocols between countries would also need to be considered.

Table 10. Estimated number of seals bycaught in UK net fisheries in 2022, by ICES Division. Estimates rounded to nearest integer. (From Kingston et al. (2025). NB the difference in the total between this Table and in **Table 9** is a result of small differences occurring when rounding the estimates when summing across different categories.

	ICES Division	Estimated total bycatch	Two-Sided 95% LCL	Two-Sided 95% UCL	One-sided 90% UCL
North Sea	4.a	83	69	99	93
	4.b	1	0	1	1
	4.c	42	34	62	57
West Scotland	6.a	-	-	-	-
West Scotland offshore	6.b	13	11	16	15
Irish Sea	7.a	2	2	8	6
Porcupine	7.c	2	2	3	3
Eastern Channel	7.d	66	48	127	108
Western Channel and Celtic Sea	7.e	137	112	198	179
	7.f	81	67	115	104
	7.g	11	9	26	20
	7.h	11	9	17	15
	7.j	1	1	2	2
Biscay	8	1	1	1	1
	Total	**451**	**365**	**675**	**604**

Gear type

Most (93%) of the seal bycatch estimated for 2022 was in large mesh tangle and trammel nets (Table 11). Effort in these fisheries is highly focused in areas 7d, e & f (61% of UK tangle net effort). Reflecting this, recent 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 midwater trawl fisheries in 2019, 2020, 2021 or 2022. 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 individual seals 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.

Table 11. Estimated number of seals bycaught in UK net fisheries in 2022 by metier. Estimates rounded to nearest integer.

Metier	Estimated annual bycatch	Two-Sided 95% LCL	Two-Sided 95% UCL	One-sided 90% UCL
Drift Oth	0	0	14	9
Drift Pel	0	0	10	6
Gill	15	3	44	33
Gill Hake	0	0	27	17
Gill Light	0	0	126	79
Gill Light Flatfish	18	0	100	70
TangTram	419	348	499	471
Total	**452**	**351**	**820**	**685**

Due to logistical and sampling design constraints 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.

Moyes et al. (2025) conducted a statistical analysis of the bycatch rates estimated from UKBMP data collected between 1996 and 2023. This analysis was conducted to explore relationships between bycatch per haul (BpH) rates and potential explanatory variables to gain a better understanding of the factors influencing or associated with bycatch rates. This analysis indicated that seal BpH varied by season with a dip in summer months and an increase in winter. This is consistent with current understanding that much of the observed bycatch is of juvenile grey seals. BpH fluctuated annually over the duration of the study, but no clear trend was observed. Tangle and trammel nets were associated with the highest rates of seal bycatch. Rates decreased as water depth increased, across the depth range 10 m to 150 m within which most of the observations occur. This could relate to the density distribution and/or foraging behaviour of seals, to other environmental variables not considered in this analysis (e.g., turbidity) or to bycatch risk being related to the vertical proportion of the water column that is occupied by fishing gear. The most notable finding of this analysis was that the presence of ADDs (also known as 'Pingers' to differentiate from the more powerful ADDs used in various applications to specifically deter seals) was associated with higher rates of bycatch, with a 2.4 times increase in BpH associated with ADDs. This is possibly due to a 'dinner bell' effect which has been previously reported (Bordino et al., 2002; Carretta and Barlow, 2011) whereby seals learn to associate the presence of acoustic devices on static nets with a source of food. Importantly, Moyes et al. (2025) also reported a significant reduction in harbour porpoise bycatch rates associated with ADD use. The potential that measures to reduce bycatch of one protected species can increase bycatch rates of another protected species clearly needs further investigation and mitigation.

ICES Working Group on Bycatch

The Working Group on Bycatch of Protected Species (WGBYC) collates and analyses information from across the Northeast Atlantic and adjacent sea areas (Baltic, Mediterranean, and Black Seas) related to the bycatch in commercial fishing operations of protected and sensitive species.

The aims of the group and its activities are to improve understanding of the impacts of bycatch on protected species populations and to collate and share information on bycatch mitigation activities. WGBYC reports annually on information received following a formal data call. Each report provides an overview of data collection activities including details of reported monitoring and fishing effort data, and bycatch records that were submitted to the WGBYC database. In 2022 and 2023, WGBYC developed a new approach, a 'Bycatch Evaluation and Assessment Matrix' (BEAM v.1) to provide improved information. The main objective of BEAM is to provide a systematic and transparent methodology to support population impact assessments using standardised fishing effort data, monitoring effort data, and bycatch data obtained through the annual ICES data calls. This is combined with information on available mortality thresholds and a judgement on within group Subject Matter Expertise (SME) to provide an evaluation of the likely reliability and utility of bycatch assessments for different areas and species. The long-term goal is to use this approach for all relevant species to provide a comprehensive overview and assessment of data quality issues, likely bycatch threats, and inform on where improvements to various elements of the BEAM matrix (such as data collection, markers of sustainability, etc.) are required. A full quantitative BEAM assessment for seal species has not been possible at the ecoregion scale (e.g. Greater North Sea or Celtic Seas) but bycatch rates for several ICES areas at the sub-ecoregion scale have been generated. The estimates available from ICES Divisions relevant to UK waters are indicated in Table 12. The large estimate for Division 4.b associated with midwater trawls (OTM) might appear to be at odds with the fact that the vast majority of all UK seal bycatch is associated with set nets. The OTM estimate for 4.b includes international effort, the majority of which is by Danish vessels (84%). The remaining effort is made up of vessels from Germany (1%), France (5%), UK (3%), Netherlands (2%) and Sweden (5%). The ICES estimate was also produced at metier level 4 (which includes all OTM effort in 4.b regardless of the target species) and so could lead to some error in the estimation process if bycatch rates differ between specific fisheries. Work is ongoing within ICES to improve the reliability of the procedures for ICES estimates.

Table 12. Grey seal bycatch rates reported by ICES area and metier in ICES (2024). Total bycatch rates are calculated for 2023 on the basis of data submitted to ICES data calls. Note these include data from outside of UK waters. OTB=Bottom Otter Trawl, OTM=Midwater Otter Trawl, GNS=Set Gillnet, GTR=Trammel Nets

Ecoregion	ICES Division	Metier	Estimated total grey seal bycatch (95% Confidence intervals)
Greater North Sea	4.a	OTB	10 (1.5-73.1)
	4.b	OTM	706 (173.2-2878.5)
Celtic Seas	7.e	OTB	23 (3.3-164.6)
	7.f	GNS	105 (57.6-192.6)
	7.h	GTR	88 (25.7-301.8)
	Total		**932**

Bycatch monitoring methods

In the UK, the Bycatch Monitoring Programme (UKBMP) is a broadscale at-sea fishery dependent data collection programme focussed on the bycatch of sensitive species including marine mammals, seabirds, marine reptiles and rare fish species. It is conducted by a consortium of organisations, led by the University of St Andrews, including the Centre for Environment, Fisheries and Aquaculture Science (Cefas), the UK Centre for Ecology and Hydrology (UKCEH), the National Federation of Fishermen's Organisations (NFFO) and the Scottish Fishermen's Federation (SFF)). The UKBMP currently relies on data collected by observers on fishing vessels and sampling typically covers all major vessel categories (inshore and offshore) although as noted above, effort is concentrated in the fisheries and locations associated with higher levels of bycatch including static net, midwater trawl, demersal trawl, longline and purse seine fisheries. In the UK static net sampling is focussed mainly in the SW. Observer effort has recently been increased in static net fisheries off the west coast of Scotland and on pelagic trawlers in Scotland.

The UKBMP recently conducted a review and SWOT analysis on the suitability of Electronic Monitoring (EM) for broadscale protected species bycatch monitoring. The work indicates that there is clear potential for EM to augment more traditional data collection approaches but that there remain some challenges for broadscale multi-taxa bycatch monitoring including issues related to species identification, appropriate deployment patterns, industry uptake, and data handling, review and cost considerations.

ICES (2024) report that several European countries are deploying EM efforts to collect protected species bycatch data. Denmark, France, and Sweden submitted EM data from 2023 through the 2024 WGBYC data call. Spain also deployed efforts through EM programmes, but data were not included in the WGBYC data calls. The UK is planning to submit EM data from the Clean Catch programme to ICES in 2025R. In some countries (e.g. France), EM data can only be analysed with respect to cetaceans as no agreements with the vessels are in place for other ETP species. Considering the data submitted to ICES and reported in ICES (2024), along with at-sea observers, EM is the source of most bycatch records reported, with 52% of reported mammal bycatch incidents recorded by EM in 2023, though EM efforts have thus far mainly focussed on specific fisheries with previously known bycatch.

However, in relation to EM some challenges are still to be addressed. Species identification and the resource required to analyse the data collected are key challenges. Artificial intelligence approaches are currently being developed through several research projects to improve EM. A summary of responses to the ICES datacall on EM is provided in Table 13. We do not have access to information that would allow an evaluation of the extent to which these projects are specifically developing capability to identify seals.

Table 13. Summary of responses to the ICES datacall on EM (ICES, 2024).

Project	Website/link	Information
Marine Beacon	https://marinebeacon.eu/	2024-2027. Focuses on monitoring of ETP species bycatch through AI, with the aim to approach real-time monitoring and to reduce costly manual analysis of all the footage by pinpointing bycatch events.
OBSCAMe+	**https://www.ascobans.org/sites/default/files/document/accobams-ascobans_jbwg1_pres5.2f_obscame-scientific-program-understand-marine-mammals-bycatch_tachoires.pdf**	2023-2025. Linked to the OBSCAMe+ project on gillnetters, also aims to detect and classify bycatch events through AI, while looking to improve anonymization algorithms.
OBSDEV		2025 – 2027. Will focus on AI with the aim to adapt the algorithms to detect and classify bycatch for trawlers.

OPTIFISH	https://optifish.eu/	2024-2026. EM video footage will be used to create training data sets for the developing deep neural networks for species identification, counts and measurement.
Clean Catch	**https://www.cleancatchuk.com/**	Clean Catch is developing and testing tools for monitoring bycatches, including a smartphone application (the Clean Catch app) and the use of EM. In 2024, the programme released a self-reporting app to collect data on bycatches of sensitive species for use by multiple gear types following development and testing by fishers. Clean Catch uses EM on a subset of vessels where skippers are self-reporting bycatch events to assess the quality of these data types. Due to the high resource requirements to analyse the EM data, the project continues to collate images and contribute to collaborative databases required for training AI, in collaboration with the UK's Bycatch Monitoring Programme.
Insight360	**https://insight360monitoring.org/**	Developing a cetacean bycatch EM system. This project began in 2021 and is due to be delivered in 2024. Five vessels have EM installed to collect image and voice records. Research is continuing to improve software and hardware features such as automatic haul detection and speech to text tools.

Bycatch Mitigation

As reported in SCOS (2024), there has been little attention paid to bycatch mitigation methods for UK seals. Most work carried out globally has focused on the mitigation of otariid mortality in trawl fisheries (Tilzey et al., 2006; Hamilton and Baker, 2015; Lyle et al., 2016). A detailed answer to a similar question was also 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. Königson et al., 2015) could avoid or reduce seal bycatch but the work on alternative gears has mainly been prompted by efforts to reduce seal depredation (rather than bycatch) that was making some fisheries economically unviable. However, there are likely to be significant challenges with this approach. 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 (or any other proposed gear). Analysis by Cosgrove et al. (2016) suggested higher rates of seal bycatch in tangle nets was associated with larger mesh sizes. Therefore, changes 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 or other ETP species. Changes to fishing practices 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, but as reported above (Moyes et al., in review) recent evidence suggests that the widespread use of acoustic devices designed to reduce cetacean bycatch on large numbers of nets may raise concerns about increasing seal bycatch. Some "seal safe" pinger models are available but may not be practical for large-scale net fisheries. With seal targeted acoustic deterrents there are also concerns about impacts on non-target species as a result of the introduction of additional noise into the marine environment.

Trials of seal-specific acoustic deterrents show they were effective at reducing depredation in Finnish trap-net fisheries (Lehtonen et al., 2022, 2023). Similarly, in Estonia work is being conducted in the "Püügivahendi parendamise toetus" (Support for improvement of fishing gear) project. Acoustic devices near fyke nets were implemented to deter seals as a measure to reduce seal depredation. If these measures reduce depredation, they may also be effective at reducing bycatch. Further, a selective grid was used at the mouth of the fyke to avoid the entrance of seals (similar to otter guards common in the mouth of fyke nets deployed in estuaries and freshwater to prevent otters being trapped in nets).

The use of devices such as the Targeted Acoustic Startle Technology (TAST) has also shown some promise in studies investigating the potential to reduce seal depredation (Cox et al., 2024a; Walmsley et al., 2025) and could therefore be effective at reducing bycatch. However, further research is necessary to determine the practicality and cost-effectiveness of large-scale deployment in fisheries to reduce seal bycatch. Work is ongoing at the University of Cork conducting further trials in summer 2025 using baited nets (Samantha Cox, personal communication). Cox et al. (2024) also demonstrated that cetacean detections did not significantly differ between test and control nets, or periods when the prototype was on/off on the test net, indicating there should be no disturbing effect on cetaceans, or any increased risk of cetacean bycatch.

Trials are also planned by researchers at the University of Cork in a tangle-net fishery targeting crayfish, testing the effectiveness of flashing lights on head-ropes (netlights) to reduce seal bycatch in the fishery, as part of the EU Horizon project Marine Beacon.

SMARTTRAWL (Fisheries Innovation and Sustainability, 2023), a system using automatic species identification and controllable fish diversion grids to reduce non-target species bycatch in trawls 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.

The following information relating to seal bycatch mitigation was reported to ICES WGBYC in response to the 2024 data call (ICES, 2024):

In Denmark, investigation is ongoing in the gillnet fishery to determine if a reduction in net-height and twine-diameter can lead to a reduction in bycatch of seabirds, cod, seals and porpoises. No results are available yet.

In Germany, the MiniSeine project (Institute of Baltic Sea Fisheries, January 2022-December 2023) developed a Danish seine reduced in size to be operable from a small gillnetter vessel (<12 m).

Comparable catches to a gillnet were obtained while reducing the probability of harbour porpoise, seabird, and seal bycatch, and protecting the fish from seal depredation (ICES, 2024).

Japan reported that from 2014 to 2022, a monitoring programme utilising automated seal detection technology has been carried out on video images of Kuril harbour seal interacting with the salmon set-net fishery (September 2022 – April 2024). An analysis of the efficiency of the automated image-detection software showed a 90% recognition rate. Detection on longer recordings will be evaluated in the future.

6. **SCOS will provide updates on the prevalence and impact of other seal and fisheries interactions across the UK within rivers, in sea fisheries and at aquaculture sites. SCOS will also provide current information regarding the use of deterrence devices and other efforts to exclude or mitigate seals from rivers, fisheries, and aquaculture facilities.**

The interactions between seals, sea fisheries, aquaculture, and river fisheries have been summarised in recent SCOS reports and a summary and update are provided here.

Rivers

Seals frequent rivers and freshwater environments in the UK and globally, although in recent years, reports of seal incursions into river environments have been increasing. The predation of fish in rivers is of concern and is reported to be affecting the conservation status and economic benefits of recreational fishing. Previous research has shown that a small proportion of seals become specialized as river users. Increasing grey seal populations may be associated with increases in river use, including the potential to have forced harbour seals into more marginal habitats, including rivers.

As highlighted in Thompson *et al*. (2021), there is no single, effective non-lethal solution to address the problem of seal predation in rivers. The most effective methods are likely to be those that 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. Seal behaviour in rivers can be very site- and species-specific, and individual observation studies are recommended to understand individual behaviour and tailor mitigation methods to each river.

Acoustic deterrents have shown promise for use in preventing and reducing seal predation in rivers. Active deterrence will likely be made more effective by timely detection of seals and triggering deterrents in their presence. Minimising the use of deterrents and targeting them only at times when seals are actively involved in predation should reduce the likelihood of seals habituating to the deterrents and reduce the frequency and duration of disturbance to non-target species. SMRU trials of a manually triggered Targeted Acoustic Startle Technology (TAST by Genuswave ltd.) in the presence of harbour seals swimming upriver towards the device resulted in 100% effective deterrence, with all seals immediately stopping travel upriver and moving back downstream (Harris et al. in review). Results of trials in the River North Esk in winter 2024/25 testing a TAST system linked to a prototype automated detection system (multibeam sonar) to trigger the deterrent signal in the presence of seals are currently being analysed, but preliminary results suggest that the automatically triggered TAST signals were successful at deterring the majority of seals from travelling up the river. Genuswave's TAST system has also been tested in salmon rivers in the Pacific Northwest (USA) where it achieved an up to 80% reduction in predation (Williams et al. In prep) and an estimated 55% increase in fish passage (Williams et al. 2021a). Trials by Scottish River District Fisheries Boards using mobile OTAQ Seal Fence devices have been reported as variable (FMS, 2025). Veneranta et al., (2024) reported on trials of a line of Ace Aquatech US3 devices across a river in Finland, highlighting that fishing stations upstream of the devices reported higher catches and fewer seal sightings.

Sea Fisheries – depredation

Depredation in UK commercial fisheries was reviewed in SCOS (2022). It is well known that fishers in the UK report frequent and significant losses due to seal depredation with static nets being the most affected, followed by drift nets and lines (MMO, 2019). A range of studies have demonstrated that depredation rates vary by location (often being higher nearer areas of higher seal density), by depth, haul speeds and sequence, season and soak time. These highlight options for alterations of fishing practice to reduce depredation although according to responses detailed in MMO (2019), this has been ineffective in the UK to date.

There are currently no published quantitative estimates of the level or impact of depredation in any UK fishery, or on the factors affecting rates. SCOS (2021) recommended effort focused on developing a quantitative understanding of the level and extent of depredation in UK fisheries to identify locations and timings of interactions that warrant further investigation and to inform mitigation strategies. A further recommendation included a quantitative investigation of data collected by onboard observers as part of the UK Bycatch Monitoring Programme.

The remaining available approaches to reducing depredation are gear modification and active deterrents to disrupt seals' foraging activities and/or drive them away from the fishery. As far as SCOS are aware there are limited gear modification options available for reducing opportunities for interactions with static tangle nets. Further investigation of the potential in UK fisheries for gear modifications and the potential for the adoption of 'seal-safe' gears of the type that have been successful in Baltic fisheries is warranted.

Some progress has been made on the development and testing of potential acoustic deterrent-based mitigation measures, some of these have already been reported on above under question 5 in relation to their potential to also mitigate seal bycatch. Walmsley et al., (2024) and Cox et al., (2024) report that the TAST device shows promise for the reduction of depredation on static net fisheries, but further research and development is required.

Sea Fisheries – competition

There is considerable overlap in seal diet composition and fish species targeted in commercial fisheries so there is the potential for fishing-induced changes in prey availability to impact seal populations, and for seal predation to reduce the fish available for commercial fisheries. A review of the impacts on fish populations of increasing seal populations was provided in SCOS (2019) and SCOS (2021).

SCOS (2019, 2021) highlighted that predicting ecosystem effects of predator populations is complex and requires a multispecies modelling approach, informed by suitable data. This requires information on fish abundance and distribution, spatial and temporal patterns of seal predation, spatial and temporal distribution of fishing effort, and an understanding of multispecies functional responses. Work is underway to fill several of the data gaps highlighted in SCOS 2019.

Understanding seal diet is key to being able to predict ecosystem effects of increasing populations. SCOS note that available data are now more than 10 years old and may not provide an accurate description of seal diets in areas where fish stocks and seal populations have changed. There are now studies underway to update our estimates of grey and harbour seal diet in the southeast of England SMU and around Scotland, and a reassessment of the potential for competition with commercial fisheries can be undertaken once this work is complete.

Aquaculture

Previous recent SCOS reports have provided detailed reviews of the interactions between seals and aquaculture in Scotland, including options for mitigation (SCOS 2021, 2023). Little new work in this area has been published since these reviews.

Options available include the use of anti-predator nets, double netting, and acoustic deterrent devices (ADDs). There is generally a lack of published evidence for the effectiveness of most ADDs at reducing seal depredation. The exception to this is the studies into the effectiveness of the Targeted Acoustic Startle Technology device (TAST), demonstrating a 91-97% percent reduction in seal depredation on salmon farms in Scotland (Götz & Janik, 2016).

As a result of concerns about the potential impacts on cetaceans (e.g. Findlay et al., 2024), and the need for an EPS licence if the ADD model has the potential to disturb cetaceans (in Scotland), ADD use in Scotland is not currently practiced by the industry. However, some studies have concluded that specific acoustic devices have no impact on some cetacean species (e.g. Götz & Janik, 2015, 2016; Coram et al., 2024). The cessation of ADD use by the sector coincident with the cessation of licensing for lethal control specifically for the health and welfare of farmed fish could also provide the opportunity to compare seal depredation rates before and after these changes, but to date there have been no documented studies investigating changes in seal activity at aquaculture sites.

SCOS are aware of a collaborative study underway by SMRU, the ADD manufacturer Ace Aquatec and the aquaculture company Scottish Sea Farms to investigate the efficacy of ADDs on reducing seal predation. Data analysis is currently ongoing.

The interactions between seals, sea fisheries, aquaculture, and river fisheries have been summarised in previous SCOS Advice, and a comprehensive summary and update is provided here. Concerns relate mainly to the damage to these fisheries by seal predation. Changes in seal abundance, primarily the increase in the grey seal population over the last few decades, as well as recent changes to legislation no longer allowing the lethal removal of seals to protect fisheries, have led to increased concerns about these interactions.

Rivers

Seals frequent rivers and freshwater environments in the UK and globally. 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 10,000 years ago. Seal predation in rivers has been documented in many studies throughout the Pacific Northwest (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). Anderson (1990) highlights anecdotal reports of seals in several rivers along 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).

In Scotland, concerns about seals in rivers have largely focused on predation on salmonid fish. The predation of salmonid fishes in rivers is potentially a significant pressure affecting the conservation status of these populations 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 some seals learn to use the riverine habitats to exploit opportunities to eat salmon and sea trout. The numbers of seals in rivers and the incidence of salmon in their diets vary seasonally and presence of seals is often associated with particular times of year when the availability of salmon is at its highest. For example, Middlemas et al. (2005) presented evidence for a type three functional response with seal numbers increasing with salmon density in rivers following an aggregative response of predator to prey.

Graham et al. (2011) indicated, using photo-ID, that it was a small number of seals using the surveyed river areas, suggesting that some individuals are 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 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 normal tidal limit (NTL) although most 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, are required to quantify the number and turnover of seals using any river.

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 for this species. 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.

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. There are many press reports of both grey and harbour seals apparently foraging successfully in the rivers Ouse, Wharfe, Swales, Aire, Wear, and Tyne with reports of several harbour seals on the banks of the river Ouse in Cambridgeshire 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). It is clear that the occurrence of seals in rivers is not a particularly new or unusual occurrence. Reports of seal activity in rivers in eastern England were discussed in SCOS (2024). In several of those rivers, particularly in south-east England, it is unlikely that salmonids form a significant part of the diet because these rivers don't support salmon populations and sea trout are rare in most of these rivers, but there is a general absence of information on the prey consumed. In the river Nene, a group of five resident harbour seals are reported to have had a significant impact on fish stocks in the river – according to the Environment Agency; they have recently conducted a survey which showed that a large proportion of large adult fish are now absent from a stretch of river. Detailed information on the prey that seals are feeding on in the Nene is lacking but the River Nene is known for supporting a variety of coarse fish species including roach, bream, barbel, pike, perch, carp, and tench. This continues to be a very sensitive issue, and an application has been submitted by the local angling association to catch and translocate these seals back to the coastal habitat.

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 (photo-identified) adult female grey seal 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 being present in Loch Ness for several months. A harbour seal was present in Rochford Reservoir in Essex in December 2022 and was reported in the media to be 'trapped'. 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).

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). Seal behaviour in rivers can be very site- and species-specific and individual observation studies are recommended to understand individual behaviour and tailor how mitigation is applied at each river.

Attempts to capture and relocate animals have had limited success where this has been tried (reviewed in Thompson *et al*., 2021). The available evidence from attempts to translocate harbour seals, California sea lions, and fur seals suggests that catching and relocating pinnipeds is not effective at removing predation problems. Consequently, translocation is no longer practiced in the USA or in Tasmania. There is one anecdotal report from the early 1980s of a translocation of a 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.). Capture of seals in rivers is extremely challenging and there are limited options available. Methods have been developed by SMRU to capture free swimming seals in rivers where flow rates are typically low or where seals are known to actively hunt close to riverbanks (Graham and Harris, 2010). However, success relied on first gathering considerable behavioural knowledge about specific individuals. This highlights the difficulty of, and level of personnel resources required, to catch a small number of seals in relatively benign conditions of small, slow flowing rivers. Floating baited cage traps and various sweep netting and tangle netting options have been explored as options in larger rivers in Scotland (Harris and Northridge, 2018). Popup nets encircling haulouts on riverbanks have been successful (Harris and Northridge, 2018). Although a floating seal trap was developed in 2016, difficulties associated with finding a suitable site in the River Dee for deployment and with sourcing suitable bait (due to perceived biosecurity issues), hindered the development of this approach and this has not yet been trialed. Darting is not recommended due to the significant risk of drowning.

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 structures 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. Indeed, in some circumstances, whole-river temporary traps are being deployed to filter out upstream migrating non-native pink salmon. However, further investigation into how this engineering might be tailored to meet seal exclusion needs or seal capture needs is required. 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.

Active deterrence will likely be made more effective by timely detection of seals and triggering deterrents in their presence. Compared with the use of physical barriers, this approach has a substantial advantage of minimal disturbance to non-target animals and recreational river users. Targeting them only at times when seals are actively involved in predation or when they are at sensitive locations should also reduce the likelihood of seals habituating to the deterrents. SMRU trials of a manually triggered Targeted Acoustic Startle Technology (TAST) signal in the presence of harbour seals swimming upriver towards the device resulted in 100% effective deterrence, with all seals immediately stopping travel upriver and moving back downstream (Harris et al. in Press). Results of trials in the River North Esk in winter 2024/25, testing a prototype linked automated detection system (multibeam sonar) to trigger the deterrent signal in the presence of seals, are being analysed, but preliminary results suggest that the automatically triggered TAST signals were successful at deterring seals from travelling up the river, although contrary to the manual trials occasionally seals managed to pass. These data are currently being analysed to determine possible explanations for variations in effectiveness, including acoustic shadows on the riverbank. This work is due to be reported to the Scottish Government by the end of 2025. It is important to note that 100% effectiveness is highly unlikely to be achieved in the long term from any mitigation method and consideration should be given to methods that significantly reduce the numbers of incursions of seals up rivers. Further resources and capacity are required to trial this system in a wider range of environments, extending to grey seals, and over the longer term.

Genuswave's targeted acoustic startle technology (TAST) has also been trialed extensively in salmon rivers in the Pacific Northwest, USA. Unlike the experiments in Scottish salmon rivers, these deployments tested the standard (un-triggered) TAST system. A recent meta-analysis across multiple study sites shows that TAST caused a 59% to 80% reduction in seal depredation on salmon when the device was operating correctly (Williams et al. in prep). In addition to a reduction in depredation, a 55% estimated increase in fish passage was found (Williams et al. 2021 a). It is also important to note that these projects involved the use of single units which did not fully cover the area monitored. This differing deployment scenario likely explains the lower efficacy compared to a previous fish farm study that demonstrated a 91 to 97% reduction in depredation (Gotz and Janik, 2015,2016). Furthermore, variability in efficacy found across study sites was caused by differences in sound propagation, and insufficient area coverage due to limited deterrence ranges. The highest efficacy occurred in a location where transmission loss was lower (Williams et al. 2021a), while efficacy decreased in areas where transmission loss was higher (Williams et al. 2021b). Studies that did not control for distance and included predation events that were outside of the effective deterrence range also reported lower efficacy (McKeegan et al. 2024). These results are helpful in informing future TAST deployments, as the described challenges could be addressed by operating coordinated arrays of TAST units to achieve sufficient area coverage.

A recent study in Finland (Veneranta et al., 2024) details the deployment of a line of Ace Aquatech US3 ADDs across the river Iijoki, which enters the Baltic Sea. Researchers deployed a series of ADDs (AceAquatec US3 model) across a narrow section of the river, approximately 3 km upstream from the estuary. These devices emitted randomized sound pulses within the 8–11 kHz frequency range, designed to deter grey and ringed seals. Fishing stations upstream of the ADD line reported increased whitefish catches, decreased damage to fishing gear and catch, and fewer seal sightings. The authors of this study highlight that long-term assessments of impacts of ADDs are still needed to verify the overall effectiveness. While the ADDs effectively reduced seal interactions, the deterrence was not absolute. Some seals managed to bypass the barrier. They also conclude that the feasibility of ADDs needs to be balanced against their economic and social viability, thereby highlighting the importance of case-by-case cost–benefit assessments: "*From an economic point of view, ADDs are relatively expensive (in our study, ~21 k€ per unit, with an expected lifespan of 10+ years declared by the manufacturer) and their installation, operation and care in rivers requires considerable time and resources*." Their analysis concludes that the immediate economic value of the river fishery is unlikely to exceed the cost of ADDs, at least without considerable state subsidies.

Fisheries Management Scotland (FMS) received funding in 2023 from the Marine Fund Scotland to purchase 19 OTAQ Sealfence Portable Acoustic Deterrent Devices. This device is marketed as a "*mobile acoustic system designed to deter seals and sea lions in a wide range of underwater situations. The device uses a robust, underwater projector (fitted with 25m of Kevlar reinforced cable) to emit an omnidirectional sound which seals and sea lions will find uncomfortable at anything inside the system's 40m effective range*[2] FMS distributed these ADDs to twelve District Salmon Fisheries Boards across Scotland to be used as "mobile ADDs, mounted on suitable watercraft" to increase the capacity for river managers to deter seals from Scottish Rivers. FMS undertook a survey following the first full year of use by river managers to determine Responses were very variable and it is not clear from the information provided exactly how devices had been deployed or how effectiveness was measured. In terms of the effectiveness of the devices, three respondents felt they were not effective, two felt they were effective, one moderately effective, and one less effective. One of the survey respondents had not yet had the opportunity to trial the device and two rivers did not respond to the survey. The assessment of efficacy was reported to be variable in some locations, depending on the nature of the terrain and mode of deployment. Several respondents reported that the manual deployment of the device using watercraft was labour intensive and one

[2] https://offshore.otaq.com/content/uploads/sites/3/2020/03/OTAQ-Sealfence-Portable-specification-sheet-ENG-R1.pdf

reported that a jet ski was more effective than a canoe due to the ability to manoeuvre and ensure that the ADD can be activated when the seals are within the effective range of the ADD.

A summary of research on the effectiveness of acoustic deterrents in rivers was provided in SCOS (2024). An updated version of the summary table is provided here in Table 14.

Table 14. Summary of global studies testing the efficacy of Targeted Acoustic Startle Technology (TAST) Device in rivers and fisheries

Local lead /reference	Institution	Species/ application	Funding	Research topic & reported results
Rob Williams Williams et al. (in prep)	Oceans Initiative, WA, USA	Harbour seals Salmon Rivers	Puget Sound Partnership, Salish Sea Marine Survival Project	Various projects in the Pacific Northwest (Whatcom Creek, Ballard Locks, Olympia, and Nisqually, 2020-2023). • Meta-analysis of projects from 2020-2023 modelling estimate effects size regarding deterrence and predation reduction. • TAST achieved a reduction in seal predation on salmon by 59% to 80% (at study sites where no technical malfunction occurred TAST) • Deterrence effect of seals (distance increase)
Rob Williams Williams et al. (2021, a)		Harbour seals Salmon Rivers	Puget Sound Partnership, Salish Sea Marine Survival Project	Predation on salmon decreased by 77% (within 50 m). Fish passage increased by 55%

Rob Williams Williams et al. (2021, b)	Oceans Initiative, WA, USA	Harbour seals, Steller sea lions (low numbers) Salmon Rivers (fish ladder)	Puget Sound Partnership, Salish Sea Marine Survival Project	Employing Targeted Acoustic Startle Technology (TAST) to deter harbor seal predation on endangered salmonids at the Ballard Locks, Seattle, WA. Final Report, March 5, 2021 • 49% reduction in predation events when TAST was on. • Modelled 45% increase in fish passage (i.e. endangered salmon) at the fish ladder. Multi-unit deployment may improve efficacy further (as single unit provides insufficient coverage of the whole area).
Laurie Jemison Jemison et al. (2024)	Alaska State Department of Fish & Game, AK, USA	Steller sea lions Fishery (application) & tidal feeding aggregations (experiments)	NOAA BREP grant (bycatch reduction grant)	Preserving catch of salmon troll fishermen while reducing interactions with Steller sea lions (SSL): targeted acoustic startle technology (TAST) to deter SSLs from troll gear in Southeast Alaska. Final report. • 91% to 94% reduction in predation events within 40 m of TAST (best estimates from two model specifications). Localised effect with no change in foraging behaviour at distances of >40 m. • Significant reduction in seal surfacing and distance increase in response to TAST within a range of up to 35-50 m. Potential for reducing bycatch of sea lions.
Samantha Cox Cox et al. (2024)	University College Cork, Republic of Ireland	Grey seals Gillnet fishery	Predation: EU (Marie Curie), Marine Institute PAM: SEAFICS, “Seals and Fisheries	• Passive acoustic monitoring study to investigate potential effects on cetaceans. • 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.

			Co-existing Sustainably”	
David Whyte, Thomas Goetz & Vincent Janik Whyte et al. (2021)	Rosehearty Fishing Association, University of St Andrews, Marine Scotland Science, NECFRIG. UK.	Grey seals Handline mackerel fishery	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 • deterrence effect of TAST on seal activity directly around fishing vessels • seal detections on the vessels’ fish finder (sonar) decreased by 97%
MMO (Marine Management Organisation), ABPmer: Suzannah Walmsley, UK Walmsley et al. (2025)	DEFRA/MMO	Grey seals		• Study on inshore gillnets using a paired design with test nets (protected by TAST) and control nets (unprotected). • 74% increase in catch in the test net compared to a control net as the result of reducing seal depredation
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 • The study did not control for distance meaning that predation events were recorded in a wider area, including at distances that

				were outside the expected deterrence rage of TAST: *"…some individuals deemed 'present' under sound exposure conditions may have been outside the effective zone. Individuals outside this zone cannot be expected to startle, cease foraging, or show an avoidance response"*. • Given these caveats, a 43.8% reduction in predation events on endangered salmon was found. • More reliable estimate by Williams et al. (in prep) based on analysis of combined raw data from multiple studies across different locations and years into a single coherent analysis.
Tobias Schaffeld	University of Veterinary Medicine, Hannover, Germany	Grey seals		Keeping grey seals away from a swimming zone. Highly effective in achieving deterrence within a confined area (manuscript in prep).

Sea fisheries

An update on current levels of bycatch in UK fisheries is provided in the answer to Question 5 above. This answer mainly addresses other types of interactions with sea fisheries, namely depredation of catch/damage to gear, and competition for a shared resource. Seals can also act as vectors for parasites that affect fisheries. For example, seals are vectors for cod worm, the nematode *Psuedoterranpva decipiens* (Hauksson, 2011). Hauksson (2011) reported that the prevalence, abundance and density of cod worm larvae were highest in the fish caught closest to shore, which was also in closest proximity to grey seal colonies and in the shallowest waters. Infections of Baltic cod by cod worm, were reported to have increased following the significant increase of the Baltic grey seal population in the region (Buchmann, 2023). In addition to cod worm, seal stomachs are infected with other anisakids, including *Contracaecum osculatum*, *Anisakis simplex*, and *Phocascaris* spp., whose larvae also are found in groundfish (Scott and Fisher 1958; Brattey and Ni 1992; Brattey and Stenson 1993). Marcogliese et al., (1996) highlighted that observed changes in the distribution and abundance of parasites in the Gulf of St. Lawrence may be caused by a combination of increases in grey and harp seal densities concomitant with climatic changes affecting bottom temperature. They predicted that should water temperatures increase, abundance of cod worm will also increase in fish and seals in the Gulf of St. Lawrence. These aspects of seal/fisheries interaction have received relatively little attention in UK fisheries.

Sea fisheries - depredation

Depredation in UK commercial fisheries was reviewed in SCOS (2022). It is well known that fishers in the UK report frequent and significant losses due to seal depredation (MMO, 2019). According to an online survey of UK fishers published by the MMO (MMO, 2019), frequent problems with interactions with seals and gillnets were reported by over 80% of respondents. In the North Sea and Eastern Channel, drift nets and lines were also reported to be subject to frequent interactions. Interactions with pots/traps and trawls were reported to be of a more occasional nature. It is felt strongly by the fishing industry that impacts of seals on fishing operations have increased and that effective solutions are necessary (MMO, 2019).

Elsewhere in Europe, increasing grey seal populations have been highlighted as a concern for depredation in specific fisheries, mainly static net fisheries, e.g. the monkfish static net fishery in Brittany in northern France (Massey et al., preprint), in Irish gillnet and entangling net fisheries (Cosgrove et al., 2015) and the Baltic net, hook and line and trap fisheries (Fjälling et al., 2005; Königson, et al., 2009; Königson, et al., 2015; Blomquist and Waldo, 2021; Glemarec et al., 2024). Glemarec et al., (2024) recently estimated that about 45% of cod and 6% of flatfish gillnet catches are stolen by grey seals in the Central Baltic Sea. They also found that depredation levels increased with increased soak time, with the authors suggesting that grey seals revisit a net where they found cod in the days following their first depredation attempt to steal the freshly captured cod. In the Baltic, several studies have shown that fishers could switch from gillnets to seal-safe gears, i.e. specially designed pots and fish traps that aim to protect the catch from the seals, while maintaining catch rates to acceptable levels (Kindt-Larsen et al., 2023, Königson et al., 2015).

Cosgrove et al., (2015) carried out a targeted study of depredation by seals in Irish fisheries, based on 91 observer days in gillnet fisheries for hake and pollack, and trammel/tangle net fisheries for turbot and crawfish. They estimated that 18% of pollack, 10% of hake and 59% of monkfish landings were depredated by seals. Cosgrove et al., (2015) showed that several aspects of fishing activity affected depredation and bycatch rates in bottom set tangle nets for pollack and hake. Soak time, depth, haul speeds and haul sequence, noise from fishing activity, season, day/night deployment, and net type all affected depredation as well as location, particularly in terms of distance to nearest concentration of seal haulout sites.

In Brittany, France, Massey et al., (preprint) found that seal depredation occurred on 18.5% of monitored net sets and resulted in the removal of 5.3% of total monkfish catches. The probability and levels of depredation observed varied with location, with a higher probability of depredation closer to haul outs and between the months of March and May. Depredation rate was lower in trammel nets than in gill nets and decreased with the length of the net. The authors suggest several practical measures related to these patterns that could be adopted by fishers to potentially reduce depredation in this fishery.

There are currently no published quantitative estimates of the level or impact of depredation in any UK fishery. SCOS (2021) recommended effort focused on developing a quantitative understanding of the level and extent of depredation in UK fisheries to identify locations and timings of interactions that warrant further investigation and to inform mitigation strategies. A further recommendation included a quantitative investigation of data collected by onboard observers as part of the UK Bycatch Monitoring Programme.

There are two primary approaches to reducing conflicts between sea fisheries and seals. The first involves reducing the opportunities for seals to inflict damage by means of gear modifications and/or the timing and location of fishing activities to minimise the number and duration of interactions. The second involves deploying some form of deterrent to disrupt seals' foraging activities or drive them away from the fishery. The studies reviewed above all highlight that factors such as soak time and location could significantly affect rates of depredation, indicating the potential for reduction of depredation by modifying some aspects of fishing practice. However, many of the fishers who responded to an MMO (2019) survey reported taking actions to reduce impacts, including reducing soak times, moving to different sites, attending gear, reducing noises that may attract seals and adjusting rigging (for pots), but also reported that these methods were not effective long-term solutions because seals rapidly adapted to them. As far as SCOS are aware there are limited gear modification options available for reducing opportunities for interactions with static tangle nets. Further investigation of the potential in UK fisheries for gear modifications and the potential for the adoption of 'seal-safe' gears of the type that have been successful in Baltic fisheries is warranted. Some progress has been made on the development and testing of potential acoustic deterrent-based mitigation measures, some of these have already been reported on above under question 5 in relation to their potential to also mitigate seal bycatch. The work presented by Walmsley et al., (2025) describing trials of the Targeted Acoustic Startle Technology (TAST) on seal depredation in an inshore gillnet fishery was previously reported in SCOS as MMO (2020). This work indicated significant increases in catches in nets equipped with TAST devices compared to control nets. Statistical modelling demonstrated a 74% increase in total catch on the test net compared to the control net. Similarly, Cox et al. (2024a) reported that preliminary analysis of data from a pilot trial of the TAST device in a gill-net pollack fishery off southwest Ireland indicated an overall decrease in depredation rates at test nets compared to control nets although highlighted that sample sizes were low and further work was necessary to draw firm conclusions. Further trials are planned for summer 2025 using baited nets. The TAST has also been tested in hook and line fisheries in Scotland and the United States. In a jigging fishery in the Moray Firth, TAST achieved a 97% reduction in grey seals presence under the vessel based on fishers reporting sighting on their echosounders (Whyte et el. 2021). In Alaska, TAST has been tested by the Department of Fish & Game on otariid pinnipeds (Steller sea lions) in a series of trials around haulout sites, in tidal feeding aggregations (where sea lions predate on salmon) and salmon fishing vessels ("trolling"). TAST treatments caused a significant reduction in sea lion surfacing within a range of up to 35-50 m. In tidal feeding aggregations, TAST achieved a between 91% and 94% reduction in predation events within 40 m of the unit. Deterrence effects were localised with no change in foraging behaviour at distances of >40 m.

TAST devices in early trials were designed for stable deployment on fixed aquaculture cages, and it was highlighted by Walmsley et al., (2024) that developments are required to increase the robustness and reliability of devices, and size reduction and modifications are also required to allow streamlined net-based deployments. Since that study was conducted, Genuswave have developed a new TAST design (FisherySafe) which constitutes a self-contained unit with a much smaller footprint, smaller integrated single transducer and internal battery. These have been tested in some fisheries applications, such as on gillnets in Ireland (Cox et al. 2024 a) and in hook and line salmon fisheries in Alaska (Jemison et al. 2024) and the manufacturers highlight that they should allow for a more streamlined, net-based deployment to reduce the handling and lost time requirements for fishers. Cost-benefit analyses would be useful to determine the optimal balance between depredation reduction and the cost of mitigation measures

Suuronen et al., (2025) reports on trials of new seal deterrent applications developed and tested by the Natural Research Resources Institute Finland (Luke) and provides guidelines regarding the appropriate use of deterrents. They describe experiments where the suitability and effectiveness of raft-mounted and portable deterrents using the Otaq Seal Fence were studied pairs of pontoon-traps, one equipped with a deterrent and the other without, were compared. The deterrent was placed near the funnels of the trap and during two fishing seasons, the average salmon catch was 64 percent higher in traps with a deterrent (Lehtonen et al. 2022). Although some seal-induced damage occurred, salmon fishers have apparently continued to use the deterrents with satisfactory results. Lehtonen et al., (2024) reported on the development of seabed mounted Ace Aquatech US3 ADDs to create "seal free areas" but no data were presented to allow any assessment of the effectiveness of the systems. Research is ongoing regarding the use of portable deterrents in other coastal fisheries such as pontoon-trap fishing for whitefish. Suuronen et al., (2025) also report that Luke, in collaboration with the Aalto design factory, has built and assessed a prototype of an autonomously moving ADD to protect larger areas than a stationary ADD can cover. So far, there are no results on the efficiency of the autonomous ADD.

Sea fisheries - competition

There is considerable overlap in seal diet composition and fish species targeted in commercial fisheries so there is the potential for fishing induced changes in prey availability to impact seal populations, and for seal predation to reduce the fish available for commercial fish catches. A review of the impacts on fish populations of increasing seal populations was provided in SCOS (2019) and SCOS (2021). Clearly, predation by seals is large enough to be a potential factor in the dynamics of some fish populations (e.g., grey seal predation has been shown to be an important factor in the failure of cod stock recovery in southern Gulf of St. Lawrence (Neuenhoff et al., 2019), although in other cases, seals have minimal impact, e.g., harp seal consumption of cod off Newfoundland was found not to be an important driver of the northern cod stock (Buren et al., 2014), and in the northern Gulf of St Lawrence, although harp seal consumption did affect cod dynamics it was not as important a driver as fishing or water temperature (Bousquet et al., 2014). However, uncertainties in several factors, e.g., fine scale variation in seal diet composition, the spatial and temporal overlap between seals and fisheries at sea and overlap between the size distribution of prey eaten by seals and selectivity of the fisheries all combine to mean that confidence in predictions of effect levels will be low. SCOS (2019) concluded that it was unlikely that seal population growth is a major factor driving recent fish stock declines. Consumption of cod by seals in the North Sea was estimated to represent a small percentage of estimated stock size. Other factors such as overfishing, climate change, the destruction of nursery grounds, and discard bans are considered more important than seal predation (ICES, 2024).

Trijoulet et al., (2018) conducted bioeconomic modelling of the impacts of grey seal predation on the west of Scotland demersal fisheries (cod, haddock, and whiting) and concluded that large whitefish trawlers are most sensitive to seal predation due to their higher cod revenues, but seal impacts are minor at the aggregate fishery level. Importantly, the results of this study were sensitive to the choice of seal functional response (how predation rate varies with the abundance of the prey) highlighting the need for information on this critical parameter. SCOS (2019, 2021) highlighted that predicting ecosystem effects of predator populations is complex and requires a multispecies modelling approach. This requires information on fish abundance and distribution, spatial and temporal patterns of seal predation, spatial and temporal distribution of fishing effort, and an understanding of multispecies functional responses. Work is underway to fill several of the data gaps highlighted in SCOS 2019. For example, the EcoSTAR project under the INSITE II programme has developed multispecies functional response models for seals and porpoises and integrating outputs within a North Sea ecosystem model which is being used to model scenarios of future change.

Understanding seal diet is key to being able to predict ecosystem effects of increasing populations and as detailed in SCOS (2019, 2020), the results of previous major studies of seal diet in the UK 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 sampling (2010/11) 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. SCOS note that these data are now more than 10 years old and may not provide an accurate description of seal diets in areas where fish stocks and seal populations have changed. 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). There are now studies underway to update our estimates of grey and harbour seal diet in the southeast of England SMU and around Scotland, and a reassessment of the potential for competition with commercial fisheries can be undertaken once this work is complete.

Aquaculture

Previous recent SCOS reports have provided detailed reviews of the interactions between seals and aquaculture in Scotland, including options for mitigation (SCOS 2021, 2023). Little new work in this area has been published since these reviews.

Coram et al., (2021) conducted a review of the use and efficacy of ADDs in aquaculture and concluded that there were significant limitations with the available data and that further research was necessary to address the key knowledge gaps in relation to depredation by seals in aquaculture and the efficacy of acoustic deterrence. Controlled experimental trials are required to understand the efficacy of ADDs in reducing depredation and to understand any effects on non-target species. This is particularly important in the context of the changing scientific understanding of the potential impacts on non-target species, and current regulatory frameworks. Research is also required to better understand the efficacy of alternative management measures, and further recommendations on this were provided in Thompson et al., (2021), which considers the non-lethal management options for seal predators at finfish farms in a broader context.

Options available include the use of anti-predator nets and double netting. For example, Scottish Sea Farms have adopted Seal Pro netting and are due to have double netting in place at all fish farms in Shetland by mid-2025[3]. Other options include submersible cage designs, including those that would allow moving into areas further offshore and consolidating farms into a smaller number of larger pens. The assumption with the latter being that the bigger the pen, the greater the opportunity for fish to shoal nearer the middle and out of access from the seal at the net edges. No information is available about the effectiveness of these measures at reducing seal depredation.

As a result of concerns about the potential impacts on cetaceans (e.g. Findlay et al., 2024), and the need for an EPS licence if the ADD model has the potential to disturb cetaceans, ADD use in Scotland is not currently practiced by the industry. Although a small number of studies have concluded that specific acoustic devices have no impact on some cetacean species (e.g Götz & Janik, 2015, Götz & Janik, 2016, Cox et al., 2024b).

As suggested in SCOS (2023), the coincident cessation of both licencing to shoot seals to protect the health and welfare of farmed fish and the use of ADDs by the sector may provide an opportunity to retrospectively assess the effectiveness of these two previously widely used active control measures. There have been anecdotal reports from the industry of increases in predation at fish farms since the commercial use of ADDs has been stopped but these have not been verified. To date there have been no targeted studies to assess changes in seal predation rates or levels of seal activity at aquaculture sites coincident with the cessation of ADD use. However, the industry has continued to record salmon mortality and there may have been some monitoring of seal sightings over the transition period that could provide a basis for such a comparison.

There is generally a lack of published evidence for the effectiveness of most ADD devices at reducing seal depredation on salmon farms. The exception to this is the studies into the effectiveness of the TAST demonstrating a 91-97% reduction in seal depredation on salmon farms in Scotland (Götz & Janik, 2016).

SCOS are aware of a collaborative study underway by SMRU, the ADD manufacturer Ace Aquatec and the aquaculture company Scottish Sea Farms, funded by the Sustainable Aquaculture Innovation Centre with matched funding from Industry partners. This project aimed to conduct a long-term randomised controlled trial of an acoustic seal deterrent under real-world conditions. This involved the installation of low-frequency Ace-Aquatec RT1 ADDs at several sites in Shetland and the monitoring of seal depredation rates over the course of a production cycle (18 months). The deterrent was controlled remotely by researchers via cellular network, allowing treatment periods to

---

[3] https://www.shetnews.co.uk/2024/09/19/double-netting-system-aims-reduce/

be controlled independently of farm activities. The main challenges have been related to EPS licensing for research - the most heavily predated farms (according to site operators) were not permitted for inclusion in trial, reducing the planned sample size and resulting power to detect an effect considerably. Acoustic data from these sites may also provide insights into the distribution of low- and mid- frequency cetaceans such as killer whales and dolphin species in relation to the RT1 operation. Additionally, a previous trial in Orkney will be extended in duration to increase sample size, allowing a better understanding of the responses of harbour porpoises to the low-frequency signal. Data analysis is currently ongoing.

Health and disease

> **7. SCOS will provide current information on population health and disease concerns for harbour and grey seals in the UK. SCOS will describe current efforts to monitor seals for known or emerging health threats and provide updates on any recent outbreaks or emerging diseases (regionally and globally) that may impact the conservation and management of grey and harbour seals in the UK.**

Both infectious and non-infectious disease processes can impact population health by reducing survival, reproduction and resilience to environmental change. Currently, from a conservation and management perspective, infectious disease concerns for UK seal populations include primarily Highly Pathogenic Avian Influenza (HPAI) and Phocine Distemper Virus (PDV). As of March 2025, both grey and harbour seals have tested positive for HPAI (H5N5 and H5N1, and H5N1, respectively) in the UK. There are currently no instances of large-scale outbreaks in UK seals, but in the absence of widespread, regular testing, it is unknown to what extent HPAI may be circulating. H5N1 has resulted in large scale mortalities of phocids globally. A total of 12 (of the 33) pinniped species has now tested positive although the total number of species affected remains unknown due to the variation in ongoing global surveillance efforts. HPAI continues to circulate in poultry, wild birds and carnivores in Europe, and as such, there remains the potential for spill-over to UK seals.

In March and April 2023, 17.5% of harbour seals (7/40), and 5% of grey seals (1/20) sampled in the Wash Special Area of Conservation were seropositive (had circulating antibodies) for PDV. There are currently no known large-scale outbreaks in UK seals, but it is unknown to what extent PDV may be circulating.

There is no routine health or disease surveillance in marine mammals in the UK, and as such, only sporadic findings of viral and bacterial infections have been reported in seals. Routine health and disease surveillance through coordinated efforts involving strandings schemes, rescue and rehabilitation centres, and live captures for research is critical to better understand population health.

In Scotland, although there is no specific new mechanism, Marine Directorate Licensing (MD-LOT) have confirmed they will provide a rapid response (within a working day) in the event of an urgent responsive need to sample seals. In the rest of the UK, however, the delay between application and granting of authority to conduct studies requiring capture and/or sampling of live seals for research 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 must be a priority.

Population health and disease concerns for harbour and grey seals in the UK

Both infectious and non-infectious disease processes can impact population health by reducing survival, reproduction and resilience to environmental change. Infectious diseases are caused, most commonly, by pathogens including viruses, bacteria, and parasites. These can spread through seal populations though a combination of direct contact between individuals, exposure to contaminated environments, spillover events from other species, and a combination thereof. Non-infectious disease processes are caused by, for example environmental, anthropogenic or genetic factors and include exposure to chemical contaminants, exposure to harmful algal blooms, changes in prey distribution and abundance, and genetic bottlenecks. These can result in chronic health issues including malnutrition, immune dysfunction, hormonal disruption and lowered reproductive success.

Non-infectious and infectious disease processes will often interact, typically with non-infectious stressors often exacerbating infectious disease outcomes. For example, contaminant exposure, environmental variability or poor nutrition can result in impaired immune responses (Williams et al., 2025), making seals more susceptible to infections. Additionally, environmental variability may result in changes in at-sea behaviour or haul-out patterns, increasing contact between species and thus increasing the potential spread of infectious pathogens (VanWormer et al., 2019). Ultimately, these could have population level impacts through mass mortality events or chronic reproductive failure, leading to changes in population structure and trajectories. Below are detailed infectious diseases of potential concern in UK seals, as well as information on other non-infectious disease processes that could impact harbour seal populations in particular.

Infectious Disease Concerns

Highly Pathogenic Avian Influenza (HPAI): There have been very few reports of mortalities of HPAI in wild mammals in the UK, with just a small number of species, including seals, otters and foxes, testing positive between 2021 and 2025. Small numbers of seals were tested every year over this period, with cases of HPAI reported in 2021, 2022 and 2025. However, due to the absence of routine disease surveillance in UK seal populations, the true extent of HPAI, or other influenza infections in seal populations cannot be determined. The small number of positive samples from seals are summarised in

Table 15, and were collected from stranded carcases. It is not known if these seals were symptomatic or if infection was a contributing factor in their deaths.

The most recent, and largest number of positive individuals were grey seals sampled on a breeding colony at Blakeney Point, in North Norfolk in early 2025. Forty grey seal carcasses (mostly pups) were sampled, and 15 (37.5%) tested positive for HPAI H5N5 (

Table 15). Sampling efforts in seals were undertaken by the avian influenza national reference laboratory in collaboration with APHA's Diseases of Wildlife Scheme following a mortality event in great black-backed gulls that tested positive for HPAI. As for previous cases, it is not known if the seals were symptomatic or if HPAI infection was a contributing factor in their deaths. Pup production estimates are not available for the 2024/2025 season. However, the number of adults and pups found dead at the end of the season were not higher than would be expected given the size of the colony (last estimated for the 2023/2024 season. Thus, there does not appear to have been a significant outbreak or associated mass mortality.

Table 15. Confirmed findings of HPAI in seals in the UK between 2021 and 2015. Updated April 2025, details from GOV.UK. N.B. A small number of seals were also retrospectively tested in 2023 and 2024, but none were positive.

Location	Year	Month	HPAI Strain	Positive Cases	Species
North Norfolk, England	2025	March	H5N5	13	Grey seal
North Norfolk, England	2025	February	H5N5	2	Grey seal
Cornwall, England	2022	October	H5	1	Grey seal
Cornwall, England	2022	October	H5N1	1	Grey seal
Cornwall, England	2022	September	H5N1	1	Grey seal
Cornwall, England	2022	September	H5N1	1	Grey seal
Cornwall, England	2022	September	H5N1	1	Grey seal
Fife, Scotland	2022	July	H5N1	1	Harbour seal
Orkney, Scotland	2022	June	H5N1	1	Harbour seal
Highland, Scotland	2022	March	H5N1	1	Harbour seal
Aberdeenshire, Scotland	2021	October	H5N1	1	Grey seal

A recent report (GOV.UK, 2024) prepared by the UK Health Security Agency (UKHSA) on behalf of the joint Human Animal Infections and Risk Surveillance (HAIRS) group summarised the current situation with respect to influenza of avian origin (AIV) in UK seal populations. It was recommended that a review of seal health surveillance across the UK takes place, with the long-term aim to establish routine disease surveillance in marine mammals in the UK. The review highlighted that prior to the H5N1 pandemic, other influenza subtypes (H3N8 and H5N8) have been detected in UK seals since 2017 (Venkatesh et al., 2020; Floyd et al., 2021). However, due to the absence of routine disease surveillance, it cannot be determined if AIV detection in the two grey and two harbour seals in the aforementioned studies is incidental, or if AIVs are in constant circulation in UK seal populations.

AIV is not considered endemic in UK bird populations, and whilst outbreaks can occur at any time of year, there is typically a seasonal increase of AIV infections associated with the arrival of infected migratory birds over winter. Their arrival can result in local avian transmission either directly between birds, or indirectly when birds encounter environmental contamination, including faeces and feathers. Cross-species transmission can then take place in coastal regions where there is both direct and indirect contact between infected birds and seals either at haul out sites or when feeding on a common food source (Fereidouni et al., 2016). As such, we might expect AIV infections in seals to show the same seasonal patterns as in birds, rather than developing endemicity. As well as infections through contact with infected birds, seal movements (grey seals in particular) from other

European countries where AIV infections have either been detected, or resulted in mass mortalities (Table 16), could also present a risk of disease introduction into UK seal populations. The two PDV epidemics, for example, affected centres of seal abundance around the North Sea, including those of the UK. This disease spread, along with data from both electronic and passive tags and genetic studies, demonstrates connectivity between these centres. Given the recent mass mortalities in seal species in other parts of the world (details below), and evidence of infection in grey and harbour seals in the UK and across Europe, there is the potential for a disease outbreak in UK seals.

Table 16. Published AIV detections in seals around Europe and the North Sea.

Species	Infection	Year	Individuals impacted	Location	Reference
Harbour seals	H10N7	2014 - 2015	Mass mortality >2,000	Sweeden, Denmark, Germany, the Netherlands	(Bodewes et al., 2015)
Grey seals	H5N8	2016 - 2017	2 positives	Poland (Baltic)	(Shin et al., 2019)
Harbour seals	H5N8	2021	1 positive	Denmark (North Sea)	(Postel et al., 2022)
Harbour seals	H5N8	2021	3 positives	Germany (North Sea)	(Statens Serum Institut, 2022)

Phocine Distemper Virus: Phocine distemper virus (PDV) remains a major concern for UK seal populations as it can cause large-scale mortality events. Two previous outbreaks of PDV have severely affected harbour seal populations in European and UK waters, in 1988 and 2002, when approximately 18,000 and over 20,000 seals died, respectively. Given the length of time since the previous outbreak, there will be very few (if any) immune survivors remaining, and as such, with no population immunity, another PDV epidemic may be expected and will likely cause high harbour seal morbidity and mortality rates again in the southern North Sea (Bodewes et al., 2013; Ludes-Wehrmeister et al., 2016). This is of particular concern now as it is thought that populations will likely have limited immunity to the virus, as few individuals will still be alive since the last outbreak, and the majority of the population will therefore have had no prior exposure. This makes harbour seal populations especially vulnerable to new introductions and subsequent spread of the virus. In addition, this population recently experienced a decline, the causes of which are still unknown, which may mean that it has reduced resilience to additional challenges.

Antibodies to PDV have been detected in European seals since 2002, the prevalence of which has varied over time and across regions and have been largely linked to the 2002 epizootic. However, there is little published evidence of current disease exposure in seals across Europe. For example, in 466 samples from harbour and grey seals collected from Dutch coastal waters between 2002 and 2012, antibodies were detected in most seals in 2002 and 2003, while post 2003, antibodies were detected only in seals that likely had survived the 2002 epizootic (Bodewes et al., 2013). In German and Danish waters, following the 2002 epizootic, antibody prevalence declined over time, with no sustained exposure detected six to eight years after the outbreak (Ludes-Wehrmeister et al., 2016). In a longitudinal screening study between 2002 and 2019 of 298 pinnipeds in the Baltic and the North Sea, only one adult harbour seal tested positive (presence of viral RNA in tracheal swabs and lung tissue samples) for PDV in 2002, which was associated with the 2002 epizootic (Stokholm et al., 2023). Similarly, between 2015 and 2017, a total of 80 stranded dead harbour seals were tested from the German North Sea coastline (presence of viral RNA in tracheal swabs), and were negative for PDV (Siebert et al., 2024). However, recent work by SMRU has shown that seal populations in The Wash, Southeast England, have been exposed to PDV since the last outbreak, with 17.5% of sampled harbour seals (7/40), and 5% of sampled grey seals (1/20) testing antibody-positive in 2023. These seropositive seals were asymptomatic. Further work is necessary to establish if the disease is endemic in this population, or if these preliminary seroprevalence results are indicative of a recent introduction that did not result in an epidemic and faded out, which is typical for morbillivirus infections (Harris et al., 2008). While there is no evidence of an increase in reports of stranded seals in severe respiratory distress and of carcasses, as was documented in the two previous PDV epizootics, we cannot rule out the potential that there may have been some mortality associated with this recent introduction considering the estimated loss of > 1,500 harbour seal individuals in the SAC between 2018 and 2019.

Streptococcus zooepidemicus: Clusters of dead stranded grey seals in northeast England tested positive for *Streptococcus zooepidemicus* in 2024, although it remains unclear if this was the primary cause of death, or a secondary infection. Seals were primarily adult males, in good nutritional condition, with no evidence of recent feeding and no evidence of trauma. However, they showed possible extensive purulent effusion and deeply congested lungs (Rob Deaville, Cetacean Strandings Investigation Programme, personal communication). There was no indication of a wider outbreak. *S. zooepidemicus* is known to cause a mild, purulent pneumonia, but has also been associated with oral ulcers and skin infections (Baker et al., 1998). The bacterium is commonly found in the oral cavity of grey seals, and was isolated as a co-infection during both the 1988 and 2002 PDV outbreaks (Akineden et al., 2007). Thus, assessing the health of seal populations and specific pathogen exposure is vital to understanding both disease susceptibility and transmission of this bacterial infection, and therefore predict outbreaks that could have population-level impacts.

Other pathogens:

Phocine herpesvirus infections in seals are associated with disease and sometimes high mortality, primarily in young or otherwise compromised animals, and circulate in harbour seal populations in Europe (Roth et al., 2013; Bodewes et al., 2015) and North America (Goldstein et al., 2003). Recent work by SMRU showed that 58% of harbour seals, and 80% of grey seals sampled in the Wash in 2023 were seropositive for herpesvirus. High seroprevalence rates seen here are similar to those seen across other harbour and grey seal populations. For example, seroprevalence in harbour seals ranged between 77 to 100% in Svalbard (Roth et al., 2013), 42 to 77% in Alaska and Russia (Zarnke et al., 2006) and up to 99% of adults in California (Goldstein et al., 2003). The virus is thought to shed on the mucosa of the eye and nose (Roth et al., 2013), and generally infections are associated with both high morbidity and mortality, especially in young seals. In harbour seals, regular outbreaks have been documented in Europe (Harder et al., 1997; Martina et al., 2002), and in the Pacific (King et al., 2001). Symptoms vary and can include upper-respiratory disease, interstitial pneumonia, hepatitis and adrenal necrosis (Gulland et al., 1997). Overall, it is predicted that annual variation in seroprevalence and active infections might reflect different frequencies of reactivation of the latent virus that can be influenced by environmental factors and other infectious pathogens that impact immune competence of the animals (Roth et al., 2013). Extrinsic factors such as stress responses or concurrent disease therefore likely affect the severity of the disease in harbour seals (Goldstein et al., 2004). Stress is also thought to not only make individuals more susceptible to infection but also prolong shedding (largely through nasal secretions) (Baily et al., 2019). SMRU's recent findings highlight the potential for using variation and/or changes in herpesvirus seroprevalence rates as an indicator of population-level stress impacts.

Since 2020, a collaborative effort between Teesside University, the Zoological Society of London, the Cetacean Strandings Investigation Programme (CSIP), Defra and the British Divers Marine Life Rescue (BDMLR) have been investigating the causes of '**mouth rot**' observed predominantly in harbour seal pups and juveniles along the east coast of England. Typically, pups have been observed with muzzle swelling, facial wounds and abscesses, and ulceration of the hard palate. The team suggest that mouth rot is likely the result of a combined viral and bacterial infection, with multiple pathogens involved, but concluded that calicivirus infection accounts for the majority of cases (Bojko and Arrow, 2024). In the few cases with mouth rot, but no detectable calicivirus, they suggest that herpesvirus infection, or infection with especially pathogenic bacteria such as *Treponema sp*., could account for the lesions (Bojko and Arrow, 2024). It was highlighted that other factors should be considered alongside infection with these pathogens when outlining a management strategy for the disease.

Non-Infectious Disease Concerns

Marine mammals are exposed to various contaminants of anthropogenic origin, including heavy metals, plastics and persistent organic pollutants (POPs). In mammals, POPs in particular are known to disrupt endocrine, reproductive, and immune systems, and can lead to adverse health effects including metabolic disorders, reduced immunocompetence, developmental issues, neurobehavioral impairment and cancer. While bans on their release in Europe over the last 40 years initially lowered environmental POP levels, they remain ubiquitous in the marine environment and are therefore still a risk to marine mammals as concentrations are biomagnified up through food webs. As a result, seals are often described as sentinels of marine environment POP levels. POP work in the UK has focused on measuring primarily polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and organochlorine pesticides (OCPs) in seals.

While there is no recent published data for UK harbour seals, previous work from the early 2000s indicated that the levels of various POPs in Scottish seals were *lowest* in the regions of greatest harbour seal population decline (such as Shetland, Orkney and the SE coast of Scotland) (Hall and Thomas., 2007). These were below the thresholds indicated as being deleterious to health (Kannan et al., 2000), suggesting that these levels were not contributing to population declines. Across other populations, more recent data investigating POP concentrations in harbour seals from Svalbard in 2009 and 2010 show a 60–90% decrease in concentrations of PCBs and OCPs since 1999 (Routti et al., 2014). Without more recent data it is not possible to investigate similar trends in temporal or spatial variability in concentrations measured in UK harbour seals.

Blubber POP concentrations have been measured more recently in grey seals. Concentrations in grey seal pups sampled on the Isle of May on the east coast of Scotland between 2015 and 2017 (Robinson et al., 2019) were below the marine mammal PCB toxicity threshold (Kannan et al., 2000). Overall, when compared to previous concentrations, the PCB levels in pups sampled in 2017 had fallen to 75% of the concentrations seen in the early 2000s (Robinson *et al*., 2019). When compared to other populations, concentrations in 2015 - 2017 were ~10 times lower than in grey seal pups sampled during the late 1990s and early 2000s in the Baltic Sea (Sørmo et al., 2003).

Similarly, in the same study, total PBDE concentrations were up to 7 times lower in 2015-2017 than in adult females also sampled on the Isle of May in 2008 (Vanden Berghe *et al.,* 2012). These recent concentrations are also an order of magnitude lower than values reported in UK grey seal pup blubber from 1998 and 1999 (Hall et al., 2003), and 2000 (Kalantizi et al., 2005). Lastly, for the OCPs, dichlorodiphenyltrichoroethane (ΣDDT), dichlorodiphenyldichloroethylene (DDE), and dichlorodiphenyldichoroethane (DDD), concentrations did not fall over the 15-year period between 2002 and 2017 (Robinson *et al*., 2019). As emphasised by the authors, the observed differences in temporal trends between contaminants highlight the need for long-term datasets to investigate and the evaluate continuing impacts of POPs on seals and on marine ecosystems more widely.

Other factors that could impact seal health, include low prey availability, poor prey quality and biotoxin exposure from harmful algal blooms (HABs), and interactions thereof. Health assessments can be used to investigate nutritional condition, as well as screen for the presence of biotoxins produced by HABs. Data from rehabilitation centres suggest that, in recent years, rescued harbour seals in the Southeast England Seal SMU appear to have particularly compromised immune systems (Himmelreich 2019). A combination of multiple acute and chronic stressors (e.g. nutritional stress) could be contributing to poor immune system function in these animals. There are projects exploring variation in prey quality, and how spatio-temporal patterns in diet relate to population trajectories.

Additionally, recent evidence shows that many important prey species, such as sandeels, flatfish and pelagic species including herring and mackerel, are contaminated with biotoxins year-round (Kershaw et al., 2021), potentially leading to chronic exposure in seals, as well as harbour seals being exposed to toxin doses that exceed lethal thresholds (Hall et al., 2024). Concentrations vary between prey species, and thus seal species-specific variation in diet (potentially mediated through changes in prey availability) will influence the extent of their exposure and potential health impacts. More details on exposure to HABs are included in Question 8 regarding the impacts of climate change.

Monitoring for known or emerging health threats

There is no routine health and disease surveillance specifically for marine mammals in the UK, and as such, only sporadic findings of viral and bacterial infections have been reported. There are strandings schemes, the UK Cetacean Stranding Investigation Programme (CSIP), and the Scottish Marine Animal Stranding Scheme (SMASS), that diagnose cause of death and investigate disease occurrence in carcasses. However, carcass collection and sampling are opportunistic not systematic, and these schemes have limited ability to detect disease and assess morbidity in populations before they affect vital rates and therefore population status. There is now much more emphasis and recognition that monitoring health is a critical means of determining or predicting changes in population dynamics as an early warning system (National Academies of Sciences, 2017).
The APHA Diseases of Wildlife Scheme also has a remit to investigate seal deaths and mass

mortalities, but given the challenges associated with the remote locations, potentially hazardous coastal habitats and protected status of seals, the coverage is opportunistic and not systematic. Combining up-to-date information from the strandings schemes and from rehabilitation centres would allow a process for identifying unusual mortality events and emerging health threats. 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 used in the United States under the Marine Mammal Protection Act (SCOS, 2022). Determination of an Unusual 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.

SMRU are currently leading two population health and disease surveillance programs including exposure to pathogens of interest, assessment of nutritional status, immune system function and stress responses. Firstly, SMRU was awarded funding from the Marine Directorate to monitor the health status of grey and harbour seals at haul out sites around Scotland through the analysis of samples collected during live captures 2025-2028. These new data will be compared to SMRU's extensive database of a suite of blood-based health markers to provide essential comparative context. Using both samples from live captures, as well as from strandings cases through close collaborations with the SMASS, SMRU will also assess antibody seroprevalence to key pathogens known to result in wide-spread mortalities, impact overall health and immunocompetence, and cause reproductive failure. Secondly, SMRU was awarded funding from Defra to process archived samples from harbour seals in Southeast England to complement ongoing work that has indicated recent disease exposure that may have played a role in the recent harbour seal decline in Southeast England. Work will now assess previous and current exposure to several pathogens known to impact seal health, survival and reproduction. This will allow SMRU to assess the relative role of disease in the declines in harbour seal abundance, the ramifications for population recovery, any mitigation that could be put in place, and to generate recommendations for ongoing routine surveillance.

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. SCOS recommend, as in SCOS 2024, that a mechanism to allow rapid permitting should be a priority to would allow a timely response to an unusual mortality event (SCOS, 2022), or to an acute change in environmental conditions that can impact seals. SCOS recognise that some progress in that regard has been made in Scotland; although there is no specific new mechanism, Marine Directorate Licensing (MD-LOT) have confirmed they will provide a rapid response (within a working day) in the event of an urgent responsive need to sample seals (e.g. harmful algal bloom, unusual mortality event).

Recent outbreaks or emerging diseases

Currently, the most significant disease-related threat for the conservation and management of UK grey and harbour seals is the spread of HPAI. During the panzootic between 2021 and 2022, H5N1

HPAI caused episodic, small-scale mortality of both pinnipeds and cetaceans in Europe (Mirolo et al., 2023; Thorsson et al., 2023) and North America (Puryear et al., 2023; Lair et al., 2024; Murawski et al., 2024). However, when the virus spread to Russia and South America, large-scale mortalities in marine mammals were observed. In Russia, more than 3,500 Northern fur seals (*Callorhinus ursinus*) died in the Sea of Okhotsk in 2023 (Sobolev et al., 2024), and potentially up to 10,000 Caspian seals (*Pusa caspica*) in 2022 (Gadzhiev et al., 2024). More than 30,000 South American sea lions (*Otaria byronia*) died along the coast of Peru and Chile between 2022 and 2023, with porpoises, dolphins, and otters also being affected in smaller numbers (Uhart et al., 2024). Then towards the end of 2023, HPAI infection resulted in the mass mortality of southern elephant seals (*Mirounga leonina*) in South America and in the sub-Antarctic. The largest die-offs were seen in elephant seals in Argentina (Uhart et al., 2024) and in South Georgia (Banyard et al., 2024). These recent, large-scale mass mortality events show that seals are susceptible to H5N1 in highly contaminated environments, and infections can result in a very high fatality rate (e.g. 95% mortality rate of elephant seal pups at Peninsula Valdez, Argentina (Uhart et al., 2024). As of March 2025, 12 different pinniped species have now tested positive for HPAI H5Nx (including H5N1) (Table 17), however, the total number of species affected remains unknown due to variation in ongoing global surveillance efforts.

Table 17. Pinniped species that have tested positive for HPAI (H5Nx). *Indicate species that have experienced mass mortality events. Species list compiled by the Food and Agriculture Organisation of the United Nations (FAO), and updated on the 26/03/2025.

Species	Location
Otariidae	
South American Fur seal (*Arctocephalus australis*)	South America*
South American sea lion (*Otaria flavescens*)	South America*
Northern Fur Seal (*Callorhinus ursinus*)	Russia*
Antarctic Fur Seal (*Arctocephalus gazella*)	South Georgia*
Phocidae	
Southern elephant seal (*Mirounga leonina*)	South America, South Georgia*
Caspian seal (*Pusa capsica*)	Russia*
Leopard seal (*Hydrurga leptonyx)*	Antarctic Peninsula
Weddell seal *(Leptonychotes weddellii)*	Antarctic Peninsula
Crabeater seal (*Lobodon carcinophaga)*	Antarctic Peninsula
Ringed seal *(Pusa hispida)*	
Grey seal	UK, North America, Europe
Harbour seal	UK, North America, Europe

Numerous HPAI subtypes have been found to infect both cetaceans (H1N3, H13N2, H13N9) and pinnipeds (H7N7, H4N5, H4N6, H3N3, H1N1, H3N8, H10N7, H5N8) (Runstadler and Puryear, 2020), but the exact mechanisms involved in viral transmission from birds to seals and cetaceans remain unclear. However, combined ecological and phylogenetic data collected from South America support mammal-to-mammal transmission in seals (Uhart et al., 2024). Earlier work, before the most recent panzootic, showed moderate attachment of AIV to the cell receptors in the respiratory tracts of both harbour and grey seals, which suggests high susceptibility to these viruses within these species (Ramis et al., 2012). We would therefore expect the UK seal populations to also be susceptible, with the potential for mass die offs depending on the time of year and number of introductions and/or spillover events.

Lastly, the numbers of HPAI cases (H5Nx) in poultry and wild birds across Europe (EFSA (European Food Safety Authority 2025), has increased between December 2024 and March 2025, compared to the same period last year. Currently, the main findings of the latest report published in March 2025 highlight that there continue to be outbreaks amongst poultry and wild birds, particularly in waterfowl, and for the first time since spring 2024, several HPAI detections were reported in domestic cats and wild carnivores in Europe. We would therefore expect the UK seal populations to come into contact with the virus, as has been shown with the recent positive cases detected in grey seals along the east coast of England. 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, these are less likely to have population-level implications for UK seals. However, should seal-seal transmission and/or multiple spillovers take place of a highly virulent strain, during the breeding season, or during the moult for example, an outbreak could impact UK seal populations.

Climate change and extreme weather events

8. SCOS will provide current information on the impacts of climate change and extreme weather events on UK seal populations.

Climate change is already having a range of effects in the seas around the UK, but predicting the population consequences of climate change for seals is difficult. There is little information on the relationships between environmental drivers and seal population dynamics, so it is unlikely that cause and effect will be reliably assigned to specific aspects of climate change with respect to changes in seal populations. However, changes could potentially have both indirect (e.g. changes in prey availability) and direct impacts (e.g. loss of breeding/haulout sites) on seals.

Changes in timing and intensity of stratification and locations of shelf-sea fronts will influence patterns of productivity and fish distributions and will likely affect prey availability to seals. These changes could have either positive or negative effects on seals in the UK. Observed trends in UK seal populations show that in the number of seals has been increasing in the southern North Sea since surveys began despite indications that distributions of currently preferred prey have shifted northwards.

Ocean warming has caused sea level rise (SLR) of approximately 0.2 m since 1950 and is expected to further raise sea levels by approximately 0.4 to 0.8 m by the end of the 21st century. Changes in sea level and resulting increased wave action on breeding beaches may reduce breeding and haulout site availability in some areas. Increased storminess in terms of maximum and average wind speeds and frequency of storm systems may lead to increased wave action on breeding sites which can increase pup mortality. Seals may be able to adapt by moving breeding sites if alternative sites are available. Recent analyses of potential impacts of SLR on grey seal breeding sites suggest that a large proportion of existing sites, particularly at low lying east coast locations will be at significantly increased risk of flooding by the end of this century.

A recurring theme in ocean climate temperature modelling studies is the prediction that Marine Heat Waves (MHWs) will increase in frequency, severity and longevity in the coming decades. Some areas of the UK waters experienced an extreme category 4 MHW in June 2023 with sea surface temperatures (SST) 4-5°C above normal. Additional less extreme SST anomalies occurred in September 2023, in May 2024, and during spring 2025. 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 in Scotland does not indicate any increase associated with these MHW events. Aerial surveys in August 2022 and 2023 did not indicate that harbour seal numbers in east Scotland and east England fell between 2022 and 2023. Conversely, compared to 2022, grey seal counts were much lower in 2023 in east Scotland, but grey seal numbers further south, at Donna Nook, were much higher in 2023. Seal counts were therefore equivocal and do not show a consistent decline coincident with the MHW. On the other side of the Atlantic, however, 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.

There is uncertainty in the predicted effects of climate change on frequency and intensity of Harmful Algal Blooms (HABs) in UK waters. However, given the potential severity of both chronic and acute exposure impacts on the health of seals, and other marine mammals globally, UK grey and harbour seals could experience population-level impacts. Longterm monitoring efforts are required to enable identification of trends in infectious disease prevalence. As described in 7 above, the movement of Arctic pinnipeds into UK waters and the introduction of novel pathogens into immunologically naïve grey and harbour seal populations is a concern.

The observed temperatures during the MHW 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. Overall, 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. 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 may have limited the effects of the MHW on the benthic and demersal fish populations which provide a large proportion of the diets of both grey and harbour seals in UK waters.

Long-term studies are required to be able to detect changes in body condition and reproductive output and investment, and to be able to link these with changes in environmental conditions. There is also a need for finer scale regular assessments of fish stocks at appropriate temporal and geographical scales, to be able to link these with changes in environmental conditions and changes in seal condition and reproductive success.

Marine mammals in the UK face an increase in the potential cumulative impacts from climate change and other anthropogenic pressures, which can make it difficult to determine the impacts of climate change, specifically. As a result, there is currently uncertainty when predicting the effects of climate change on seals. Additionally, there are a wide range of interacting factors driving population change at each trophic level, so it is extremely difficult to disentangle their effects and identify specific causes or predict the extent of impacts on seal populations. Albouy et al. (2020) carried out an assessment of the vulnerability of all marine mammal species to global warming and produced a ranked list of species by vulnerability to climate change effects. Grey seals (16) and harbour seals (20) appeared on a list of the top twenty most vulnerable species of marine mammals to climate change extinction risk.

Changes in cold temperate waters, such as the seas around the UK, may be profound, and will likely impact on continental shelf marine predators such as seals. However, in UK waters, the projected changes in the physical environment, such as air and water temperatures, water depth and salinity, are not predicted to exceed the homeostatic ranges for UK seals. Both grey and harbour seals occur in temperate coastal waters as far south as Brittany and the Wadden Sea in Europe, and Pacific harbour seals breed as far south as San Diego in California. Summer water and air temperatures at these locations exceed those currently experienced by seals in southern England. Indeed, existing summer conditions at the southern limit of current ranges are generally higher than projected temperatures in the UK over the next century under high warming scenario predictions. However, although harbour seals in other parts of their range experience higher summer temperatures, it is unclear what effects increased summer temperatures may have on breeding behaviour and breeding success of both harbour and grey seals in the southern UK.

The seas around the British Isles, have warmed faster than the global average over the past 50 years. SST in the North-east Atlantic and North Sea have risen by between 0.1 and 0.5°C per decade over the past century, and the rate of warming has been particularly rapid since the 1980s (Dye *et al*., 2013, Cornes *et al*., 2023). These rapid changes in the marine environment are having profound impacts on the ecosystem that may affect the distributions and availability of prey species and may have direct impacts on seal foraging success and reproductive performance. As well as these shifts in prey distribution and abundance, other predicted impacts on seals are linked to a potential reduction in haulout and breeding habitat, increased mortality as a result of storm surges, changes in breeding phenology, increased exposure to biotoxins from harmful algal blooms and the introduction of new viral and bacterial pathogens that can impact health. These are discussed individually below.

Range Shifts: Prey

Over the last 40 years, the SST around the UK has increased by approximately 0.3°C per decade, with the greatest increases measured in the southern North Sea (Cornes et al., 2023). These temperature changes have resulted in changes in the distribution of species as well as contributed to major regime shifts in the North Sea in particular (Beaugrand et al., 2003; Sguotti et al., 2022; Bode, 2024). In response, shifts in cetacean distribution in the UK have been observed, including an increase in warm water adapted species (e.g. short-beaked common dolphin and striped dolphin), and a decrease in cold water adapted species (e.g. Atlantic white-sided and white-beaked dolphin) (Williamson et al., 2021). These changes in distribution patterns are thought to be in response to northward shifts in the main prey of both warm and cold-water species which are sensitive to environmental changes including warming sea surface temperatures.

In contrast, a southward shift in harbour porpoise summer distribution within the Greater North Sea was observed between 1994 and 2005, and then later confirmed in 2016 (Geelhoed et al., 2022). Similarly, North Sea bottlenose dolphins are expanding their range southwards, the drivers of which remain unknown (Ellis et al., In Press), but could be related to preferred prey availability. Seals are top predators with a similar diet to delphinids; therefore, prey shifts are also likely to have impacted UK seals. However, as with bottlenose dolphins and harbour porpoises, the most noticeable distribution change in seals has been the large increase in grey seal numbers in the southern North Sea, and harbour seal numbers have increased substantially in the southern North Sea and decreased in the northern North Sea. It is interesting that all four of the main marine mammal species in the North Sea have shown a generally southward trend.

Important prey species, including North Sea stocks of cod, plaice and haddock, have shown northward shifts (Skinner, 2009; Engelhard et al., 2011). Baudron et al. (2020) published an analysis of scientific survey data that provides an overview of changes in distribution for 19 northeast Atlantic fish species encompassing 73 commercial stocks over 30 years. All species experienced changes in distribution. Specifically, two thirds of the shifts in centre of gravity (CoG) displayed by northern species were northward. Baudron et al. (2020) concluded that the overall northward direction of the changes in distribution together with observed range contraction for northern species, and expansion of southern species ranges into UK waters, Solenette (*Buglossidium luteum*) for example, were consistent with the poleward distribution shifts expected from warming sea temperatures.

However, more recently a multi-model projection of changes in both distribution and biomass for 18 key fish species in European waters produced more varied predictions (Sailley et al., 2025). The study found that primary productivity in the North Sea and Northeast Atlantic is expected to decrease by approximately 10% by the mid-21st Century and that commercially important cold-water species like herring, cod, and haddock are projected to decline in the North Sea by 10-20% under moderate warming scenarios and by 10-80% under high emissions scenarios by 2100. Sailley et al. (2025) also predicted changes in fish distributions, but the direction and scale of movement differed between ecotypes and regions. In the Northeast Atlantic, the population centroids for most species, both demersal and pelagic, are predicted to move north. However, the magnitude of the predicted changes differs widely between species, with shifts ranging from just a few kilometres for haddock (3-25 km) to over 400 km for herring (230-430 km) by 2100. In the North Sea, the predicted changes in distribution differ between pelagic species that are predicted to move north and demersal species which are predicted to move south. These predictions were based on both mechanistic and statistical models that showed a high level of agreement. The results suggest that future trends in distribution for demersal species that form the bulk of seal prey may differ from those previously identified in the North Sea. A recent study modelling potential changes in habitat suitability suggests that sandeel range will not move, but that habitat availability is predicted to increase in the areas that they already occupy (Couce et al., 2025)

A shift in the distribution of important prey species could lead to a reduction in prey availability, and therefore body condition of seals. Boveng et al. (2020) reported preliminary results of a study of Arctic seals that included harbour seals on the Aleutian Islands that experience environmental conditions similar to northern Scotland. Though harbour seal data were limited to three sampling events during 2014–2016, they observed a striking decline in body condition: an estimated annual decrease of about 45g of body mass per centimetre of length. Harbour seal populations have undergone a long-term decline in the Aleutian Islands. The population dropped precipitously between 1980 and 1999. The decline was most dramatic in the western Aleutians, where counts dropped by 86%, to about 5,500 individuals. The cause of the original decline is unknown, and the population has not recovered since. The estimates of recent declines in body condition represent almost a 20% decrease in body mass. Such decreases would have serious consequences for individual and population fitness. The researchers consider that the recent declines in body condition are likely an acute response to the recent very strong North Pacific marine heat wave, presumably mediated through reduced prey availability, rather than a continued chronic response to whatever has caused the long-term decline in numbers.

Range Shifts: Seals

Even with changes in the distribution of pelagic and demersal prey species, Atlantic populations of grey and harbour seals have not followed the expected northward trend. For grey seals on both sides of the Atlantic the numbers of seals in the southern parts of the range are increasing rapidly while populations in the central and northern parts of the range have stabilised leading to a southward trend in the centre of mass of the population. Similarly, for harbour seals in Europe, a southward shift in the centre of mass of the population has been recorded over the past 30 years despite the disproportionate effects of PDV epizootics in the southern North Sea. The drivers of the different population trajectories are not known, but the changes in seal distribution do not simply map directly to changes in distribution of their existing prey species. Nor do they conform to the broad scale northward movement in response to increased air and water temperature associated with climate change.

Species distributions are not usually determined by physical capabilities alone, and while there is evidence for shifts in important prey species, the distributions of both prey *and* competing predator species will influence the distribution of seals. So, the consequences of changes in the physical environment will be difficult to predict. If we could assume that competitors, prey, and other factors would maintain their current relation to variables such as water temperature and depth, we could use the current distribution patterns to predict future distributions under different climate change scenarios.

Boehme *et al.* (2012) and Zicos et al. (SCOS-BP 17/07) used location fixes and water temperature records from the extensive telemetry datasets for harbour seals, and grey seals in both the UK and Canada, to derive predicted distributions based entirely on water depth and sea surface temperature in the North Atlantic. Zicos et al. then explored potential habitat shifts across the entire Atlantic ranges of both species under two scenarios of climate change, the lowest and highest scenarios of warming as determined for the IPCC's 2014 report. The low warming scenario predicted an overall compression of core habitat, with slight loss of habitat in the northern and extensive habitat loss in the southern edges of distribution in the North Atlantic. In the high warming scenario, there was a general northward shift in predicted core habitat for both species. In geographical terms the predicted northern expansion of habitat would exceed the southern contraction so that both species would be predicted to have larger foraging habitat extents in the future.

The rapid increase in grey seal populations in the southern North Sea and the widely reported occurrence of predatory male grey seals will have negative impacts on harbour seal populations. of predation

Terrestrial Habitat Changes: Breeding and Haul Out Availability

Most of the research on the impact of climate change in terms of terrestrial habitat change on seals has focused on high latitudes, particularly the Arctic, where dramatic changes in ice volume and extent are already having profound effects on habitat availability. Grey seals are traditionally ice breeders in parts of Canada and in the Baltic, and changes in ice availability, and timing of freeze up and ice break up are already having direct impacts on ice breeding grey seals. In the Gulf of St Lawrence in eastern Canada, grey seals are increasingly breeding on land, and the distribution of breeding sites is shifting northwards. In the Baltic, changes in timing of freeze up and ice break up are changing the breeding habitat availability and are also forcing seals to breed on land. This change in breeding habitat is causing either direct mortality or reducing lactation efficiency and pup growth rates potentially due to physiological water balance issues (Hammill et al., 2007; Mart Jüssi et al., 2008).

Global mean sea levels are projected to rise by 0.43-0.84 m by 2100 compared to 1986-2005 (IPCC, 2021). Any seal responses to previous sea level rises (SLR) since the last ice age would not have been influenced by human activity patterns. Today, however, changes to land use, such as converting coastal areas to urban, industrial and agricultural uses, and the construction of coastal barriers will likely exacerbate any impacts, causing coastal squeeze, preventing inland migration of coastal species (Kirwan and Megonigal, 2013; Schile et al., 2014; Nevermann et al., 2023; IPCC, 2019). In the face of future sea level rise it is likely that coastal defences will be maintained along large sections of coastline, particularly in estuaries. If the upper tidal limit is fixed by sea defences, any increase in mean sea level is likely to reduce the amount of suitable intertidal habitat available to seals as haulout sites. This would affect both species, but the effects on harbour seals are likely to be more pronounced because a substantial proportion of the UK harbour seal population use intertidal banks in estuaries for haulout and pupping.

Thus, projected sea level rise may pose significant challenges to both UK seal species. SLR may reduce the amount of available breeding and haulout areas to seals, when compounded by the formation of human coastal flooding defences to protect land and properties, restricting the area inland where seals could move. Throughout their range grey seals normally breed on uninhabited islands or remote sections of coast. However, since the early 1980s large breeding colonies have developed on the mainland coast, in low-lying coastal areas around the central and southern North Sea (SCOS, 2022). Low-lying coastal areas will be vulnerable to SLR and extreme sea levels from storm surges (Evans and Bjørge, 2013). For example, on the Netherlands coast, grey seals breed on sandbanks which are flooded in extreme tides and high storm surges (Brasseur et al., 2015). If inundation from a storm surge coincides with the pre-weaning period, there is a risk of pups being permanently separated from their mothers and washed away from breeding sites and either drowning or starving.

In other parts of the world, the impact of SLR on the terrestrial habitat of pinnipeds has been investigated for Northern elephant seals (*Mirounga angustirostris*) where the results show that most current and potential haul-out sites at the Point Reyes Peninsula, California, will largely be inundated by 2050 (Funayama et al., 2013). Additionally, in California, Pacific harbour seal (*Phoca vitulina richardii*) habitat is likely to decrease with projected SLR, and habitat flooding from storm events (Backe et al., 2021). In the Baltic Sea, it is predicted that currently suitable haul out sites for both grey and harbour seals will be lost due to future SLR (van Beest et al., 2022).

Breeding grey seals at some sites may be particularly vulnerable to SLR and storm surge related extreme water levels around the coast of the UK. Separation of females from pups, and pups being washed away from breeding sites has been recorded at various breeding sites in the UK and there are apparent correlations between wind strength and pup stranding reports (Keely et al., 2025). Rising mean sea levels will exacerbate storm surge inundation on coastlines (Lowe and Gregory, 2006). There is no compelling evidence for any projected future increases in atmospheric storminess from climate change (Feser et al., 2015; Kendon et al., 2023), and the UK State of the Climate Report 2019 (Kendon et al., 2023) states that there are no compelling trends in storminess when considering maximum gust speeds over the last four decades. Thus, there have been no studies that have so far shown a link between changes in UK storminess and climate change (Kendon et al., 2023). However, the frequency and magnitude of extreme high-water levels in the UK are expected to increase over the 21st century under all Representative Concentration Pathways (RCP) scenarios Lowe et al. (2018) used to predict future greenhouse gas concentrations. Rising sea levels will raise the frequency and severity of wave action on coastlines, and therefore storm surges have the potential to impact grey seal breeding success by increasing pup mortality,y as observed in Welsh grey seal pupping colonies in 2017 (Büche and Stubbings, 2017, 2019) and due to storm Arwen at Fast Castle, Southeast Scotland in 2021 (unpublished data; National Trust for Scotland). Such mortality events will likely increase in frequency and severity as sea levels rise, and seals breeding on exposed, cliff-backed beaches may be at risk of increased levels of pup mortality as they have limited opportunities to avoid storm surges (SCOS, 2022).

Wyles (2024) used aerial survey images and LiDAR imagery to characterise the local topography of all key grey seal breeding colonies in East Scotland, Northeast England and Southeast England SMUs. Met Office predictions of SLR and extreme sea levels from storm surges for present day (2018) and the future (2100) were used to estimate potential loss in breeding area. Results show inundation from SLR and storm surges across all breeding areas, with regional differences in the magnitude of the impact. Results show that by the end of the century a future 1 in-10-year storm will inundate more habitat than a current day 1-in-100-year storm, at all breeding sites studied. Breeding sites of Donna Nook, Blakeney Point and Horsey are most at risk due to regional differences in SLR projections and the topography of these low lying, open coast breeding sites. Whitecoat pup heights above sea level were estimated at the Farne Islands and used to assess inundation risk to pups. Results suggest that more pups will be at risk from a 1-in-10-year storm surge in 2100 (~50% of whitecoat pups) compared to 2018 (~37% of whitecoat pups), highlighting the potential impact storm surges could have on pup mortality on rocky shore and island breeding sites around the UK.

Warmer temperatures are more likely to impact animals in terms of thermoregulation when on land during breeding or haul out since opportunities to cool down are reduced. Even in cooler air temperatures of Autumn in the UK grey seal females spend more time by pools on days with higher air temperatures and lower wind speed (Twiss et al., 2002). Lactation appears to be a time of heightened cellular stress for grey seal females when additional thermal challenges may exacerbate other stressors (Armstrong et al., 2023). If females cannot reduce metabolic costs during higher temperatures they may end lactation early, with potential impacts on pup survival (Shuert et al., 2020). That study showed that high temperature and lack of access to water can reduce pup weaning mass and increase likelihood of pup abandonment in grey seals breeding at temperate sites such as the Isle of May.

Oceanographic Changes: Circulation and Primary Productivity

Future predictions of marine climates around the UK will be heavily influenced by what happens to the Atlantic Meridional Overturning Circulation (AMOC). The AMOC significantly warms the northeast Atlantic and drives the general climate of northwest Europe, partly through its influence on the track of the jet stream. Both direct observations (2004–2017) and sea surface temperature reconstructions, show that the AMOC has weakened since 1900 (IPCC, 2019). The data timeseries are too short to confirm that the weakening is due to anthropogenic forcing, but CMIP5 model simulations show similar weakening of AMOC due to anthropogenic forcing. Overall, the AMOC is projected to weaken in the 21st century, although a collapse is very unlikely. This weakening is projected to cause a decrease in marine productivity in the North Atlantic and an increase in storms in Northern Europe (Couespel et al., 2021; IPCC, 2019). Both reduced productivity and increased storminess could have potential population level effects on UK seal populations.

The Marine Climate Change Impacts Partnership (MCCIP, 2020) predicts a decrease in inflow of Atlantic Ocean water into the North Sea by 2100. Specifically, projections suggest that the inflow of Atlantic water through the northern waters between Scotland and Norway could decrease as increased freshwater input into the North Atlantic from melting glaciers and rivers decreases the salinity of the surface water and affects the density-driven circulation patterns. This would ultimately lead to significant changes in the salinity, nutrient levels, and circulation patterns in the North Sea that may have consequences for prey distribution, but to date there are no published estimates of the potential impacts of such changes.

At smaller spatial scales, earlier stratification of warmer water and changes in the timing of plankton blooms and secondary production blooms will likely have effects throughout the food chain (Wiltshire and Manly, 2004). Such changes have already been detected in the North Sea at several trophic levels. This may have knock on effects on the timing of prey availability that could affect seal body condition though impacts on foraging efficiency at key stages of their life cycle. Specifically, Sailley et al. (2025) predict a general decrease in primary productivity and reduction of demersal fish biomass as a consequence of temperature induced changes in oceanographic conditions that will likely impact seal populations. In terms of foraging behaviour itself, seals use tidal fronts, currents and eddies as they are thought to concentrate prey (Hastie et al., 2016). Thus, changes in flow patterns and currents as well as locations of frontal systems may also impact seal foraging habitat quality. None of these possible effects have been studied in terms of their potential impacts on seals in UK waters.

There are concerns that extensive wind farm developments in the North Sea could have impacts on stratification. For example, Carpenter et al. (2016) used a combination of modelling and in-situ measurements to show that offshore windfarms could potentially impact the large-scale stratification of shelf waters but only if farms covered a large proportion of the shelf. However, they were expected to have very little impact on large-scale stratification in the North Sea at the deployed capacity in 2016. Some indication of the potential effects of OWF infrastructure at the current construction levels is emerging which suggest that multiple wind farms could have a cumulative impact at a regional scale (Christiansen et al., 2023)

Oceanographic Changes: Acidification and Low Oxygen

Increased atmospheric CO_2 is absorbed by sea water which causes a reduction in pH and may have already lowered global ocean pH by 0.1 pH units since the industrial revolution (Orr et al., 2005). North Sea pH has decreased at a rate of around 0.0035 pH units per year (Williamson et al., 2017). Ocean acidification may have direct and indirect impacts for the recruitment, growth and survival of exploited species. Effects are likely to be more important for shellfish (Pinnegar et al., 2017) but changes to larval fish behaviour and reduced survival and recruitment have been reported (Munday et al., 2010); for example, projected ocean acidification levels (from IPCC RCP 8.5) double daily mortality rates of cod larvae (Stiasny et al., 2016). The potential impacts of ocean acidification are an active field of research and the effects on future prey availability for seals are, as yet, unknown.

Reduced oxygen concentrations in marine waters have been cited as a major cause for concern globally (Diaz and Rosenberg, 2008), and there is evidence (Queste et al., 2013) that areas of low oxygen saturation have started to proliferate in the North Sea. However, the European Environment Agency (2019) suggested that hypoxic or reduced oxygen levels were mainly restricted to Scandinavian fjord waters with some reduced oxygen levels recorded on the North Sea near the Oyster grounds. To what extent these are the result of long-term climate change remains unclear, and it is also unknown whether such changes will impact upon fish (Pinnegar et al., 2017).

Changes in Breeding Phenology

The timing of periodic, usually annual, events in the life cycles of animals can be influenced by and may provide sensitive indicators of environmental changes. As such, significant changes in timing of breeding in seals may be a useful indicator of the effects of climate change on seal populations (Bowen et al., 2020; Bull et al., 2021). Such changes may have important implications for the timing of other events such as moult and may affect the timing of variation in foraging effort.

Bull et al. (2021) associated lagged SST indices with changes in pupping dates of grey seals in the Skomer Marine Conservation Zone; an SST increase of 2^{o}C was associated with an advance in pupping date of approximately seven days. They concluded that the temperature index may have been related to transient changes in age distribution due to “immigration” of older mothers that tend to give birth earlier in the season. The Seal Research Trust reported that the pupping season in mainland Cornwall (~170 pups) has shifted earlier from September/ October during 2017-2021 to September/ August since 2022. However, this pattern has not been consistent across the UK. Spatiotemporal patterns in phenology around Scotland and the English east coast will be examined as part of a current SMRU PhD project.

Bowen et al. (2020) studied pupping phenology in the large Sable Island grey seal population in Canada, over a 30-year period and showed much smaller magnitude changes that they ascribed to long term demographic changes, with a gradual increase in the proportion of older females that pupped earlier. Bowen et al. also showed that females of all ages responded to environmental forcing with the detrended Atlantic Multidecadal Oscillation (AMO) from the previous year and mean North Atlantic Oscillation (NAO) in the previous 3 years explaining 80% of the variation. They also concluded from neonatal and subsequent body mass measurements from 2768 pups that the shift in birth date had no impact on pup weaning mass.

Other work based on long-term studies of individual grey seals on North Rona, Scotland, has shown that maternal mass affected breeding likelihood, and skipping breeding appears to be an individual mass-dependent constraint moderated by previous reproductive output and local environmental conditions (Smout et al., 2020). Long-term monitoring efforts are required to detect potential changes in health and inter-annual variability in condition of seals associated with climate change.

Spread of Infectious Diseases

A recent review (Cohen et al., 2020) described four fundamental ways in which climate change can affect host-pathogen dynamics:

- Increased host stress: Many taxa will exhibit a stress in response due to changes in their physical environments. These can result in stress-induced reductions in host immune responses, which makes them vulnerable to infection and can inhibit host recovery.
- Increased pathogen virulence: Elevated temperatures can increase the virulence of many marine pathogens by increasing pathogen metabolism, ultimately resulting in higher transmission rates.
- Pathogen range expansion: Regionally, warming waters may allow pathogens to expand further into host habitat and into previously unimpacted environments.
- Host range changes: Shifts in species distributions due to altered habitat or a change in the distribution of prey may increase exposure rates and transmission of certain pathogens into previously unimpacted environments.

As seals use both terrestrial and marine environments, it has been suggested that they are more particularly likely to be impacted by the introduction of novel pathogens due to their increased potential exposure in both environments (Sanderson and Alexander, 2020). Range expansions of pathogens into previously unexposed, and therefore immunologically naïve populations may result in high mortality events. These are most likely to occur through a combination of pathogen range expansion and host range changes, as described above. For example, there are current concerns regarding the re-emergence of phocine distemper virus (PDV) due to receding Arctic sea ice resulting in increased inter-species contact, or altered intra-species dynamics and movements which ultimately lead to an increased likelihood of emergence or transmission of a novel virus (VanWormer et al., 2019).

In the UK, altered intra-species dynamics, and contact with new species will arise from an increased occurrence of rare species whose range does not normally include UK waters, or so called "extra-limital" sightings. These can be used as an indication of unusual environmental conditions. For pinnipeds, specifically, around the UK in the last 20 years, there have been sightings largely of vagrant cold-water species, including bearded seals, hooded seals, harp seals and ringed seals (Sea Watch Foundation). Most recently, a walrus was sighted from March to August 2021 along the west coast, and another in September 2021 in Northumberland. The reasons for the movements of vagrant individuals like these is not well understood, but a recent review highlighted potential changes in pathogen occurrence in Arctic marine mammals (Barratclough et al., 2023), and as such, these individuals could act as vectors for specific pathogen introduction, and re-introduction, into UK seal populations. They highlighted evidence of several pathogens circulating in Arctic phocid species with the potential to cause unusual mortality events including PDV, *Brucella*, *Paramyxoviruses,* influenza A and *Toxoplasma gondii*. There is a clear need for surveillance to understand baseline disease levels and circulating pathogens in UK seals to understand the potential population level impacts of the introduction of novel pathogens of concern.

In another review, Sanderson and Alexander (2020) evaluated the occurrence of infectious disease-induced mass mortality (ID MME) events in marine mammals between 1955 and 2018. They conclude that extrinsic factors significantly influenced ID MMEs, with seasonality linked to the frequency and severity of these events. Importantly, they showed that global yearly SST anomalies were positively correlated with occurrence of ID MMEs. With climate change associated with increased SSTs and the frequency of extreme seasonal weather events, Sanderson & Alexander concluded that epizootics causing MMEs are likely to increase in both severity and temporal occurrence with significant consequences for marine mammal survival. With increasing SSTs, UK seals could therefore be impacted by ID MMEs as marine pathogens that were previously restricted to warmer, more southerly waters might be able to become established in UK waters (Baker-Austin *et al.*, 2017).

Harmful Algal Blooms (HABs)

Biotoxin producing harmful algal blooms (HABs) have become a global environmental and human health problem. HABs can impact seals through changes in the abundance of their prey due to marine fish kills (Oh et al., 2023), and through exposure to biotoxins when contaminated prey are consumed (Hall et al., 2024). The conditions under which algal blooms become toxic are still not fully understood, and have been linked to a range of environmental variables including temperature, nutrient availability, macroalgae agglomerations, and most recently, microbial communities (Mudge et al., 2025). Given the incomplete understanding of HAB biology and ecology, it is currently not possible to reliably predict the potential effects of climate related HAB changes on UK seal populations. However, recent evidence shows that many important prey species, such as sandeels, flatfish and pelagic species including herring and mackerel, are contaminated with biotoxins year-round (Kershaw et al., 2021), potentially leading to chronic exposure in seals. Chronic, low-dose exposure to biotoxins can have long-term sub-lethal health effects. For example, domoic acid exposure increased the risk of cardiac disease in sea otters (Miller et al., 2021; Moriarty et al., 2021), as well as neurobehavioural and short-term memory deficits (Cook et al., 2015), adult-onset epilepsy, hippocampal pathology (Krucik et al., 2023), and reproductive failure (Goldstein et al., 2009) in California Sea Lions (*Zalophus californianus*).

Ingestion of acute, high doses of biotoxins can be fatal, and have resulted in several mass mortality events and strandings among marine mammals worldwide due to HAB toxicosis since the late 1990s

(Scholin et al., 2000; Landsberg, 2002; Flewelling et al., 2005). Recent work also shows that harbour seals in Scotland have been exposed to toxin doses that exceed lethal threshold (Hall et al., 2024), although no mass mortality events associated with HAB toxicosis in UK seals have been documented. Concentrations vary between prey species, and thus seal species-specific variation in seal diet (potentially mediated through changes in prey availability) will influence the extent of their exposure and potential health impacts. Lastly, an increased frequency of HABs could also have more indirect effects, as can result in a reduction in prey availability for seals.

Regardless of the uncertainty surrounding the predictions for an increase in frequency or duration of HABs in UK waters (see below), the potential for such events to cause both chronic and acute health impacts, including large scale mortality events, means that further investigation is warranted. Such work could include measuring biotoxin concentrations in important prey species, especially during recognised bloom events as identified by Plymouth Marine Laboratory (2022) through their near real-time monitoring designed as alert systems for aquaculture site operators and fish health managers. This would help to understand potential maximal biotoxin exposure concentrations for seals around the UK, and therefore help predict the extent of mortalities due to acute, high dose ingestion (e.g. Hall et al., 2024). Such work could also include assessing evidence of chronic biotoxin exposure in seal carcasses in terms of cardiomyopathy and hippocampal damage, as has been observed in other marine mammals. This would help to understand the extent to which seals may be affected by sub-lethal impacts of biotoxin (especially domoic acid) exposure.

There is some debate about the likely future patterns of HABs in UK waters (Bresnan et al., 2020). Increased water temperature will have different effects on different algal species, but experimental studies of growth and survival rates of a range of species have suggested that HABs are likely to increase due to climate change rather than decrease in the North Sea (Peperzak, 2003). As well as impacts on growth and survival, projections of sea surface temperature also suggest that the habitat of most phytoplankton species will shift north and may lead to more frequent HABs in the central and northern North Sea (Townhill et al., 2018). Gobler et al. (2017) investigated potential changes on a larger scale and came to similar conclusion, that increasing ocean temperatures have already facilitated the intensification of certain HABs in terms of both the frequency of blooms and their duration.

However, Edwards et al. (2006) used long term data from the northeast Atlantic and North Sea (1960s to early 2000s) to investigate spatial variability in the frequency of HABs. Significant increases through time were restricted to the waters off Norway and there was a general decrease along the eastern coast of the United Kingdom. The most prominent feature in the interannual bloom frequencies over the preceding four decades was anomalously high frequencies in the late 1980s in the northern and central North Sea areas. Dees et al. (2017) examined long term data sets from the Northeast Atlantic and North Sea for one toxic algal genus, *Dinophysis* and found that over the modelled period (1982–2015) and the whole Continuous Plankton Recorder time series (1958–2015), there was no statistically significant positive relationship between *Dinophysis* abundance and SST. They also showed that periods of large *Dinophysis* blooms in the 1970s and 1980s, were followed by a period of briefer bloom events lasting until 2014. Dees *et al.* concluded that there was no increasing trend in number or annual duration of blooms.

During the MHW of 2023, there was evidence of a *Noctiluca scintillans* bloom in the central North Sea. While this species is not toxin-producing, intense blooms of this species can be responsible for environmental hazards, such as 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 and Rowland, 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 harmful *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). To date we are not aware of any indications that the 2023 North Sea MHW event has caused similar changes in UK waters.

Marine Heat Waves

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 MHW temperature anomalies were neither as extreme nor as long lasting as the June 2023 MHW (Figure 5). 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 5). An 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. SST was again anomalously high around the British Isles in spring 2025 although the intensity of this event is lower than the 2023 and 2024 events. 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. Some preliminary findings associated with these MHW events in seals and other species are detailed below.

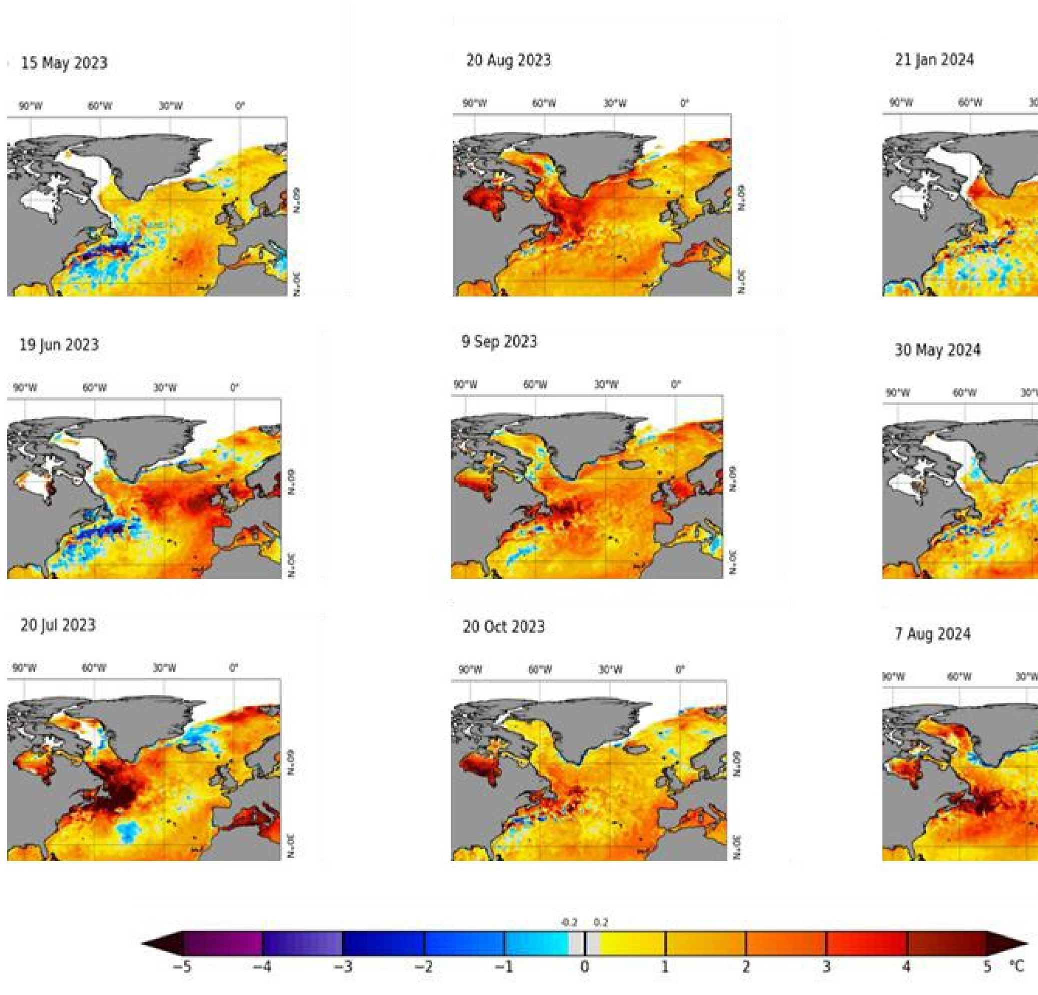

Figure 5. Maps of SST anomalies in the North Atlantic between spring 2023 and summer 2024 (modified from NOAA, 2024

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 2023 MHW, but there was an apparent uptick in strandings reports, mainly of harbour seals, in July and August immediately after the MHW (SMASS in press). However, 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 in a future SCOS meeting. Because of ongoing Highly Pathogenic Avian Influenza (HPAI) precautions, no seal postmortems were carried out in 2023 or in 2024, 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, there is substantial variation in August grey seal haulout counts and thus these apparent changes 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 were higher in 2023 (~6,000) compared to 2022 (~3,500) (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).

Prey Availability

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.

Grey Seal Breeding Success

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). Several 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.

Impacts on Seabirds

Preliminary reports from seabird colonies on the Scottish and English North Sea coasts (F. Daunt personal communication) suggest that provisioning rates and breeding success were not depressed in the 2023 summer breeding season. This may indicate that prey availability was not severely impacted by the high-water temperatures in the short term. However, a mortality event affecting auks in autumn 2021 may have been linked to unusually warm, settled temperatures that might have altered prey availability (F. Daunt personal communication). As the 2023 MHW was more severe than the 2021 event it is not clear why foraging success appears to have been unaffected in 2023. The ongoing H5N1 avian influenza epidemic is currently impacting auk mortality rates and may have masked possible enhanced mortality associated with the MHW event.

Other MHWs

In the absence of data on the effects of the UK MHW it may be informative to examine effects of previous MHWs in similar ecosystems. The best known MHW event of recent years was “the Blob”, a multiyear temperature anomaly in the eastern North Pacific and Alaskan waters between 2014 and 2017 which had wide ranging effects throughout the ecosystem. The effects varied between regions and habitats and ranged from early responses detected in 2014 to delayed effects on several fish and seabird species. For example:

- Large increase in sea lion strandings along the US west coast (NOAA, 2024)
- Large scale, repeated extreme mortality events in seabirds (Jones et al., 2023)
- Recruitment failures for several fishery species (McClatchie et al., 2016; Laurel and Rogers, 2020)
- Large but variable changes in distributions of marine top predators (ranging from fish to baleen whales) (e.g., Welch et al., 2023)
- Reduced size and marine survival of salmon, and in 2014 the salmon returning to the Fraser River in British Columbia avoided U.S. waters because of high ocean temperatures (NOAA, 2022)
- The loss of kelp forests and the abalone and urchin fisheries that depend on kelp (Rogers-Bennett and Catton, 2019)
- Increased harmful algal blooms (HABs) including *Pseudo-nitzschia* blooms and increased domoic acid production that resulted in shellfish fishery closures (McCabe et al., 2016)
- Unusual Mortality Events involving large cetaceans in Alaska potentially linked to HABs (Savage, 2017)
- Changes in humpback whale (*Megaptera novaeangliae*) foraging areas that increased overlap with the Dungeness crab (*Metacarcinus magister*) fishery (Santora et al., 2020) with consequent increases in entanglements

Not all species were adversely affected. For example, catch per unit effort of 18 common fish species and total fish assemblage biomass in eelgrass meadows in the northern California Current were significantly higher during heatwave years (Robinson et al., 2022), and some Rock fish species showed increased growth and increased biomass during heatwave years (NOAA, 2022).

Repeated MHWs in New Zealand waters have been associated with major ecological impacts (Salinger et al., 2019; Thomsen et al., 2019) including:

- Die off of extensive bull kelp beds and consequent disruption of the associated ecosystem
- Dramatic changes in fish distribution with warm water species occurring outside their normal ranges
- Changes in timing of spawning in some exploited stocks (e.g. red snapper spawned 6 weeks earlier)
- Significantly increased mortality at marine salmon farms where sustained summer temperatures above 18°C were the dominant stressor in a multifactorial event, suppressing fish immunity and resulting in elevate mortality (Cook et al., 2025)

Clearly the effects of large scale and/or repeated MHWs can be dramatic with large changes in marine ecosystems (e.g. Cheung et al., 2021). A recurring theme in ocean climate temperature modelling studies is the prediction that MHWs will increase in frequency, severity and longevity in the coming decades. At present the ability to detect effects on seals in UK waters is limited to monitoring strandings records and detecting changes in indices of population size but it is challenging to link changes in these to specific events such as MHWs.

Events such as the 2023 MHW highlight the utility of long-term studies to detect changes in body condition and reproductive output and investment, to be able to link these with changes in environmental conditions, as well as emphasising the need for finer scale regular assessments of fish stocks at appropriate temporal and geographical scales, to be able to link these with changes in environmental conditions and changes in seal condition and reproductive success.

Emerging techniques for monitoring UK seal populations

9. **SCOS will provide a summary of the emerging techniques used globally to survey and count seal haulouts and breeding colonies, and comment on their potential utility in the UK population monitoring programme.**

Seal populations are typically monitored on land where seals haul out and breed, rather than at sea. Such monitoring involves numerous methodological decisions, regarding the survey platform, camera system, image processing, counting method, and estimation method. SMRU's current monitoring programme is conducted through manned aerial surveys of haulout and breeding colonies; images are taken and later counted by researchers. The survey programme typically covers around 95% of UK seals; counts/pup production estimates for the remainder of UK seals are compiled from available ground-based (or drone) survey data held by other organisations (e.g. National Trust, NGOs). The counts are then used, in combination with other information (e.g. telemetry data), to model the abundance of seals, and trends therein.

Here, emerging techniques are reviewed and evaluated in terms of their current, and likely future, potential to augment or replace the current monitoring programme. The most promising emerging methods are associated with the survey platform and counting methods. The number and spatial extent of seal haulouts and breeding colonies in the UK means drones are not an appropriate platform for the majority of the SMRU survey programme. However, drone surveys can be the most appropriate platform for some accessible study areas of a limited spatial extent, especially when additional information is required (e.g. animal condition). The relatively low temporal and spatial resolution of opportunistic observations, and issues with image quality and cloud-cover in satellite imagery, mean they are not a viable option to augment or replace SMRU surveys.

While counting of images is still typically conducted by researchers, Citizen Science and Artificial Intelligence (AI) are also being used in other projects, with mixed success. In particular, AI is a promising future avenue but there are no fully operational systems in use that involve the classification of seals (e.g., species, age) in images from manned aerial surveys.

SCOS conclude that the current SMRU aerial survey programme is the most appropriate solution for monitoring seal populations in the UK. If and when future drone capabilities and legislation allow, SMRU should consider augmenting or replacing parts of the manned aerial surveys if funding is available. In the longer-term, AI-counting techniques would be advantageous, but the development and implementation of effective AI-counting techniques would require significant additional resources. Nevertheless, SMRU should continue to build a training set of annotated images to facilitate such development, and to allow retrospective application of AI techniques to historic images. SCOS highlight that adoption of new techniques would need to be predicated on an ability to account for changes in methods to ensure continuity of time-series and to maximise comparability across the UK and Europe.

Seal populations are typically monitored on land where seals haul out and breed, rather than at sea. SMRU currently operate an effective survey programme to monitor the populations of both seal species in the UK. Such a survey programme must consider many factors and trade-offs, including resources, the survey platform and camera system, and image processing, seal counting, and estimation methods. New technologies and emerging techniques represent potential opportunities to improve or refine the current survey programme in each of these areas.

To facilitate interpretation of the potential of these emerging techniques, we summarise the current SMRU population monitoring programme, providing context of techniques used elsewhere. We then discuss the key emerging techniques - survey platform (drones and satellites) and different counting methods (Citizen Science and Artificial Intelligence) - and their potential utility for SMRU surveys. It should be noted that any adoption of new techniques must not significantly alter SMRU's capacity for data collection and analysis, to avoid disrupting the consistent time-series of seal population data. They also need to consider comparability with surveys conducted elsewhere in Europe. New techniques and technologies can only be implemented with a clear understanding of their funding and technical skills requirements.

SMRU population monitoring programme

SMRU conduct aerial surveys of harbour and grey seal haulouts in August (Thompson et al., 2019; SCOS-BP 25/01) and grey seal breeding colonies (September to December; Russell et al., 2019; SCOS-BP 25/02). SMRU focus their survey efforts on Scotland and eastern England, which host around 95% of the UK holdings of both species (SCOS-BP 25/01 & 25/02). Additional counts and estimates are provided by individual organisations. SMRU have recently extended their grey seal breeding surveys to include the east coast of England. Historically, these have been ground counted by other organisations, but their increased size made this increasingly difficult.

August surveys – harbour and grey seals

The August surveys are the main monitoring method for harbour seals; they occur during the harbour seal moult when a high proportion of the population are hauled out. For grey seals, the pup production estimates generated from breeding season surveys (see below) are the primary source for trends in abundance, but the August surveys nonetheless provide critical data on the abundance and distribution of grey seals during the main foraging season.

The August surveys are conducted via a mixture of methods according to local geography. Due to the rocky shore-dominated coastline, surveys on the west and north coasts of Scotland require thermal imaging to reliably detect seals. They are flown with helicopter carrying a gyro-stabilised gimbal, containing a thermal imaging video camera (required to detect well-camouflaged seals on rocks and seaweed), a HD colour video camera, a laser range finder, and a digital stills camera with a 300mm lens (used to identify species). The haulout sites on the east coast of England and Scotland are predominantly sandy beaches where seals are relatively easy to spot. These sites are therefore surveyed using a single engine fixed-wing light aircraft and oblique photography (70-300mm zoom lens), with seals being spotted by observer(s) in the aircraft. A twin-engine fixed-wing aircraft (oblique photography) is used to survey the offshore islands in Scotland (e.g. Flannan Isles, North Rona, Sule Skerry) not covered by the helicopter surveys.

Following the surveys, the most appropriate set of images (with a GSD of approx. 0.5-1.5cm/pixel) of a given group of seals are chosen and counted using DotDotGoose (Ersts, 2024), a purpose-built tool for manually counting objects in images. For both species, the raw counts are used to assess trends in abundance within Special Areas of Conservation (SAC) and by Seal Monitoring Unit (SMU; SCOS-BP 25/03).

Population-level abundance is estimated by scaling the survey counts. Telemetry data have been used to estimate a conversion factor, the percentage of the population of each species hauled out during the survey window: 72% (95% CI 54 - 88%; Lonergan et al., 2013) of harbour seals and 25% (95% CI 21 - 29%; Russell & Carter, 2021) of grey seals are estimated to be hauled out and thus available to count. These percentages are used to scale up the counts to account for seals that are at sea during the surveys. These scalars are based on a limited sample size and spatial extent, and thus targeted deployment of telemetry devices together with application of cutting-edge analytical techniques would lead to improvements in the estimates of the conversion factors and the uncertainty therein, ultimately increasing the robustness of abundance estimates.

A limited number of harbour seal pup surveys are also conducted in The Wash during the breeding season in mid-summer (typically late June-early July). These are carried out using the same methods as described above for the east coasts of England and Scotland, i.e. fixed-wing aircraft and oblique photography. Outside of the UK, most harbour seal surveys are conducted using fixed-wing aircraft and also focus on the moult (Banga et al., 2022) and/or the breeding season (Galatius et al., 2023).

Grey seal breeding surveys

For grey seal pup surveys, SMRU have used a new vertical camera system (Phase One PAS150) since 2023. It consists of a single 150MP medium format digital camera with a fixed 70mm lens, set in a gyro-stabilised mount. Flying at an altitude of 1,100 ft (335 m), it covers a swath width of 256m at a ground sample distance (GSD) of 1.8cm/pixel. This compares with the previous system (Hasselblad) of two 40MP medium format digital cameras, with a combined swath width of 340m at a GSD of around 2.5cm/pixel that had been used from 2012-2022. Note that the increase in resolution from 2.5 to 1.8cm/pixel does not translate an equivalent increase in image quality due to technical differences between the camera systems (e.g. physical size of each individual pixel on the sensor). The survey platform remains a twin-engine fixed-wing light aircraft.

Key colonies, representing over 90% of UK pup production, are surveyed every two to three years. The duration of the pupping season at any one colony is longer than the duration of stay of individual pups. As such, the count of pups from an individual survey represents an unknown proportion of the pups that will be born in that year. Thus, each colony is surveyed multiple times (usually five) in a given breeding season. Photographs are then enhanced to maximise the ability of observers to detect whitecoat and moulted pups, and to distinguish between them. The overlapping images are stitched together into a single orthomosaic to avoid double counting of pups. This is carried out using Correlator3D (C3D) software (SimActive Inc., 2025), an industry-standard photogrammetry solution for generating high quality aerial survey mosaics. The combination of the new camera system and stitching software represents a significant improvement in mosaic quality for counting pups. It can correct for difficult terrain, perspective shifts, and complex image overlaps from adjacent flight lines, which was not possible with the previous camera system. C3D outputs a georeferenced orthorectified image for each colony, which is then imported into QGIS for manual counting and classification of pups (as whitecoats or moulted).

The total counts of whitecoat and moulted pups for each colony are then input into a "pup production model" to derive a birth curve and estimate pup production. Within this model (Russell et al., 2019), the counts are combined with information about the observation process (probability of detecting a pup, and of correctly classifying it) and life history traits (the age at which pups complete moult, the age at which they leave the colony). A comparison of the counts generated from the Hasselblad and Phase One systems, and estimated observation parameters, are reported in SCOS 25/06. This will be used to inform the parametrisation of the pup production model which is currently in development.

Outside the UK, grey seals are typically surveyed during the moult and/or during the breeding season (den Heyer et al., 2021; Schop et al., 2024; Wood et al., 2022), though for many places (e.g. the majority of the European holdings) grey seals are also counted during August harbour seal moult surveys. These surveys generally use fixed-wing aircraft, with some use of helicopters and increasing implementation of drones at individual colonies/haulouts. The UK and Canada hold the majority of the global population of grey seals. In Canada, grey seal population monitoring is focussed on pup production in a similar way to the SMRU monitoring programme (den Heyer et al., 2021, 2024). However, in Canada a single survey to count all pups is completed and the birth distribution is estimated at the larger colonies by first estimating the duration of 4 developmental stages from individual mark-resighting of pups on Sable Island, and then fitting a model to staging (stages 1 to 5, stage 5 (fully moulted) is assumed to final and permanent stage) a subset of pups throughout the breeding season, either on the ground on Sable Island or from high resolution imagery or low-flying helicopters at the other larger colonies (den Heyer et al., 2024). This approach, which requires colony-specific staging data, which is not possible in the UK due to the number, distribution of key colonies and the variation in timing of breeding. In Canada and elsewhere, at colonies with smaller numbers of grey seals, maximum (peak) pup counts (i.e. a single survey) are used to examine trends. However, in the UK there is substantial variation across colonies and years in the scalar between maximum pup count and estimated pup production.

Platforms

Globally, the survey platform used for pinniped surveys varies from observers on the ground (Udevitz et al., 2005), boat (Sayer and Witt, 2018), fixed-wing aircraft (Christman et al., 2022), helicopter, drones (Álvarez-González et al., 2023), and satellite (LaRue et al., 2011; Gonçalves et al., 2020). Counting on foot has been shown to be biased for large colonies (SCOS-BP 24/08), while boat-based counts are not useful for colonies with complex terrain and suffer from similar inaccuracies as ground counting methods (Stone & Davis 2025).

Drones

Drones have been used to survey seal haulout sites and colonies both in the UK and abroad (Álvarez-González et al., 2023). The high image quality associated with drones versus conventional imaging via aircraft, and comparatively low cost, make drones excellent tools for collecting data on small scales (such as for an individual colony). Drone surveys allow for rapid and repeatable deployments at very low Ground Sampling Distances (GSD)s) - sub-1cm/pixel is possible (Stone & Davis, 2025; SCOS-BP 25/06). This opens the door for new opportunities in seal monitoring (reviewed in Larsen & Johnston, 2024) including the identification and tracking of individual animals, body volume estimation, as well as population censuses.

The greatest potential for regular drone surveys to replace aerial surveys in the UK lies in targeted operations at the large grey seal breeding colonies on the east coast of England (Farne Islands, Donna Nook, Blakeney, and Horsey). Current SMRU fixed-wing surveys can efficiently photograph all four colonies in a single five-hour flight. Considerable obstacles remain before this portion of the fixed-wing survey programme can be replaced with drones. Nevertheless, over the last several years, the potential of using drones at these sites has been explored in collaboration with other organisations (National Trust, Natural England). Indeed, in 2023, a regular set of drone surveys were conducted for the Farne Islands (commissioned by the National Trust). These surveys are dependent on access to the islands by boat, and there is uncertainty on whether that survey programme will continue.

Horsey represents perhaps the most suitable colony in this region for drone surveys at present, despite its length (>8km) and large size (approx. 3km^2). The colony itself is a relatively narrow (generally <200m width) strip of sandy beach and dunes, simplifying drone flight planning and safety considerations. Due to its mainland location, access is also not constrained by sea state or boat availability. Natural England have recently completed a pilot project to investigate the utility of drone surveys at Horsey with promising results (Natural England, 2025). There are currently no plans for Natural England to conduct the requisite number of surveys for pup production estimation at the site over a season.

The other colonies on the east coast of England each cover a very large area. This presents a significant obstacle for maintaining safe operating practises for drone flights. For example, at Blakeney, visual line of sight (VLOS) operations rules would require drone operators to walk through (and operate from) high density areas of the colony. Beyond visual line of sight (BVLOS) operations require specific approval from the UK Civil Aviation Authority (CAA, 2025) and add significant complexity to flight planning. However, changes to legislation are increasing the viability of BVLOS flights, with numerous past and future trials ranging from mail delivery to offshore windfarm inspection being conducted (CAA, 2024). Continued progress in this area is likely to streamline the process for acquiring BVLOS flight permissions in the future. Similar VLOS safety considerations for multi-drone surveys of a penguin colony in Antarctica required the movement of a ground observer across the colony, ready to take control or recover the drone in the event of emergency (Shah et al., 2020). The safety pilot for the drones (which automatically flew preprogrammed routes) had the advantage of an elevated viewpoint to maintain a sightline to the drones throughout the flight – no such viewpoint exists for Blakeney. The penguin colony surveys used four drones to cover an area of around 2km^2 in thirteen flights over three hours (albeit with certain geographical and meteorological limitations that do not apply on the east coast of England). Scaling this up to cover the 3-5km^2 survey areas at each of Donna Nook, Blakeney Point, and Horsey, the logistics of surveying each of these by drone quickly become prohibitive. It is worth noting that Shah et al. (2020) implemented path optimisation algorithms (known as the *Drone Route Problem* (DRP)) to significantly reduce the time it took to survey a relatively large area with geographical constraints using multiple drones. Creating optimised routes and having the drones fly these predetermined paths dropped survey time to three hours, compared to two days when flown manually by a human pilot. Optimising to solve the DRP is a challenging but promising field of study (Amorosi et al., 2024) and should be considered when planning future drone surveys to survey seals in the UK.

An additional consideration is the inherent observation error associated with pup surveys. Different camera systems, whether on drones or on aircraft, output imagery with differing properties, such as resolution, pixel size, sensor readout speed, colour, dynamic range, and brightness. SMRU aerial surveys are flown with consistent altitude, speed, and camera specifications to minimise these differences between colonies and years, allowing for greater consistency in pup counts. Imagery differences influence the observation parameters within the pup production model; that is the probability of detecting and correctly classifying pups. For each system, the differences in observation parameters need to be accounted for to enable robust estimation of pup production and spatio-temporal trends therein. With the current model, the absence of information on the change in observation parameters when transitioning from film (up to 2010) to digital (from 2012) aerial surveys resulted in an approximately 25% jump in pup production estimates. Estimating these observation parameters is not straightforward (see SCOS-BP 25/06 for details). Indeed, assessing the impacts of SMRU's transition from Hasselblad to Phase One camera system and estimating the observation parameters involved flying a full survey with both the old and new camera systems within a few minutes of each other, with concurrent drone flights at the Isle of May and Farne Islands, to gain a direct comparison of each type of imagery with as little spatiotemporal variation as possible. A lack of consistency in drone model, camera system, or the survey designs between organisations or between surveys would compromise the utility of the resulting datasets.

Drone surveys at the colonies and haulouts in Scotland represent a significantly greater challenge (than eastern England), which is unlikely to be overcome in the near term. The grey seal breeding surveys in Scotland cover over 60 colonies, most of which are on islands, five times each. To survey all colonies once by fixed-wing aircraft usually requires four or more flights over three or four days. Most current consumer/commercial drones have flight times measured in tens of minutes. To cover those same colonies by drone would require multiple boat and/or helicopter trips to access each colony, followed by a series of drone flights, before a long journey to the next colony. This would take many days per survey round and is not a realistic solution. Even if multiple teams could coordinate to simultaneously survey colonies around the country, some colonies remain prohibitively difficult to access (especially in poor weather), and the manpower requirements would dwarf a conventional fixed-wing aerial survey. For reference, a large-scale wildlife survey in Tsavo, Kenya estimated UAV survey costs to be ten times higher than their current light aircraft survey programme, without accounting for human resource costs (Lamprey et al., 2020). The August surveys across the entire coastline of west and north Scotland, as well as large areas of the North Sea coast, present an even greater obstacle for drone surveys for all the reasons given earlier, and the desire for as close to synoptic surveys of whole SMUs within one tidal survey window. Long endurance drones (such as the Insitu ScanEagle), which have been trialled for seal surveys in the Arctic (Moreland et al., 2015), would be inhibited by the need to comply with CAA B/VLOS operational requirements, as well as their high purchase price (potentially >£1 million) and operating costs.

A final consideration for a large-scale drone survey programme is the large volume of data generated. Drones must typically operate at much lower altitudes than aircraft to achieve a comparable GSD, due to payload restrictions limiting the capabilities of drone camera systems. This produces a smaller image footprint, leading to a greater number of images being needed to cover a given area. For example, to cover Staple Island in the Farne Islands (a small island approximately 320x260m) at a GSD of 1.80cm/pixel, a DJI Mavic 3E (a mid-range commercial drone) would need >120 photos across eight survey lines (allowing for acceptable overlap between images), taking around nine minutes. Compare this to the eight photos across a single survey line in around ten seconds for the current SMRU aerial surveys. Increased numbers of images have higher storage requirements and are much more computationally demanding to generate orthomosaics from. There is also a greater chance that a seal will move between images when swath width is reduced, and a survey takes longer to complete. This increases the likelihood of an animal being duplicated or missed out entirely in stitched images.

Given the obstacles described above, as well as the limited resources available to SMRU, it is currently not feasible to effectively replace parts of SMRU's existing aerial survey programmes with drones. However, SMRU will continue to work closely with organisations (e.g. the National Trust, Natural England) that are trialling or conducting drone surveys.

Satellites and Opportunistic Images

Very High Resolution (VHR) satellite imagery (i.e. GSD ≤50cm/pixel) is becoming increasingly available, with around ten commercial companies selling archival images, and more constellations of 30cm-class VHR satellites coming online (such as Planet's *Pelican* and Maxar's *Worldview Legion*). The highest resolution images have a GSD of 30cm/pixel, but full colour multispectral imagery typically reaches a maximum of 50cm/pixel. Google Earth is a free software allowing access to both archival VHR satellite imagery and images from fixed-wing aircraft. The latter type of images are at a higher resolution (15 - 25cm/pixel) than those from satellite, but are available at a lower temporal frequency than satellite (up to twice a year).

Opportunistic observations, from either satellites or fixed-wing aircraft, have been used to monitor some marine mammal populations (reviewed by Khan et al., 2023). Google Earth images from fixed-wing aircraft were used to count the number of grey seals on sandy haulout sites in the USA (Moxley et al., 2017). Given the image resolution, the utility of opportunistic images is restricted to featureless habitats (e.g. sandy beaches) and haulouts of single species. In the case of satellite imagery, to allow individual seals to be distinguished, it is further restricted to species that do not haul out in high densities. In the UK, seals breed and haul out on a multitude of habitats, and there is a need to be able to identify species (or classes for grey seal pups). For these reasons, the resolution of images from opportunistic observations precludes their general use in the SMRU seal population monitoring programme. However, images found on Google Earth and other online mapping platforms have occasionally proved useful for confirming the presence of seals at sites that were not previously known to be regular haulout or breeding sites.

Satellite imagery-based counting has been tested for a variety of species, including nesting seabirds (LaRue et al., 2014; Fretwell et al., 2017), cetaceans (Cubaynes et al., 2019; Green et al., 2023; Iacozza et al., 2024; Sanikommu et al., 2025), and pinnipeds (LaRue et al., 2011, 2014, 2017; McMahon et al., 2014; Gonçalves et al., 2020; Fudala and Bialik, 2022; Laborie et al., 2023; Sherbo et al., 2023), at GSDs down to 30cm/pixel. Pinniped studies primarily focus on ice-dwelling species such as Weddell and crabeater seals, and/or very large species like southern elephant seals and walrus, as these characteristics make identification of animals from low resolution imagery simpler.

LaRue et al. (2017) offer criteria to assess the suitability of Very High Resolution (VHR) satellite imagery for monitoring wildlife populations. The three minimum necessary (but not sufficient) criteria they identified are: 1) an open landscape (animals cannot be hidden by terrain or vegetation); 2) strong contrast between animals and their surroundings (animals must stand out against the background, e.g. seals on ice); 3) large size of target animal (animal must be large enough to be visible in images). The ability to differentiate target species from other features in the images (animals must not appear the same as rocks, for example) was also considered very important. Other secondary criteria suggested were habitat associations (the animal only occurs in certain kinds of habitat), temporal exclusivity (animals only occur in that location at predictable times), and colonialism (animals in large aggregations are easier to detect). Finally, ground truthing is a helpful addition to increase confidence in satellite detections, but was not deemed essential to success.

When applied to our use-case, i.e. counting grey seal pups during breeding, and grey and harbour seals during the harbour seal moult – only a select few locations meet many (or any) of the criteria posited above. Taking the poor GSD into consideration further limits the utility of current satellite imagery for monitoring any of the UK's seal populations. The current best resolution commercially available imagery is insufficient to confidently distinguish between southern elephant seal adults and pups (Fudala and Bialik, 2022), let alone to distinguish between harbour and grey seals or to classify grey seal pups as whitecoat or moulted. There are likely to be future improvements to the resolution of available imagery from satellites (current military satellites are speculated to achieve a GSD of <10 cm/pixel). The lifting of restrictions on commercial satellite imaging in 2020 (Office of Space Commerce, 2023) may result in higher resolution commercial imagery in the coming decades, but the eventual technological limit is likely to be significantly below the resolution required to detect seals on many habitats, and to distinguish species or age classes. If future advances in satellite imagery were to produce a similar GSD as current Google Earth fixed-wing images (around 10-15cm/pixel), in theory, they could be used to count seals at a limited number of haulout sites (sites that are featureless and predominantly single species). At such resolutions, differing "social distancing" and haul out habits between grey and harbour seals (Hoekendijk et al., 2023) may enable species differentiation at multi-species haulouts.

Even if sufficient resolution could be achieved, however, there are still significant drawbacks to satellite-based image collection. Perhaps the largest of these is the frequent lack of cloud-free skies over study sites. This can produce large gaps in a dataset, sometimes spanning several years where no cloud-free images were taken during necessary periods for surveys (such as during the breeding season), and is cited as a major reason why satellite imagery is unsuitable as a sole data source (Attard et al., 2025). The ongoing launch of new VHR constellations may alleviate this to some extent by providing more frequent coverage of any given site, but they will never entirely remove the risk of cloudy imagery. Some Synthetic Aperture Radar (SAR) satellite constellations offer the ability to "see through" clouds at a GSD of 25cm/pixel (Umbra Space (2023) have demonstrated resolutions as high as 16cm/pixel). However, SAR satellites do not operate in the visible light spectrum, instead generating imagery from radio waves. This lack of visual data would make the identification of species (for August surveys) incredibly challenging, and the classification of pups (as whitecoat/moulted – for grey seal breeding surveys) impossible, regardless of resolution. SAR is therefore inherently unsuitable for both of these survey programmes. In the future, dependent on cost, it could potentially be used in a limited manner; to detect seal presence/absence at haulout sites or for counts at single species haulouts on featureless backgrounds.

Satellite imagery must be purchased from commercial providers. This can be archived imagery, taken routinely as satellites pass overhead, or specifically tasked for the satellite to collect. The latter option guarantees correct spatiotemporal coverage of desired areas but comes at a significant cost. Tasking a single snapshot of sandbanks within The Wash, without guarantee of completely cloud-free coverage, was quoted to cost over £10,000 (in 2025). SAR coverage was limited to areas of 25km^2, at a cost of over £2,500. Archived imagery may not offer complete (or any) coverage of required locations at the required times of day or season. Within the survey programme, surveys need to be conducted at specific times (within two hours either side of low tide in August, and for grey seal breeding, four to five approximately equally spaced daylight surveys across the season). It is critical that the August surveys are as synoptic as possible across an SMU and satellite overlap with the August survey window would be restricted to a limited number of days which would vary along sections of coast within SMUs. Indeed, a single group of haulout sites may not necessarily be covered within a single satellite pass. The high likelihood of cloud would further reduce the number of potential surveys days and would likely entirely negate the utility of satellites for grey seal pup surveys during worsening autumn and winter weather. The altitude of SMRU aerial surveys almost completely removes the impact of cloud, and survey schedules can be adjusted at short notice to ensure suitable survey conditions. For satellite imagery, there is a final problem that, depending on the position of the satellite during imaging, some parts of the image are likely to be at a significantly oblique angle, which can be detrimental to image quality. Given all of the above, it seems very unlikely that satellite imagery could usefully augment or replace parts of the aerial survey programme in future.

Counting Methods

Counts of seals in Europe are predominantly conducted by researchers either in real-time or from photographs. However, in some areas, seals are counted either through Citizen Science (e.g. Satellites Over Seals; LaRue et al., 2020), or increasingly using Artificial Intelligence (AI) techniques. Given that the SMRU August surveys involve selecting the most appropriate photographs, species identification, and most use a combination of thermal video and high-resolution photographs, there are added complications associated with applying assisted counting techniques to them. Thus, here we focus on the grey seal breeding surveys, which are the most time-consuming counting task, and, theoretically, the easiest to augment.

Counting – Citizen Science

Citizen Science techniques are most useful for counting high resolution images with no requirement for identification to species or class. Even in these circumstances, compared to experienced counters, non-experienced counters detect fewer individuals (Wood et al., 2021) and generate a significant number of false positives (LaRue et al., 2020), requiring a high number of repeat counts. If more detail about species and/or age class is needed, it is recommended to employ counters with field experience of the target species, and to offer specific training and standardised workflows to reduce variation between counters (Attard et al., 2024). A preliminary investigation within SMRU comparing classifications on the ground (assumed truth) with those from concurrent aerial survey images indicated that the ability of counters to distinguish whitecoat and moulted pups varied markedly, and the most common classification of pups did not necessarily align with that of the most experienced and accurate counter. Gaining the required number of counts to ensure high detection rate is slow (Wood et al., 2021) and observation error is explicitly considered in the pup production model. Thus, currently Citizen Science techniques, although likely valuable for public engagement, are unlikely to result in a more efficient or robust counting method.

Counting – Artificial Intelligence

The use of Artificial Intelligence (AI), most typically Convolutional Neural networks (CNNs), to support population monitoring is a promising and rapidly developing avenue (Hollings et al., 2018; Corcoran et al., 2021) . Such tools have been applied to a range of aerial and satellite surveys of many different species and habitats, including pinnipeds. Counting with AI can be fully- or semi-automated. Fully automated approaches produce complete counts with no human supervision, while semi-automated methods typically output images with probable seals annotated for human review. Evidence suggests fully automated models are not yet ready for use on aerial survey images; human verification of results is still crucial for accuracy in complex environments (Delplanque et al., 2024). However, the same study found that semi-automated models can significantly decrease the workload of human interpretation of images, with adequate model training.

Many efforts have combined drone surveys and AI image processing, with promising results. Automated counts of drone imagery can produce counts of adult seals that are >97% of those produced by trained human counters (Hawkins et al., 2023). However, such results are generally limited to very high-quality images of simpler environments with low animal density. Closely grouped colonies, complex backgrounds, and shadows all radically reduce model performance. This last issue is especially relevant, as the SMRU grey seal breeding surveys cover some colonies that are heavily shaded (such as the base of north-facing cliffs), and a low sun angle can create strongly contrasting shadows across images. Use of thermal images in tandem with traditional cameras to improve animal detection has produced mixed results for AI (Seymour et al., 2017; Krishnan et al., 2023; Matern et al., 2025), although it may improve detection rates for human observers (Hinke et al., 2022).

A primary requirement of the SMRU grey seal breeding surveys is not just the ability to detect pups, but also to correctly classify them. While progress has been made with distinguishing between adults and pups (Seymour et al., 2017; Hinke et al., 2022; Hawkins et al., 2023; Santini et al., 2025), pups still tend to have lower detection rates than larger adults, and we are not aware of any model implementation that can successfully classify pups as whitecoat/moulted. The use of CNNs (YOLO v3) for this purpose from SMRU surveys has been trialled through a Master's project based at Computer Science, University of St Andrews (Terzic unpub. data). This showed considerable potential, but development halted due to a lack of resources. Building bespoke CNNs (e.g. in Python) or adapting CNNs (e.g. YOLO) necessitates considerable expertise in AI and typically requires a lot of time and computing resources to fine-tune model outputs. Various GUI-based AI software products have been developed to streamline this process, some key examples being AIDE, Picterra, and VIAME.

AIDE, Annotation Interface for Data-driven Ecology (Kellenberger et al., 2020), is an open-source web-based system that supports annotation, machine learning and a human feedback loop. However, it does not yet support georeferenced images (Kellenberger et al., 2018) and thus its application for SMRU surveys is limited.

Picterra has been used for detecting harbour seals from drone images (Infantes et al., 2022); the body size of seals was measured automatically, and this was used to classify pups from other ages. However, its utility to distinguish whitecoat versus moulted grey seal pups (which can be of a similar size) on varied habitat from comparatively low-resolution images from aerial survey is unknown. Furthermore, it is a web-based system with the cost being charged per gigabyte uploaded; the use of such a system would be prohibitively slow and expensive for a large-scale survey programme such as that conducted by SMRU.

VIAME (Video and Image Analytics for Marine Environments) is an open-source software developed by Kitware in collaboration with NOAA (National Oceanic and Atmospheric Administration). This involvement of NOAA in its development means that, particularly in the US, VIAME has been the main AI software considered for seal population monitoring. For example, VIAME was used, with limited success, to detect and classify Antarctic fur seals (pups versus non pups) from drone images (Hinke et al., 2022). NOAA have also conducted a preliminary study using VIAME to detect grey seal pups from fixed-wing surveys, but, to our knowledge, that work is on hold (Josephson and Murray, personal communication) and images are still counted manually.

A recent development in use of VIAME has been through a project led by Marine Mammal Laboratory, NOAA, focussed on the detection and classification (age and sex) of Steller sea lions (Sweeney et al., 2025). Kitware were formally involved in this project providing support and changes to VIAME to facilitate the automation of aerial image processing and analyses. These sea lion surveys are similar to the grey seal breeding surveys conducted by SMRU; NOAA use a fixed wing aircraft with three vertical cameras providing overlapping images. That project has led to increased functionality within VIAME that will likely be applicable to other species. Indeed, it is possible to input unstitched images into VIAME with two potential methods available to mitigate against double counting. Such functionality would negate the need to stitch images, substantially reducing pre-processing time. However, it should be noted that the performance of these two methods has not yet been evaluated. That project has made great strides in the use of AI for seal population monitoring, and perhaps represents a blueprint for augmenting the UK grey seal surveys with AI, but significant hurdles must be overcome before a similar system can be used here. The researchers at NOAA note that substantial funding was required to enable an effective collaboration with Kitware, and an immense investment of researcher time was required for the project. Developing such a system for streamlining or automating counting of UK seal survey imagery would require substantial additional staff time, funding, IT resources (e.g. high-performance computing facilities) and programming expertise.

AI techniques are rapidly developing, and clearly they will eventually become a key component to support seal population monitoring. However, current models do not yet represent a complete solution for image processing and cannot wholly replace human counting of surveys. To our knowledge, currently no seal population monitoring programmes have fully integrated AI systems to facilitate counting of seals from fixed-wing vertical-camera aerial survey images, much less from oblique imagery. As emphasised above, the development of any AI system for SMRU aerial surveys, especially given the variation in terrain and the requirement to classify pups, would clearly only be possible through dedicated funding to provide the required resources and time for both AI experts and seal researchers to develop and implement such techniques. Nevertheless, SMRU should continue to build a training set of annotated images. Such a dataset will facilitate future development of effective techniques by SMRU and/or collaborators. Furthermore, it provides the possibility of retrospective application of AI to historic imagery, which could ultimately increase the accuracy and consistency of historic counts.

Recommendations for research

10. Based on previous advice, SCOS will synthesise any outstanding suggested areas for further seal research and indicate which may be of highest priority.

Table 18 outlines outstanding high priority areas of research that are required to ensure SCOS can provide robust advice to continue to support the effective management and conservation of UK seals. Note that planned or ongoing work that is already funded (including by the NERC National Capability National Public Good funding stream which underpins the SCOS process) is not included in the table, and thus realisation of these remaining priorities is subject to the availability of funding and capacity. The level of priority of each will depend on the perspectives of different stakeholders and the different management and policy areas they cover. It would therefore be challenging for SCOS to evaluate all relevant perspectives and prioritise accordingly.

Nonetheless, data on the abundance and distribution (and spatial and temporal variations therein) of seal populations underpins much of the SCOS advice, and thus outstanding research in this area is of highest priority. SMRU conduct a comprehensive seal monitoring programme, which along with survey data provided by partner organisations, provides the data required to inform an understanding of spatio-temporal trends in abundance. However, for harbour seals, the data available to scale survey counts to population size are outdated and limited. Furthermore, there is a paucity of data on the demographic parameters driving the currently observed unfavourable population trajectories.

Until relatively recently, most of the Northeast Atlantic grey seal metapopulation was held by Scotland and Northeast England (>90%). Likely because of populations in northern Scotland reaching carrying capacity, there has been rapid increase in abundance in Southeast England and continental Europe (from < 1000 pups in 2000 to ~19,000 in 2023) which combined now hold > 20% of the Northeast Atlantic total during the breeding season, and likely a substantially higher percentage during summer. This increase, and the associated increased seasonal movements between SMUs and with continental Europe, have posed issues for population estimation and management. In addition to pup production estimates, there is now an increased need for robust estimates of abundance outside of the breeding season, where resources are acquired for breeding, which can be obtained from surveys during the harbour seal moult in August. In SCOS 2024, it was agreed that the UK population model was no longer fit for purpose, in large part due to its assumptions of closed populations.

Table 18. Outstanding SCOS recommendations for further research required to inform effective conservation and management of UK seal populations

Management issue/theme/question	**Research required/recommendation**	**Where discussed in more detail**
Estimating grey and harbour seal population size and trends (underpins all SCOS advice, UK national and international reporting, SAC management and informs the ability to manage human activities that impact upon seals)	Harbour seals: Population monitoring and management is based on converting aerial survey counts to total population estimates. The relationships between counts and population depend on robust estimates of the proportion of the population hauled out. The existing conversion factors are old, based on small samples, and limited in both spatial and seasonal coverage. To improve the estimates and increase efficiency of survey effort SCOS recommends the following: • The deployment of satellite flipper tags on harbour seals to provide a suite of conversion factors to allow surveys at other times of day, and from other times of year to be included in the population monitoring programme. Broadening the survey window on fine (time of day) and broad (seasonal) scales will maximise resource efficiency of the SMRU survey programme. • The deployment of these satellite tags on harbour seals to provide much-needed sex-age-specific data on the proportion of seals hauled out during the August survey window, increasing robustness of overall abundance estimates. • Critically such data would provide age- and sex-specific survival and movement patterns to inform our understanding of demographic processes and impacts therein. Grey seals: The development of a grey seal population metapopulation model is critical to our continuing ability to reliably monitor and	Q1 Seal popn status & trends

	manage the UK grey seal population and to reduce current uncertainty in total population size. To fill knowledge gaps required for this SCOS recommends the following: • Development and subsequent large-scale deployment of small satellite flipper tags – this would address two critical knowledge gaps: (1) dispersal and survival of pups, and the spatial relationship between initial dispersal and recruitment into the breeding population, (2) seasonal movements of adults. • These tagging efforts should be accompanied by large scale genetic sampling. Genetic information would provide movement data for the grey seal metapopulation model, increased understanding of the population scale at which bycatch should be considered and provide data to facilitate estimation of population size through Close-kin mark-recapture models.	
Understanding the drivers of harbour seal population declines	In addition to the deployment of satellite tags discussed above, which is required for underpinning our understanding of population dynamics of both species of seal, specifically in relation to the observed harbour seal declines around the UK, SCOS recommends the following research is required: • To investigate the potential role of changes in food availability, and/or competition between species for prey, 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 latest information for much of the UK is more than ten years old. There are	Q1 Seal popn status & trends Q3 Popn structure & Demography: Harbour seals

	now studies underway to update our estimates of grey and harbour seal diet in the southeast of England SMU and around Scotland and the work should enable a reassessment of the potential role that prey availability may have had in these declines. • Routine health and disease surveillance through coordinated efforts involving strandings schemes, rescue and rehabilitation centres, and live captures for research is critical to better understand population health and ensure early detection and monitoring of infectious diseases in the UK, and to understand the potential for disease and health status to contribute to observed population trends. • Considering recent advances in techniques including drone technology, SCOS recommends that, a scoping study should be carried out to assess the feasibility of developing studies of harbour seal survival, fecundity and indicators of condition at additional sites around the UK. This exercise should consider the resource requirements of collecting data at appropriate temporal and geographical scales and assess the cost/benefit of such studies in relation to other data requirements.	
Reducing impacts of seals in rivers predating on fish stocks	• Continued investigation of non-lethal measures for control of seals in rivers is required 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. Multiyear deployments, individual variability, different species and	Q5 Rivers SCOS 2024 Q16, Q17, Q18, Q19 SCOS 2023 Q2

	different environments are all factors that require further work to explore. • Further research into the behaviour of seals in rivers could lead to better and more tailored management measures. This would include an understanding of individual and site-specific variability, and learning.	
Interactions with commercial fisheries: • Understanding and reducing seal bycatch	• The grey seal metapopulation model mentioned above would improve our ability to evaluate and manage the impact of bycatch on grey seal populations. This would enable us to address the mismatch in scale at which bycatch is monitored and reported versus the scale at which seal populations are monitored (and managed). Such a metapopulation model would also allow assessment of impacts of bycatch considering the large-scale movement of juvenile grey seals from NW Scotland into the SW of the UK where most of the bycatch occurs. • Effort should be directed towards improved species determination and, when possible, the sex and age class of bycaught seals (which would feed into the grey seal metapopulation model). Additionally, samples for genetic analysis should be collected. These samples could confirm species, sex and could be analysed to identify the source populations and/or estimate individual age. • The inclusion of non-UK vessels in bycatch estimates to quantify total bycatch is also required to improve the ability to quantify total bycatch levels and impacts to UK seals. This would require co-ordination with other countries fishing in UK waters to provide comparable data at a spatial resolution that would allow the separation of UK and non-UK effort, and bycatch estimates for all fisheries impacting seals in UK and adjacent waters. • There is a need to investigate the finding that ADD (‘pinger’) use on static net	Q5 – Bycatch SCOS 2024 Q8, Q9, Q10, Q11 SCOS 2022 Q11, Q13, Q14

	fisheries to reduce bycatch of cetaceans has led to increased rates of seal bycatch, and adaptations and development of mitigation strategies may be required. • Further work is required to robustly incorporate the direct impacts of bycatch and depredation on seals and fisheries, respectively into existing multispecies ecosystem models that are being used to predict, the impact of fisheries management and offshore oil and gas infrastructure decommissioning options under multiple climate change scenarios, on fish density and distributions, and ultimately on both seal populations and fisheries.	
• Competition with commercial fisheries	• 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. As noted above, there are now studies underway to update our estimates of grey and harbour seal diet in the southeast of England SMU and around Scotland. • A reassessment of the potential for competition with commercial fisheries should be undertaken once this work is complete and these data can be incorporated into multi-species ecosystem models.	Q6 – Sea fisheries SCOS 2021 Q25 SCOS 2019 Q13
• Depredation of catch and gear damage	• A structured monitoring programme using an integrated approach involving the industry is required to progress the collection and collation of robust quantitative information on the scale and extent of seal damage to catch and fishing gear, to identify where and when specific problems occur, and to guide the development and design of mitigation and management strategies. • The UK Protected Species Bycatch Monitoring Scheme has collected data for 20 years on the bycatch of marine mammals through on-board observations, some of which is associated with depredation. It has also collected	Q6 – Sea fisheries SCOS 2024 SCOS 2022 Q13, Q14 SCOS 2021 Q24

	information on seal-damaged fish recovered from nets. SCOS recommend that additional resources should be allocated to conduct a quantitative assessment of these data.	
Predicting impacts of renewable energy developments on seals	• In relation to the impacts of tidal energy devices on seals; recent research on fine scale behaviour of seals around devices should provide information at the range of spatial scales required to effectively derive empirical avoidance rates to operating turbines – however, work is required to appropriately combine estimates across scales to derive an overall avoidance rate that can be used as a scalar on current collision risk model outputs and how this new data is then incorporated into models. • In addition, there are currently no dedicated studies on grey seal interactions with tidal energy devices; this remains a key data gap with respect to understanding the potential risks of tidal turbines to this species. • Research is required into the effects of operational arrays of tidal turbines. It is uncertain how the risks associated with single turbines will scale up to large turbine arrays; it is likely to be complex, depending on individual behaviour and learning over repeated encounters. It will be important to consider how seal responses to arrays might be monitored at a variety of spatial scales and what technologies are available to measure this. • Furthermore, there is a need for the development of methods to allow more robust predictions of the number of individuals potentially exposed to anthropogenic impacts to feed into Environmental Impact Assessments and Strategic Environmental Assessments. This should include the use of existing telemetry to incorporate estimates of the turnover of individuals at sea in specific areas and individual fidelity to specific	Q12 Interactions with tidal turbines SCOS 2024 Q32 SCOS 2018 Q9 SCOS 2017 Q8 SCOS 2016 Q11 SCOS 2015 Q9 SCOS 2014 Q37

	areas – the development of assessment methods which can take information on these parameters into account will greatly increase robustness relative to existing approaches. • Research on harbour and grey seal behavioural responses (and energetic consequences) to offshore wind farm construction is also required to improve the robustness of impact assessments. Data to inform species specific noise dose response relationships is required.	
Seal health and disease	• There remains a need for the coordinated development and adoption of PDV and Avian Influenza response plans for seals, across all UK nations. 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 globally, some urgency should be applied to this effort. • Routine health and disease surveillance through coordinated efforts involving strandings schemes, rescue and rehabilitation centres, and live captures for research is critical to better understand population health and ensure 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.	Q7 Health and disease SCOS 2024 Q34 & Q35

Additional (non-standing) Questions

Question submitted by the Marine Directorate, Scottish Government	**11. Can SCOS advise on the usage of grey seal SACs both within and outwith the breeding season?**

For the most part, SAC site designations for grey seals were on the basis of breeding numbers (pup production). Indeed, ~35% of UK pup production occurs on Scottish and English SACs, whereas these SACs only account for <30% of the UK August count. Abundance within SACs during both the breeding season (pup production) and August are given as percentages of the SMU and UK totals in Table 19.

Due to movements within and between seasons, the total proportion of the UK population which visits a SAC at some point in the year is likely much higher than 35%. Indeed, once pups leave breeding beaches, after high initial densities around their breeding site, they often associate with multiple haul outs over a broad geographic area during their exploratory phase. Even once this phase ends, grey seals typically use multiple haul out sites during the foraging season, which may or may not, differ from where they moult or breed.

Such movements make management of SACs difficult, especially when the proportion of the UK holding within each SMU varies throughout the year (Table 3**). For example, at a UK level, East Scotland SMU holdings in August are less than half what they are in the breeding season. Almost 60% of East Scotland pup production is within SACs (~5.7% of UK pup production) but only 3.6% of August SMU count is within the SACs (0.2 % of UK August count). Thus, the estimated density at-sea associated with these SACs represents an unknown fraction of the seals that use the SAC and therefore cannot be used for the basis of a robust estimate of the impact of any activities on the breeding population of a SAC. Indeed, the seals hauling out in a SAC in August may or may not subsequently breed in that SAC. As such, although the SAC status affords protection of the breeding population during the breeding season, for the vast majority which disperse to forage, it does not afford protection for the rest of the year when interactions with anthropogenic activities are most prevalent and resources for breeding are acquired. Indeed, some of the seals that pup in East Scotland likely range into Southeast England, and even into continental Europe. Without extensive tracking of individuals from SAC, it is not possible to link the SAC breeding abundance with activities at-sea during the rest of the year. The mismatch in holdings across seasons, also extends to pups, as pups born at SACs leave the breeding colonies and are less likely to subsequently be hauled out at a SAC in summer. Initially after leaving the colony, there will be high at-sea densities locally, but at-sea estimates of young-of-the-year (< 1 year old) are not available.**

Table 19. The latest August counts and pup production estimates for each SAC in Scotland and England. The associated proportion of the SMU and UK holdings are also shown. Note that to provide percentages of August SMRU totals, the most recent counts were used, where as at a UK scale the composite counts were used. The Scottish component of the Berwickshire & North Northumberland Coast (BNNC) SAC transects the Fast Castle colony. Thus, for context, the totals are shown for Fast Castle as a whole (grey) as well as the BNNC portion. The Fast Castle total does not contribute to the total UK holdings in Scottish and English SACs.

SMU	SAC	**Most recent August data**				**Pup production**			
		SAC count	(year)	% of SMU	% of UK	SAC estimate	(year)	% of SMU	% of UK
2. West Scotland	Treshnish Isles	161	(2023)	3.6	0.4	1272	(2022)	23.8	1.6
3. Western Isles	Monach Islands	614	(2022)	17.7	1.5	13475	(2022)	72.6	17.0
	North Rona	147	(2023)	4.2	0.4	301	(2019)	1.6	0.4
4. North Coast & Orkney	Faray & Holm of Faray	228	(2019)	2.6	0.6	1915	(2022)	9.0	2.4
7. East Scotland	Isle of May	97	(2021)	3.6	0.2	1833	(2023)	24.3	2.3
	BNNC (Scottish component)	0	(2021)	0.0	0.0	2680	(2023)	35.6	3.4
	Fast Castle (inc. SAC)	0	(2021)	0.0	0.0	4730	(2023)	62.8	6.0
8.Northeast England	BNNC (English component)	4251	(2023)	91.1	10.4	3866	(2023)	95.9	4.9
9.Southeast England	Humber Estuary	6008	(2023)	55.2	14.7	2326	(2023)	14.1	2.9
11.Southwest England	Isles of Scilly Complex	397	(2023)	54.5	1.0	373	(2016)	76.1	0.5
	Lundy	75	(2023)	10.3	0.2	71	(2024)	14.5	0.1
Total					**29.3**				**35.5**

Question submitted by NRW	12. **Can SCOS indicate whether there has been any updated information, since last SCOS, on harbour or grey seal interactions with tidal turbines**

Several studies report changes in harbour seal distributions and behaviour in response to operational tidal turbines. However, there are currently no dedicated studies on grey seal interactions with tidal turbines. Although existing studies represent good progress in our understanding of how harbour seals behave in response to operating turbines at scales of 10's to 1,000's of metres, information on the fine scale (3-dimensional) 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 deployed a combined active sonar and passive acoustic tracking system alongside an operating tidal turbine off the north of Scotland; results confirm that seals are regularly detected and tracked within several tens of metres of the turbine (704 seals detected during 338 days of monitoring with 347 detected during turbine operation), and that they exhibit a degree of avoidance during operation. Preliminary analysis of the individual seal tracks from the sonar system shows that a small number of seals move in close proximity (within 2 m) to the rotor swept area.

SCOS considers that there is clear evidence of avoidance, with 11-93% reductions in seal abundance in the vicinity of tidal turbines, or in response to playback of turbine noise at a range of different scales from 30 to 2000 m from the turbines. SCOS therefore recommends that collision risk estimates based on 0% avoidance should be given little weight, and that research efforts are now focused on ensuring that new behavioural data are utilised appropriately and avoidance rates derived at different spatial scales are correctly combined to produce overall avoidance rates to operating turbines.

There are currently no dedicated studies on grey seal interactions with tidal energy devices. However, there are a number of studies that report changes in harbour seal distributions in response to operational tidal turbines, including to the Strangford Lough turbine (Joy et al., 2018), to playbacks of tidal turbine sounds (Hastie et al., 2018; Robertson et al., 2018), and to the MeyGen turbine array (Onoufriou et al., 2021). The mean changes in abundance at tidal turbines, and the scale that a response was measured at, were reported in SCOS (2024) (included and updated here for reference: Table 20).

Although these studies represent good progress in our understanding of how harbour seals behave in response to operating turbines at meso- (tens of metres) to macro- (hundreds of metres) scales, information on the micro-scale (metres) movements of individual seals around operating turbines has remained a critical research gap with respect to deriving avoidance rates and understanding the potential impacts of tidal turbines. However, a NERC and Scottish Government funded research project 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. This has detected and tracked individual seals in high resolution (metres) within ~30 m of the turbine and will provide data to quantify the movements patterns around the turbine.

Results confirm that seals are regularly detected within ~30 m of the operational turbine (704 seals detected during 338 days of monitoring). Modelling of the seal presence has shown that seals exhibit a significant relationship with tidal flow speed such that seals are present less frequently during periods of high tidal flows; further, when comparing seal presence between periods of turbine operation and non-operation, the model predicted a decrease in presence during turbine operation in flow speeds of ≥2.3 ms^{-1} (mean reduction of 77% at the highest flow speed; 95% CI: 22%–93%) (Montabaranom et al., 2025). Further analysis of the proximity and movements of the individuals tracks of seals is currently ongoing but initial results show that sixteen of the seal tracks (~2% of all tracks detected in the sonar swath) crossed the rotor swept area in the horizontal plane or passed very close (< 2m) to it, and were thus considered at a higher risk of collision. It is important to highlight that it was not possible to confirm collisions in the sonar data. Further, seal species differentiation is not possible in the data and, given that both grey and harbour seals are present in the study area, the derived tracks likely reflect include 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.

Table 20. Summary of previous studies measuring the avoidance of operating turbines, or their sounds, by harbour seals. The table shows the estimated mean change in abundance (%), the tidal turbine and location of the study, the scale that a response was measured at, and the reference for the study.

Mean % change in abundance	Source	Scale	Reference
-68% (95% CIs: -37%, -83%)	SeaGen turbine (Strangford Lough)	200m	Joy et al. (2018)
-27% (95% CIs: -11%, -41%)	Acoustic playback of turbine sounds (Kyle Rhea, Skye)	500m	Hastie et al. (2018)
No significant change	Acoustic playback of turbine sounds (Puget Sound, U.S.)	1,000m	Robertson et al. (2018)
-28% (95% CIs: -11%, - 49%)	MeyGen array (Pentland Firth)	2,000m	Onoufriou et al. (2021)
-77% (95% CIs: -22%, –93%)	Atlantis AR1500 turbine, MeyGen array	30m	Montabaranom et al. (2025)

Previous studies including the preliminary sonar tracking data 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). Critically, although the avoidance metrics from these previous studies could be applied independently as avoidance scalars in existing collision risk models, each has been derived at a different spatial scale. In future, it will be important to ensure that avoidance rates derived at each of the spatial scales are appropriately combined to produce overall avoidance rates to operating turbines. SMRU have developed a proposal to hold an expert workshop bringing together experts and stakeholders to discuss the advantages and limitations of current collision risk modelling frameworks with the view to establishing the most appropriate way to integrate new behavioural data and derive a strategy for collision risk modelling that can be applied to future tidal turbine arrays.

Further, to quantitatively assess the potential impact of tidal turbines on seals (as well as other potential impacts), static density estimates of seals in tidal development areas are often used. For the UK such estimates are usually taken from at-sea density maps generated using habitat association models (Carter et al. 2022). However, these estimates represent a snapshot of mean seal density at a given point in time, and translating this into numbers of seals which could be exposed to continuous activities such as tidal turbines is not straightforward. First, the density estimates, and associated uncertainties, are of mean model predictions averaged across tidal cycles, days, and months. Indeed, the values are based on insights from telemetry data, giving a mean of 82.36% and 86.16% of harbour and grey seals being at sea at any one time. Thus, the mean number in each cell will be close to 1.21 and 1.16 higher at high tide for harbour and grey seals, respectively. Second, these estimates do not provide information about the turnover of individuals at turbine locations. Indeed, this will vary markedly by grid cell. For grid cells which are travelled through but are not generally used for foraging activity, we might expect almost a complete turnover of individuals each hour. At the other extreme, for grid cells which are predominantly foraging, the same individual may stay within a small number of cells for over a week. These variations will have important implications for the assessment of impacts at individual and population level. Given these issues, a key research priority is to develop methods to facilitate a more realistic prediction of the number of individuals exposed to continuous anthropogenic impacts over appropriate time periods. The existing telemetry data could be used to examine grid cell changeover rates, and individual fidelity to areas.

References

Akineden, Ö., Alber, J., Lämmler, C., Weiss, R., Siebert, U., Foster, G., et al. (2007). Relatedness of Streptococcus equi subsp. zooepidemicus strains isolated from harbour seals (Phoca vitulina) and grey seals (Halichoerus grypus) of various origins of the North Sea during 1988–2005. *Veterinary Microbiology* 121, 158–162. doi: 10.1016/j.vetmic.2006.11.015

Albouy, C., Delattre, V., Donati, G., Frölicher, T. L., Albouy-Boyer, S., Rufino, M., et al. (2020). Global vulnerability of marine mammals to global warming. *Scientific Reports* 10, 548. doi: 10.1038/s41598-019-57280-3

Allen, P. J., Amos, W., Pomeroy, P. P., and Twiss, S. D. (1995). Microsatellite variation in grey seals (Halichoerus grypus) shows evidence of genetic differentiation between two British breeding colonies. *Molecular Ecology* 4, 653–662. doi: 10.1111/j.1365-294X.1995.tb00266.x

Álvarez-González, M., Suarez-Bregua, P., Pierce, G. J., and Saavedra, C. (2023). Unmanned Aerial Vehicles (UAVs) in Marine Mammal Research: A Review of Current Applications and Challenges. *Drones* 7, 667. doi: 10.3390/drones7110667

Amorosi, L., Carroll, D., Carroll, P., and Esposito Amideo, A. (2024). Optimal Drone Routing for Seal Pup Counts., in *Optimization in Green Sustainability and Ecological Transition*, eds. M. Bruglieri, P. Festa, G. Macrina, and O. Pisacane (Cham: Springer Nature Switzerland), 147–156. doi: 10.1007/978-3-031-47686-0_13

Anderson, S. (1990). *Seals*. London: Whittet Books.

Armstrong, H. C., Russell, D. J. F., Moss, S. E. W., Pomeroy, P., and Bennett, K. A. (2023). Fitness correlates of blubber oxidative stress and cellular defences in grey seals (Halichoerus grypus): support for the life-history-oxidative stress theory from an animal model of simultaneous lactation and fasting. *Cell Stress and Chaperones* 28, 551–566. doi: 10.1007/s12192-023-01332-1

Attard, M. R. G., Phillips, R. A., Bowler, E., Clarke, P. J., Cubaynes, H., Johnston, D. W., et al. (2024). Review of Satellite Remote Sensing and Unoccupied Aircraft Systems for Counting Wildlife on Land. *Remote Sensing* 16, 627. doi: 10.3390/rs16040627

Attard, M. R. G., Phillips, R. A., Oppel, S., Bowler, E., and Fretwell, P. T. (2025). Feasibility of using very high-resolution satellite imagery to monitor Tristan albatrosses Diomedea dabbenena on Gough Island. *Endangered Species Research* 56, 187–199. doi: 10.3354/esr01396

Backe, K., Hines, E., Nielsen, K. J., George, D., Twohy, E., and Lowry, M. (2021). Effects of sea-level rise and storm-enhanced flooding on Pacific harbour seal habitat: A comparison of haul-out changes at the Russian and Eel river estuaries. *Aquatic Conservation: Marine and Freshwater Ecosystems* 31, 1749–1759. doi: 10.1002/aqc.3574

Badger, J. J., Bowen, W. D., den Heyer, C. E., and Breed, G. A. (2020). Variation in individual reproductive performance amplified with population size in a long-lived carnivore. *Ecology* 101, e03024. doi: 10.1002/ecy.3024

Badger, J. J., Bowen, W. D., den Heyer, C. E., and Breed, G. A. (2021). Reproductive success is influenced by early development: the covariation of natal body size and reproductive performance in grey seals (Halichoerus grypus). *bioRxiv*, 2021.07.10.451928. doi: 10.1101/2021.07.10.451928

Baines, M., Earl, S., Pierpoint, C., and Poole, J. (1995). The West Wales grey seal census. *CCW contract science report* 131.

Baker, J. R., Jepson, P. D., Simpson, V. R., and Kuiken, T. (1998). Causes of mortality and non-fatal conditions among grey seals (Halichoerus grypus) found dead on the coasts of England, Wales and the Isle of Man. *Veterinary Record* 142, 595–601. doi: 10.1136/vr.142.22.595

Banga, R., Russell, D., Carter, M., Chaudry, F., Gilles, A., Abel, C., et al. (2022). Seal Abundance and Distribution. London: OSPAR Commission. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/seal-abundance-and-distribution

Banyard, A. C., Bennison, A., Byrne, A. M. P., Reid, S. M., Lynton-Jenkins, J. G., Mollett, B., et al. (2024). Detection and spread of high pathogenicity avian influenza virus H5N1 in the Antarctic Region. *Nature Communications* 15, 7433. doi: 10.1038/s41467-024-51490-8

Barratclough, A., Ferguson, S. H., Lydersen, C., Thomas, P. O., and Kovacs, K. M. (2023). A Review of Circumpolar Arctic Marine Mammal Health—A Call to Action in a Time of Rapid Environmental Change. *Pathogens* 12. doi: 10.3390/pathogens12070937

Baudron, A. R., Brunel, T., Blanchet, M.-A., Hidalgo, M., Chust, G., Brown, E. J., et al. (2020). Changing fish distributions challenge the effective management of European fisheries. *Ecography* 43, 494–505. doi: 10.1111/ecog.04864

Beaugrand, G., Brander, K. M., Alistair Lindley, J., Souissi, S., and Reid, P. C. (2003). Plankton effect on cod recruitment in the North Sea. *Nature* 426, 661–664. doi: 10.1038/nature02164

Bergman, A. (1999). Health condition of the Baltic grey seal (Halichoerus grypus) during two decades. APMIS 107:270-282.

Bergman, A. and Olsson, M. (1986). Pathology of Baltic grey seal and ringed seal females with special reference to adrenocortical hyperplasia: Is environmental pollution the cause of a widely distributed disease syndrome? Finn. Game Res. 44:47-62

Berta, A., and Churchill, M. (2011). Pinniped taxonomy: Review of currently recognized species and subspecies, and evidence used for their description. *Mammal Review* 42, 207–234. doi: 10.1111/j.1365-2907.2011.00193.x

Bigg, M. A., Ellis, G. M., Cottrell, P., and Milette, L. (1990). *Predation by harbour seals and sea lions on adult salmon in Comox Harbour and Cowichan Bay, British Columbia*. Nanaimo, B.C.: Dept. of Fisheries and Oceans, Biological Sciences Branch, Pacific Biological Station.

Bode, A. (2024). Synchronized multidecadal trends and regime shifts in North Atlantic plankton populations. *ICES Journal of Marine Science* 81, 575–586. doi: 10.1093/icesjms/fsad095

Bodewes, R., Bestebroer, T. M., van der Vries, E., Verhagen, J. H., Herfst, S., Koopmans, M. P., et al. (2015). Avian Influenza A(H10N7) virus-associated mass deaths among harbor seals. *Emerg Infect Dis* 21, 720–722. doi: 10.3201/eid2104.141675

Bodewes, R., MorickDanny, van de , Osinga ,Nynke, Rubio García ,Ana, Sánchez Contreras ,Guillermo J, et al. (2013). Prevalence of phocine distemper virus specific antibodies: bracing for the next seal epizootic in north-western Europe. *Emerging Microbes & Infections* 2, 1–5. doi: 10.1038/emi.2013.2

Bojko, J., and Arrow, N. (2024). UK seal “mouth rot” cases investigation by Teeside University /BDMLR. *Cetacean Stranding Investigation Programme - ME6042*.

Bond, I. (2024). Tees Seals Research Programme, Monitoring Report No. 33. (1989–2024).

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, 833–842. doi: 10.1111/j.1748-7692.2002.tb01076.x

Boveng, P. L., Ziel, H. L., McClintock, B. T., and Cameron, M. F. (2020). Body condition of phocid seals during a period of rapid environmental change in the Bering Sea and Aleutian Islands, Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 181–182, 104904. doi: 10.1016/j.dsr2.2020.104904

Bowen, W. D., den Heyer, C. E., Lang, S. L. C., Lidgard, D., and Iverson, S. J. (2020). Exploring causal components of plasticity in grey seal birthdates: Effects of intrinsic traits, demography, and climate. *Ecology and Evolution* 10, 11507–11522. doi: 10.1002/ece3.6787

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

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

Boyd, I. L. (1985). Pregnancy and ovulation rates in Grey seals (Halichoerus grypus) on the British coast. *Journal of Zoology* 205, 265–272. doi: 10.1111/j.1469-7998.1985.tb03533.x

Boyle, D. P. (2012). Grey Seal Breeding Census: Skomer Island 2011. Wildlife Trust of South and West Wales.

Brasseur, S. M. J. M., Aarts, G. M., and Kirkwood, R. J. (2015). Habitat quality for Grey Seals in the Dutch Wadden Sea. Den Burg: IMARES. Available at: https://edepot.wur.nl/329708

Bresnan, E., Baker-Austin, C., Campos, C. J. A., Davidson, K., Edwards, M., Hall, A., et al. (2020). *Impacts of climate change on human health, HABs and bathing waters, relevant to the coastal and marine environment around the UK*. Marine Climate Change Impacts Partnership. doi: 10.14465/2020.arc22.hhe

Büche, B., and Bond, S. (2023). Grey Seal Breeding Census Skomer Island 2023. The Wildlife Trust of South and West Wales.

Büche, B., and Stubbings, E. (2017). Grey Seal Breeding Census, Skomer Island 2017. Wildlife Trust of South and West Wales.

Büche, B., and Stubbings, E. (2019). Grey Seal Breeding Census Skomer Island 2018. The Wildlife Trust of South and West Wales.

Bull, J. C., Jones, O. R., Börger, L., Franconi, N., Banga, R., Lock, K., et al. (2021). Climate causes shifts in grey seal phenology by modifying age structure. *Proceedings of the Royal Society B: Biological Sciences* 288, 20212284. doi: 10.1098/rspb.2021.2284

CAA (2024). New trials set to help unlock drone deliveries and inspections in the UK | UK Civil Aviation Authority. Available at: https://www.caa.co.uk/newsroom/news/new-trials-set-to-help-unlock-drone-deliveries-and-inspections-in-the-uk/ (Accessed May 21, 2025).

CAA (2025). Beyond Visual Line of Sight (BVLOS) | UK Civil Aviation Authority. Available at: https://www.caa.co.uk/drones/moving-on-to-more-advanced-flying/beyond-visual-line-of-sight-bvlos/ (Accessed April 28, 2025).

Cadhla, O., Keena, T., Strong, D., Duck, C., and Hiby, L. (2013). Monitoring of the breeding population of grey seals in Ireland, 2009–2012. Irish Wildlife Manuals, No. 74. *National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Dublin, Ireland*.

Carretta, J. V., and Barlow, J. (2011). Long-Term Effectiveness, Failure Rates, and “Dinner Bell” Properties of Acoustic Pingers in a Gillnet Fishery. *Marine Technology Society Journal* 45, 7–19. doi: 10.4031/MTSJ.45.5.3

Carroll, D., Infantes, E., Pagan, E. V., and Harding, K.C. (2025). Approaching a population-level assessment of body size in pinnipeds using drones, an early warning of environmental degradation. *Remote Sensing in Ecology and Conservation* 11, 156–171. doi: 10.1002/rse2.413

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

Carpenter JR, Merckelbach L, Callies U, Clark S, Gaslikova L, et al. (2016) Potential Impacts of Offshore Wind Farms on North Sea Stratification. PLOS ONE 11(8): e0160830. https://doi.org/10.1371/journal.pone.0160830

Carter, M. I. D., Russell, D. J. F., Embling, C. B., Blight, C. J., Thompson, D., Hosegood, P. J., et al. (2017). Intrinsic and extrinsic factors drive ontogeny of early-life at-sea behaviour in a marine top predator. *Scientific Reports* 7, 15505. doi: 10.1038/s41598-017-15859-8

Carter, T. J., Pierce, G. J., Hislop, J. R. G., Houseman, J. A., and Boyle, P. R. (2001). Predation by seals on salmonids in two Scottish estuaries. *Fisheries Management and Ecology* 8, 207–225. doi: 10.1046/j.1365-2400.2001.00247.x

Cheung, W. W. L., Frölicher, T. L., Lam, V. W. Y., Oyinlola, M. A., Reygondeau, G., Sumaila, U. R., et al. (2021). Marine high temperature extremes amplify the impacts of climate change on fish and fisheries. *Science Advances* 7, eabh0895. doi: 10.1126/sciadv.abh0895

Christiansen, N., Daewel, U., Djath, B., & Schrum, C. (2022). Emergence of Largescale hydrodynamic structures due to atmospheric offshore wind farm wakes. *Front. Mar. Sci*, 9.

Christman, C. L., London, J. M., Conn, P. B., Hardy, S. K., Brady, G. M., Dahle, S. P., et al. (2022). Evaluating the use of thermal imagery to count harbor seals in aerial surveys. *Mamm Biol* 102, 719–732. doi: 10.1007/s42991-021-00191-6

Cohen, J. M., Sauer, E. L., Santiago, O., Spencer, S., and Rohr, J. R. (2020). Divergent impacts of warming weather on wildlife disease risk across climates. *Science* 370, eabb1702. doi: 10.1126/science.abb1702

Cook, K. m, Dunn, M. R., Behrens, E., Pinkerton, M. H., Law, C., and Cummings, V. J. (2025). Marine heatwaves and fisheries in Aotearoa New Zealand: review of potential effects on marine ecosystems and fishstocks.

Cook, P. F., Reichmuth, C., Rouse, A. A., Libby, L. A., Dennison, S. E., Carmichael, O. T., et al. (2015). Algal toxin impairs sea lion memory and hippocampal connectivity, with implications for strandings. *Science* 350, 1545–1547. doi: 10.1126/science.aac5675

Corcoran, E., Winsen, M., Sudholz, A., and Hamilton, G. (2021). Automated detection of wildlife using drones: Synthesis, opportunities and constraints. *Methods in Ecology and Evolution* 12, 1103–1114. doi: 10.1111/2041-210X.13581

Cornes, R., Hermanson, L., Hunter, W., Kent, E., Rabe, B., and Renshaw, R. (2023). "The Impacts of Climate Change on Sea Temperature around the UK and Ireland," 18pp. doi: 10.14465/2023.reu08.tem

Cosgrove, R., Gosch, M., Reid, D., Sheridan, M., Chopin, N., Jessopp, M., Cronin, M. (2015). Seal bycatch in gillnet and entangling net fisheries in Irish waters. *Fisheries Research* 183, 192–199. doi: 10.1016/j.fishres.2016.06.007

Couespel, D., Lévy, M., and Bopp, L. (2021). Oceanic primary production decline halved in eddy-resolving simulations of global warming. *Biogeosciences* 18, 4321–4349. doi: 10.5194/bg-18-4321-2021

Cox, S., Goetz, T., Tully, O., Kleyn, T., Palma Pedraza, S., Hiley, H., et al. (2024a). Assessing the suitability of targeted acoustic startle technology (TAST) to reduce high seal depredation rates at static-net fisheries using a multi-step pilot trial design., in *SMM Conference Abstract*.

Cox, S. L., Kleyn, T., Hiley, H., Tully, O., Pedraza, S. P., and Goetz, T. (2024b). Assessment of acoustic exposure & presence of cetaceans around static-net fisheries equipped with targeted acoustic startle technology (TAST) to mitigate seal depredation.

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

Cubaynes, H. C., Fretwell, P. T., Bamford, C., Gerrish, L., and Jackson, J. A. (2019). Whales from space: Four mysticete species described using new VHR satellite imagery. *Marine Mammal Science* 35, 466–491. doi: 10.1111/mms.12544

Dees, P., Bresnan, E., Dale, A. C., Edwards, M., Johns, D., Mouat, B., et al. (2017). Harmful algal blooms in the Eastern North Atlantic Ocean. *Proceedings of the National Academy of Sciences* 114, E9763–E9764. doi: 10.1073/pnas.1715499114

Delplanque, A., Linchant, J., Vincke, X., Lamprey, R., Théau, J., Vermeulen, C., et al. (2024). Will artificial intelligence revolutionize aerial surveys? A first large-scale semi-automated survey of African wildlife using oblique imagery and deep learning. *Ecological Informatics* 82, 102679. doi: 10.1016/j.ecoinf.2024.102679

den Heyer, C. E., and Bowen, W. D. (2017). Estimating Changes in Vital Rates of Sable Island Grey Seals Using Mark-recapture Analysis. DFO Can. Sci. Advis. Sec. Res. Available at: https://publications.gc.ca/collections/collection_2017/mpo-dfo/Fs70-5-2017-054-eng.pdf

den Heyer, C. E., Bowen, W. D., Dale, J., Gosselin, J.-F., Hammill, M. O., Johnston, D. W., et al. (2021). Contrasting trends in gray seal (Halichoerus grypus) pup production throughout the increasing northwest Atlantic metapopulation. *Marine Mammal Science* 37, 611–630. doi: 10.1111/mms.12773

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*. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat. Available at: https://open-science.canada.ca/handle/123456789/2737 (Accessed April 29, 2025).

den Heyer, N., Bowen, W., 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 (2022). Stock assessment of northwest Atlantic grey seals (Halichoerus grypus) in Canada in 2021. Dartmouth, N.S.: Canadian Science Advisory Secretariat. Available at: https://open-science.canada.ca/bitstreams/ef3baaaf-55a0-4938-8377-bbd94ce56faa/download

Diaz, R. J., and Rosenberg, R. (2008). Spreading Dead Zones and Consequences for Marine Ecosystems. *Science* 321, 926–929. doi: 10.1126/science.1156401

Dye, S., Hughes, S. L., Tinker, J., Berry, D. I., Holliday, N. P., Kent, E. C., et al. (2013). "Impacts of climate change on temperature (air and sea)," in *Marine Climate Change Impacts Partnership Science Review 2013*, eds. J. M. Baxter, P. J. Buckley, and C. J. Wallace (Lowestoft, UK: MCCIP Secretariat), 12. Available at: http://www.mccip.org.uk/media/13164/2013arc_backingpapers_1_temp.pdf

Edwards, E., Davies, I., Gerich, G., Green, M., Leaver, D., McKie, J., et al. (2025). Tidal Industry Seal Project. Managing the consenting risk of harbour seal collision in the Scottish tidal energy industry. Available at: https://www.emec.org.uk/projects/ocean-energy-projects/environmental-monitoring/tidal-industry-seal-project/

Edwards, M., Johns, D. G., Leterme, S. C., Svendsen, E., and Richardson, A. J. (2006). Regional climate change and harmful algal blooms in the northeast Atlantic. *Limnology and Oceanography* 51, 820–829. doi: 10.4319/lo.2006.51.2.0820

Edwards-Jones, A., Watson, S. C. L., Szostek, C. L., and Beaumont, N. J. (2024). Stakeholder insights into embedding marine net gain for offshore wind farm planning and delivery. *Environmental Challenges* 14, 100814. doi: 10.1016/j.envc.2023.100814

EFSA (European Food Safety Authority), ECDC (European Centre for Disease Prevention and Control, EURL (European Union Reference Laboratory for Avian Influenza), Alexakis, L., Buczkowski, H., Ducatez, M., et al. (2025). Scientific report: Avian influenza overview December 2024–March 2025. *EFSA Journal 2025*, 73. doi: 10.2903/j.efsa.2025.935

Ellis, G. K., Arso Civil, M., Cheney, B. J., Tapp, S., and Sparling, C. E. (In Press). Bottlenose dolphin ecology in coastal northeast England: Baseline abundance and connectivity of the East Coast Scotland population using photo identification in an area of range expansion.

Engelhard, G. H., Pinnegar, J. K., Kell, L. T., and Rijnsdorp, A. D. (2011). Nine decades of North Sea sole and plaice distribution. *ICES Journal of Marine Science* 68, 1090–1104. doi: 10.1093/icesjms/fsr031

Esrts, P. J. (2024). DotDotGoose. Available at: https://biodiversityinformatics.amnh.org/open_source/dotdotgoose (Accessed May 14, 2025).

Evans, P. G., and Bjørge, A. (2013). Impacts of climate change on marine mammals. *MCCIP Science Review*, 134/148.

Fereidouni, S., Munoz, O., Von Dobschuetz, S., and De Nardi, M. (2016). Influenza Virus Infection of Marine Mammals. *EcoHealth* 13, 161–170. doi: 10.1007/s10393-014-0968-1

Feser, F., Barcikowska, M., Krueger, O., Schenk, F., Weisse, R., and Xia, L. (2015). Storminess over the North Atlantic and northwestern Europe—A review. *Quarterly Journal of the Royal Meteorological Society* 141, 350–382. doi: 10.1002/qj.2364

Fietz, K., Galatius, A., Teilmann, J., Dietz, R., Frie, A. K., Klimova, A., et al. (2016). Shift of grey seal subspecies boundaries in response to climate, culling and conservation. *Molecular Ecology* 25, 4097–4112. doi: 10.1111/mec.13748

Fisheries Innovation and Sustainability (2023). Smartrawl - Fisheries Innovation & Sustainability. Available at: https://fisorg.uk/smartrawl/ (Accessed May 23, 2025).

Fisheries Managment Scotland (2025). The use of acoustic deterrent devices to deter seals in-river: initial results of a user survey for deployments carried out in 2024.

Flewelling, L. J., Naar, J. P., Abbott, J. P., Baden, D. G., Barros, N. B., Bossart, G. D., et al. (2005). Red tides and marine mammal mortalities. *Nature* 435, 755–756. doi: 10.1038/nature435755a

Floyd, T., Banyard, A. C., Lean, F. Z. X., Byrne, A. M. P., Fullick, E., Whittard, E., et al. (2021). Encephalitis and Death in Wild Mammals at a Rehabilitation Center after Infection with Highly Pathogenic Avian Influenza A(H5N8) Virus, United Kingdom. *Emerg Infect Dis* 27, 2856–2863. doi: 10.3201/eid2711.211225

Fretwell, P. T., Scofield, P., and Phillips, R. A. (2017). Using super-high resolution satellite imagery to census threatened albatrosses. *Ibis* 159, 481–490. doi: 10.1111/ibi.12482

Fudala, K., and Bialik, R. J. (2022). Seals from outer space - Population census of southern elephant seals using VHR satellite imagery. *Remote Sensing Applications: Society and Environment* 28, 100836. doi: 10.1016/j.rsase.2022.100836

Funayama, K., Hines, E., Davis, J., and Allen, S. (2013). Effects of sea-level rise on northern elephant seal breeding habitat at Point Reyes Peninsula, California. *Aquatic Conservation: Marine and Freshwater Ecosystems* 23, 233–245. doi: 10.1002/aqc.2318

Gadzhiev, A., Petherbridge, G., Sharshov, K., Sobolev, I., Alekseev, A., Gulyaeva, M., et al. (2024). Pinnipeds and avian influenza: a global timeline and review of research on the impact of highly pathogenic avian influenza on pinniped populations with particular reference to the endangered Caspian seal (Pusa caspica). *Frontiers in Cellular and Infection Microbiology* Volume 14-2024. Available at: https://www.frontiersin.org/journals/cellular-and-infection-microbiology/articles/10.3389/fcimb.2024.1325977

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

Geelhoed, S., Authier, M., Pigeault, R., and Gilles, A. (2022). Abundance and distribution of cetaceans. London: OSPAR Commission.

Gillespie, D., Oswald, M., Hastie, G., and 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* Volume 9-2022. Available at: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.850446

Gobler, C. J., Doherty, O. M., Hattenrath-Lehmann, T. K., Griffith, A. W., Kang, Y., and Litaker, R. W. (2017). Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans. *Proceedings of the National Academy of Sciences* 114, 4975–4980. doi: 10.1073/pnas.1619575114

Goldstein, T., Gulland, F. M. D., Aldridge, B. M., Harvey, J. T., Rowles, T., Lambourn, D. M., et al. (2003). ANTIBODIES TO PHOCINE HERPESVIRUS-1 ARE COMMON IN NORTH AMERICAN HARBOR SEALS (PHOCA VITULINA). *Journal of Wildlife Diseases* 39, 487–494. doi: 10.7589/0090-3558-39.3.487

Goldstein, T., Mazet, J. A. K., Gulland, F. M. D., Rowles, T., Harvey, J. T., Allen, S. G., et al. (2004). The transmission of phocine herpesvirus-1 in rehabilitating and free-ranging Pacific harbor seals (Phoca vitulina) in California. *Veterinary Microbiology* 103, 131–141. doi: 10.1016/j.vetmic.2004.06.017

Goldstein, T., Zabka, T. S., DeLong, R. L., Wheeler, E. A., Ylitalo, G., Bargu, S., et al. (2009). THE ROLE OF DOMOIC ACID IN ABORTION AND PREMATURE PARTURITION OF CALIFORNIA SEA LIONS (ZALOPHUS CALIFORNIANUS) ON SAN MIGUEL ISLAND, CALIFORNIA. *Journal of Wildlife Diseases* 45, 91–108. doi: 10.7589/0090-3558-45.1.91

Gonçalves, B. C., Spitzbart, B., and Lynch, H. J. (2020). SealNet: A fully-automated pack-ice seal detection pipeline for sub-meter satellite imagery. *Remote Sensing of Environment* 239, 111617. doi: 10.1016/j.rse.2019.111617

Götz, T., & Janik, V.M. (2015). Target-specific acoustic predator deterrence in the marine environment. Animal Conservation, 18(1), 102-111. https://doi.org/10.1111/acv.12141

Götz, T., and Janik, V. M. (2016). Non-lethal management of carnivore predation: long-term tests with a startle reflex-based deterrence system on a fish farm. *Animal Conservation* 19, 212–221. doi: 10.1111/acv.12248

GOV.UK (2024). Influenza of avian origin in UK seal populations: qualitative assessment of the risk to the UK human population. *GOV.UK*. Available at: https://www.gov.uk/government/publications/avian-influenza-in-uk-seal-populations-hairs-risk-assessment/influenza-of-avian-origin-in-uk-seal-populations-qualitative-assessment-of-the-risk-to-the-uk-human-population (Accessed May 23, 2025).

Graham, I. M., Harris, R. N., Matejusová, I., and Middlemas, S. J. (2011). Do 'rogue' seals exist? Implications for seal conservation in the UK. *Animal Conservation* 14, 587–598. doi: 10.1111/j.1469-1795.2011.00469.x

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.

Granquist, S. M., and Hauksson, E. (2019). Aerial census of the Icelandic grey seal (Halichoerus grypus) population in 2017: Pup production, population estimate, trends and current status. *Marine and Freshwater Research in Iceland. HV* 2.

Green, K. M., Virdee, M. K., Cubaynes, H. C., Aviles-Rivero, A. I., Fretwell, P. T., Gray, P. C., et al. (2023). Gray whale detection in satellite imagery using deep learning. *Remote Sensing in Ecology and Conservation* 9, 829–840. doi: 10.1002/rse2.352

Gulland, F. M. D., Lowenstine, L. J., Lapointe, J. M., Spraker, T., and King, D. P. (1997). HERPESVIRUS INFECTION IN STRANDED PACIFIC HARBOR SEALS OF COASTAL CALIFORNIA. *Journal of Wildlife Diseases* 33, 450–458. doi: 10.7589/0090-3558-33.3.450

Hall, A. J., Bernie J., M., and Richard J., B. (2001). Factors affecting first-year survival in grey seals and their implications for life history strategy. *Journal of Animal Ecology* 70, 138–149. doi: 10.1111/j.1365-2656.2001.00468.x

Hall, A. J., Kershaw, J. L., Fraser, S., Davidson, K., Rowland-Pilgrim, S., Turner, A. D., et al. (2024). Estimating the risks of exposure to harmful algal toxins among Scottish harbour seals. *Harmful Algae* 136, 102653. doi: 10.1016/j.hal.2024.102653

Hall, A. J., Mackey, B., Kershaw, J. L., and Thompson, P. (2019). Age–length relationships in UK harbour seals during a period of population decline. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29, 61–70. doi: 10.1002/aqc.3104

Hall, A. J., McConnell, B. J., and Barker, R. J. (2002). The effect of total immunoglobulin levels, mass and condition on the first-year survival of Grey Seal pups. *Functional Ecology* 16, 462–474. doi: 10.1046/j.1365-2435.2002.00649.x

Hall, A. J., Thomas, G. O., and McConnell, B. J. (2009). Exposure to Persistent Organic Pollutants and First-Year Survival Probability in Gray Seal Pups. *Environ. Sci. Technol.* 43, 6364–6369. doi: 10.1021/es9004398

Hamilton, S., and 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, 200–206. doi: 10.1016/j.fishres.2014.07.010

Hammill, M. O., and Gosselin, J. F. (1995). Grey seal (Halichoerus grypus) from the Northwest Atlantic: female reproductive rates, age at first birth, and age of maturity in males. *Can. J. Fish. Aquat. Sci.* 52, 2757–2761. doi: 10.1139/f95-864

Hammill, M. O., Gosselin, J. F., and Stenson, G. B. (2007). Abundance of Northwest Atlantic grey seals in Canadian waters. *NAMMCOSP* 6, 99–115. doi: 10.7557/3.2726

Hammill, M. O., Rossi, S., Mosnier, A., den Heyer, C., Bowen, W., and Stenson, G. (2023). *Grey seal abundance in Canadian waters and harvest advice*. Canadian Science Advisory Secretariat (CSAS).

Hanson, N., Thompson, D., Duck, C., Moss, S., and Lonergan, M. (2013). Pup Mortality in a Rapidly Declining Harbour Seal (Phoca vitulina) Population. *PLOS ONE* 8, e80727. doi: 10.1371/journal.pone.0080727

Harder, T. C., Vos, H., de Swart, R. L., and Osterhaus, A. D. M. E. (1997). Age-related disease in recurrent outbreaks of phocid herpesvirus type-I infections in a seal rehabilitation centre: evaluation of diagnostic methods. *Veterinary Record* 140, 500–503. doi: 10.1136/vr.140.19.500

Harding, K. C., Fujiwara, M., Axberg, Y., and Härkönen, T. (2005). Mass-dependent energetics and survival in Harbour Seal pups. *Functional Ecology* 19, 129–135. doi: 10.1111/j.0269-8463.2005.00945.x

Harding, K. C., Salmon, M., Teilmann, J., Dietz, R., and Harkonen, T. (2018). Population Wide Decline in Somatic Growth in Harbor Seals—Early Signs of Density Dependence. *Frontiers in Ecology and Evolution* Volume 6-2018. Available at: https://www.frontiersin.org/journals/ecology-and-evolution/articles/10.3389/fevo.2018.00059

Harris, C. M., Travis, J. M. J., and Harwood, J. (2008). Evaluating the Influence of Epidemiological Parameters and Host Ecology on the Spread of Phocine Distemper Virus through Populations of Harbour Seals. *PLOS ONE* 3, e2710. doi: 10.1371/journal.pone.0002710

Harris, R. N., and Northridge, S. P. (2019). Seals and Salmon Interactions. St Andrews: Sea Mammal Research Unit, University of St Andrews.

Harris, R.N., Coram, A.J., Tapp, S. & Sparling, C.E. (in review) How to deter seals? A manually triggered acoustic deterrent study. Submitted to Marine Mammal Science.

Harvey, J. T., and Goley, D. (2011). Determining a correction factor for aerial surveys of harbor seals in California. *Marine Mammal Science* 27, 719–735.

Harwood, J., and Prime, J. H. (1978). Some Factors Affecting the Size of British Grey Seal Populations. *Journal of Applied Ecology* 15, 401–411. doi: 10.2307/2402600

Hastie, G. D., Russell, D. J. F., Benjamins, S., Moss, S., Wilson, B., and Thompson, D. (2016). Dynamic habitat corridors for marine predators; intensive use of a coastal channel by harbour seals is modulated by tidal currents. *Behavioral Ecology and Sociobiology* 70, 2161–2174. doi: 10.1007/s00265-016-2219-7

Hastie, G. D., Russell, D. J. F., Lepper, P., Elliott, J., Wilson, B., Benjamins, S., et al. (2018). Harbour seals avoid tidal turbine noise: Implications for collision risk. *Journal of Applied Ecology* 55, 684–693. doi: 10.1111/1365-2664.12981

Hawkins, S., Lundberg, A., Lundberg, A., Oliver, G., and Condit, R. (2023). Estimating a seal population using automated counts of drone photographs., in *Applications of Machine Learning 2023*, (SPIE), 31–40. doi: 10.1117/12.2676277

Hewer, H. R. (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, 593–623. doi: 10.1111/j.1469-7998.1964.tb04631.x

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

Hilbrebirdobs blogspot (n.d.). Available at: https://hilbrebirdobs.blogspot.com/

Hinke, J. T., Giuseffi, L. M., Hermanson, V. R., Woodman, S. M., and Krause, D. J. (2022). Evaluating Thermal and Color Sensors for Automating Detection of Penguins and Pinnipeds in Images Collected with an Unoccupied Aerial System. *Drones* 6, 255. doi: 10.3390/drones6090255

Hoekendijk, J. P. A., Grundlehner, A., Brasseur, S., Kellenberger, B., Tuia, D., and Aarts, G. (2023). Stay close, but not too close: aerial image analysis reveals patterns of social distancing in seal colonies. *Royal Society Open Science* 10, 230269. doi: 10.1098/rsos.230269

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

Hollings, T., Burgman, M., van Andel, M., Gilbert, M., Robinson, T., and Robinson, A. (2018). How do you find the green sheep? A critical review of the use of remotely sensed imagery to detect and count animals. *Methods in Ecology and Evolution* 9, 881–892. doi: 10.1111/2041-210X.12973

Hooper, T., Austen, M., and Lannin, A. (2021). Developing policy and practice for marine net gain. *Journal of Environmental Management* 277, 111387. doi: 10.1016/j.jenvman.2020.111387

Huber, H. R., Jeffries, S. J., Brown, R. F., Delong, R. L., and Vanblaricom, G. (2001). CORRECTING AERIAL SURVEY COUNTS OF HARBOR SEALS (PHOCA VITULINA RICHARDSI) IN WASHINGTON AND OREGON. *Marine Mammal Science* 17, 276–293. doi: 10.1111/j.1748-7692.2001.tb01271.x

Iacozza, J., Sherbo, B., and Watt, C. (2024). A semi-automated method using object-based image analysis (OBIA) to detect and enumerate beluga whales in summer from very high-resolution (VHR) satellite imagery. *PLOS ONE* 19, e0307716. doi: 10.1371/journal.pone.0307716

ICES (2024). Working Group on Bycatch of Protected Species (WGBYC). ICES Scientific Reports. Available at: https://ices-library.figshare.com/articles/report/Working_Group_on_Bycatch_of_Protected_Species_WGBYC_/24659484

ICES (2025). Working Group on Marine Mammal Ecology (WGMME). doi: 10.17895/ices.pub.26997367.v3

Infantes, E., Carroll, D., Silva, W. T. A. F., Härkönen, T., Edwards, S. V., and Harding, K. C. (2022). An automated work-flow for pinniped surveys: A new tool for monitoring population dynamics. *Front. Ecol. Evol.* 10. doi: 10.3389/fevo.2022.905309

Institute of Baltic Sea Fisheries (2023). en: MiniSeine – a small Danish seine for German coastal fishing. Available at: https://www.thuenen.de/en/institutes/baltic-sea-fisheries/projects/fisheries-and-survey-technology/miniseine-eine-kleine-snurrewade-fuer-die-deutsche-kuestenfischerei (Accessed May 23, 2025).

IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. (In Press). Available at: https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/

Jemison, L, T Götz, A Daugherty, M Kemp, and Z Brown. (2024): Preserving catch of salmon troll fishermen while reducing interactions with Steller sea lions (SSL): targeted acoustic startle technology (TAST) to deter SSLs from troll gear in Southeast Alaska. 05/01/2021 - 10/31/2024. Final report for NMFS, Award no. NA20NMF4720268. Alaska Department of Fish and Game, Juneau.

Jones, T., Parrish, J. K., Lindsey, J., Wright, C., Burgess, H. K., Dolliver, J., et al. (2023). Marine bird mass mortality events as an indicator of the impacts of ocean warming. *Marine Ecology Progress Series* HEAT. doi: 10.3354/meps14330

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

Kauhala, K., Ahola, M. P., and 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. doi: 10.5735/086.049.0502

Kauhala, K., Korpinen, S., Lehtiniemi, M., and 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. doi: 10.1016/j.ecolind.2019.03.022

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. doi: 10.1007/s13364-019-00454-1

Kellenberger, B., Marcos, D., and Tuia, D. (2018). Detecting mammals in UAV images: Best practices to address a substantially imbalanced dataset with deep learning. *Remote Sensing of Environment* 216, 139–153. doi: 10.1016/j.rse.2018.06.028

Kellenberger, B., Tuia, D., and Morris, D. (2020). AIDE: Accelerating image-based ecological surveys with interactive machine learning. *Methods in Ecology and Evolution* 11, 1716–1727. doi: 10.1111/2041-210X.13489

Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A., Williams, J., Sparks, T., et al. (2023). State of the UK Climate 2022. *International Journal of Climatology* 43, 1–83. doi: 10.1002/joc.8167

Kershaw, J. L., Jensen, S.-K., McConnell, B., Fraser, S., Cummings, C., Lacaze, J.-P., et al. (2021). Toxins from harmful algae in fish from Scottish coastal waters. *Harmful Algae* 105, 102068. doi: 10.1016/j.hal.2021.102068

Khan, C. B., Goetz, K. T., Cubaynes, H. C., Robinson, C., Murnane, E., Aldrich, T., et al. (2023). A Biologist's Guide to the Galaxy: Leveraging Artificial Intelligence and Very High-Resolution Satellite Imagery to Monitor Marine Mammals from Space. *Journal of Marine Science and Engineering* 11, 595. doi: 10.3390/jmse11030595

King, D. P., Lie, A. R., Goldstein, T., Aldridge, B. M., Gulland, F. M. D., Haulena, M., et al. (2001). Humoral immune responses to phocine herpesvirus-1 in Pacific harbor seals (Phoca vitulina richardsii) during an outbreak of clinical disease. *Veterinary Microbiology* 80, 1–8. doi: 10.1016/S0378-1135(00)00369-2

Kingston, A. R., Moyes, F., Thomas, L., and Northridge, S. P. (2025). UK Bycatch Monitoring Programme Report for 2024.

Kirwan, M. L., and Megonigal, J. P. (2013). Tidal wetland stability in the face of human impacts and sea-level rise. *Nature* 504, 53–60. doi: 10.1038/nature12856

Königson, S., Lövgren, J., Hjelm, J., Ovegård, M., Ljunghager, F., and Lunneryd, S.-G. (2015). Seal exclusion devices in cod pots prevent seal bycatch and affect their catchability of cod. *Fisheries Research* 167, 114–122. doi: 10.1016/j.fishres.2015.01.013

Krishnan, B. S., Jones, L. R., Elmore, J. A., Samiappan, S., Evans, K. O., Pfeiffer, M. B., et al. (2023). Fusion of visible and thermal images improves automated detection and classification of animals for drone surveys. *Sci Rep* 13, 10385. doi: 10.1038/s41598-023-37295-7

Krucik, D. D. R., Cook, P., Cathey, M., Meegan, J. M., Gomez, F. M., Bonn, W. V., et al. (2023). Adult-onset epilepsy and hippocampal pathology in a California sea lion (Zalophus californianus): A case study of suspected in utero exposure to domoic acid. *NeuroToxicology* 96, 13–18. doi: 10.1016/j.neuro.2023.02.010

Laborie, J., Authier, M., Chaigne, A., Delord, K., Weimerskirch, H., and Guinet, C. (2023). Estimation of total population size of southern elephant seals (Mirounga leonina) on Kerguelen and Crozet Archipelagos using very high-resolution satellite imagery. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1149100

Lair, S., Quesnel, L., Signore, A. V., Delnatte, P., Embury-Hyatt, C., Nadeau, M.-S., et al. (2024). Outbreak of Highly Pathogenic Avian Influenza A(H5N1) Virus in Seals, St. Lawrence Estuary, Quebec, Canada(1). *Emerg Infect Dis* 30, 1133–1143. doi: 10.3201/eid3006.231033

Lamprey, R., Pope, F., Ngene, S., Norton-Griffiths, M., Frederick, H., Okita-Ouma, B., et al. (2020). Comparing an automated high-definition oblique camera system to rear-seat-observers in a wildlife survey in Tsavo, Kenya: Taking multi-species aerial counts to the next level. *Biological Conservation* 241, 108243. doi: 10.1016/j.biocon.2019.108243

Landsberg, J. H. (2002). The Effects of Harmful Algal Blooms on Aquatic Organisms. *Reviews in Fisheries Science* 10, 113–390. doi: 10.1080/20026491051695

Larsen, G. D., and Johnston, D. W. (2024). Growth and opportunities for drone surveillance in pinniped research. *Mammal Review* 54, 1–12. doi: 10.1111/mam.12325

LaRue, M. A., Ainley, D. G., Pennycook, J., Stamatiou, K., Salas, L., Nur, N., et al. (2020). Engaging 'the crowd' in remote sensing to learn about habitat affinity of the Weddell seal in Antarctica. *Remote Sensing in Ecology and Conservation* 6, 70–78. doi: 10.1002/rse2.124

LaRue, M. A., Lynch, H. J., Lyver, P. O. B., Barton, K., Ainley, D. G., Pollard, A., et al. (2014). A method for estimating colony sizes of Adélie penguins using remote sensing imagery. *Polar Biol* 37, 507–517. doi: 10.1007/s00300-014-1451-8

LaRue, M. A., Rotella, J. J., Garrott, R. A., Siniff, D. B., Ainley, D. G., Stauffer, G. E., et al. (2011). Satellite imagery can be used to detect variation in abundance of Weddell seals (Leptonychotes weddellii) in Erebus Bay, Antarctica. *Polar Biol* 34, 1727–1737. doi: 10.1007/s00300-011-1023-0

LaRue, M. A., Stapleton, S., and Anderson, M. (2017). Feasibility of using high-resolution satellite imagery to assess vertebrate wildlife populations. *Conservation Biology* 31, 213–220. doi: 10.1111/cobi.12809

Laurel, B. J., and Rogers, L. A. (2020). Loss of spawning habitat and prerecruits of Pacific cod during a Gulf of Alaska heatwave. *Can. J. Fish. Aquat. Sci.* 77, 644–650. doi: 10.1139/cjfas-2019-0238

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, 106328. doi: 10.1016/j.fishres.2022.106328

Lehtonen, E., Lehmonen, R., and Suuronen, P. (2023). Potential of creating seal-free fishing areas with seal deterrents. *Fisheries Research* 264, 106736. doi: 10.1016/j.fishres.2023.106736

Lonergan, M., Duck, C. D., Thompson, D., Moss, S., and 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, 2201–2209. doi: 10.1093/icesjms/fsr161

Lonergan, M., Duck, C., Moss, S., Morris, C., and 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. doi: 10.1002/aqc.2277

Lowe, J. A., and Gregory, J. M. (2006). Understanding projections of sea level rise in a Hadley Centre coupled climate model. *Journal of Geophysical Research: Oceans* 111. doi: 10.1029/2005JC003421

Luck, C., Jessopp, M., Tully, O., Cosgrove, R., Rogan, E., and 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, e01213. doi: 10.1016/j.gecco.2020.e01213

Ludes-Wehrmeister, E., Dupke, C., Harder, T. C., Baumgärtner, W., Haas, L., Teilmann, J., et al. (2016). Phocine distemper virus (PDV) seroprevalence as predictor for future outbreaks in harbour seals. *Veterinary Microbiology* 183, 43–49. doi: 10.1016/j.vetmic.2015.11.017

Lundy Field Society (2023). Annual Report No. 72. Available at: www.lundy.org.uk

Lyle, J. M., Willcox, S. T., and Hartmann, K. (2016). Underwater observations of seal–fishery interactions and the effectiveness of an exclusion device in reducing bycatch in a midwater trawl fishery. *Can. J. Fish. Aquat. Sci.* 73, 436–444. doi: 10.1139/cjfas-2015-0273

Lyman, R. L., Harpole, J. L., Darwent, C., and Church, R. (2002). Prehistoric Occurrence of Pinnipeds in the Lower Columbia River. *Northwestern Naturalist* 83, 1–6. doi: 10.2307/3536507

Manx Wildlife Trusts (2023). Calf of Man Seal Survey Report. Prepared by Begbie BP, Kenny D, & Howe L.

Mart Jüssi, Tero Härkönen, Eero Helle, and Ivar Jüssi (2008). Decreasing Ice Coverage Will Reduce the Breeding Success of Baltic Grey Seal (Halichoerus grypus) Females. *AMBIO: A Journal of the Human Environment* 37, 80–85. doi: 10.1579/0044-7447(2008)37[80:DICWRT]2.0.CO;2

Martina, B. E. E., Jensen, T. H., van de Bildt, M. W. G., Osterhaus, A. D. M. E., and Harder, T. C. (2002). Variations in the severity of phocid herpesvirus type 1 infections with age in grey seals and harbour seals. *Veterinary Record* 150, 572–575. doi: 10.1136/vr.150.18.572

Matern, W. A., Fleishman, A. B., Gilbert, I., Wilson, X., Beddow, J.-M., Garfield, I., et al. (2025). Evaluating the Efficacy of Drone-Based Thermal Images for Measuring Wildlife Abundance and Physiology. *Marine Mammal Science* n/a, e70019. doi: 10.1111/mms.70019

McCabe, R. M., Hickey, B. M., Kudela, R. M., Lefebvre, K. A., Adams, N. G., Bill, B. D., et al. (2016). An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophysical Research Letters* 43, 10,366-10,376. doi: 10.1002/2016GL070023

McCarthy, M., Cammen, K., Granquist, S., Dietz, R., Teilmann, J., Thøstesen, C., et al. (2025). Range-wide population structure and recent evolutionary history of the grey seal. *Molecular Ecology*, 34:e17824 doi: http://doi.org/10.1111/mec.17824

MCCIP, Stoker, B., Turrell, W. R., Robinson, K., Howes, E., Buckley, P. J., et al. (2020). Marine climate change impacts: report card 2020. Marine Climate Change Impacts Partnership. Available at: https://www.mccip.org.uk/sites/default/files/2021-07/mccip-report-card-2020_webversion.pdf

McClatchie, S., Field, J., Thompson, A. R., Gerrodette, T., Lowry, M., Fiedler, P. C., et al. (2016). Food limitation of sea lion pups and the decline of forage off central and southern California. *Royal Society Open Science* 3, 150628. doi: 10.1098/rsos.150628

McMahon, C. R., Howe, H., Hoff, J. van den, Alderman, R., Brolsma, H., and Hindell, M. A. (2014). Satellites, the All-Seeing Eyes in the Sky: Counting Elephant Seals from Space. *PLOS ONE* 9, e92613. doi: 10.1371/journal.pone.0092613

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. doi: 10.1371/journal.pone.0067576

Middlemas, S. J., Barton, T. R., Armstrong, J. D., and Thompson, P. M. (2005). Functional and aggregative responses of harbour seals to changes in salmonid abundance. *Proceedings of the Royal Society B: Biological Sciences* 273, 193–198. doi: 10.1098/rspb.2005.3215

Miller, M. A., Moriarty, M. E., Duignan, P. J., Zabka, T. S., Dodd, E., Batac, F. I., et al. (2021). Clinical Signs and Pathology Associated With Domoic Acid Toxicosis in Southern Sea Otters (Enhydra lutris nereis). *Frontiers in Marine Science* Volume 8-2021. Available at: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.585501

Mirolo, M., Pohlmann ,Anne, Ahrens ,Ann Kathrin, Kühl ,Bianca, Rubio-Garcìa ,Ana, Kramer ,Katharina, et al. (2023). Highly pathogenic avian influenza A virus (HPAIV) H5N1 infection in two European grey seals (Halichoerus grypus) with encephalitis. *Emerging Microbes & Infections* 12, 2257810. doi: 10.1080/22221751.2023.2257810

MMO (2019). Assessing Options for Non-Lethal Seal Deterrents: Stakeholder Engagement Report. A report produced for the Marine Management Organisation. MMO. Available at:

https://assets.publishing.service.gov.uk/media/5d441665ed915d705f6d4b2b/MMO1131_SEReport_Public_190725.pdf

Montabaranom, J., Gillespie, D., Longden, E., Rapson, K., Holoborodko, A., Sparling, C., et al. (2025). Seals exhibit localised avoidance of operational tidal turbines. *Journal of Applied Ecology* 62, 242–252. doi: 10.1111/1365-2664.14844

Moreland, E. E., Cameron, M. F., Angliss, R. P., and Boveng, P. L. (2015). Evaluation of a ship-based unoccupied aircraft system (UAS) for surveys of spotted and ribbon seals in the Bering Sea pack ice. *J. Unmanned Veh. Sys.* 3, 114–122. doi: 10.1139/juvs-2015-0012

Moriarty, M. E., Tinker, M. T., Miller, M. A., Tomoleoni, J. A., Staedler, M. M., Fujii, J. A., et al. (2021). Exposure to domoic acid is an ecological driver of cardiac disease in southern sea otters☆. *Harmful Algae* 101, 101973. doi: 10.1016/j.hal.2020.101973

Morris, C., and Duck, C. (2019). Aerial thermal-imaging survey of seals in Ireland, 2017 to 2018. *Irish Wildlife Manuals*.

Morris, C., Duck, C., and Thompson, D. (2021). Aerial surveys of seals in Scotland during the harbour seal moult, 2016–2019. *NatureScot Res Rep* 1256, 68.

Moxley, J. H., Bogomolni, A., Hammill, M. O., Moore, K. M. T., Polito, M. J., Sette, L., et al. (2017). Google Haul Out: Earth Observation Imagery and Digital Aerial Surveys in Coastal Wildlife Management and Abundance Estimation. *BioScience* 67, 760–768. doi: 10.1093/biosci/bix059

Moyes, F., Smout, S., Thomas, L., Kingston, A., and Northridge, S. P. (In Review). Factors associated with bycatch of marine mammals in United Kingdom static net fisheries. *ICES Journal of Marine Science*.

Mudge, M. C., Riffle, M., Chebli, G., Plubell, D. L., Rynearson, T. A., Noble, W. S., et al. (2025). Harmful algal blooms are preceded by a predictable and quantifiable shift in the oceanic microbiome. *Nature Communications* 16, 3986. doi: 10.1038/s41467-025-59250-y

Munday, P. L., Dixson, D. L., McCormick, M. I., Meekan, M., Ferrari, M. C. O., and Chivers, D. P. (2010). Replenishment of fish populations is threatened by ocean acidification. *Proceedings of the National Academy of Sciences* 107, 12930–12934. doi: 10.1073/pnas.1004519107

Murawski, A., Fabrizio, T., Ossiboff, R., Kackos, C., Jeevan, T., Jones, J. C., et al. (2024). Highly pathogenic avian influenza A(H5N1) virus in a common bottlenose dolphin (Tursiops truncatus) in Florida. *Communications Biology* 7, 476. doi: 10.1038/s42003-024-06173-x

National Academies of Sciences, E., and Medicine (2017). *Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals*. Washington, DC: The National Academies Press. doi: 10.17226/23479

Natural England (2025). How new technologies are helping us monitor one of England's largest grey seal colonies. Available at: https://naturalengland.blog.gov.uk/2025/02/26/how-new-technologies-are-helping-us-monitor-one-of-englands-largest-grey-seal-colonies/ (Accessed April 25, 2025).

Nevermann, H., AghaKouchak, A., and Shokri, N. (2023). Sea level rise implications on future inland migration of coastal wetlands. *Global Ecology and Conservation* 43, e02421. doi: 10.1016/j.gecco.2023.e02421

Nikolic, N., Thompson, P., de Bruyn, M., Macé, M., and Chevalet, C. (2020). Evolutionary history of a Scottish harbour seal population. *PeerJ* 8, e9167. doi: 10.7717/peerj.9167

Nilssen, K. T., Bjørge, A., and Biuw, M. (2021). Status for kystsel - anbefaling av jaktkvoter 2022. Møte i Sjøpattedyrutvalget, Tromsø, 24–25 October 2021.

NOAA (2022). Looking Back at The Blob - Chapter 2: Marine Heat Wave Intensifies, "Completely Off the Chart" | NOAA Fisheries. Available at: https://www.fisheries.noaa.gov/feature-story/looking-back-blob-chapter-2-marine-heat-wave-intensifies-completely-chart (Accessed May 23, 2025).

NOAA (2024). 2013-2016 California Sea Lion Unusual Mortality Event in California (CLOSED) | NOAA Fisheries. Available at: https://www.fisheries.noaa.gov/national/marine-life-distress/2013-2016-california-sea-lion-unusual-mortality-event-california (Accessed May 23, 2025).

NOAA Eliminates Restrictive Operating Conditions From Commercial Remote Sensing Satellite Licenses – Office of Space Commerce (2023). Available at: https://www.space.commerce.gov/noaa-eliminates-restrictive-operating-conditions-from-commercial-remote-sensing-satellite-licenses/ (Accessed April 29, 2025).

Oh, J.-W., Pushparaj, S. S., Muthu, M., and Gopal, J. (2023). Review of Harmful Algal Blooms (HABs) Causing Marine Fish Kills: Toxicity and Mitigation. *Plants* 12. doi: 10.3390/plants12233936

Olsen, M. T., Islas, V., Graves, J. A., Onoufriou, A., Vincent, C., Brasseur, S., et al. (2017). Genetic population structure of harbour seals in the United Kingdom and neighbouring waters. *Aquatic Conservation: Marine and Freshwater Ecosystems* 27, 839–845. doi: 10.1002/aqc.2760

Onoufriou, J., Russell, D. J. F., Thompson, D., Moss, S. E., and 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. doi: 10.1016/j.renene.2021.08.052

Orr, A., Banks, A., Mellman, S., Huber, H., DeLong, R., and Brown, R. (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.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., et al. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437, 681–686. doi: 10.1038/nature04095

Peperzak, L. (2003). Climate change and harmful algal blooms in the North Sea. *Acta Oecologica* 24, S139–S144. doi: 10.1016/S1146-609X(03)00009-2

Pinnegar, J. K., Garrett, A., Simpson, S. D., Engelhard, G. H., and van der Kooij, J. (2017). Fisheries. *MCCIP Science Review 2017*, 73–99. doi: https://doi.org/10.14465/2017.arc10.007-fis

Pinnegar, J. K., and Rowland, C. (2024). Turning up the heat: Advancing UK science to better predict and respond to marine heatwaves – Marine Science. Available at: https://marinescience.blog.gov.uk/2024/09/26/turning-up-the-heat-advancing-uk-science-to-better-predict-and-respond-to-marine-heatwaves/ (Accessed May 23, 2025).

Plymouth Marine Laboratory (2022). Harmful Algal Bloom Monitoring - PML Applications. Available at: https://pml-applications.co.uk/services/harmful-algal-bloom-monitoring/ (Accessed May 23, 2025).

Poncet, S., Parent, S., Sicard, M., Le Baron, M., Gaultier, M., Hemon, A., et al. (2024). Monitoring seals in France–2022-2023 Extended summary of the collective report of the National Seal Network.

Postel, A., King ,Jacqueline, Kaiser ,Franziska K., Kennedy ,Johanna, Lombardo ,Mara Sophie, Reineking ,Wencke, et al. (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, 725–729. doi: 10.1080/22221751.2022.2043726

Puryear, W., Sawatzki, K., Hill, N., Foss, A., Stone, J. J., Doughty, L., et al. (2023). Highly Pathogenic Avian Influenza A(H5N1) Virus Outbreak in New England Seals, United States. *Emerg Infect Dis* 29, 786–791. doi: 10.3201/eid2904.221538

Queste, B. Y., Fernand, L., Jickells, T. D., and Heywood, K. J. (2013). Spatial extent and historical context of North Sea oxygen depletion in August 2010. *Biogeochemistry* 113, 53–68. doi: 10.1007/s10533-012-9729-9

Ramis, A. J., van Riel, D., van de Bildt, M. W. G., Osterhaus, A., and Kuiken, T. (2012). Influenza A and B virus attachment to respiratory tract in marine mammals. *Emerg Infect Dis* 18, 817–820. doi: 10.3201/eid1805.111828

Ransijn, J. M., Hammond, P. S., Leopold, M. F., Sveegaard, S., and Smout, S. C. (2021). Integrating disparate datasets to model the functional response of a marine predator: A case study of harbour porpoises in the southern North Sea. *Ecology and Evolution* 11, 17458–17470. doi: 10.1002/ece3.8380

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

Robertson, F., Wood, J., Joslin, J., Joy, R., and Polagye, B. (2018). Marine Mammal Behavioral Response to Tidal Turbine Sound. Univ. of Washington, Seattle, WA (United States). doi: 10.2172/1458457

Robinson, C. L. K., Yakimishyn, J., and Evans, R. (2022). Minimal effects of the 2014-16 marine heatwave on fish assemblages found in eelgrass meadows on the southwestern coast of Vancouver Island, British Columbia, Canada. *Frontiers in Marine Science* Volume 9-2022. Available at: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.980703

Robinson, G., Clarke, L., Banga, R., Lindenbaum, C., Stringell, T., Griffin, R. A., et al. (2020). Grey Seal (Halichoerus grypus) Pup Production and Distribution in North Wales during 2017. Bangor: National Resources Wales.

Roffe, T. J., and Mate, B. R. (1984). Abundances and Feeding Habits of Pinnipeds in the Rogue River, Oregon. *The Journal of Wildlife Management* 48, 1262–1274. doi: 10.2307/3801787

Rogers-Bennett, L., and Catton, C. A. (2019). Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. *Scientific Reports* 9, 15050. doi: 10.1038/s41598-019-51114-y

Rossi, S. P., Cox, S. P., Hammill, M. O., den Heyer, C. E., Swain, D. P., Mosnier, A., et al. (2021). Forecasting the response of a recovered pinniped population to sustainable harvest strategies that reduce their impact as predators. *ICES Journal of Marine Science* 78, 1804–1814. doi: 10.1093/icesjms/fsab088

Roth, S. J., Tischer, B. K., Kovacs, K. M., Lydersen, C., Osterrieder, N., and Tryland, M. (2013). Phocine herpesvirus 1 (PhHV-1) in harbor seals from Svalbard, Norway. *Veterinary Microbiology* 164, 286–292. doi: 10.1016/j.vetmic.2013.03.008

Russell, D. J. F., and Carter, M. I. D. (2021). Estimating the proportion of grey seals hauled out during August surveys. Sea Mammal Research Unit, University of St Andrews.

Russell, D. J. F., Hastie, G. D., Thompson, D., Janik, V. M., Hammond, P. S., Scott-Hayward, L. A. S., et al. (2016). Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology* 53, 1642–1652. doi: 10.1111/1365-2664.12678

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

Russell, D. J. F., Morris, C. D., Duck, C. D., and Riddoch, N. G. (2022). Grey seal pup counts and estimates: east England. Sea Mammal Research Unit, University of St Andrews.

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

Sailley, S. F., Catalan, I. A., Batsleer, J., Bossier, S., Damalas, D., Hansen, C., et al. (2025). Multiple Models of European Marine Fish Stocks: Regional Winners and Losers in a Future Climate. *Global Change Biology* 31, e70149. doi: 10.1111/gcb.70149

Salinger, M. J., Renwick, J., Behrens, E., Mullan, A. B., Diamond, H. J., Sirguey, P., et al. (2019). The unprecedented coupled ocean-atmosphere summer heatwave in the New Zealand region 2017/18: drivers, mechanisms and impacts. *Environmental Research Letters* 14, 044023. doi: 10.1088/1748-9326/ab012a

Sanderson, C. E., and Alexander, K. A. (2020). Unchartered waters: Climate change likely to intensify infectious disease outbreaks causing mass mortality events in marine mammals. *Global Change Biology* 26, 4284–4301. doi: 10.1111/gcb.15163

Sanikommu, V., Bandaru, P. N., and Sigreddy, B. (2025). Spectral Reflectance of Indian Ocean Surface to Detect Blue Whales Using VHRS Images., in *2025 International Conference on Computational, Communication and Information Technology (ICCCIT)*, 715–720. doi: 10.1109/ICCCIT62592.2025.10927940

Santini, S., Codde, S., Jaime, E. M., Jian, A., Valenzuela, E., and Becker, B. H. (2025). On-Land Pinniped Classification of Multiple Species and Demographic Classes on Multiple Substrates Using Deep Learning and Aerial Imagery. *Aquatic Conservation: Marine and Freshwater Ecosystems* 35, e70111. doi: 10.1002/aqc.70111

Santora, J. A., Mantua, N. J., Schroeder, I. D., Field, J. C., Hazen, E. L., Bograd, S. J., et al. (2020). Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. *Nature Communications* 11, 536. doi: 10.1038/s41467-019-14215-w

Savage, K. (2017). Alaska and British Columbia large whale unusual mortality event summary report. Available at: https://repository.library.noaa.gov/view/noaa/17715

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., Hockley, C., and Witt, M. (2012). Monitoring grey seals (Halichoerus grypus) in the Isles of Scilly during the 2010 pupping season.

Sayer, S., Millward, S., and Witt, MJ (2020). Monitoring grey seal (Halichoerus grypus) pupping sites in Cornwall 2019/2020.

Sayer, S., and Witt, M. J. (2017a). Grey seals in the Isles of Scilly during the 2016 pupping season.

Sayer, S., and Witt, M. J. (2017b). Monitoring grey seal (Halichoerus grypus) pupping sites in Cornwall 2016.

Sayer, S., and Witt, M. J. (2018). Special Area of Conservation Condition Monitoring: Grey seals (Halichoerus grypus) in the Isles of Scilly during the 2016 pupping season. *NECR261*.

Schile, L. M., Callaway, J. C., Morris, J. T., Stralberg, D., Parker, V. T., and Kelly, M. (2014). Modeling Tidal Marsh Distribution with Sea-Level Rise: Evaluating the Role of Vegetation, Sediment, and Upland Habitat in Marsh Resiliency. *PLOS ONE* 9, e88760. doi: 10.1371/journal.pone.0088760

Scholin, C. A., Gulland, F., Doucette, G. J., Benson, S., Busman, M., Chavez, F. P., et al. (2000). Mortality of sea lions along the central California coast linked to a toxic diatom bloom. *Nature* 403, 80–84. doi: 10.1038/47481

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

Schop, J., Brasseur, S. M., Galatius, A., Hamm, T., Jeß, A., Meise, K., et al. (2023b). Grey seal numbers in the Wadden Sea and on Helgoland in 2022-2023. Wilhelmshaven, Germany: Common Wadden Sea Secretariat.

Scottish Natural Heritage (2016). Assessing collision risk between underwater turbines and marine wildlife. Available at: https://www.nature.scot/doc/assessing-collision-risk-between-underwater-turbines-and-marine-wildlife.

Seymour, A. C., Dale, J., Hammill, M., Halpin, P. N., and Johnston, D. W. (2017). Automated detection and enumeration of marine wildlife using unmanned aircraft systems (UAS) and thermal imagery. *Sci Rep* 7, 45127. doi: 10.1038/srep45127

Sguotti, C., Blöcker, A. M., Färber, L., Blanz, B., Cormier, R., Diekmann, R., et al. (2022). Irreversibility of regime shifts in the North Sea. *Frontiers in Marine Science* Volume 9-2022. Available at: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.945204

Shah, K., Ballard, G., Schmidt, A., and Schwager, M. (2020). Multidrone aerial surveys of penguin colonies in Antarctica. *Science Robotics* 5, eabc3000. doi: 10.1126/scirobotics.abc3000

Sherbo, B. A. H., Iacozza, J., O'Hara, A., Zhao, S.-T., Ghazal, M., and Matthews, C. J. D. (2023). Validation of satellite imagery for quantitative population assessment and monitoring of Atlantic walrus. *Remote Sensing Applications: Society and Environment* 32, 101065. doi: 10.1016/j.rsase.2023.101065

Shin, D.-L., Siebert, U., Lakemeyer, J., Grilo, M., Pawliczka, I., Wu, N.-H., et al. (2019). Highly Pathogenic Avian Influenza A(H5N8) Virus in Gray Seals, Baltic Sea. *Emerg Infect Dis* 25, 2295–2298. doi: 10.3201/eid2512.181472

Shuert, C. R., Halsey, L. G., Pomeroy, P. P., and Twiss, S. D. (2020). Energetic limits: Defining the bounds and trade-offs of successful energy management in a capital breeder. *Journal of Animal Ecology* 89, 2461–2472. doi: 10.1111/1365-2656.13312

Siebert, U., Lakemeyer, J., Runge, M., Lienau, P., Braune, S., Bartelt, E., et al. (2024). Investigations on the Health Status and Infection Risk of Harbour Seals (Phoca vitulina) from Waters of the Lower Saxon Wadden Sea, Germany. *Animals* 14. doi: 10.3390/ani14202920

SimActive Inc. (2025). Correlator3D. Available at: https://www.simactive.com/correlator3d-mapping-software-features (Accessed May 14, 2025).

Simpkins, M. A., Withrow, D. E., Cesarone, J. C., and Boveng, P. L. (2003). STABILITY IN THE PROPORTION OF HARBOR SEALS HAULED OUT UNDER LOCALLY IDEAL CONDITIONS. *Marine Mammal Science* 19, 791–805. doi: 10.1111/j.1748-7692.2003.tb01130.x

Skinner, J. (2009). The changing distribution of haddock Melanogrammus aeglefinus in the North Sea: effects of fishing effort and environmental variation over the last century. Univ. of East Anglia.

Smout, S., King, R., and Pomeroy, P. (2020). 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

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

SMRU Press Release (2025). St Andrews researchers appeal for the public to help them understand why UK Harbour seals are in steep decline | University of St Andrews news. Available at: https://news.st-andrews.ac.uk/archive/st-andrews-researchers-appeal-for-the-public-to-help-them-understand-why-uk-harbour-seals-are-in-steep-decline/ (Accessed May 23, 2025).

Sobolev, I., Alekseev, A., Sharshov, K., Chistyaeva, M., Ivanov, A., Kurskaya, O., et al. (2024). Highly Pathogenic Avian Influenza A(H5N1) Virus Clade 2.3.4.4b Infections in Seals, Russia, 2023. *Emerg Infect Dis* 30, 2160–2164. doi: 10.3201/eid3010.231728

Stanley, W. T., and Shaffer, K. E. (1995). HARBOR SEAL (PHOCA VITULINA) PREDATION ON SEINED SALMONIDS IN THE LOWER KLAMATH RIVER, CALIFORNIA. *Marine Mammal Science* 11, 376–385. doi: 10.1111/j.1748-7692.1995.tb00292.x

Statens Serum Institut (2022). Fugleinfluenza i dansk sæl. Available at: https://www.ssi.dk/aktuelt/nyheder/2022/fugleinfluenza-i-dansk-sael (Accessed May 23, 2025).

Steinmetz, K., Murphy, S., Cadhla, O. Ó., Carroll, E. L., Onoufriou, A. B., Russell, D. J. F., et al. (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, 160–178. doi: 10.1002/aqc.3909

Steinmetz, K., Murphy, S., Cadhla, O. Ó., Hoffman, J. I., Jung, J.-L., Barnett, J., et al. (2024). Genetic analysis in aid of delineation of Management Units for a wide-ranging marine mammal, the grey seal (Halichoerus grypus), in European waters. doi: 10.21203/rs.3.rs-4243253/v1

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

Stiasny, M. H., Mittermayer, F. H., Sswat, M., Voss, R., Jutfelt, F., Chierici, M., et al. (2016). Ocean Acidification Effects on Atlantic Cod Larval Survival and Recruitment to the Fished Population. *PLOS ONE* 11, e0155448. doi: 10.1371/journal.pone.0155448

Stokholm, I., Baechlein, C., Persson, S., Roos, A., Galatius, A., Kyhn, L. A., et al. (2023). Screening for Influenza and Morbillivirus in Seals and Porpoises in the Baltic and North Sea. *Pathogens* 12. doi: 10.3390/pathogens12030357

Stone, T. C., and Davis, K. J. (2025). Using unmanned aerial vehicles to estimate body volume at scale for ecological monitoring. *Methods in Ecology and Evolution* 16, 317–331. doi: 10.1111/2041-210X.14457

Sweeney, K., Birkemeier, B., Luxa, K., and Gelatt, T. (2025). Results of the Steller sea lion (Eumetopias jubatus) surveys in Alaska, June-July 2024. doi: 10.25923/wh71-zr38

Thomas, L., Russell, D. J. F., Duck, C. D., Morris, C. D., Lonergan, M., Empacher, F., et al. (2019). Modelling the population size and dynamics of the British grey seal. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29, 6–23. doi: 10.1002/aqc.3134

Thompson, D., Coram, A. J., Harris, R., and Sparling, C. E. (2020). *Review of non-lethal seal control options to limit seal predation on salmonids in rivers and fish farms*. Marine Scotland Science. doi: 10.7489/12369-1

Thompson, D., Duck, C. D., Morris, C. D., and Russell, D. J. F. (2019). The status of harbour seals (Phoca vitulina) in the UK. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29, 40–60. doi: 10.1002/aqc.3110

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

Thomsen, M. S., Mondardini, L., Alestra, T., Gerrity, S., Tait, L., South, P. M., et al. (2019). Local Extinction of Bull Kelp (Durvillaea spp.) Due to a Marine Heatwave. *Frontiers in Marine Science* Volume 6-2019. Available at: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2019.00084

Thorsson, E., Zohari, S., Roos, A., Banihashem, F., Bröjer, C., and Neimanis, A. (2023). Highly Pathogenic Avian Influenza A(H5N1) Virus in a Harbor Porpoise, Sweden. *Emerg Infect Dis* 29, 852–855. doi: 10.3201/eid2904.221426

Tilzey, R., Goldsworthy, S., Cawthorn, M., Calvert, N., Hamer, D., Russell, S., et al. (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.

Townhill, B. L., Tinker, J., Jones, M., Pitois, S., Creach, V., Simpson, S. D., et al. (2018). Harmful algal blooms and climate change: exploring future distribution changes. *ICES Journal of Marine Science* 75, 1882–1893. doi: 10.1093/icesjms/fsy113

Trainer, V. L., Moore, S. K., Hallegraeff, G., Kudela, R. M., Clement, A., Mardones, J. I., et al. (2020). Pelagic harmful algal blooms and climate change: Lessons from nature's experiments with extremes. *Harmful Algae* 91, 101591. doi: 10.1016/j.hal.2019.03.009

Twiss, S. D., Wright, N. C., Dunstone, N., Redman, P., Moss, S., and Pomeroy, P. P. (2002). BEHAVIORAL EVIDENCE OF THERMAL STRESS FROM OVERHEATING IN UK BREEDING GRAY SEALS. *Marine Mammal Science* 18, 455–468. doi: 10.1111/j.1748-7692.2002.tb01048.x

Udevitz, M. S., Jay, C. V., and Cody, M. B. (2005). Observer Variability in Pinniped Counts: Ground-Based Enumeration of Walruses at Haul-Out Sites. *Marine Mammal Science* 21, 108–120. doi: 10.1111/j.1748-7692.2005.tb01211.x

Uhart, M. M., Vanstreels, R. E. T., Nelson, M. I., Olivera, V., Campagna, J., Zavattieri, V., et al. (2024). Epidemiological data of an influenza A/H5N1 outbreak in elephant seals in Argentina indicates mammal-to-mammal transmission. *Nature Communications* 15, 9516. doi: 10.1038/s41467-024-53766-5

Umbra Space (2023). Umbra Space releases highest resolution commercial satellite image. Available at: https://umbra.space/blog/umbra-generates-the-highest-resolution-commercial-satellite-image-ever-released/ (Accessed May 19, 2025).

van Beest, F. M., Dietz, R., Galatius, A., Kyhn, L. A., Sveegaard, S., and Teilmann, J. (2022). Forecasting shifts in habitat suitability of three marine predators suggests a rapid decline in inter-specific overlap under future climate change. *Ecology and Evolution* 12, e9083. doi: 10.1002/ece3.9083

VanWormer, E., Mazet, J. A. K., Hall, A., Gill, V. A., Boveng, P. L., London, J. M., et al. (2019). Viral emergence in marine mammals in the North Pacific may be linked to Arctic sea ice reduction. *Scientific Reports* 9, 15569. doi: 10.1038/s41598-019-51699-4

Veneranta, L., Lehtonen, T. K., Lehtonen, E., and Suuronen, P. (2024). Acoustic seal deterrents in mitigation of human–wildlife conflicts in the whitefish fishery of the River Iijoki in the northern Baltic Sea area. *Fisheries Management and Ecology* 31, e12680. doi: 10.1111/fme.12680

Venkatesh, D., Bianco, C., Núñez, A., Collins, R., Thorpe, D., Reid, S. M., et al. (2020). Detection of H3N8 influenza A virus with multiple mammalian-adaptive mutations in a rescued Grey seal (Halichoerus grypus) pup. *Virus Evolution* 6, veaa016. doi: 10.1093/ve/veaa016

Wakelin, S., Townhill, B., Engelhard, G., Holt, J., and Renshaw, R. (2021). Marine heatwaves and cold-spells, and their impact on fisheries in the southern North Sea., EGU21-7329. doi: 10.5194/egusphere-egu21-7329

Walmsley, S. F., Oaten, J. F., Götz, T., Rodmell, D., de Rozarieux, N., and Sweeting, C. J. (2025). Effectiveness of Targeted Acoustic Startle Technology on seal depredation in an inshore gillnet fishery. *Fisheries Research* 281, 107208. doi: 10.1016/j.fishres.2024.107208

Walton, M., and Stanley, H. F. (1997). Population structure of some grey seal breeding colonies around the UK and Norway., in *European Research on Cetaceans*, 293–296.

Welch, H., Savoca, M. S., Brodie, S., Jacox, M. G., Muhling, B. A., Clay, T. A., et al. (2023). Impacts of marine heatwaves on top predator distributions are variable but predictable. *Nature Communications* 14, 5188. doi: 10.1038/s41467-023-40849-y

Westcott, S. (2002). The distribution of grey seals (Halichoerus grypus) and census of pup production in North Wales 2001. Countryside Council for Wales.

Westcott, S. (2008). Procedural guidelines for studying grey seals in southwest England, 2006. *NERR017 Natural England*.

Whyte, K. (2021). Behavioural responses by seals to offshore energy activities. PhD thesis. University of St Andrews. https://doi.org/10.17630/sta/222

Williams, R. S., Curnick, D. J., Baillie, A., Barber, J. L., Barnett, J., Brownlow, A., et al. (2025). Sea temperature and pollution are associated with infectious disease mortality in short-beaked common dolphins. *Communications Biology* 8, 557. doi: 10.1038/s42003-025-07858-7

Williams, R., Ashe, E. Janik, V.M., Mendez-Bye, A., Nielsen, K.A, Collins, M.S., Götz, T. (in prep): Testing targeted acoustic startle technology (TAST) to reduce seal predation on salmon at human-built bottlenecks (Journal of Wildlife Biology, intended submission).

Williams et al. (2021 a): Deterring Harbor seal predation on chum salmon with GenusWave Targeted Acoustic Startle Technology (TAST) at Whatcom Creek, Bellingham, WA. Final Report from Ocean Initiative. WDFW Number: 20-15475.

Williams, R., Ashe, E., Bogaard, L., Bergman, A., Goetz, T., Janik, V. (2021 b). Employing Targeted Acoustic Startle Technology (TAST) to deter harbor seal predation on endangered salmonids at the Ballard Locks, Seattle, WA. Report prepared for Puget Sound Partnership. Seattle, WA.

Williamson, G. R. (1988). Seals in Loch Ness. *Scientific Report of the Whales Research Institute*.

Williamson, M. J., ten Doeschate, M. T. I., Deaville, R., Brownlow, A. C., and Taylor, N. L. (2021). Cetaceans as sentinels for informing climate change policy in UK waters. *Marine Policy* 131, 104634. doi: 10.1016/j.marpol.2021.104634

Williamson, P., Turley, C., and Ostle, C. (2017). Ocean acidifcation. *MCCIP Science Review*, 1–14. doi: 10.14465/2017.arc10.001-oac

Wiltshire, K. H., and Manly, B. F. J. (2004). The warming trend at Helgoland Roads, North Sea: phytoplankton response. *Helgoland Marine Research* 58, 269–273. doi: 10.1007/s10152-004-0196-0

Wood, S. A., Frasier, T. R., McLeod, B. A., Gilbert, J. R., White, B. N., Bowen, W. D., et al. (2011). The genetics of recolonization: an analysis of the stock structure of grey seals (Halichoerus grypus) in the northwest Atlantic. *Can. J. Zool.* 89, 490–497. doi: 10.1139/z11-012

Wood, S. A., Josephson, E., Precoda, K., and Murray, K. T. (2022). Gray seal (Halichoerus grypus) pupping trends and 2021 population estimates in US waters.

Wood, S. A., Murray, K. T., Josephson, E., and Gilbert, J. (2020). Rates of increase in gray seal (Halichoerus grypus atlantica) pupping at recolonized sites in the United States, 1988–2019. *Journal of Mammalogy* 101, 121–128. doi: 10.1093/jmammal/gyz184

Wood, S. A., Robinson, P. W., Costa, D. P., and Beltran, R. S. (2021). Accuracy and precision of citizen scientist animal counts from drone imagery. *PLOS ONE* 16, e0244040. doi: 10.1371/journal.pone.0244040

Wyles, H. M. E. (2024). Predicting the impacts of climate change on grey seals (Halichoerus grypus) : implications for UK marine management. University of St Andrews. Available at: https://research-repository.st-andrews.ac.uk/handle/10023/30725 (Accessed May 23, 2025).

Yurk, H., and Trites, A. W. (2000). Experimental Attempts to Reduce Predation by Harbor Seals on Out-Migrating Juvenile Salmonids. *Transactions of the American Fisheries Society* 129, 1360–1366. doi: 10.1577/1548-8659(2000)129<1360:EATRPB>2.0.CO;2

Zarnke, R. L., Saliki, J. T., Macmillan, A. P., Brew, S. D., Dawson, C. E., Ver Hoef, J. M., et al. (2006). SEROLOGIC SURVEY FOR BRUCELLA SPP., PHOCID HERPESVIRUS-1, PHOCID HERPESVIRUS-2, AND PHOCINE DISTEMPER VIRUS IN HARBOR SEALS FROM ALASKA, 1976–1999. *Journal of Wildlife Diseases* 42, 290–300. doi: 10.7589/0090-3558-42.2.290

Ziryanov, S. V., and Mishin, V. L. (2007). Grey seals on the Murman coast, Russia: status and present knowledge. *NAMMCOSP* 6, 13–21. doi: 10.7557/3.2718

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

Chris D Morris, Nick G Riddoch, Callan D Duck, Dave Thompson, Simon A Waitland, Debbie JF Russell

Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, East Sands, St Andrews, Fife, KY16 8LB

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 2023, the Sea Mammal Research Unit (SMRU) carried out helicopter surveys using a thermal imager of a large proportion of the Scottish west coast of Scotland from Loch Hourn to the border representing a section of the West Scotland Seal Monitoring Unit (SMU) and the entire Southwest Scotland SMU. The results from this survey are reported here for the first time.

In August 2024, the entire coast of Northern Ireland was surveyed by helicopter. 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 England, the annual SMRU fixed-wing surveys cover the Lincolnshire and Norfolk coasts (Southeast England SMU). Various organisations around England and Wales continue to monitor seals at additional sites that can generally be covered by ground or boat-based methods.

Results from August 2024 surveys will be reported in SCOS 2025. All the data presented in this briefing paper are from the latest surveys carried out until August 2023.

Based on the most recent available August count data to 2023, the number of harbour seals counted in Scotland was **22,241**, and in England it was **3,548**. Including **818** harbour seals counted in Northern Ireland in 2021, the most recent UK harbour seal total count is **26,608**. The number of grey seals counted in Scotland was **21,306**, in England it was **17,075**, 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 **40,243**.

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 haulout 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). 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 was relatively low power (sample size of 60 individuals) to detect such effects. 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 25/02)

For the purposes of population monitoring and reporting, the UK is split into 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) used primarily for the seal licencing system which was introduced with the Marine (Scotland) Act 2010.

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

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 were 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 haulout 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 (by Seal Research Trust) 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, 2024 a,b).

To maximise the counts of seals on shore and 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 haulout sites and return into the water, and because the thermal imager cannot 'see' through rain.

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 $10km^2$.

The most recent minimum harbour seal August haulout count for UK Seal Monitoring Units (SMUs) in 2016-2023 are provided in Table 1 and are compared with four (UK) or five (Britain) 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 surveys carried out mainly between 2019 and 2023, is **22,241** (Table 1). The most recent count of harbour seals in England, obtained from surveys carried out mainly in 2022 and 2023, is **3,548** (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 2021 was **818** (Table 1). The sum of all the most recent counts carried out between 2016 and 2023 gives a UK total of **26,608** 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. See SCOS BP 25/03 for trend analyses of the August counts for Seal Monitoring Units 1 to 9.

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 $10km^2$.

The most recent total haulout count of grey seals in Scotland, obtained from August surveys carried out mainly between 2019 and 2023 is **21,306** (Table 2).

There were **17,075** 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 **40,243** (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.

See SCOS BP 25/03 for trend analyses of the August counts for Seal Monitoring Units 1 to 9.

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.

Bond, I. (2024). Tees Seals Research Programme, Monitoring Report No. 33. (1989–2024). 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. 2024. Census of grey seals (Halichoerus grypus) around the Southwest England Seal Monitoring Unit by aerial survey during August 2023. JNCC Report 778 (Survey Report). JNCC, Aberdeen, ISSN 0963-8091.

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, up to 2023, of harbour seals at haulout 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. The latest population estimates use scalars derived from Lonergan *et al*. (2013).

			Harbour seal counts							Latest population estimate		
Seal Monitoring Unit / Country			**1996-1997**	**2000-2006**	**2007-2009**	**2011-2015**	**2016-2019**	**Most recent count data to 2023**		**mean**	**95% CIs**	**% of UK total**
1	Southwest Scotland		929	623	923	1,200	1,709	1,563	(2023)	2,171	(1,776; 2,894)	5.9%
2	West Scotland	a	8,811	11,666	10,626	15,184	15,600	11,754	(2022; 2023)	16,325	(13,357; 21,767)	44.2%
3	Western Isles		2,820	1,920	1,804	2,739	3,532	3,080	(2022)	4,278	(3,500; 5,704)	11.6%
4	North Coast & Orkney		8,787	4,388	2,979	1,938	1,405	*1,405*	*(2016; 2019)*	1,951	(1,597; 2,602)	5.3%
5	Shetland		5,994	3,038	3,039	3,369	3,180	*3,180*	*(2019)*	4,417	(3,614; 5,889)	12.0%
6	Moray Firth		1,409	1,028	776	745	1,077	983	(2019; 2021; 2023)	1,365	(1,117; 1,820)	3.7%
7	East Scotland		764	667	283	224	343	276	(2021; 2023)	383	(314; 511)	1.0%
SCOTLAND total			29,514	23,330	20,430	25,399	26,846	22,241	(2016; 2018: 2019; 2021-2023)	30,890	(25,274; 41,187)	83.6%
8	Northeast England	b	54	62	58	91	79	106	(2020; 2022; 2023)	147	(120; 196)	0.4%
9	Southeast England	c	3,222	2,964	3,952	4,740	3,752	3,372	(2022; 2023)	4,683	(3,832; 6,244)	12.7%
10	South England	d	10	15	15	25	40	65	(estimate)	90	(74; 120)	0.2%
11	Southwest England	d	0	0	0	0	0	0	(2023)	0	(0; 0)	0.0%
13	Northwest England	d	2	5	5	5	5	5	(estimate)	7	(6; 9)	0.0%
ENGLAND total			3,288	3,046	4,030	4,861	3,876	3,548	(2020; 2022; 2023)	4,928	(4,032; 6,570)	13.3%
WALES		e	2	5	5	10	10	1	(2023)	1	(1; 2)	0.0%
BRITAIN total			32,804	26,381	24,465	30,270	30,732	25,790	(2016; 2018-2023)	35,819	(29,307; 47,759)	96.9%
NORTHERN IRELAND		f		1,176	1,101	948	1,062	818	(2021)	1,136	(930; 1,515)	3.1%
UK total				27,557	25,566	31,218	31,794	26,608	(2016; 2018-2023)	36,956	(30,236; 49,274)	

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, 2024). 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, up to 2023, of grey seals at haulout 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. The latest population estimates use scalars derived from Russell & Carter (2021).

			Grey seal counts							Latest population estimate			
	Seal Monitoring Unit / Country		**1996-1997**	**2000-2006**	**2007-2009**	**2011-2015**	**2016-2019**	**Most recent count data to 2023**		**mean**	**95% CIs**		**% of UK total**
1	Southwest Scotland		75	206	233	374	517	760	(2023)	3,022	(2,614;	3,543)	1.9%
2	West Scotland	a	3,435	2,383	2,524	5,064	4,174	4,508	(2022; 2023)	17,924	(15,507;	21,016)	11.2%
3	Western Isles		4,062	3,674	3,808	4,085	5,773	3,473	(2022)	13,809	(11,947;	16,191)	8.6%
4	North Coast & Orkney		9,427	10,315	8,525	8,106	8,599	*8,618*	*(2016; 2019; 2023)*	34,266	(29,646;	40,177)	21.4%
5	Shetland		1,724	1,371	1,536	1,558	1,009	*1,009*	*(2019)*	4,012	(3,471;	4,704)	2.5%
6	Moray Firth		551	1,272	1,113	1,917	1,657	1,354	(2019; 2021; 2023)	5,384	(4,658;	6,312)	3.4%
7	East Scotland		2,328	1,898	1,238	2,296	3,683	1,584	(2021; 2023)	6,298	(5,449;	7,385)	3.9%
	SCOTLAND total		21,602	21,119	18,977	23,400	25,412	21,306	(2016; 2018: 2019; 2021-2023)	84,716	(73,292;	99,329)	52.9%
8	Northeast England	b	613	1,100	2,350	6,942	6,501	5,381	(2020; 2022; 2023)	21,396	(18,510;	25,086)	13.4%
9	Southeast England	c	417	2,266	1,786	5,637	8,667	10,735	(2022; 2023)	42,684	(36,928;	50,047)	26.7%
10	South England	d		2	2	5	30	50	(estimate)	199	(172;	233)	0.1%
11	Southwest England	d		425	425	500	500	729	(2023)	2,899	(2,508;	3,399)	1.8%
13	Northwest England	d		30	30	50	250	180	(estimate)	716	(619;	839)	0.4%
	ENGLAND total			3,823	4,593	13,134	15,948	17,075	(2020; 2022; 2023)	67,893	(58,738;	79,604)	42.4%
	WALES	e		750	750	850	900	1,313	(2023)	5,221	(4,517;	6,121)	3.3%
	BRITAIN total			25,692	24,320	37,384	42,260	39,694	(2016; 2018-2023)	157,829	(136,546;	185,054)	98.6%
	NORTHERN IRELAND	f		272	243	468	505	549	(2021)	2,183	(1,889;	2,559)	1.4%
	UK total			25,964	24,563	37,852	42,765	40,243	(2016; 2018-2023)	160,012	(138,435;	187,613)	

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, 2024). N'umberland coast south of Farnes 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 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, 2024). 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	6,020	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).

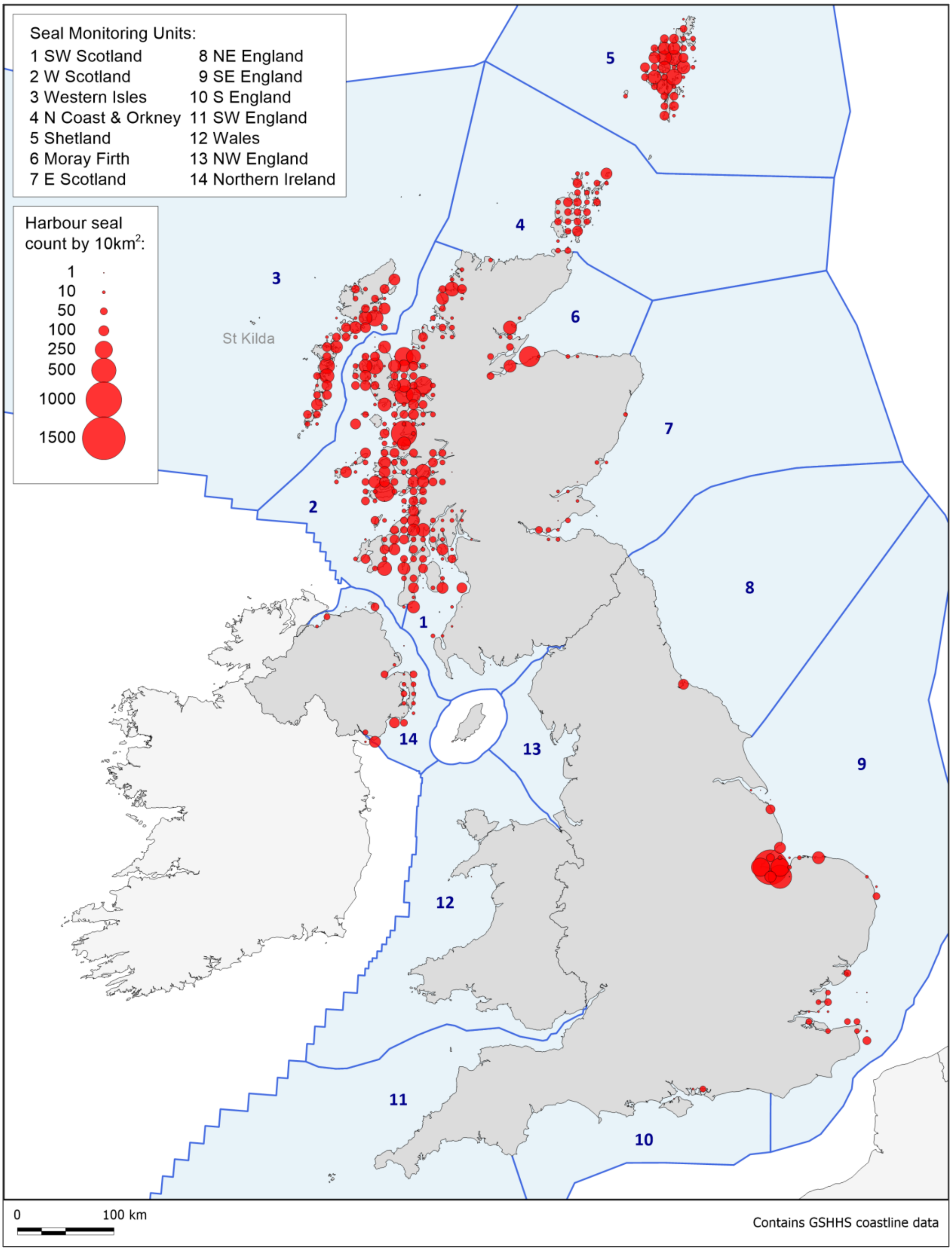

Figure 6. Map of August haulout density of harbour seals around the UK per 10 km^2 based on the most recent available count data collected up until 2023. Less than 100 harbour seals are in SMUs 10-13. Tees data from the INCA Tees Seal Research Programme, The Solent data from

Langstone Harbour Board & Chichester Harbour Conservancy. All other data from SMRU aerial surveys.

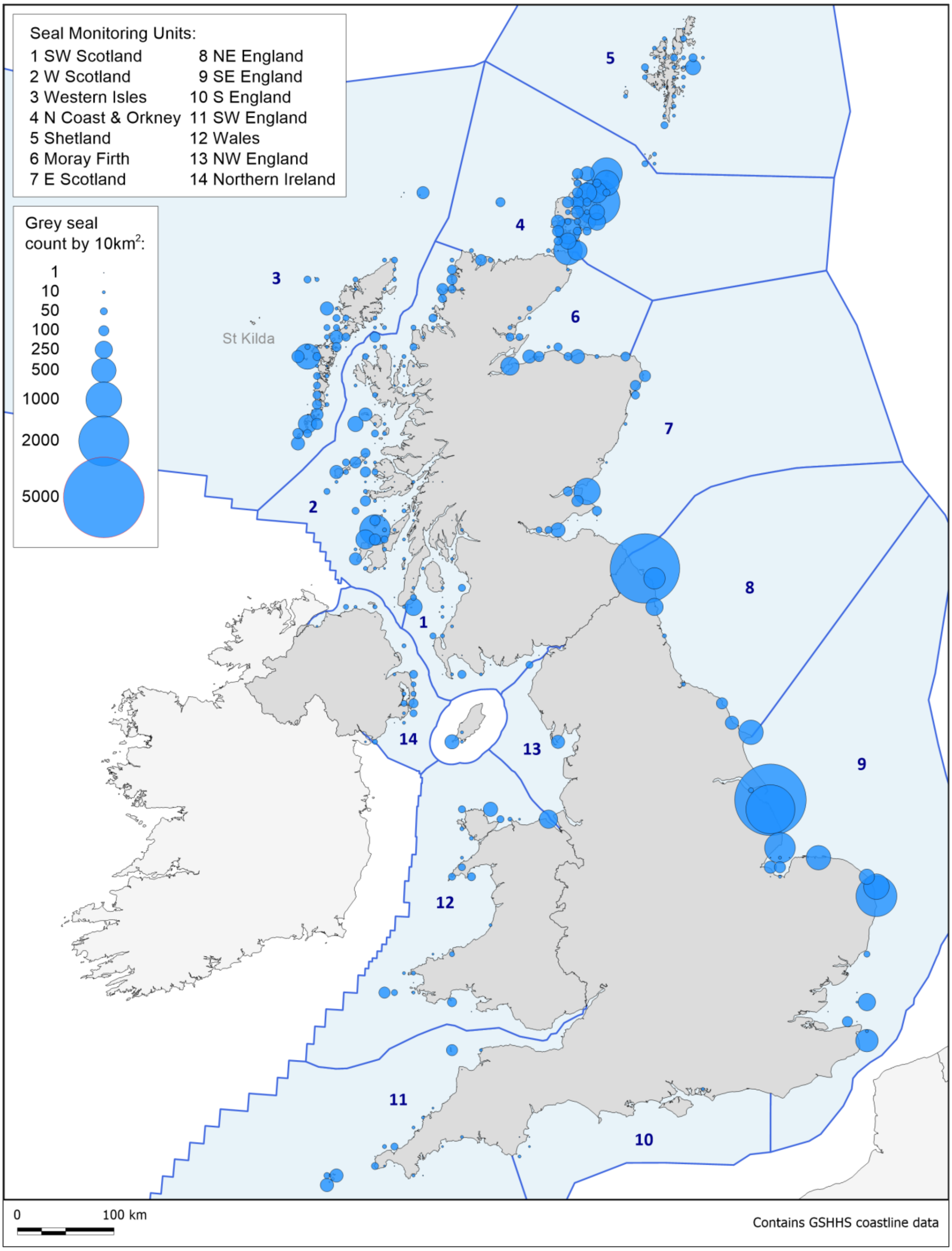

Figure 7. Map of August haulout density of harbour seals around the UK per 10 km^2 based on the most recent available count data collected up until 2023. Tees data from the INCA Tees Seal Research Programme. Some of the counts/estimates for Seal Monitoring Units 10 - 13 are based on counts by: Langstone 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.

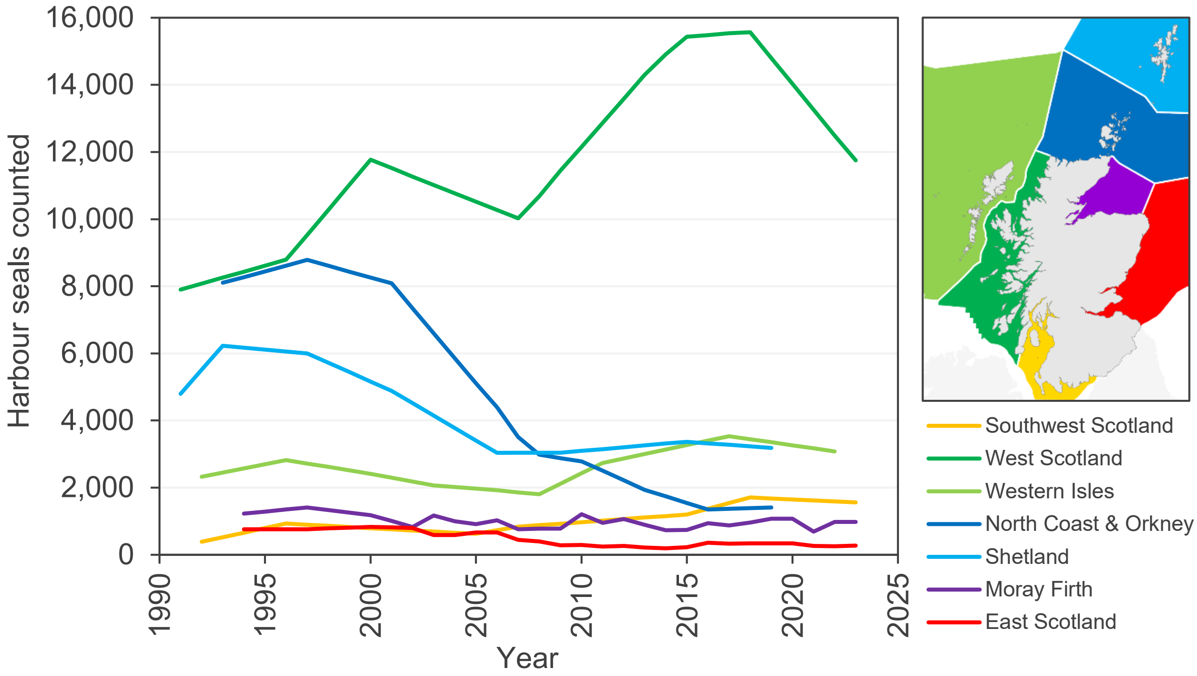

Figure 3. Comparison of August harbour seal counts in Scottish Seal Monitoring Units (SMUs) since 1991. Because SMU totals represent counts of seals distributed over large areas, individual data points may contain counts made in more than one year. For example, the 2023 data point for West Scotland contains a significant amount of data from a survey carried out in 2022 (coast north of Loch Hourn, including Skye). Interpolated values are used for years with incomplete coverage.

Most recent grey seal pup production estimates for UK breeding colonies

Chris D. Morris, Nick G. Riddoch, Callan D. Duck, Simon A. Waitland and Debbie JF. Russell
Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews KY16 8LB

Abstract

In 2023, SMRU surveyed nine grey seal breeding colonies in three Seal Monitoring Units (SMUs) along the east coast of the UK by plane using vertical photography, producing five pup counts for each site. Due to a change of survey camera system, the 2023 pup production estimates presented here should be interpreted with caution. Potential differences in estimates due to a change in methods (affecting detection and classification rates) are being investigated based on comparison flights conducted during the 2023 breeding season (SCOS 25/06). However, major differences (as found when switching from film to digital cameras in 2012; SCOS 24/03) are not expected.

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 Firth of Forth colonies (East Scotland SMU) was estimated to be approx. **7,500** in 2023, a total similar to the three previous estimates calculated since 2018. Pup production at the Farne Islands (Northeast England SMU) increased significantly compared to 2021, reaching approx. **4,000**. Total pup production in Southeast England SMU also continued to increase to around **16,500**, although numbers at one of the three big colonies (Donna Nook) have been declining since 2018.

In 2022, SMRU surveyed most of the key colonies in all other Scottish SMUs. The pup production for 2022 at the Inner Hebrides colonies surveyed (West Scotland SMU) increased to approx. **4,900**. Pup production at colonies surveyed in the Outer Hebrides (Western Isles SMU) reached a high of approx. **18,250**. The two main colonies on the north coast could only be photographed once in 2022, so the latest estimate for this North Coast & Orkney SMU subdivision is around **650** pups from surveys in 2019. In contrast to the main breeding regions in western Scotland and in eastern England, the total production estimate for Orkney in 2022 dropped to **20,500**, the lowest estimate in over 10 years. The production estimate at colonies in the Moray Firth SMU also declined to around 1,700 in 2022.

The latest pup production estimate for all colonies regularly surveyed by SMRU in SMUs 1-9 totals around **74,000**. Adding **5,100** pups estimated to be born at other sites (ground counted or less frequently monitored) gives a UK total of around **79,000**. This is the highest total estimate on record and is made up by the national totals of around **55,100** pups born in Scotland, around **21,000** pups born in England, around **2,500** pups born in Wales, and around **500** pups born in Northern Ireland. Trend analyses for grey seal pup production estimates in SMUs 2-9 are presented in SCOS 25/03.

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 Aero Technika camera 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 new system was used to survey colonies in the North Sea, from the Firth of Forth to Suffolk, 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 older Hasselblad camera system as soon as the first aircraft had completed a site. The pup production estimates from the 2023 surveys using the PAS150 system are presented in this briefing paper. An initial analysis of the comparison flights is presented and discussed in SCOS 25/06.

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 three to six 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 from counts for colonies surveyed in 2023 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 2023, SMRU successfully surveyed the main Scottish and English grey seal breeding colonies in the central and southern North Sea (from the Firth of Forth to Suffolk) 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.

Compared to the Hasselblad system used from 2012-2022, which was made up of two H4D 40MP cameras mounted at opposing angles of 12 degrees from vertical in SMRU's custom-built Image Motion Compensating cradle (Figure 2), the new PAS150 system is based around a single 150MP Phase One iXM-RS camera installed in a gyro-stabilised mount (SOMAG-CSM40) that actively keeps the camera pointing straight down during image collection. At a survey altitude of 1,100 ft (335 m), the 70 mm fixed lens produces a ground sample distance (GSD) of approx. 1.8cm/pixel. As previously, a series of transects were flown over each breeding colony, ensuring that all areas used by pups were photographed with sufficient overlap between frames. Figures 3 shows an example of a survey flown with the dual Hasselblad camera system in 2012. Images were saved directly to a solid-state drive (SSD) as RAW files which were downloaded and backed up onto secondary SSDs as soon as sufficient intervals between/following survey sessions allowed.

When processing the imagery, all RAW image files were first checked and adjusted for brightness and sharpness using the camera manufacturer's proprietary software (Phase One iX-Process). Exported TIFF files are then stitched together into a single orthomosaic using Correlator3D software (SimActive Inc., 2025), an industry-standard photogrammetry solution for generating high quality aerial survey mosaics. The georeferenced images created by this software are then linked as raster layers in QGIS for manual counting and classification of pups (as whitecoats or moulted pups), producing a database containing each counted pup with precise coordinates. Figure 4 shows an example (from a 2012 Hasselblad survey) of counting pups on a stitched image using Manifold GIS. For a complete description of processing methods used for the Hasselblad imagery see previous SCOS reports (e.g. SCOS 24/01).

The pup production model allows different misclassification proportions to be incorporated. Up until 2010 (while still operating a film camera), the pup production model used a fixed value of 50% for the proportion of correctly classified moulted pups, because there was a significant risk of misclassifying moulted pups as whitecoats on the large format film photographs. 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 distribution of the main grey seal breeding colonies in the UK are shown in Figure 1. In 2023, SMRU surveyed the nine main grey seal breeding colonies within the three SMUs covering the central and southern North Sea coast (East Scotland, Northeast England, Southeast England).

Using the standard pup production model run described above, pup production at the Firth of Forth colonies (East Scotland SMU) was estimated to be approx. **7,500**. Within this SMU, production on the Isle of May has continued the decline observed through the 2010s and was estimated to be over 22% lower in 2023 compared to the highest estimates in 2010/2012. At the other two major colonies in the East Scotland SMU (Inchkeith and Fast Castle), which both grew very significantly throughout the 2010s, the latest estimates suggest that growth rates have either slowed or reached zero. The 2022 surveys, covering the rest of Scotland, had indicated that overall pup production in the regions to the north of the East Scotland SMU (in the Moray Firth and in Orkney, within the most productive SMU over the last 30 years) has potentially been declining since the late 2010s.

In contrast to areas in the northern North Sea, overall pup production to the south, in eastern England, has continued to increase rapidly (+56% in five years from 2018 to 2023). Pup production at the Farne Islands (Northeast England SMU) increased significantly compared to 2021, reaching approx. **4,000** in 2023. Total pup production in Southeast England SMU also continued to increase to around **16,500**, with production at Blakeney Point (Norfolk), now the largest breeding colony in the UK, estimated to be just under 9,000 in 2023 (>20% increase since 2021). Further east, at Horsey, pup production grew even more (+23% from 2021-2023). Despite the significant increases observed in the east English SMUs, not all major colonies in this part of the UK have been growing. After reaching a peak of over 2,800 pups in 2018, production at Donna Nook (Lincolnshire) has continued to decline to around 2,300 in 2023.

Together with the highest pup production estimates on record from 2022 aerial surveys for the southern part of West Scotland SMU (~**4,900**) and for the Western Isles SMU (~**18,250**), the relatively low 2022 estimates for Orkney (~**20,500**) and the Moray Firth (~**1,700**), the 2019 estimate for the North Coast (~**650**), and older estimates for less frequently monitored colonies around Scotland (~**1,570** spread across many different sites, mainly in W Scotland, Western Isles, and Shetland), the 2023 estimate for East Scotland (~**7,500**) contributes to the latest total estimate of ~**55,100** pups born in Scotland.

Together with an estimated ~**550** pups born at various sites in England, monitored by various organisations using ground counts (mainly in the Southwest England SMU), the ~**20,500** pups estimated from the 2023 aerial surveys in eastern England contribute to the latest total estimate of ~**21,000** pups born in England.

Around **2,500** pups were estimated to have been born in Wales from various data collected by different organisations up until 2023, and approx. **500** pups are estimated to have been born in Northern Ireland from older DAERA data. Combining these national totals produces a pup production estimate of round **79,100** for the whole of the UK. This is the highest total on record.

Table 1 gives an overview of the latest pup production estimates by SMU and country, Table 2 presents the time series of pup production for colonies regularly monitored by SMRU aerial surveys since 1960, aggregated by SMU (subdivision), and Table 3 shows the most recent estimates used for less frequently monitored or ground counted sites and areas.

As described above for Southeast England, even if 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 10 show pup production estimates in different SMUs either grouped by location (West Scotland - South, Figure 6), grouped based on location and when the colonies were established (Western Isles, Figure 7), grouped only by when they were established (Orkney, Figure 8), or by individual colony (Firth of Forth, Figure 9, and eastern England, Figure 10). 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 aerial survey methods between 2010 and 2012 (switch from film to digital camera). The average increase associated with this change has been estimated to be 22.5 % (95% CI: 14.3, 30.7; SCOS BP 24/03).

See SCOS BP 25/03 for trend analyses by SMU as well as for grey seal SACs.

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. Latest grey seal pup production estimates to 2023 by UK Seal Monitoring Units. Note that the values for non-aerially surveyed colonies ('other') are approximate (and rounded). The survey years are given in parentheses.

Seal Monitoring Unit (subdivision)		Latest grey seal pup production estimates: Colonies regularly surveyed by plane		Other colonies		Total	% of UK total
1 SW Scotland		0		5	(2020)	5	0.0%
2 W Scotland - North		4,893	(2022)	450	(2005-2019)	5,343	6.8%
3 Western Isles		18,272	(2022)	300	(2008)	18,572	23.5%
4 N Coast & Orkney		21,143	(2019-2022)	20	(2010-2019)	21,163	26.7%
5 Shetland		0		760	(2012)	760	1.0%
6 Moray Firth		1,715	(2022)	0		1,715	2.2%
7 E Scotland		7,502	(2023)	35	(2023)	7,537	9.5%
SCOTLAND TOTAL		53,525		1,570		55,095	69.6%
8 NE England		3,997	(2023)	35	(2016-2018)	4,032	5.1%
9 SE England		16,485	(2023)	5	(2023)	16,490	20.8%
10 S England	a	0		5	(2023)	5	0.0%
11 SW England	b	0		490	(2016-2023)	490	0.6%
13 NW England	c	0		10	(2023)	10	0.0%
ENGLAND TOTAL		20,482	(2023)	545		21,027	26.6%
12 WALES	d	0		2,500	(to 2023)	2,500	3.2%
14 NORTHERN IRELAND	e	0		500	(to 2020)	500	0.6%
UK TOTAL		74,007		5,115		79,122	

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 breeding colonies regularly monitored by SMRU aerial surveys aggregated by Seal Monitoring Unit (subdivision), from 1960 to 2023.

The totals in the last column combine the most recent estimates available for each SMU (subdivision). The dotted lines in this column indicate an SMU (sundivision) being added for the first time. 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 (indicated by the dashed line), 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 (highlighted by the dashed lines) 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. A recent change of survey camera system from Hasselblad cameras to a Phase One PAS150 in 2023 could produce slightly different estimates. Comparison surveys between these two systems were conducted in East Scotland and England in 2023 and initial results are presented in SCOS BP 25/06.

	Seal Monitoring Unit (subdivision)								***Total***
Year	**W Sco - South**	**Western Isles**	**North Coast**	**Orkney**	**Moray Firth**	**E Scotland**	**NE England**	**SE England**	***(most recent)***
1960				2,048			1,020		*3,068*
1961		3,142		1,846			1,141		*6,129*
1962							1,118		*6,106*
1963							1,259		*6,247*
1964				2,048			1,439		*6,629*
1965				2,191			1,404		*6,737*
1966		3,311		2,287			1,728		*7,326*
1967		3,265		2,390			1,779		*7,434*
1968		3,421		2,570			1,800		*7,791*
1969				2,316			1,919		*7,656*
1970		5,070		2,535			1,987	19	*9,611*
1971				2,766			2,041		*9,896*
1972		4,933					1,617		*9,335*
1973				2,581			1,678		*9,211*
1974		6,173		2,700			1,668		*10,560*
1975		6,946		2,679			1,617		*11,261*
1976		7,147		3,247			1,426		*11,839*
1977				3,364			1,243		*11,773*
1978		6,243		3,778			1,162		*11,202*
1979		6,670		3,971			1,320		*11,980*
1980		8,026		4,476			1,118		*13,639*
1981		8,086		5,064			992	43	*14,185*
1982		7,763		5,241			991	54	*14,049*
1983							902		*13,960*
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)*

	Seal Monitoring Unit (subdivision)								***Total***
Year	**W Sco - South**	**Western Isles**	**North Coast**	**Orkney**	**Moray Firth**	**E Scotland**	**NE England**	**SE England**	***(most recent)***
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	911	16,625		2,241	1,309	549	*37,156*
1999	2,787	11,759		15,720		2,034	843	629	*34,683*
2000	3,223	13,472	905	16,546		2,514	1,171	773	*38,604*
2001	3,032	12,427		18,196		2,253	1,247	818	*38,878*
2002	3,096	11,248	950	17,952		2,509	1,200	988	*37,943*
2003	3,386	12,741	966	18,652		2,664	1,266	1,138	*40,813*
2004	3,385	12,319	817	19,123		2,706	1,133	1,426	*40,909*
2005	3,427	12,397	877	18,126		2,818	1,138	1,525	*40,308*
2006	3,501	11,719	701	19,335	1,284	2,793	1,254	1,684	*42,271*
2007	3,118	11,342	630	19,184	1,201	2,957	1,164	1,958	*41,554*
2008	3,317	12,279	557	17,813	1,098	3,230	1,318	2,283	*41,895*
2009		11,887		18,548	1,043	3,770	1,346	2,611	*43,079*
2010	3,108	11,831		18,562		4,054	1,498	2,962	*43,615*
2011							1,555	3,271	*43,981*
2012	4,088	14,134		22,920	1,602	5,217	1,603	3,766	*53,887*
2013							1,575	4,437	*54,530*
2014	4,054	14,331	683	23,777	1,653	5,860	1,740	5,505	*57,603*
2015							1,876	6,420	*58,654*
2016	4,541	15,732	706	23,849	1,959	6,426	2,295	7,500	*63,008*
2017							2,131	8,590	*63,934*
2018						7,325	3,011	10,105	*67,228*
2019	4,694	16,931	637	23,321	1,955	7,641			*68,295*
2020									*68,295*
2021						7,378	3,198	14,125	*72,239*
2022	4,893	18,272		20,506	1,715				*70,724*
2023						7,502	3,997	16,485	*74,007*

[1] 2008 production estimates were used as a proxy for seven colonies in the Western Isles 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 or monitored infrequently.

Abbreviations: 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; SRT - Seal Research Trust; 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
Orkney	Fers Ness, Eday	SMRU; aerial photo	2019	21
Shetland	Various sites	NatureScot; GC	2012	761
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**	**~1,570**
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
South England	Isle of Wight	RSPB	2023	2
Southwest England	Lundy	Landmark Trust; GC	2023	66
	Isles of Scilly	SRT; boat & GC	2016	228
	Cornwall mainland	SRT; GC	2023	191
	Devon mainland	SRT; GC	2016	~ 5
Northwest England	South Walney	Cumbria W.T.; GC	2023	10
ENGLAND	**Total**		**to 2023**	**~ 550**
WALES[1]	**Total**	NRW & RSPB; GC	**to 2023**	**~2,500**
NORTHERN IRELAND	**Total**	DAERA; boat	**to 2020**	**~ 500**

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

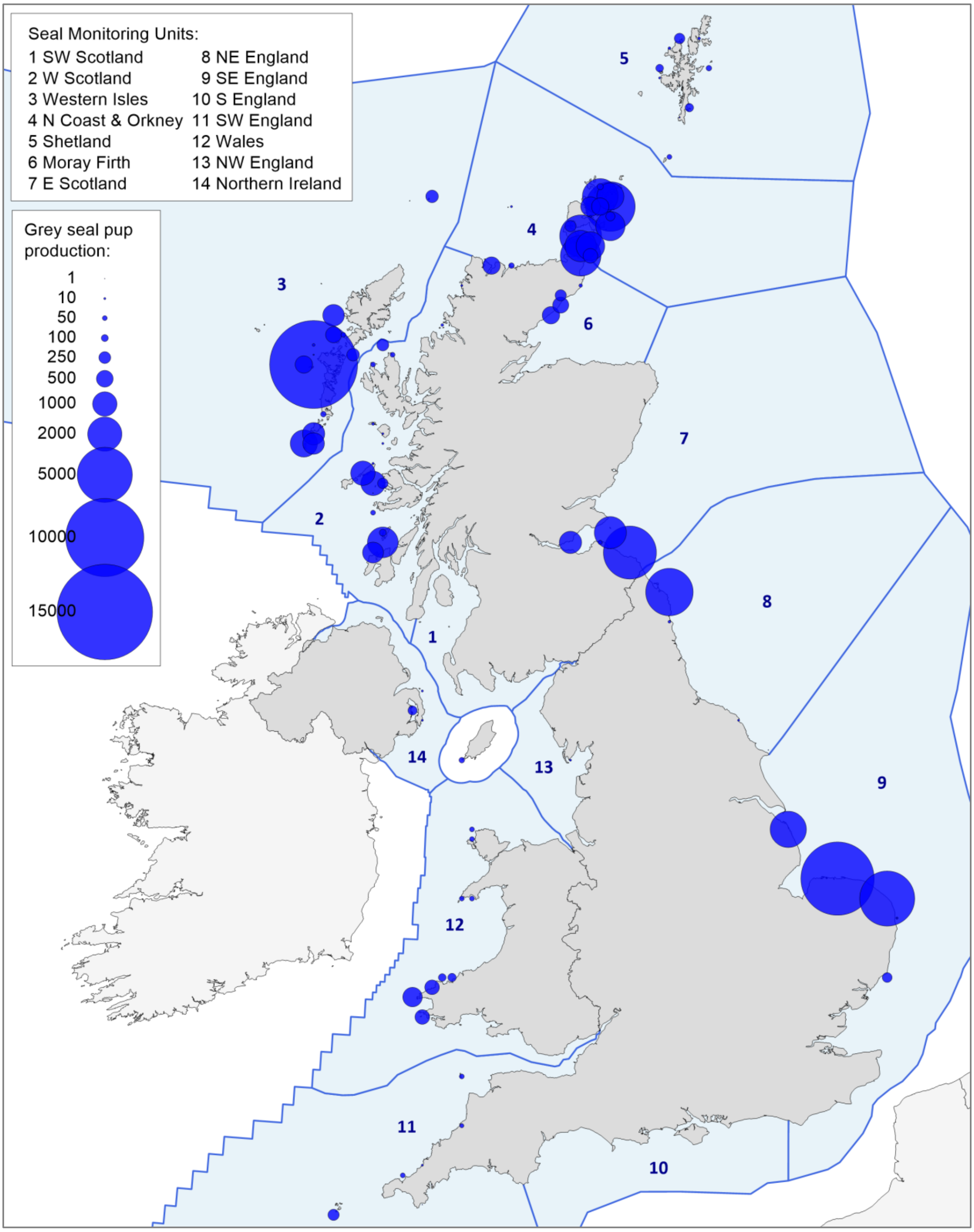

Figure 1. The most recent pup production estimates available (up to 2023) for grey seal breeding colonies in the UK aggregated by 10 km^2. Smaller numbers of grey seals will breed at locations other than those indicated here, including in caves.

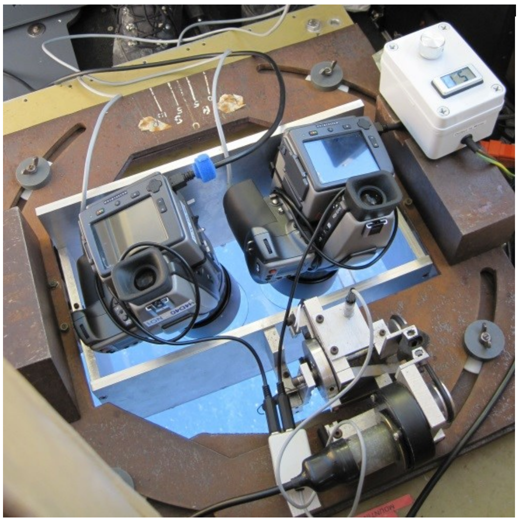

Figure 2. Two Hasselblad H4D-40 medium format cameras fitted in SMRU's Image Motion Compensation (IMC) mount. Each camera is set at an angle of 12 degrees to increase strip width. The cradle holding the cameras rocks backwards and forwards during photo runs. Rocking speed is set depending on the altitude and the ground speed of the aircraft. The camera shutters are automatically triggered and an image captured every time the cameras pass through the vertical position on each front-to-back pass. Images are saved directly to a computer as 60MB Hasselblad raw files and can be instantly viewed and checked using a small LED screen. The H4D-40 can take up to 40 frames per minute allowing for ground speeds of up to 130 kts at 1100 ft (providing 20% overlap between consecutive frames). The resulting ground sampling distance is approximately 2.5 cm/pixel.

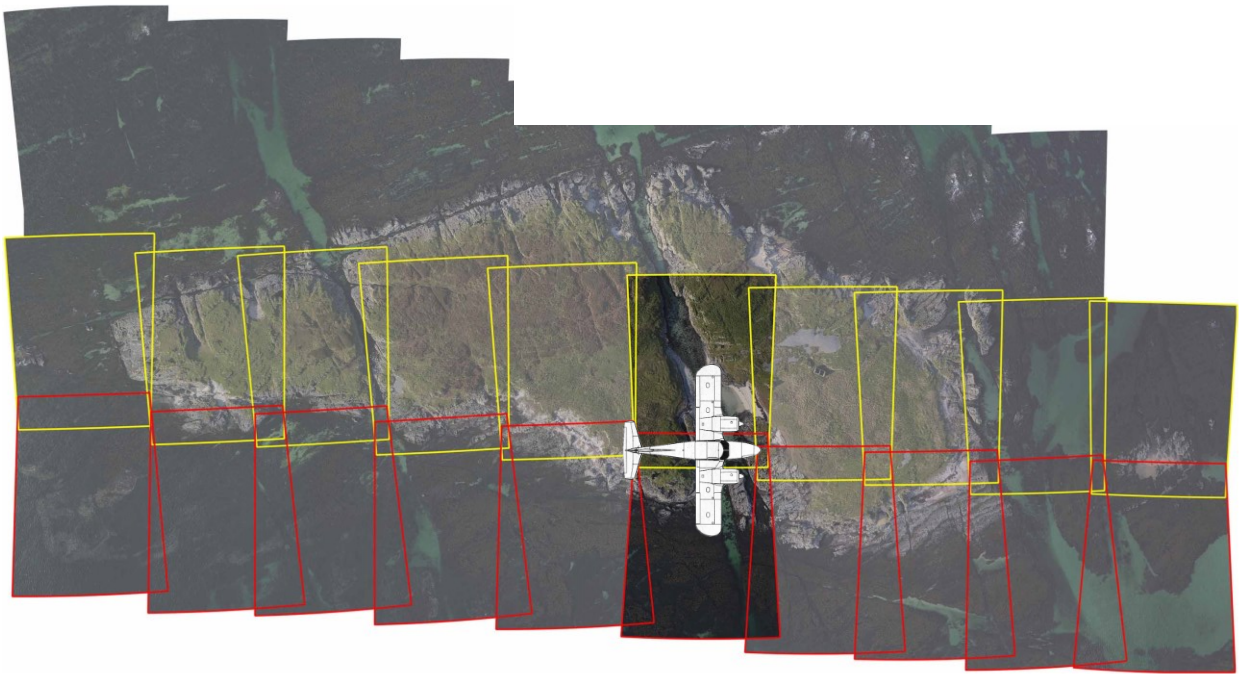

Figure 3. The individual footprints of each pair of photographs taken on a run over Eilean nan Ron, off Oronsay in the Inner Hebrides, flying at 1,100 ft (red: left-hand camera; yellow: right-hand camera).

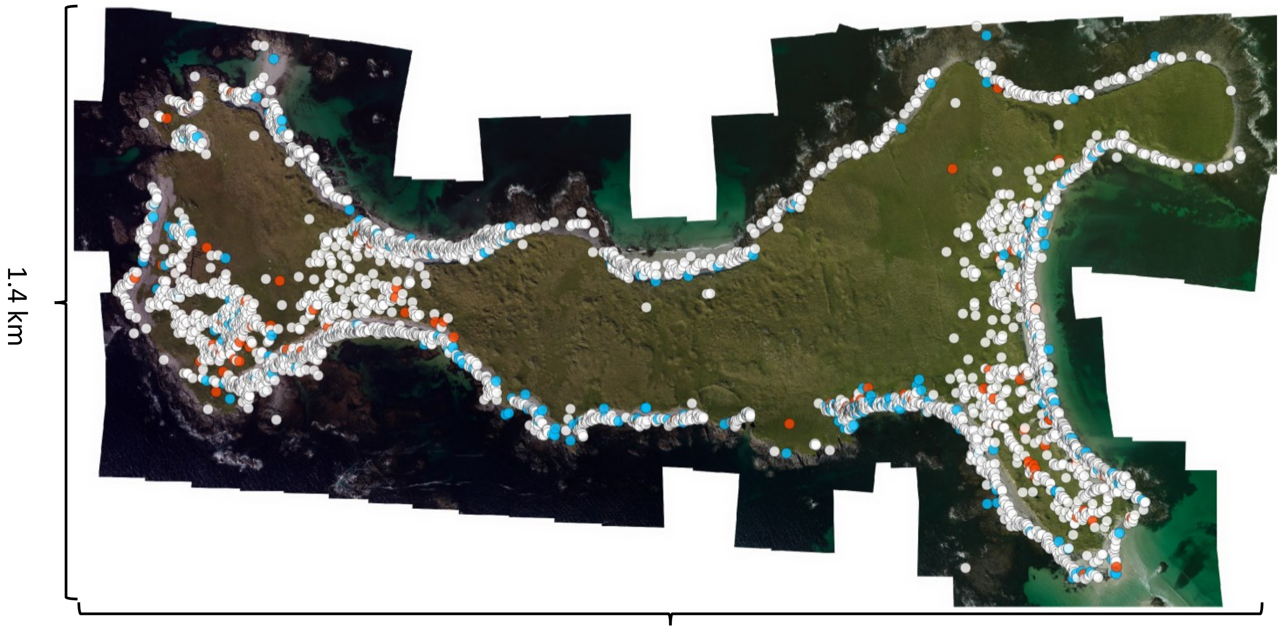

Figure 4. Ceann Iar, the second biggest of the Monach Isles in the Outer Hebrides, is one of the largest grey seal breeding colonies in Europe (approx. 7,000 pups were born here in 2022). This screenshot shows white-coated (white), moulted (blue) and dead pups (red) counted from approximately 200 stitched 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.

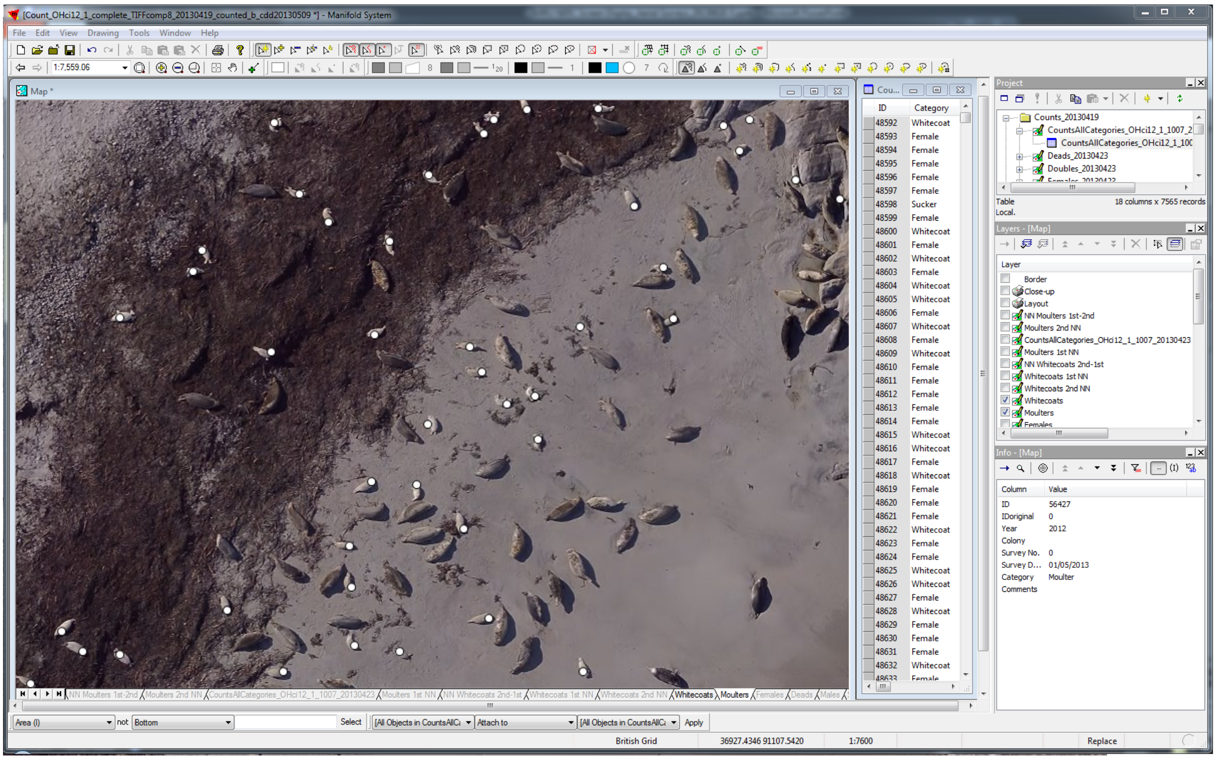

Figure 5. Manifold GIS 8.0® screenshot showing grey seal pups counted on Ceann Iar. Pups are marked and classified as whitecoats, moulted pups, or dead pups.

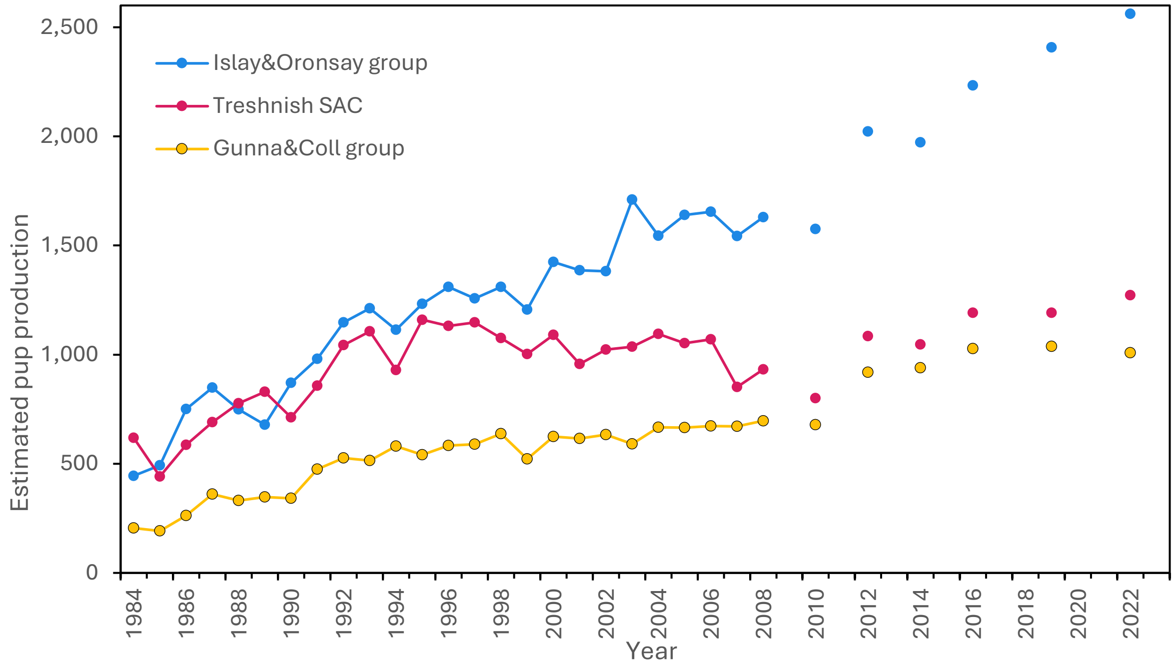

Figure 6. Grey seal pup production at aerially surveyed colonies in West Scotland – South (SMU 2a), grouped by location. The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 25/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

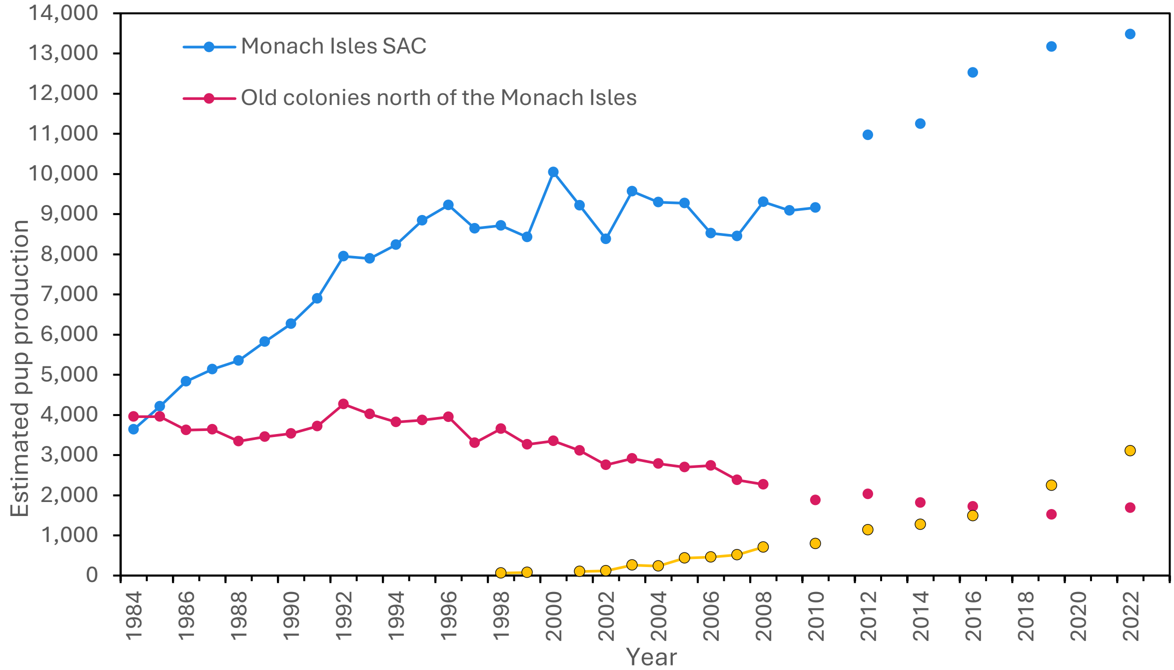

Figure 7. Grey seal pup production at aerially surveyed colonies in the Western Isles (SMU 3), comparing breeding colonies on the Monach Isles, long established (old) colonies to the north, and newly established colonies to the south of the Monachs. The change in methodology from film to digital is likely 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 25/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

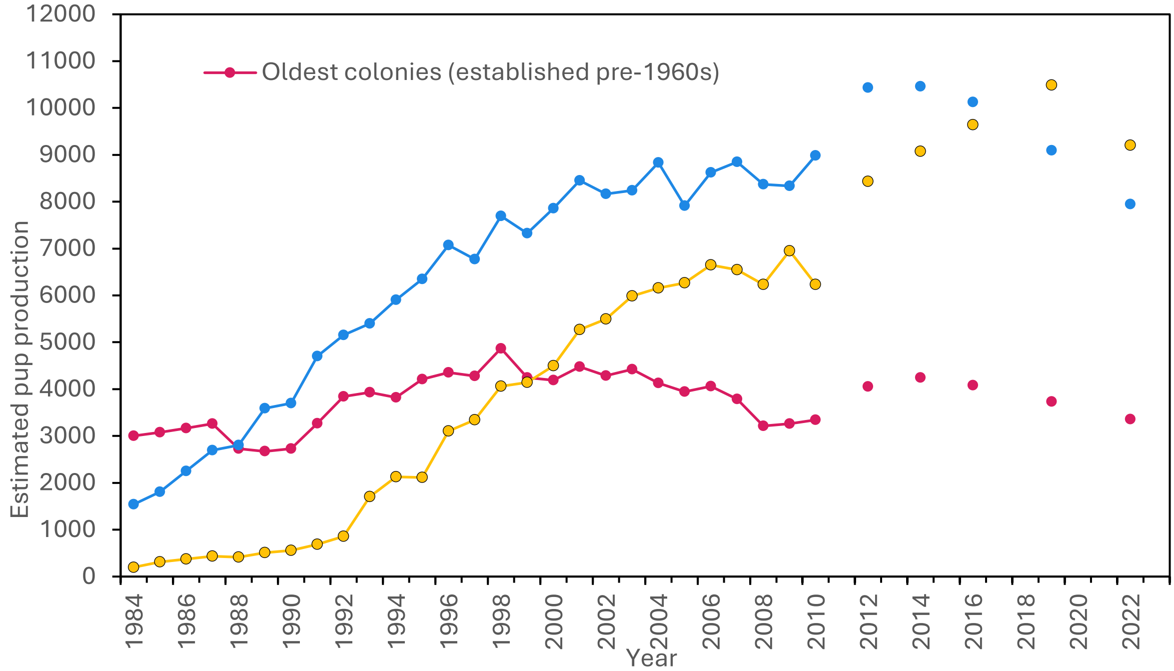

Figure 8. Grey seal pup production at colonies in Orkney (SMU 4b), comparing colonies well established before the 1960s, colonies established during the 1960s and colonies established more recently. The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 25/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

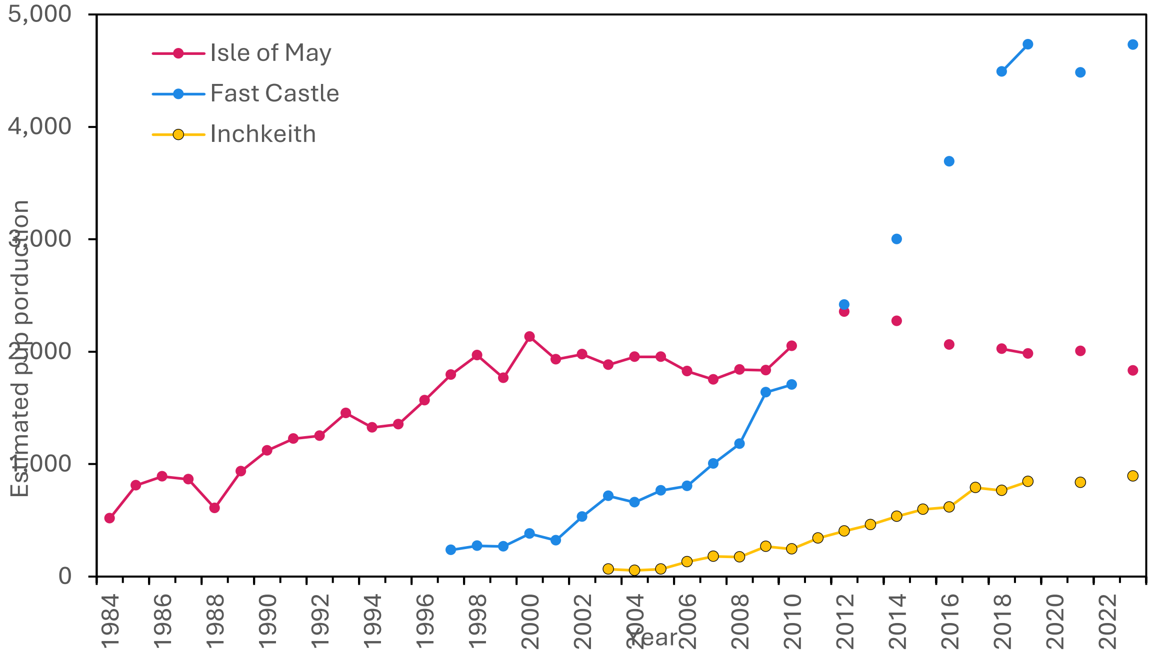

Figure 9. Grey seal pup production at the main colonies in the Firth of Forth (SMU 7, East Scotland). The change in methodology from film to digital is likely to be responsible for a step increase of around 22.5 % (95% CI: 14.3, 30.7) between 2010 and 2012 (SCOS BP 24/03). See SCOS BP 25/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

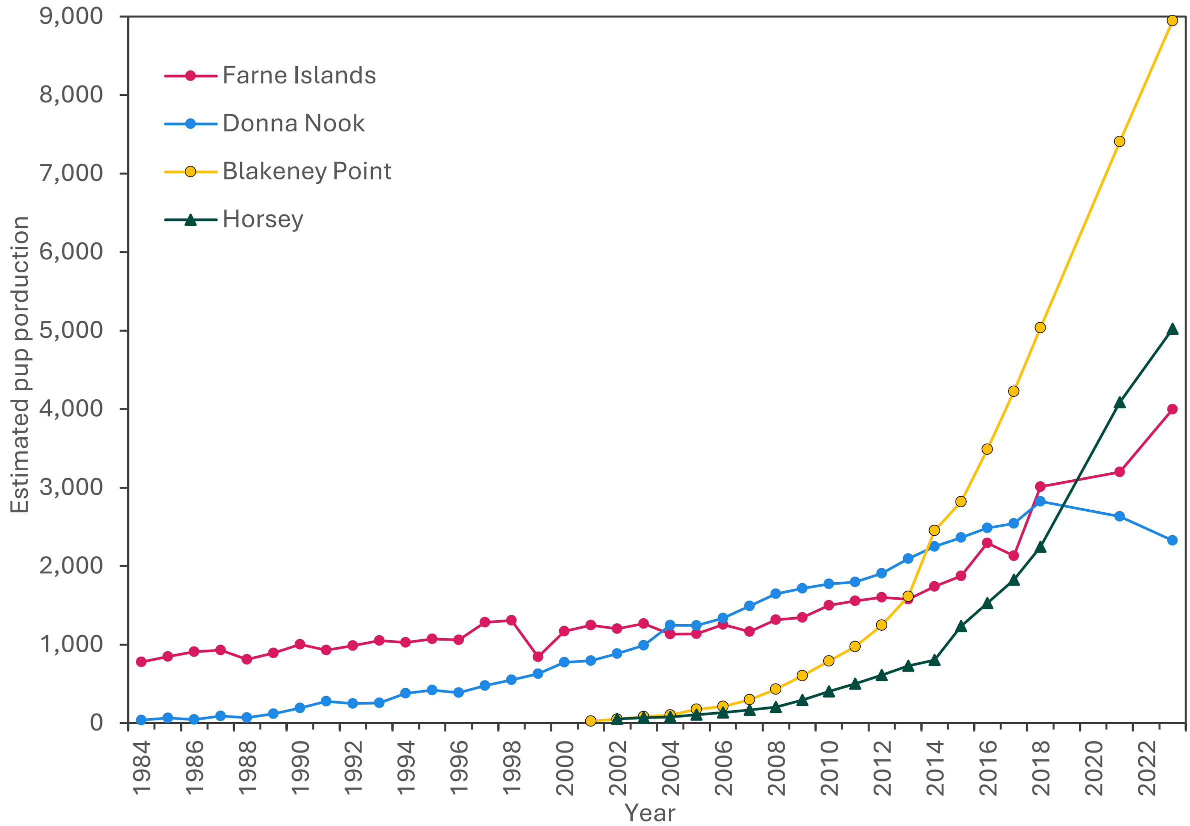

Figure 10. Grey seal pup production at the main colonies in eastern England (SMUs 8 and 9). See SCOS BP 25/03 for more information on pup production trends for SMUs 1-9 as well as for SACs.

Trends in seal abundance and grey seal pup production

Debbie JF Russell, Callan D Duck, Chris D Morris, Dave Thompson and Simon A Waitland

Sea Mammal Research Unit, The University of St Andrews, St Andrews, Fife, KY16 8LB

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 (August in the UK). 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 25/01), and for grey seals, pup production estimates (SCOS 25/02). 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 as much as possible, maximising the data available; these counts are input into statistical models to generate trends. For grey seals, pup production and August counts should be considered in combination, as the former represents a powerful and consistent way to evaluate trends, and the latter represents where seal acquire their resources. The trends have been updated (compared to SCOS 2024) for August counts in SMUs 1-3 (western Scotland) and for grey seal pups in SMUs 7-9; East Scotland SMU and eastern England SMUs).

For August count data, at least three models were considered with regard to year; no trend, an exponential trend, and a nonlinear (smooth) trend. In addition, for harbour seals in SMUs 4-9, step changes in abundance and trends around 2002 were offered. For harbour seals, an additional model was fit for western Scotland SMUs (not fit in SCOS BP 24/03). For grey seal pup production, the previously quantified impact of the change in method (film to digital aerial surveys in Scottish SMUs, and ground to digital aerial surveys for Eastern English SMUs) was accounted for. The new estimates for 2023 (eastern England) were based on a new camera system (Phase One).

For both species SAC trends were generally less favourable than for the SMU that encompassed them. For harbour seals, with the exception of Southwest Scotland (predicted to be stable), all SMUs for which there are notable numbers (SMUs 1-7, and 9) abundance was predicted to be declining and/or depleted. It should be noted that the most recent survey data for SMUs 5 & 6 are now over 5 years old (2019).

Grey seal abundance (August counts and pup production) either showed no trend or was increasing in all SMUs (with the potential exception of Shetland). Pup production in West Scotland and Western Isles was 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 SMUs, summer abundance was also predicted to be increasing. In contrast, August counts in the Western Isles are variable but showed no apparent trend. Pup production and August counts (latest data 2019) in North Coast and Orkney were stable. For Shetland, there was an indication of a decline in pup production but August counts showed no trend. In all east coast SMUs (SMUs 6-9) pup production was predicted to be increasing. The August counts were 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 holdings 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 25/01), and for grey seals pup production estimates (SCOS 25/02). 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 as much as possible, maximising the data available. For West Scotland, recognising the geographic extent of the SMU, and that coverage is often over multiple years, three subdivisions (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 24/03; 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 (majority of 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 resources for pup production were acquired. It should be noted that the proportion of grey seals hauled out in August is relatively low (compared to harbour seals that are moulting). 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 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) and reduced funding, major grey seal colonies in Scotland and on the east coast of England are now currently surveyed every two or three years.

Fitting trends in pup production over the entire time series is complicated by a change in survey methodology from (see below) from film (up to 2010) to digital (aerial; 2012 onwards) surveys for most Scottish SMUs, and from ground to aerial (digital) surveys for eastern England (2018 onwards). For logistical and technical reasons, it was not possible to directly cross-calibrate the film and digital aerial surveys. In Scottish SMUs for which 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 (over and above any underlying trends). The changes in pup production associated with the two changes in methods introduced above, were estimated previously (SCOS BPs 24/03 and 24/08) and used in this BP.

Assessment Metrics

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 the 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- (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 (UK SMUs), 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 used 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 was 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 was 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 was 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, as in SCOS 2024, 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 differed from 80% confidence intervals considered in OSPAR QSR 2023.

Changes compared to SCOS 2024

August counts

The new August count data available for this BP are from helicopter surveys conducted in Southwest Scotland SMU (1) West Scotland SMU (2; mainly central and southern subdivisions) in 2023 (SCOS BP 25/01). Additional analyses were conducted for SMUs 1-3 (not conducted for SCOS BP 24/03; see Methods for details).

Grey Seal Pup Production

The new estimates for this BP were for SMUs 7 – 9 (East Scotland, Northeast England and Southeast England; SCOS BP 25/02). The surveys from which these estimates were derived used a new Phase One (hereafter PAS) digital camera system. It is not expected that this change in methods resulted in markedly different estimates than would have been generated using images from the previous system (Hasselblad; see SCOS 25/06). Nevertheless, to avoid the current PAS-derived estimates impacting the estimation of changes in pup production associated with historic changes in method (film to digital and ground to digital aerial surveys), the previous estimated changes (SCOS 24/03 and 24/08) were applied to this time-series.

Methods

All analyses were conducted in R (R Core Team 2023). Model selection was conducted using AIC.

August surveys

For the most part, the counts represent a single year. However, in some cases surveys were conducted over multiple years; the resulting count was assigned to the year that encompassed the majority of the total (focal year). Indeed, West Scotland SMU was surveyed over August 2022 (northern subdivision and part of central) and 2023 (southern subdivision and rest of central). For both species, at the SMU level, the majority of seals were counted in 2023 (56% for harbour seals, and 74% for grey seals). However, due to their differing distributions within the SMU, for the central subdivision the focal year differed between the species (2022 for harbour seals and 2023 for grey seals).

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 proxy counts in years when the whole area was surveyed can be used to assess how representative the proxy trends are of the SMU trends. Indeed, the latest August counts, and for proxies 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. For all datasets, at least three models were fitted: an intercept-only GLM (null model; i.e. no 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 declines in North Coast & Orkney, Shetland, and Moray Firth SMUs during multi-year gaps in surveys that spanned 2002, and indications of changes in trend around 2002 in 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 an intercept 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.

For SMUs 1-3, additional analyses were conducted. West Scotland is the largest SMU both in terms of geography (coastline) and proportion of the UK total for harbour seals, and is thus split into three subdivisions (2a-2c: South, Central, and North). For all 3 western Scotland SMUs, and the constituent subdivisions of West Scotland, the latest count was lower than the count from the previous survey. The trend analyses described above was conducted separately on each SMU, subdivision and SAC; the restricted frequency of surveys (every 4-6 years) meant the power to detect initial declines was very limited. Visual inspection of the data for the SMUs and subdivisions indicated similar patterns across western Scotland. As such two additional GAMs were fit considering SMU 1, the subdivisions of SMU 2 (but not SMU 2 as a whole), and SMU 3 (hereafter regions). In the first GAM, the count was modelled as a function of region and a region-specific smooth of year. In the second GAM, the count was modelled as a function of region, a global smooth of year, and a region-specific smooth of year (model 3 in Pedersen *et al*. 2019). The first GAM was similar to analyses described above, but by fitting the regions in one model, it provided a fit metric (AIC) for comparison with the second GAM. By including a global smooth across regions, there was increased power to detect a trend, with the region-level smoother allowing the region-specific patterns to also be represented. Both these additional models had the advantage of the SMU 2 subdivisions being used to predict the overall SMU trend (rather than fitting the overall SMU trend separately) which minimised the masking of trends (by combining across subdivisions) and the use of data across multiple survey years being assigned to a single year.

Grey seal pup production

Pup production estimates were used for SMUs 2-9, whereas for SMU 5 (Shetland), peak counts from NatureScot ground surveys were used. Note pup production in SMU 1 (Southwest

Scotland) is thought to be < 10, and thus was not considered here. For Scottish SMUs, the estimates were derived from aerial survey counts (SCOS BP 25/02), although historic estimates for some East Scotland colonies 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 (Table 3).

Pup production (peak count for Shetland) was modelled as a function of year assuming negative binomial errors (see Russell *et al.* 2019 for details). The estimated jump (22.5 %; 95% CI: 14.3 - 30.7) in pup production associated with the change in survey methods (film to digital Hasselblad surveys; SCOS BP 24/03) was applied within a GAM framework to all Scottish SMUs (and SACs) which are aerially surveys (i.e. all except Shetland). It should be noted that only the mean estimated jump (i.e. not including the associated uncertainty), was incorporated. Visually, the estimated jump appeared to match the observed data for the SMUs and SACs (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 SMRU aerial-based estimates. The ground- and aerial-based (2018 and 2021) production estimates were integrated into a time-series in a colony-specific way (SCOS BP 24/08). Due to the change in the camera system between 2021 (Hasselblad) and 2023 (PAS) surveys, the generation of the time-series was not updated, but rather the methods in SCOS BP/08 applied to the new time-series. In other words, the same ground-surveyed points were excluded, and an increase of ~25% was applied to the ground-based time-series for Donna Nook (see BP 24/08 for more details)

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 were significant unless otherwise stated. Note the magnitude of change is not discussed; estimates of percentage change (Table 1) should be considered in the context of the abundance in the SMU/SACs. Note that the last count/estimate given in Table 1 may not match the latest composite count in the SCOS BP 25/01. As much as possible the values used in the analyses represent counts attributed to a single year whereas the composite counts represent means across years within the period.

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 were are not reliable indicators of trends in the wider area.

Of the two GAMs incorporating all western Scotland regions (Southwest Scotland SMU, West Scotland SMU subdivisions and Western Isles), the one with the global smooth was preferred (delta AIC of -30). This GAM was taken forward and used to generate the results presented at the SMU and subdivision level of SMUs 1 – 3. The initial results following analyses methods used for other SMUs and for these SMUs in SCOS BP 24/03 are presented in the Appendix.

For Southwest Scotland (6% of UK count), abundance was predicted to be significantly higher than at the start of the time-series. Although the latest count for the Southwest Scotland was lower than the previous count (1,563 vs 1,709), there were no significant short-term trends. Abundance was predicted to be significantly higher than in 1992 (LT).

For West Scotland (44% of UK count), there were significant negative short-term trends for all subdivisions, and West Scotland as a whole (ST1 for all subdivisions; ST6 for the south subdivision; 47% of SMU count). For all except the south subdivision, abundance was predicted to be significantly higher than in 1992 (LT).The SAC trends for West Scotland (fitted as per SCOS 24/03) varied by subdivision. SACs in the south subdivision (surveyed in 2023) were predicted to be in decline across all assessment metrics. Abundance in the Ascrib, Isay and Dunvegan SAC (central subdivision) was predicted to have decreased (ST1, ST6, LT) but not significantly so. It was, however, predicted to significantly depleted (HH 2003). It should be noted that the latter SAC was surveyed in 2022 (the two former were surveyed in 2023). Combined, the latest SAC counts in West Scotland represent ~6% of the SMU count, compared to >17% at the start of the time-series (1990).

The Western Isles (12% of UK count) was predicted to be in decline; this was marginally significant at ST1 but not at ST6 scale. There was still a strong indication that abundance was higher than in 1992 although the lower confidence interval was 0. In contrast, for the Sound of Barra SAC, although there was no significant short-term trend (ST1, ST6), abundance was predicted to be severely depleted compared to 1992 (LT). Indeed, the last SAC count (2022) represented around 3% of the SMU total compared to around 38% in 1992.

North Coast & Orkney SMU (~5% of UK count) and its encompassed SAC (Sanday) were estimated to be severely depleted (HH 1993) and still in decline (ST1, ST6). The rate of decline and level of depletion were 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 (~12% of UK count), although depleted compared to the start of the time series (1992; by ~40%), was estimated to be stable. This was also the case for the Yell Sound SAC. In contrast the Mousa SAC was almost completely depleted (~98% compared to 1992), and still in decline, with a count of 7 in the last survey (2019).

Abundance in the Moray Firth SMU (~4% of UK count) was depleted by ~ a third (HH 1994) but was estimated to be stable (ST1, ST6). The Dornoch Firth and Morrich More SAC was more severely depleted (~90%) and declining (ST1, ST6); the SAC represented 5% of the SMU count in 2023 compared to around 50% in the early 1990s.

The East Scotland SMU (~1% of UK count) was severely depleted since the start of the time series (1997; by ~ 70%), and estimated to be declining (ST1, ST6). The Firth of Tay and Eden Estuary SAC was last surveyed in 2023, and although it was ~95 % depleted compared to the 1990s, it was no longer significantly declining (ST1, ST6). Indeed, there was 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 appeared to increase again, and was at a historic high (ST1, ST6, LT).

The Southeast England SMU (~13% of UK count) encompasses The Wash & North Norfolk Coast, which, in the last surveys, accounted 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. For 2023, there was no significant current trend (ST1), but a significant decrease at ST6. It is not clear if there was a step decrease in abundance between 2018 and 2019, or if it marked the start of a decline. There is no indication from the August counts (or pup counts; SCOS BP 25/05) that the population is recovering. The decrease, since the high in 2015, was estimated to be ~20% for the SMU, and ~26% for SAC. The cause of this decline, and its implications, are the focus of a SMRU research project.

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 model estimating trends in grey seal pup production for aerially surveyed SMUs incorporated the estimated 22.5 % jump in pup production associated with the change from film to digital. 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 2% of UK grey seals in August. The latest surveys (2023) represented a time-series high and abundance was estimated to have significantly increased on all time scales .

Pup production for West Scotland (~7% of UK production) appeared to have increased, after a long period of stability (ST1, ST6, LT), and for the last survey year was at a time-series high. Although not significant, there was an indication of an increase in Treshnish Isles SAC (ST1 & ST6), and it was no longer estimated to be significantly depleted compared to the historic highs in the late 1990s (when the SMU trend first levelled off). The Treshnish Isles SAC accounted for around ~25% of pup production in the SMU, but is not a key haulout accounting for less than 4% of the SMU count. The August grey seal counts in West Scotland SMU (host ~ 11% of UK count) were estimated to have increased on all time scales (ST1, ST6, LT), to a time-series high. These results were reflected in both the south and north subdivisions which together accounted for almost 80% of the SMU count (~63 and 16% respectively). In the central subdivision (~21% of SMU count) no trend was evident across the time series but the latest count was the second highest in the time-series

The Western Isles host a much larger proportion of UK pup production (~23.5%) than August count (~9%). Pup production in the Western Isles was increasing (ST1 & ST6), after a long period of stability to a time-series high. The Monach Isles SAC was also at its highest recorded level of production accounting for ~75% of the SMU's production, and although there was an indication of a recent increase, it was not significant (ST1 and ST6). In contrast, the North Rona SAC which historically was the biggest colony in the SMU, was severely depleted and continuing to decline accounting for less than 2% of the SMU's production compared to over 20% at the beginning of the time-series considered here (1984), and likely an even higher proportion in the 1960s and 1970s (Russell *et al.* 2019). August grey seals counts 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 appeared to be 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 (~50% of Shetland production) were used to investigate trends (up to 2018). The coverage (across colonies) and effort (number of surveys) was limited due to limited resources and the logistical difficulties getting to the colonies given the weather conditions at that time of year. The last year for which there were coverage of all the colonies including in the proxy was 2018. Although the trend (GLM) indicated a decreasing trend (ST1, ST6, LT), these should be treated with caution due to the use of a subset of colonies; the sensitivity of peak counts to variation in survey effort; and the last data point (coverage of all colonies in the subset) was in 2018. Nevertheless, counts at colonies in subsequent years also indicate a decline. For August counts, an exceptionally low count at the start of the time series precluded 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 was estimated to have increased (ST1, ST6, LT) whereas August counts were variable with no clear trend.

East Scotland accounts for almost 10% of pup production but only 4% of the August count. In terms of the fitted trend, production in East Scotland was significantly increasing across all time-scales). However, the last four (since 2018) pup production estimates were around 7,500 (plus or minus 175), indicating that pup production may have levelled off in the SMU. Production on the Isle of May SAC in 2023 was >20% lower than the historic high (HH 2004), and appeared to still be declining though it is not significant at the 5% level (ST1, ST6). The SAC, which until the mid-1990s represented almost 100% of the SMU's pup production, only represented under 25% in 2023. This is, to a large extent, due to the rapid increase in pup production at Fast Castle. Around 57% of the pups born at the Fast Castle colony in 2023 were born within the Berwickshire and North Northumberland Coast SAC. Likely due to the expanding nature of the colony, there were significant increased for Fast Castle as a whole but not for the SAC portion. For both SACs, pup production was significantly higher than historically (LT). Neither SACs represent key haul out areas for grey seals during the August survey.

Northeast England accounts for around 5% of UK pup production but around 13% 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 were at record levels and increasing rapidly (2023; ST1 and ST6). The SAC represented the vast majority of the August count (>90%) of the SMU.

In 2023, Southeast England accounted for over 20% of UK pup production, and ~27% of the August count. Pup production was at time-series high and increasing rapidly (ST1, ST6). In recent years, the Humber Estuary SAC (Donna Nook) represented a decreasing proportion of the pup production for the SMU as a whole. It accounted for 100% in pup production in 2000, but less than 15% in 2023. On the ST scales, there was no significant change for the SAC but it should be noted that the 2023 production estimate (2,326) was markedly lower than that in 2021 (2632). The result for August are broadly similar to pup production, though in contrast to pup production, the August counts on an SMU level are only significantly increasing on ST6 scale (but not ST1). For the Humber Estuary, as for pups, there was no significant change on either ST scale, and the count represents a decreasing proportion of the SMU total.

Conclusions

Based on the most recent surveys, in all SMUs for which there are notable numbers (SMUs 1-7, and 9) of harbour seals, abundance was predicted to be declining and/or depleted. This is with the exception of Southwest Scotland (predicted to be stable). However, it should be noted that the most recent count (2023) for Southwest Scotland was lower than the previous one (2018), and the SMU is adjacent to the West Scotland subdivision which was predicted to have declined on both the ST1 and ST6 scales (compared to only ST1 for the other two subdivisions).

For grey seals, August abundance is variable, but trends were stable or increasing across all SMUs. This was also the case for pup production, with the exception of Shetland which was predicted to be in decline. This may be associated with the levels of Killer whale predation (Sutherland 2024). After exponential increase since records began, there was an indication that East Scotland has levelled off. The considered SMUs account for > 90% and >95% of the UK grey seal August count, and pup production, respectively.

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.

Pedersen EJ, Miller DL, Simpson GL, Ross N. 2019. Hierarchical generalized additive models in ecology: an introduction with mgcv. *PeerJ* 7:e6876 https://doi.org/10.7717/peerj.6876

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		2023	1563	7	-2.6 (-5.5, 0.4)	1.6 (-18.7, 27.4)	**175.9 (109.8, 262.4; 1992)**	-3.6 (-13.5, 7.4; 2020)
2. West Scotland		2023	11754	7	**-4.8 (-7.6, -1.9)**	**-21.5 (-32.6, -8.7)**	**41.1 (17.8, 69.2; 1992)**	**-22.1 (-34.1, -8.2; 2016)**
2a. West Scotland - south		2023	5272	7	**-5.4 (-8.2, -2.5)**	**-25.9 (-39.6, -9.5)**	-0.8 (-23, 27.7; 1992)	**-27.7 (-43.8, -7.6; 2015)**
	South-East Islay Skerries SAC	2023	207	8	**-22.2 (-29.1, -14.7)**	**-71.3 (-81.5, -56.3)**	**-58.2 (-73.8, -33.9; 1992)**	**-76.5 (-85.6, -61.9; 2014)**
	Eileanan agus Sgeiran Lios mor SAC	2023	197	11	**-2.1 (-3.3, -0.9)**	**-12 (-18.5, -5.2)**	**-48.4 (-65.3, -24; 1992)**	**-50.5 (-67.3, -24.8; 1990)**
2b. West Scotland - central		2022	5563	8	**-4.2 (-7.3, -1)**	-13.2 (-25.4, 0.9)	**126.3 (86, 176.5; 1992)**	**-13.5 (-24.5, -1; 2017)**
	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	**-4.3 (-7.5, -1)**	-13.7 (-26.3, 1.2)	**140.6 (94.4, 198.6; 1992)**	**-13.9 (-25.3, -0.7; 2017)**
3. Western Isles		2022	3080	9	**-4.4 (-8.6, -0.2)**	-12.6 (-31.3, 10.6)	32.3 (0, 75.1; 1992)	-14 (-30.5, 5.8; 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)**
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		2023	760	7	**6.2 (4.3, 8.1)**	**43.2 (28.4, 59.9)**	**539.6 (263.5, 1030.9; 1992)**	-
2. West Scotland		2023	4508	6	**2.5 (0.9, 4.2)**	**16.2 (5.6, 28.3)**	**117.4 (32.2, 261.7; 1992)**	-
2a. West Scotland - south		2023	2846	7	**2.7 (1.3, 4.2)**	**17.5 (8.1, 28)**	**129.9 (49.8, 257.5; 1992)**	-
	Treshnish Isles SAC	2023	161	7	0	0	0	-
2b. West Scotland - central		2023	954	7	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	3473					
	excluding offshore islands	2022	3232 (93%)	9	0	0	0	-
	Monach Islands SAC	2022	614	9	0	0	0	-
	North Rona SAC	2023	147					
4. North Coast & Orkney		2019	8618	10	-0.4 (-6, 5.6)	-0.3 (-22, 27.5)	**57.7 (23.6, 101.8; 1992)**	-12.7 (-31.8, 11.7; 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	6038	51	-0.4 (-8.7, 8.6)	6.2 (-32.6, 67.1)	**5195.3 (2883.9, 9336.9; 1992)**	-0.6 (-16.4, 18; 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 (91%)	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		2023	7502 (99%)	34	**3.8 (2.2, 5.5)**	**26.1 (15.5, 37.6)**	**427.7 (372.4, 491.9; 1992)**	-
	Isle of May SAC	2023	1833	34	-1.6 (-3.6, 0.5)	-9.3 (-18.7, 1)	**20.1 (5.8, 36.3; 1992)**	**-23.5 (-32, -13.7; 2004)**
	BNNC SAC	2023	2680	7	-1.1 (-5, 2.9)	15.3 (-3.2, 37.2)	**223.3 (167.8, 290.9; 2012)**	-1.8 (-9.2, 6.2; 2021)
	Fast Castle	2023	4730	21	**3.2 (0.7, 5.7)**	**26.7 (12.1, 43.1)**	**>1000 (1997)**	-
8. Northeast England	Farne Islands (BNNC SAC)	2023	3997 (99%)	37	**10.1 (7.9, 12.3)**	**74.7 (56.6, 94.7)**	**299.7 (247.9, 358.7; 1992)**	-
9. Southeast England		2023	16294 (99%)		**10.6 (8.3, 13.1)**	**97.6 (82.9, 113.6)**	**>1000 (2001)**	-
	Humber Estuary SAC	2023	2326	43	0.2 (-1.4, 1.8)	4.8 (-3.8, 13.8)	**>1000 (1992)**	-

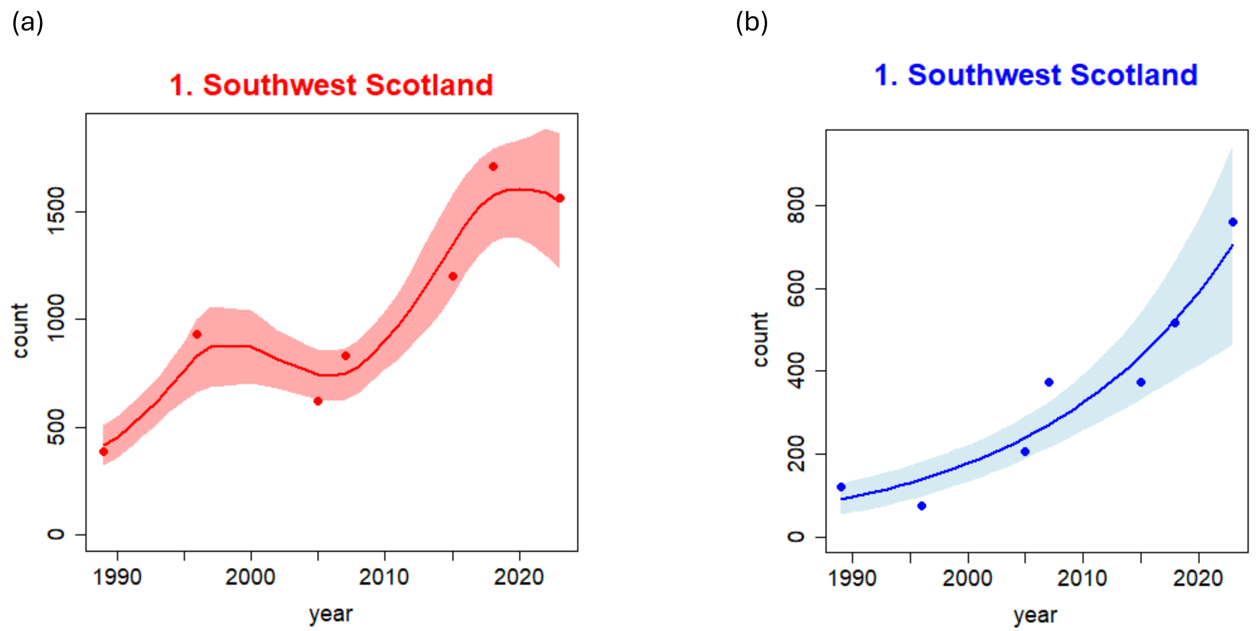

Figure 1. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the Southwest Scotland SMU. The *filled circle* points represent the values used to fit the trends.

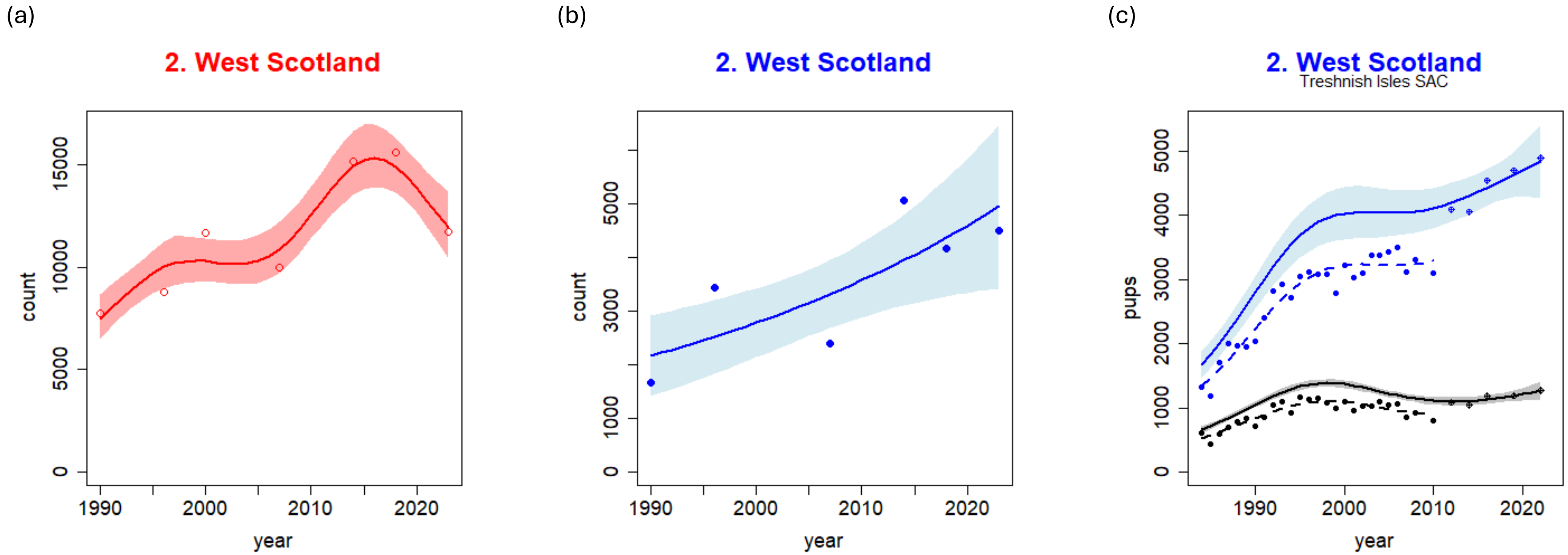

Figure 2i. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the West Scotland SMU and encompassed SACs (c only). For (a) the trend was fitted on the basis of the data on the subunit scale. The *filled circle* 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*).

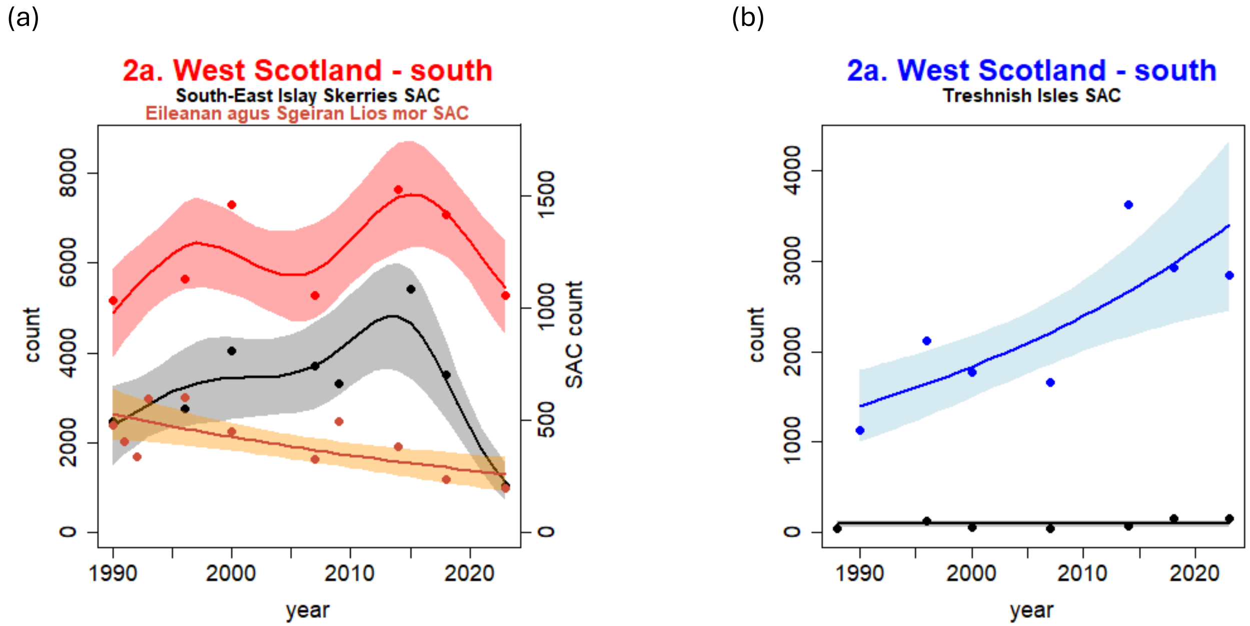

Figure 2ii. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the southern part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

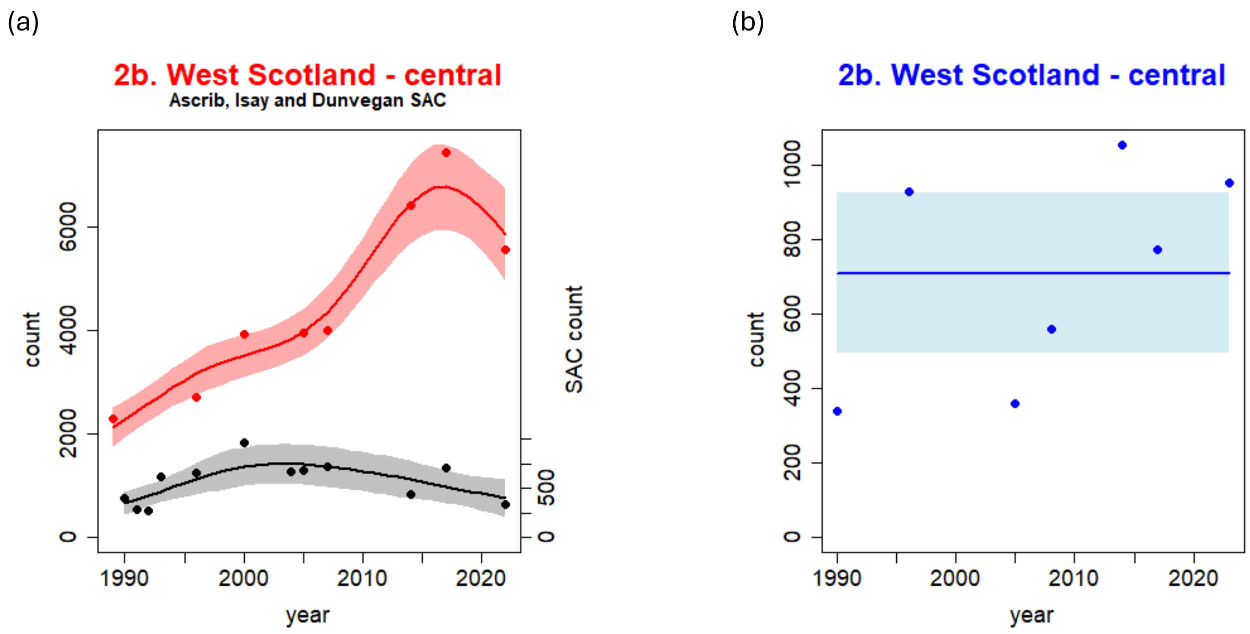

Figure 2iii. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the central part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).

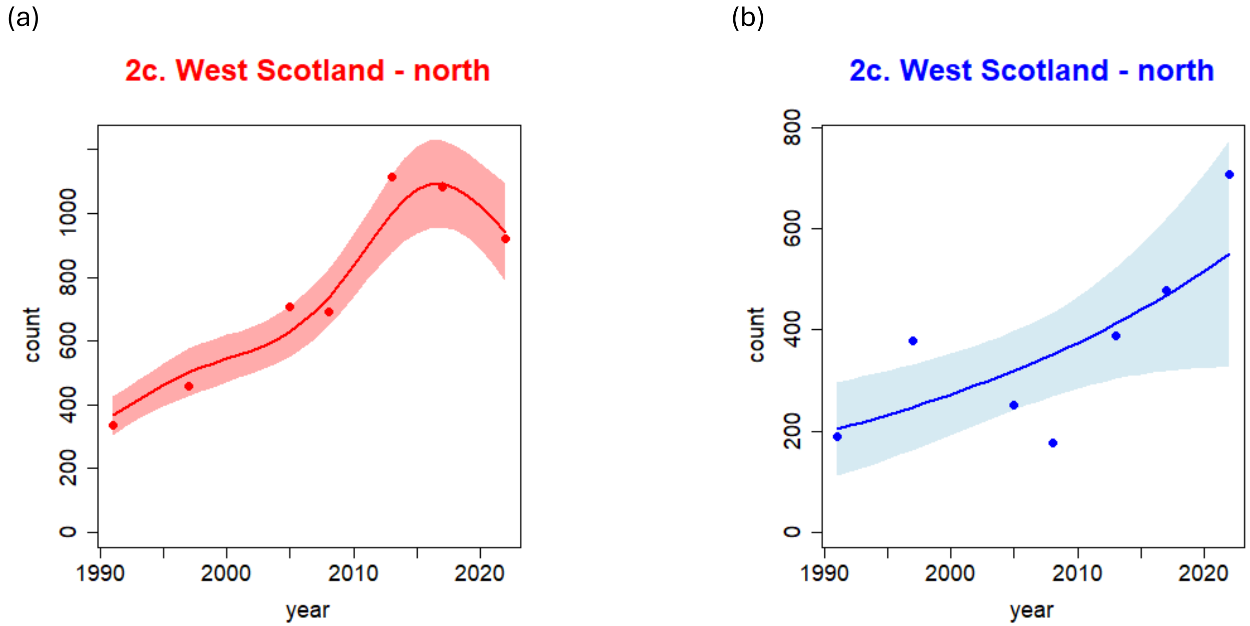

Figure2iv. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts in the northern part of West Scotland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends.

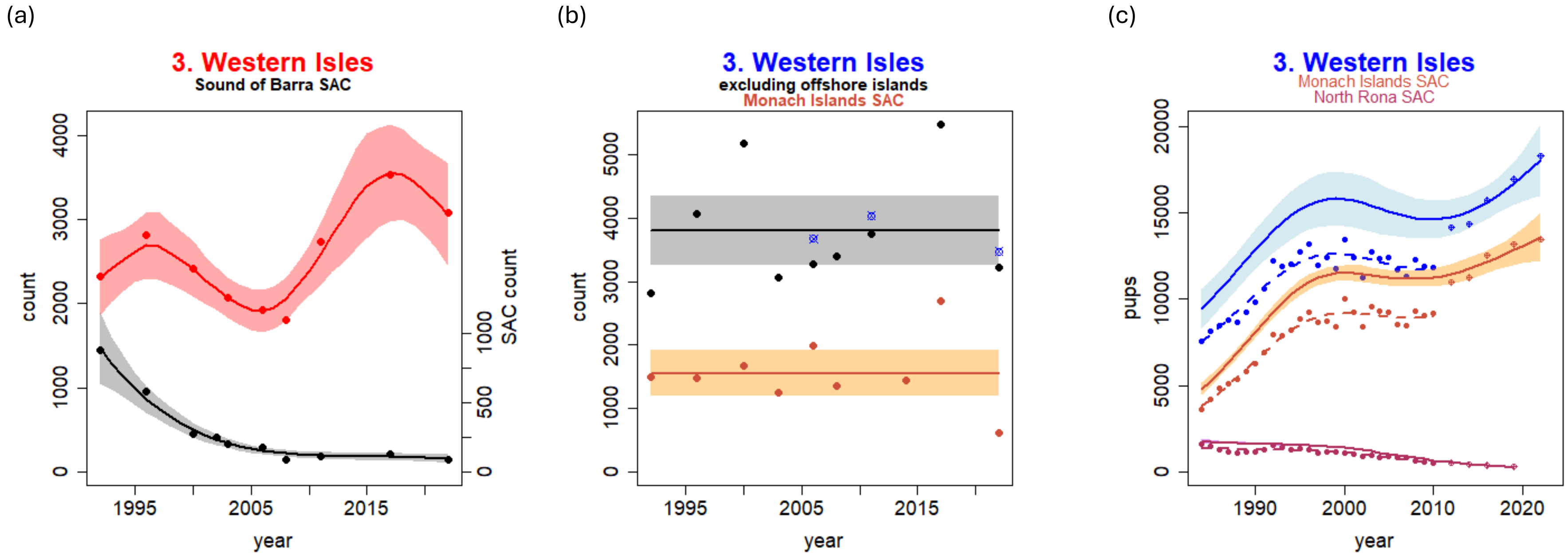

Figure 3. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the West Scotland SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The *circle 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).

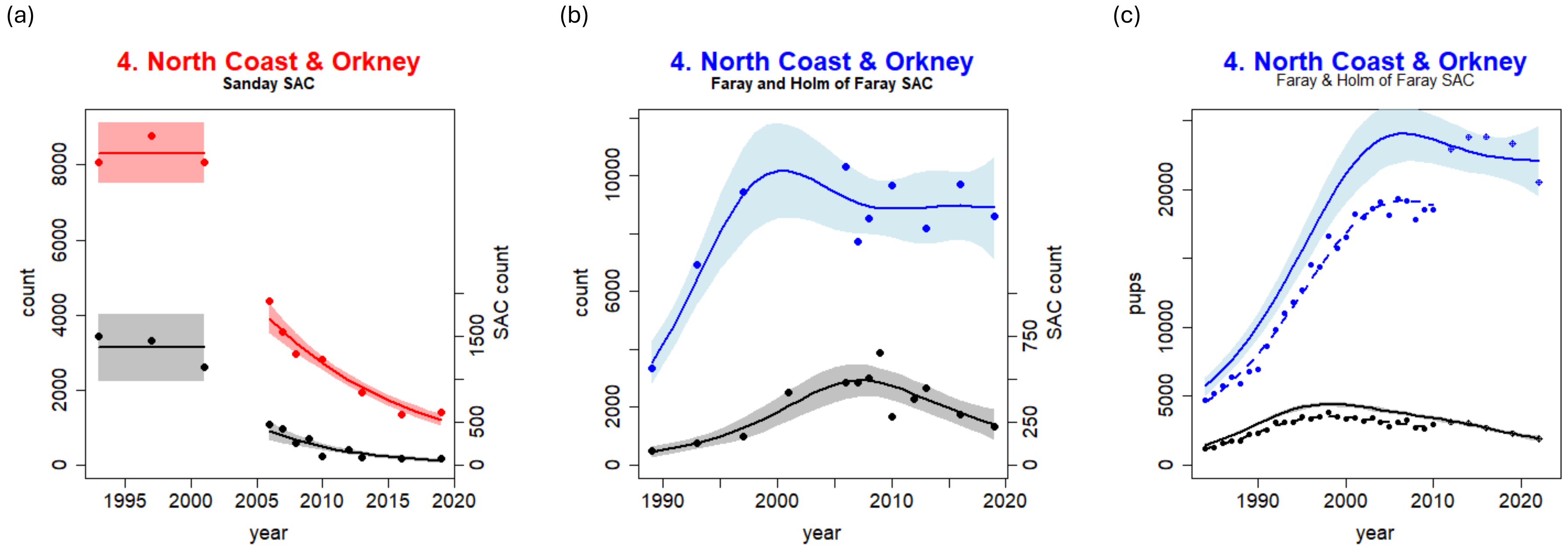

Figure 4. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the North Coast & Orkney SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. 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).

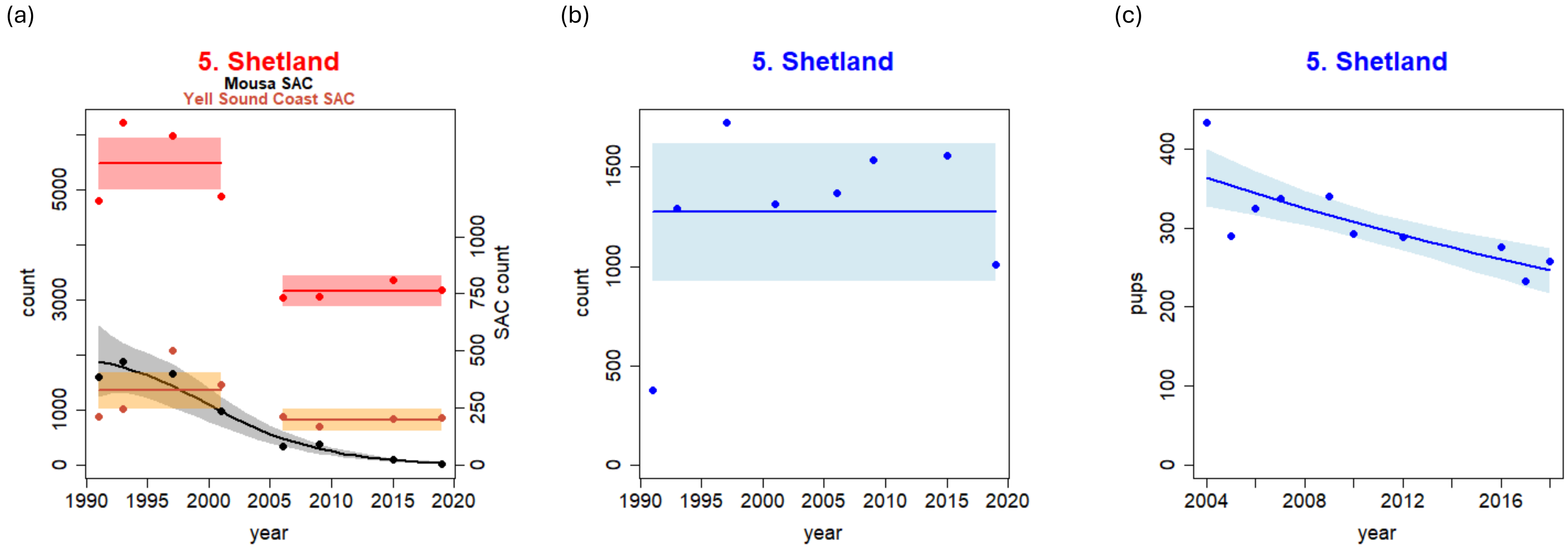

Figure 5. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal peak counts (c) in the Shetland SMU and encompassed SACs. The *filled circle* points represent the values used to fit the trends. Note the different axes for the SACs (a).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

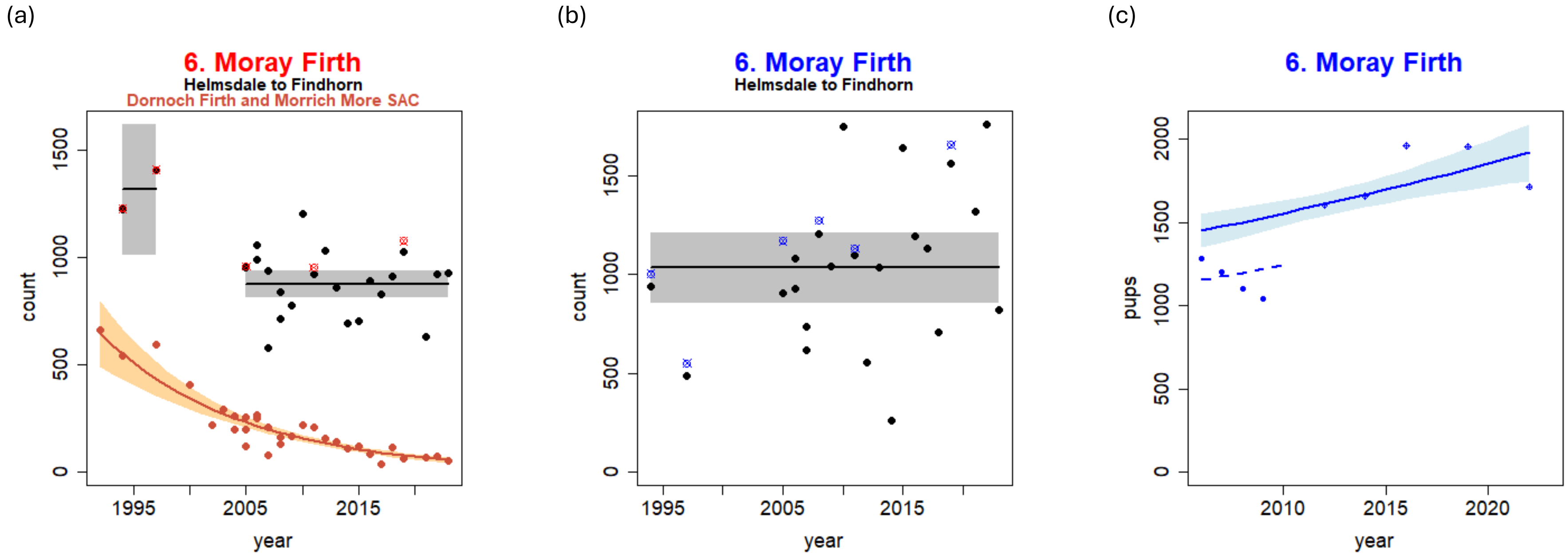

Figure 6. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Moray Firth SMU (subset for a) and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the 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).

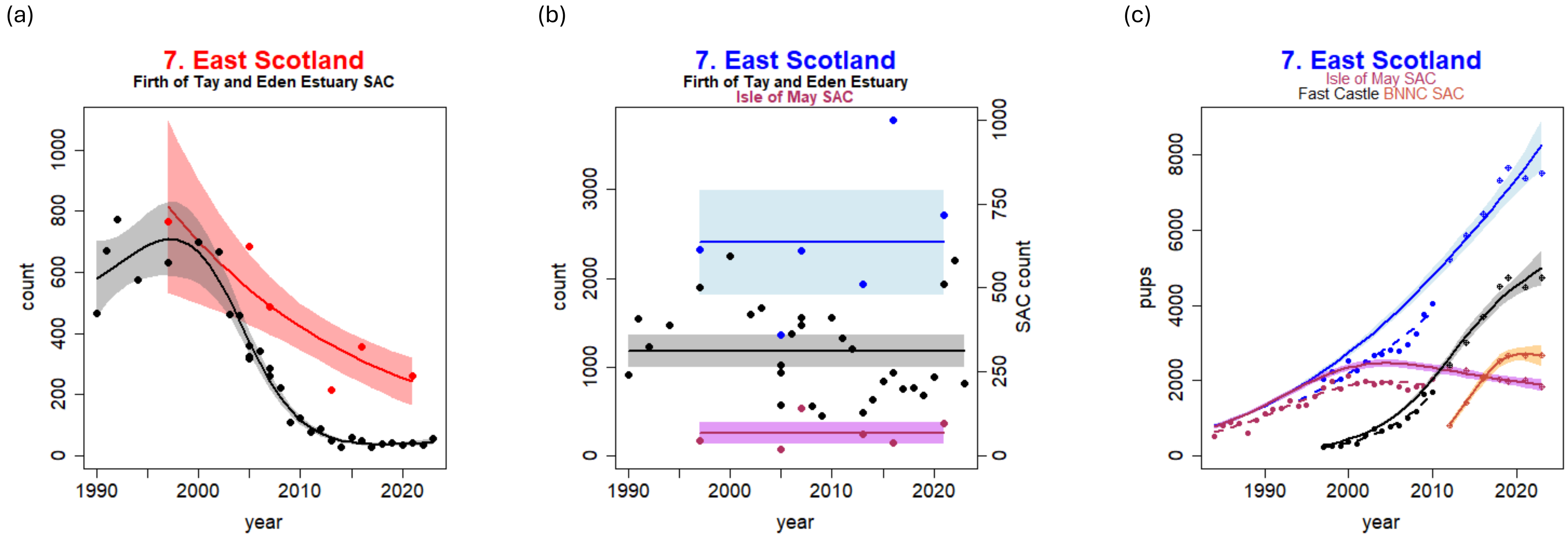

Figure 7. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the East Scotland SMU and encompassed SACs. The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. The dashed 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).

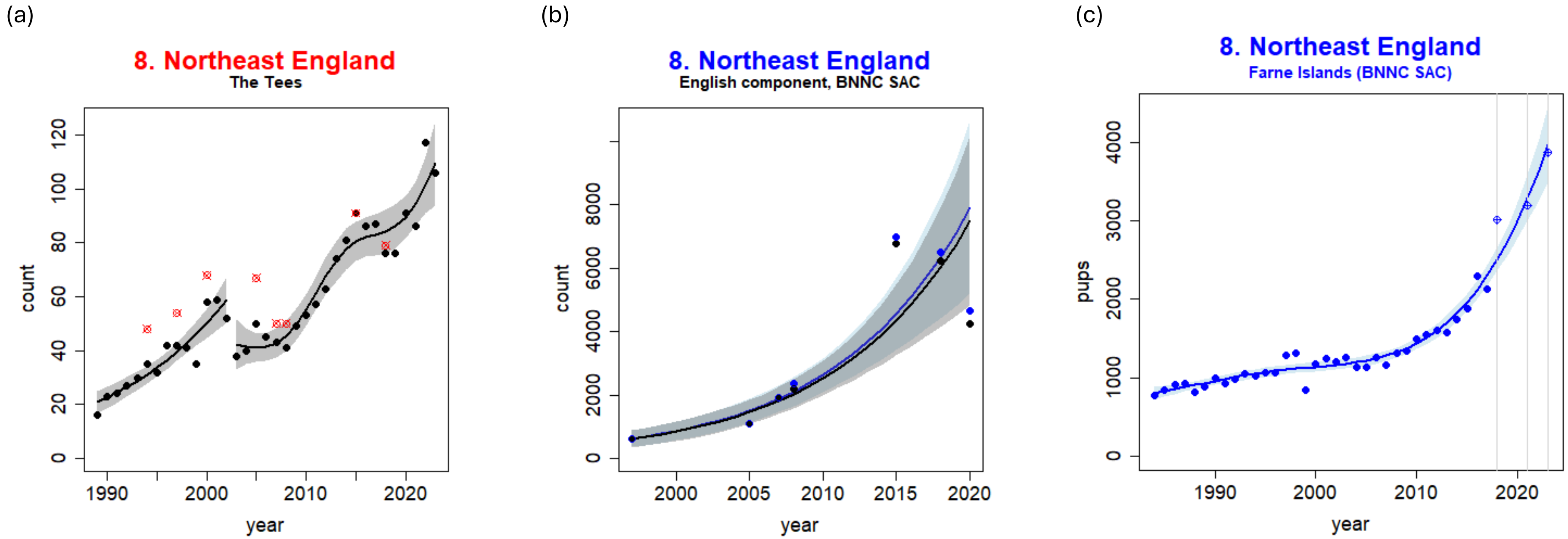

Figure 8. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Northeast England SMU and encompassed SAC(s). The *filled circle* points (and *circle plus* in c) represent the values used to fit the trends. 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 grey lines indicate years for which estimates were derived from digital aerial surveys (circle plus).

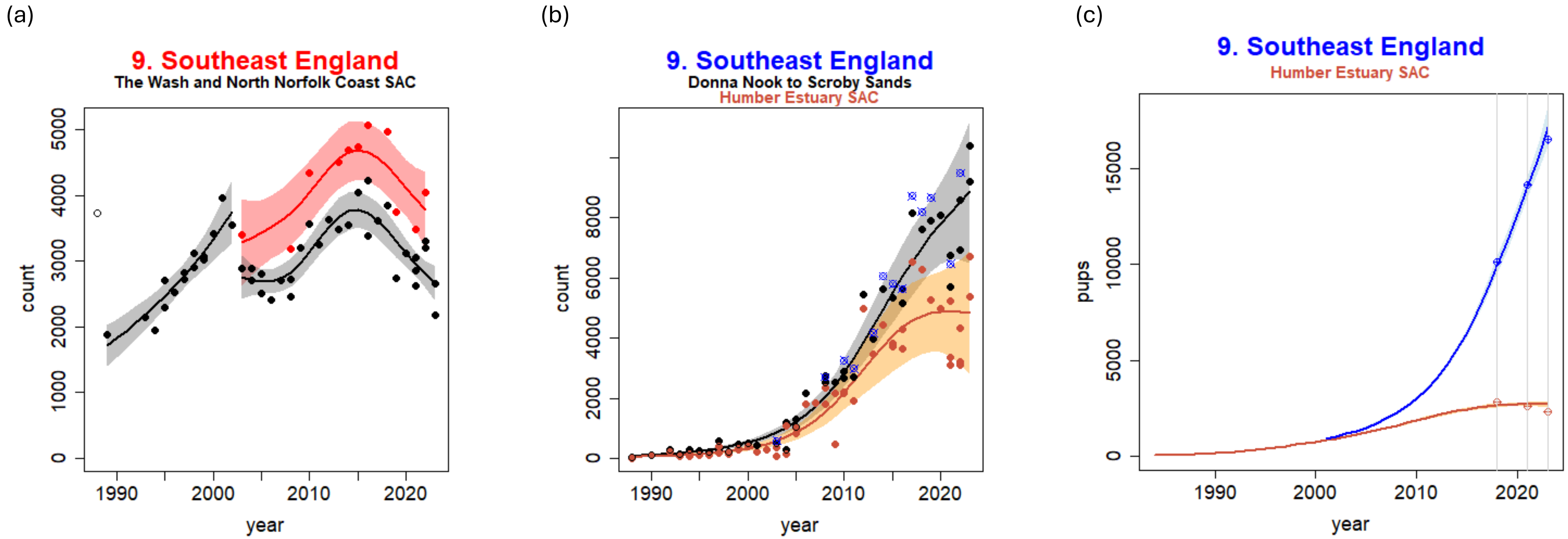

Figure 9. The predicted trend and associated 95% confidence intervals for harbour (a) and grey (b) seal August counts, and grey seal pup production (c) in the Southeast SMU and encompassed SACs. The *filled circle* points (a and b) represent the values used to fit the trends. The *circle* point (a) was 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), grey lines indicate years for which estimates were derived from digital aerial surveys (circle plus). 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).

Provisional regional Potential Biological Removal (PBR) values for UK seals in 2025

Debbie JF Russell, Chris D Morris, Dave Thompson and Callan D Duck

Sea Mammal Research Unit, University of St Andrews, St Andrews, KY 16 8LB

Abstract

This briefing paper provides Potential Biological Removal (PBR) values for the grey and harbour seal “populations” that haul out in each of the Seal Monitoring Units (SMUs) in the UK. Sets of possible values are tabulated for each SMU using the equation in Wade (1998) with different values of that equation’s recovery factor. A value, and associated justification, is suggested for this parameter for each SMU and the resulting PBR is highlighted. The PBR values are calculated using the latest composite counts in each SMU; it should be noted that some of these counts are over 5 years old. The PBR estimates, especially for declining SMUs should be considered in that context.

There are numerous changes compared to SCOS 2024. Other than the extension to all UK SMUs with notable populations (previously only Scottish SMUs were considered), the other main change compared to SCOS 2024, is that instead of using the August count directly as Nmin for harbour seals, the count is scaled. Specifically, the count is raised using the 20th percentile of the distribution of the scalar used to account for seals at sea during the survey windows. This is equivalent to using the 20th percentile of the population estimate, aligning with the method used for grey seals and recommended by Wade (1998). The counts have been updated for SMUs 1 and 2 (Southwest Scotland and West Scotland). Moreover, the recovery factors for harbour seals have been adjusted for these SMUs to reflect that abundance is no longer increasing. Indeed, harbour seal recovery factors across all considered SMUs are < 1. Grey seal recovery factors were all set to 1 on the basis of the stable or increasing trends. This is with the exception of SMUs 4 and 5 (North Coast & Orkney and Shetland) for which the recovery factor was set to 0.5 on the basis that the available data are > 5 years old.

Introduction

Potential Biological Removal (PBR) 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 (OSP). 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). It should be noted that the formulation of the equation allow small anthropogenic takes even from depleted or declining populations.

In previous SCOS reports, PBR values have only been estimated for SMUs in Scotland (also known as Seal Management Areas; Scottish Government). In response to queries regarding suitable PBR values in other elsewhere in the UK, this BP provides the PBR values for each species in SMUs which hold a notable abundance (population estimate > 250; SCOS BP 25/01) of that species during August.

Materials and Methods

The PBR calculation:

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

where:
PBR is a number of animals considered safely removable from the population.
$\mathbf{N_{min}}$ is a minimum population estimate (usually the 20th percentile of a distribution.)
$\mathbf{R_{max}}$ is the population growth rate at low densities (by default set 0.12 for pinnipeds), this is halved to give an estimate of the growth rate at higher populations. This estimate should be conservative for most populations at their OSP.
$\mathbf{F_R}$ is a recovery factor, usually in the range 0.1 to 1. Low recovery factors give some protection from stochastic effects and overestimation of the other 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:

$\mathbf{N_{min}}$ values used in these calculations are from the most recent summer surveys of each area, for both species:

- Harbour seals: The surveys take place during the harbour seal moult, when the majority of this species will be hauled out. Previously survey counts have been used directly as Nmin (SCOS BP 24/06). Here, in line with Wade (1998) and the approach for grey seals (below), the counts have been scaled to produce an N_{min} equivalent to the 20th percentile of the population estimate. The percentage of harbour seals estimated to be hauled out, and thus available to count, during surveys is 72% (95% CI: 54 -88; Lonergan *et al.* 2013). The 20th percentile of the distribution of multipliers from counts to abundances implied by that distribution is 1.28 (to 2 decimal places; see Table 2).
- Grey seals: The August surveys occur during a key foraging period for grey seals, and thus the proportion of the population hauled out is lower than for harbour seals. The percentage of grey seals estimated to be hauled out, and thus available to count, during surveys is 25.2% (95% CI: 21.5 – 29.1%; SCOS-BP 21/02). The 20th percentile of the distribution of multipliers from counts to abundances implied by this estimate is 3.73 (to 2 decimal places; see Table 3).

$\mathbf{R_{max}}$ is set at 0.12, the default value for pinnipeds, since very little information relevant to this parameter is available for UK 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). However, the extent that density dependent factors may have influenced growth rates in different SMUs is not known. 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 the maximum annual rates of increase were > 16% (Russell et al. 2019). However, the extent to which this increase was augmented by recruitment from other SMUs is unknown. The large grey seal population at Sable Island in Canada grew at nearly 13% p.a. for long periods (Bowen et al. 2003).

F_R 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 SMU, together with a justification for the recommended value.

Areas used in the calculations:

Figure 1 and Table 1 shows the boundaries of the Seal Monitoring Units.

Particularly for grey seals, there will probably be substantial movement of animals between these SMUs. 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) Southwest Scotland (F_R = 0.5; change from 1.0 in SCOS BP 24/06)
Abundance is apparently stable, although the last count (2023) was lower than the previous one (2018). The trajectory appears similar to the larger adjacent West Scotland SMU which is predicted to be in decline (SCOS BP 25/03) thus the same recovery factor as West Scotland and Western Isles is recommended.

2) West Scotland (F_R = 0.5; change from 1.0 in SCOS BP 24/06)
The latest count (2022/2023) in all three subunits was lower than the previous count (2017/2018), and the latest trend for West Scotland SMU is of a decline. Due to the apparent recent decrease and the importance of this SMU in terms of its holdings of the Scottish population, it is recommended that the recovery factor is set at 0.5.

3) Western Isles (F_R = 0.5)
There appeared to be 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 latest trend estimate is a significant decline (SCOS-BP 25/03). Due to the apparent recent decrease and the fact that there is an existing conservation order in place for the SMU, it is recommended that the recovery factor is left at 0.5.

4 & 5) Shetland and North Coast & Orkney (F_R= 0.1)

F_R set to minimum because populations are experiencing prolonged declines and have not shown any signs of recovery.

6) 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 SMUs are depleted and continuing to decline. 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.

7) East Scotland (F_R= 0.1)

F_R set to minimum because populations are experiencing prolonged declines and have not shown any signs of recovery.

9) Southeast England (F_R= 0.1)

F_R set to minimum because the population is depleted. It is not shown any signs of recovery, and may still be in decline.

14) Northern Ireland (F_R= 0.1)

F_R set to minimum because of sustained long-term decline.

Grey seals

SMUs 1-3, 6-9, 14 (F_R = 1.0)

August counts of grey seals are either stable (across the time series or at historic highs) or increasing (SCOS BP 25/03). Available telemetry data and the differences in the regional patterns of pup production and summer haul-out counts suggest substantial movement between SMUs (Russell *et al.* 2013; Carter *et al.* 2022) and also with the continent (Brasseur et al. 2015).

SMUs 4-5 (F_R = 0.5)

The recovery factors for North Coast & Orkney and Shetland were set to 0.5 on the basis that the available data are > 5 years old.

Results

PBR values for grey and harbour seals for each SMU for with the full range of F_R values from 0.1 to 1.0 are given in Table 2 for harbour seals and Table 3 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

Brasseur SMJM, Polanen Petel TD, Gerrodette T, Meesters EHWG, Reijnders PJH, Aarts G (2015). Rapid recovery of Dutch gray seal colonies fueled by immigration. Marine Mammal Science 31:405-426.

Carter MID, Boehme L, Cronin MA, Duck CD, Grecian WJ, Hastie GD, Jessopp M, Matthiopoulos J, McConnell BJ, Miller DL, Morris CD, Moss SEW, Thompson D, Thompson PM and Russell DJF (2022) Sympatric Seals, Satellite Tracking and Protected Areas: Habitat-

Based Distribution Estimates for Conservation and Management. Front. Mar. Sci. 9:875869.

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., 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 Monitoring Units (SMU)

Seal Monitoring Unit		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
8	Northeast England	Scottish border to Flamborough Head
9	Southeast England	Flamborough Head to Newhaven (E Sussex)
10	South England	Newhaven to Prawle Point (S Devon)
11	Southwest England	Prawle Point to Welsh border
12	Wales	Wales
13	Northwest England	Welsh border to Scottish border
14	Northern Ireland	Northern Ireland

.

Table 2. Potential Biological Removal (PBR) values for harbour seals by Seal Monitoring Unit for the year 2025. Recommended FR values are highlighted in grey cells.

SMU	2016-2023 count	Survey years	N_{min}	PBRs based on recovery factors F_R ranging from 0.1 to 1.0: 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	selected F_R	PBR
1 Southwest Scotland	1,563	(2023)	2,001	12	24	36	48	60	72	84	96	108	120	0.5	60
2 West Scotland	11,754	(2022; 2023)	15,050	90	180	270	361	451	541	632	722	812	903	0.5	451
3 Western Isles	3,080	(2022)	3,944	23	47	70	94	118	141	165	189	212	236	0.5	118
4 North Coast & Orkney	1,405	(2016; 2019)	1,799	10	21	32	43	53	64	75	86	97	107	0.1	10
5 Shetland	3,180	(2019)	4,072	24	48	73	97	122	146	171	195	219	244	0.1	24
6 Moray Firth	983	(2019; 2021; 2023)	1,259	7	15	22	30	37	45	52	60	67	75	0.1	7
7 East Scotland	276	(2021; 2023)	353	2	4	6	8	10	12	14	16	19	21	0.1	2
9 Southeast England	3,372	(2022; 2023)	4,318	25	51	77	103	129	155	181	207	233	259	0.1	25
14 Northern Ireland	818	(2021)	1,047	6	12	18	25	31	37	43	50	56	62	0.1	6

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

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

N_{min} is a minimum population estimate. The percentage of harbour seals estimated to be hauled out, and thus available to count, during surveys is 72% (95% CI: 54 - 88; Lonergan et al. 2013). The 20th percentile of the distribution of multipliers from counts to abundances implied by that distribution is 1.28040610183467.

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

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

Table 3. Potential Biological Removal (PBR) values for grey seals by Seal Monitoring Unit for the year 2025. Recommended FR values are highlighted in grey cells.

SMU	2016-2023 count	Survey years	N_{min}	PBRs based on recovery factors F_R ranging from 0.1 to 1.0: 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	selected F_R	selected PBR
1 Southwest Scotland	760	(2023)	2,832	16	33	50	67	84	101	118	135	152	169	1.0	169
2 West Scotland	4,508	(2022; 2023)	16,798	100	201	302	403	503	604	705	806	907	1,007	1.0	1,007
3 Western Isles	3,473	(2022; 2023)	12,942	77	155	232	310	388	465	543	621	698	776	1.0	776
4 North Coast & Orkney	8,618	(2016; 2019; 2023)	32,114	192	385	578	770	963	1,156	1,348	1,541	1,734	1,926	0.5	963
5 Shetland	1,009	(2019)	3,760	22	45	67	90	112	135	157	180	203	225	0.5	112
6 Moray Firth	1,354	(2019; 2021; 2023)	5,046	30	60	90	121	151	181	211	242	272	302	1.0	302
7 East Scotland	1,584	(2021; 2023)	5,903	35	70	106	141	177	212	247	283	318	354	1.0	354
8 Northeast England	5,381	(2020; 2022; 2023)	20,052	120	240	360	481	601	721	842	962	1,082	1,203	1.0	1,203
9 Southeast England	10,735	(2022; 2023)	40,003	240	480	720	960	1,200	1,440	1,680	1,920	2,160	2,400	1.0	2,400
11 Southwest England	729	(2023)	2,717	16	32	48	65	81	97	114	130	146	163	1.0	163
12 Wales	1,313	(2023)	4,893	29	58	88	117	146	176	205	234	264	293	1.0	293
13 Northwest England	180	(2023)	671	4	8	12	16	20	24	28	32	36	40	1.0	40
14 Northern Ireland	549	(2021)	2,046	12	24	36	49	61	73	85	98	110	122	1.0	122

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

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

N_{min} is a minimum population estimate. he percentage of grey seals estimated to be hauled out, and thus available to count, during surveys is 25.2% (95% CI: 21.5 – 29.1%; SCOS-BP 21/02). The 20th percentile of the distribution of multipliers from counts to abundances implied by that distribution is 3.72637.

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. UK Seal Monitoring Unit (SMUs).

The distribution and abundance of harbour seals (Phoca vitulina) during the 2024 breeding season in The Wash

Dave Thompson, Simon A Waitland and Debbie JF Russell

Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews. KY16 8LB

Abstract

This report presents preliminary results of an aerial survey of the harbour and grey seal populations along the English east coast between Donna Nook in Lincolnshire and Blakeney Point in Norfolk, including the tidal sites in The Wash, on 28th June 2024 during the harbour seal breeding season. Similar surveys have been carried out annually since 2004, with the exceptions of 2019, 2020 and 2021 when no surveys were carried out due to a combination of aircraft malfunction and travel restrictions due to Covid-19. During that period the moult counts of harbour seals underwent a marked decrease in The Wash and North Norfolk SAC.

Results suggest that:

•The harbour seal pup count for The Wash on 28/6/2024 was 896, which was 37% lower than the 2023 count and 38% lower than the mean of the seven peak counts during the preceding ten years (2014-2023).

•As in previous years, no harbour seal pups were detected at Blakeney Point, but two pups were seen at Donna Nook.

• 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 since declined significantly. The 2024 estimate represents a 26.9% decrease compared to 2015 peak.

•This reduction 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 can be used as a fecundity index. This ratio increased in the early 2000s and remained high, at around 0.4, since 2004. Despite the large drop in pup count and the observed decrease in moult counts since 2018, the fecundity index in 2024 has remained high.

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 the pup 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 1). 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 rapidly 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 (Figure 2)**Error! Reference source not found.** (SCOS 2024). The moult count for The Wash and North Norfolk (SAC) (i.e. The Wash + Blakeney) has recently 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 direct 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 may lead to temporary separation which could 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 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 2022,2023 and 2024. 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.

Survey methodology

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 each year.

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. In 2001, 2004 & 2005 images were obtained using colour reversal film in a vertically mounted 5X4" format, image motion compensated camera. Since 2006 all groups have been photographed with a handheld digital SLR camera and zoom lens. The equipment and techniques are described in detail in Thompson *et al*. (2005; 2019). All seals were identified to species and harbour seals were then classified as either pups or 1+ age class animals. No attempt was made to further differentiate the 1+ age class.

Trend analysis

The trend analyses for the peak pup counts followed the methods used in SCOS BP 24/03 (SCOS, 2024). 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 three metrics of percentage change compared to the latest year of data available (2024). These were two short-term metrics: 1 year (ST1) and 6 year (ST2), and a long-term metric (HH) from the historic high in the time series to 2024. Trends were deemed significant if the 95% confidence intervals did not encompass 0 (see SCOS BP 24/03 for more details).

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 estimating depletion, t1 was the latest year in the time series for which the highest abundance was estimated.

Results

2024 survey results

In 2024 a survey was carried out on 28th June, covering the entire coast between Donna Nook and Blakeney Point. A total of 896 pups and 2621 older seals (1+ age classes) were counted in The Wash. The 2024 pup count for The Wash was 37% lower than the 2023 count and was 38% lower than the mean of 1425 for the seven peak counts during the previous decade (2014-2023) (Table 1; **Error! Reference source not found.**). These totals include 9 pups and 37 1+age harbour seals at Brancaster.

The non-pup count, i.e. all 1+ age classes, in The Wash was 2621 which was 20% lower than the 2023 count, and 29% lower than the mean of the seven peak counts during the previous decade (2014-2023) (Table 1).

Within the Wash and North Norfolk SAC, 75 1+age harbour seals were counted at Blakeney point, but no pups were seen. An additional 68 1+age harbour seals and two pups were counted at Donna Nook, approximately 40km north of The Wash.

A total of 1144 grey seals (Halichoerus grypus) were counted in The Wash, with 319 counted at Blakeney Point, and 7236 at Donna Nook.

Trends in pup counts

Figure 2 shows the harbour seal pup counts over the period 2001 to 2024 with the fitted trend for the period 2004 to 2024, i.e. after the 2002 PDV epizootic. The 2024 pup count of 896 was the lowest in over 15 years. The estimated maximum pup count is now significantly depleted and is estimated to be 26.9% (95% CI: 7, 43) lower than the estimated peak in 2015. The trends suggest that pup production is declining, but it should be noted that for the short-term trend, i.e. over the last year, the 95% CIs for the trend cross zero (-5.6%; 95CI -11.4, 0.5).

Over the full time series (Figure 2), the annual pup counts show that there was no evidence of a decrease in pup production between 2001 and 2004, the period that includes the 2002 PDV epizootic. The 2004 count was 12% higher than the pre-epidemic count in 2001, and 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. This continued increase in pup production since 2001 contrasted with the apparent decrease in the moult counts between 2003 and 2006 (Figures 1 & 2).

Since 2015 the pup counts have decreased significantly. The timing of the onset of the decrease in pup counts is similar to the timing of the onset of the decline in the total population moult counts (Figures 1 & 2).

Trends in apparent fecundity.

A fecundity index comprising the peak pup count (taken as an index of pup production) and moult count from the preceding August (taken as an index of the total population) has been calculated for each year between 2001 and 2024 (Figure 3). The moult counts, fell between 2002 and 2003 due to the PDV epizootic and decreased further to a minimum in 2006 before beginning to recover (Figure 1). However, the pup counts increased continuously from the first post epizootic survey in 2004 (Figure 2). The different trajectories of the pup counts and the moult counts 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. The fecundity index shows a major increase from approximately 0.2 at the start of the series in 2001 up to an average of 0.45 since 2006 (Figure 9). The productivity index has varied but shown no overall trend over the past 15 years, and in 2024 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 2024, harbour seal pups were recorded on 103 separate sites within The Wash and at Titchwell Marsh, on the North Norfolk coast just outside The Wash (Figure 4). Despite the decrease in pup count, the number of groups was higher than the previous year, due to the fact that harbour seals appeared to be more widely dispersed than in previous surveys, and even within some of the larger groups, harbour seals were more widely scattered than in previous years. The largest site contained 85 pups, and 70% of pups were on the 25 largest sites. A total of 46 of the pup sites held only one or two pups. As a consequence of the wide dispersion over a large number of occupied sites, only four sites had counts of more than 5% of the total pup count, and less than 1/3 of the sites had counts representing more than 1% of the total.

As in previous years the majority of pups are found at haulout sites on the inner banks and tidal creeks in the southern part of The Wash, and despite the large decrease in the count, the overall distribution was similar to previous years. However, the relative importance of sites varies between years, but 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, when resources are available, 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 recent contraction or expansion in the distribution or number of pupping sites across The Wash.

Grey seal distribution

A total of 1144 grey seals were counted on sites within The Wash in the 28/6/2024 survey. A large majority (980 equivalent to 85%) were counted on the outer banks at the north side of the mouth of The Wash (Figure 5) . A total of 164 grey seals, including five groups of 10 or more, were found on banks in the inner Wash. In 2024 the grey seals in the inner Wash were concentrated on fewer sites than in 2023 (Figure 5). Figure 6 shows the differences in distribution of grey seals on haulout sites in The Wash between the 2017 and 2024 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 5 & 6 show that grey seals are spreading into the inner Wash, and despite the reduced count and the concentration of grey seals on fewer sites in 2024, grey seals were present on at least ten of the harbour seal pupping sites in the inner banks and tidal creeks, but whereas in 2023, approximately 30% of the harbour seal pups were found on sites with at least one grey seal (Figure 7), in 2024 only 11% of harbour seal pups were counted on sites with one or more grey seals.

Discussion

The 2022, 2023 and 2024 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 that the peak pup counts are now clearly declining. The absence of pup counts in 2019, 2020 and 2021 makes it difficult to confirm the timing of the onset of the decrease, but it appears to be coincident with the onset of the decrease in moult counts (Figures 1 & 2).

The 2024 pup count was 38% lower than the 2023 count, suggesting that the decline in pup production has continued. However, the interannual variability of the pup counts means that it is still not possible to say if the reduction is part of a continuing gradual decline or represents a step change decrease.

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 temporal pattern 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 (Thompson *et al*., 2019), 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 total population was similar to the 2001 pre-epizootic population 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 increased by a factor of 2.5 since between 2001 and 2006. The fecundity index showed no clear trend over the past 15 years. The fact that the index 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.

The fact that pup production varies widely and more rapidly than could be accounted for by changes in adult female numbers (figure 2), means that there must be wide fluctuations in fecundity and/or short-term immigration/emigration from the area. 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 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 2024 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

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

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

Galatius, A., Brasseur, S., Czeck, R., Jeß,A., Körber, P., Pund, R., Siebert, U., Teilmann, J. & Klöpper, S. (2017) Aerial surveys of Harbour Seals in the Wadden Sea in 2017:Population counts still in stagnation, but more pups than ever. http://www.waddensea-secretariat.org/ sites/default/files/downloads/TMAP_downloads/Seals/17-1109_harboursealreport2017.pdf

Härkönen, T., Dietz, R., Reijnders, P., Teilmann, J., Harding, K., Hall, A., Brasseur, S., Siebert, U., Goodman, S.J., Jepson, P.D., Dau Rasmussen, T. & Thompson, P. (2006). The 1988 and 2002 phocine distemper virus epizootics in European harbour seals. Diseases of Aquatic Organisms. 68(2):115-30.

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

Lonergan, M., Duck, C.D., Thompson, D., Mackey,B.L., Cunningham,L. & Boyd, I.L. (2007) Using sparse survey data to investigate the declining abundance of British harbour seals."; Journal of Zoology; 271(3):261-269

R Core Team. (2023). R: A language and environment for statistical computing. Austria, Vienna: The R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

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

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

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

SCOS (2024). Scientific Advice on Matters Related to the Management of Seal Populations: Report of the Natural Environment Research Council Special Committee on Seals:2024. 237 pp. https://www.smru.st-andrews.ac.uk/files/2025/05/SCOS-2024.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 21. Counts of harbour seal pups and 1+ age classes during the peak of the breeding season in The Wash from 2001 to 2024.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2022	2023	2024
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351	1586	1289	1498	1141	1417	896
1+ age classes	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	4539	3905	3443	3747	2893	3277	2619

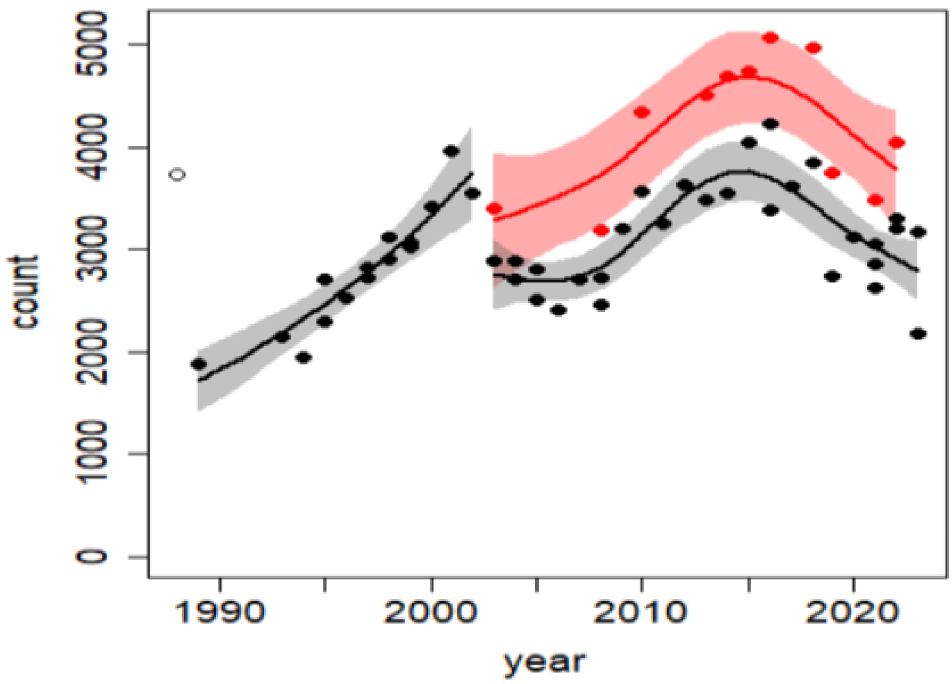

Figure 1. August moult counts of harbour seals in The Wash and North Norfolk SAC (red) and the total Southeast England SMU (grey) during the moult in August, between 1988 and 2023. Grey lines show mean trend in harbour seal counts (and 95 % confidence intervals) for The Wash and North Norfolk SAC and the red lines show the same for the SMU as a whole.

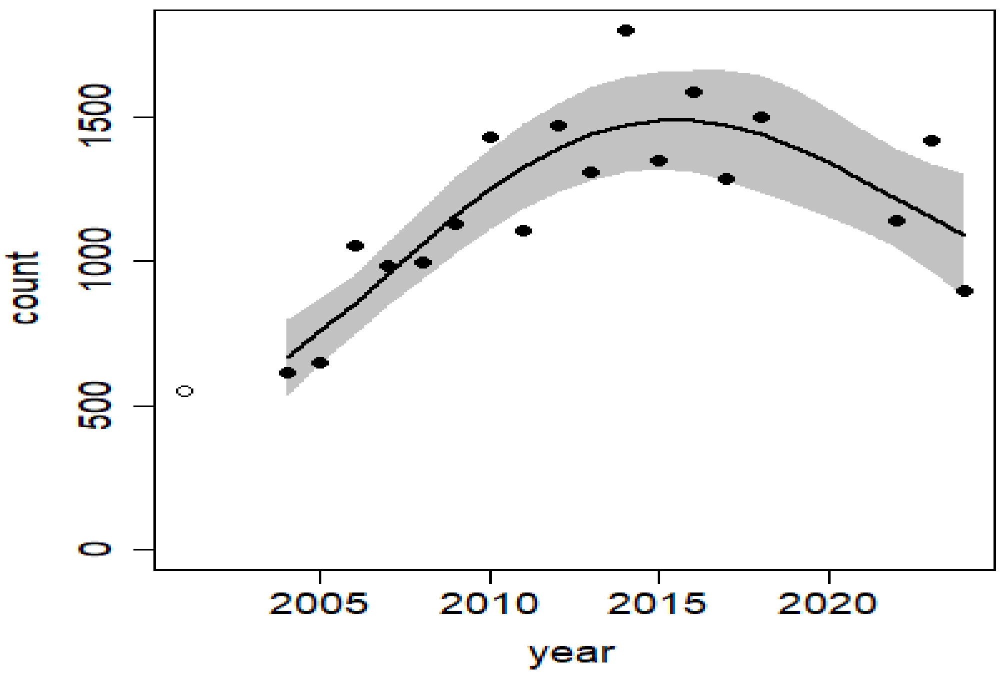

Figure 8. Maximum counts of pups in The Wash between 2001 and 2024. The fitted line is a GAM illustrating the mean trend in harbour seal pup counts between 2004 and 2024 (the shaded area shows 95 % confidence intervals about the line).

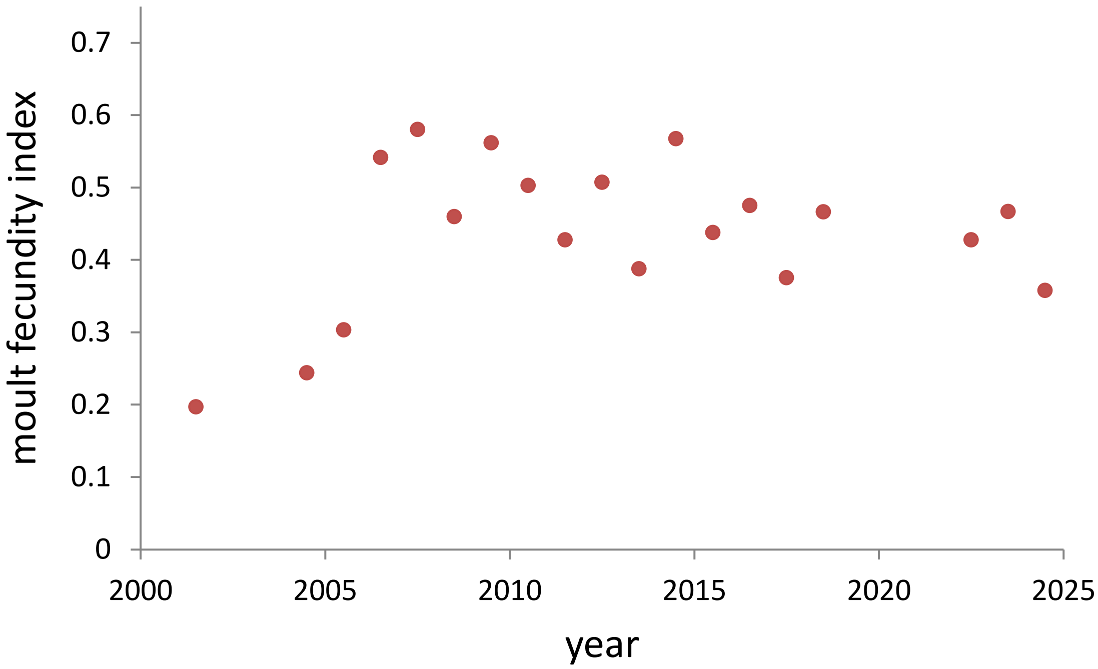

Figure 9. An index of fecundity for the Wash harbour seal population between 2001 and 2024, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size).

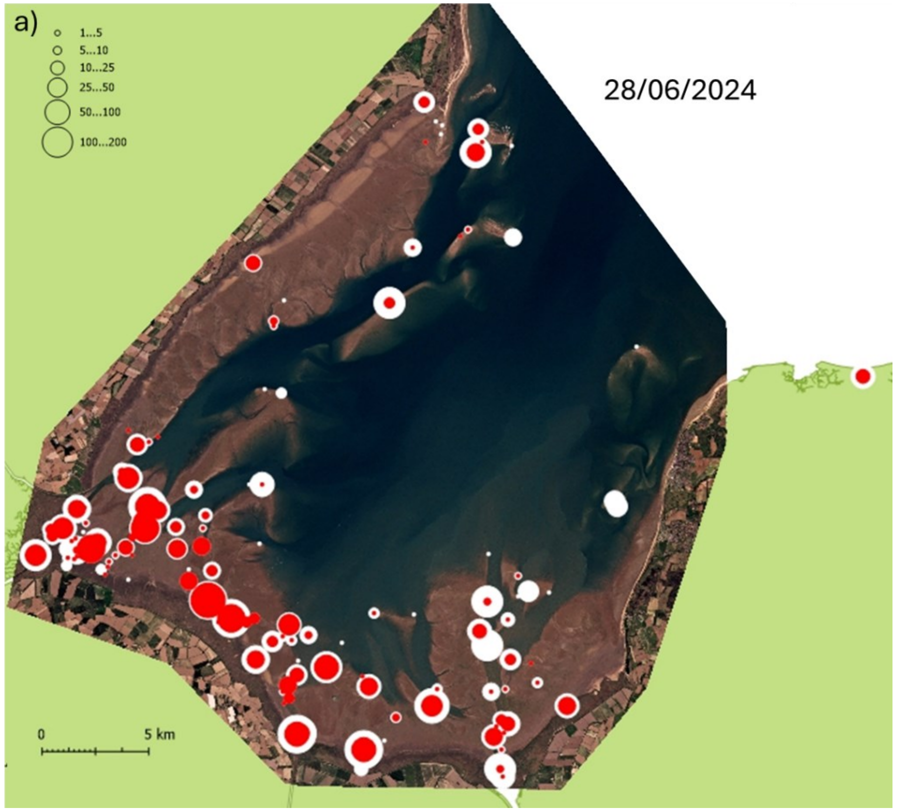

Figure 10. Distribution of pup (red) and 1+ age class (white) harbour seals in The Wash on 28/06/2024. Numbers of seals are represented by the areas of the circles on each site. Red only dots indicate pup count equalled or exceeded 1+ age class count at that site.

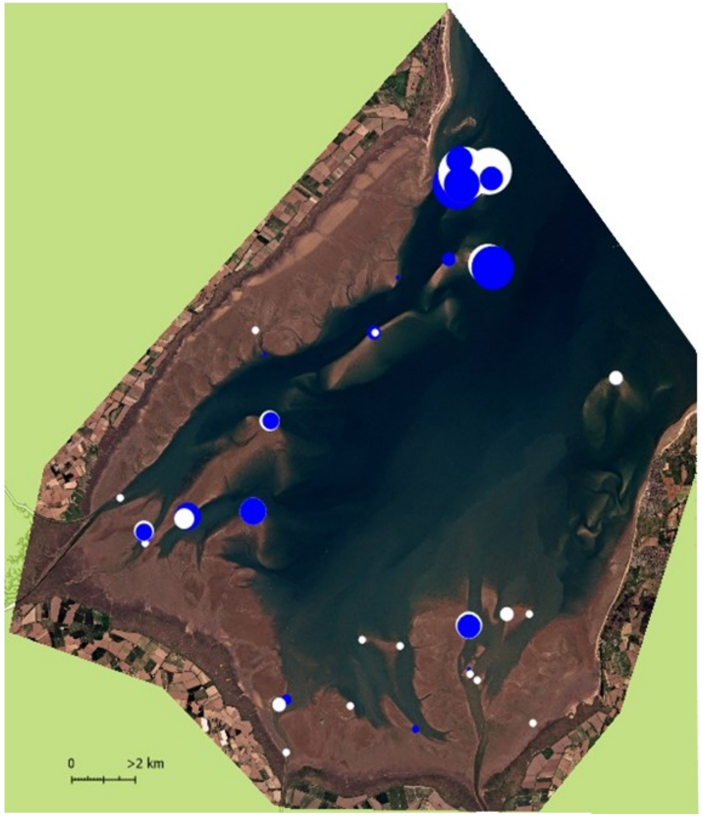

Figure 5. Distribution grey seals in The Wash on 28/6/2024 (blue) and on 1/7/2023 (white). Numbers of seals are represented by the areas of the circles on each site.

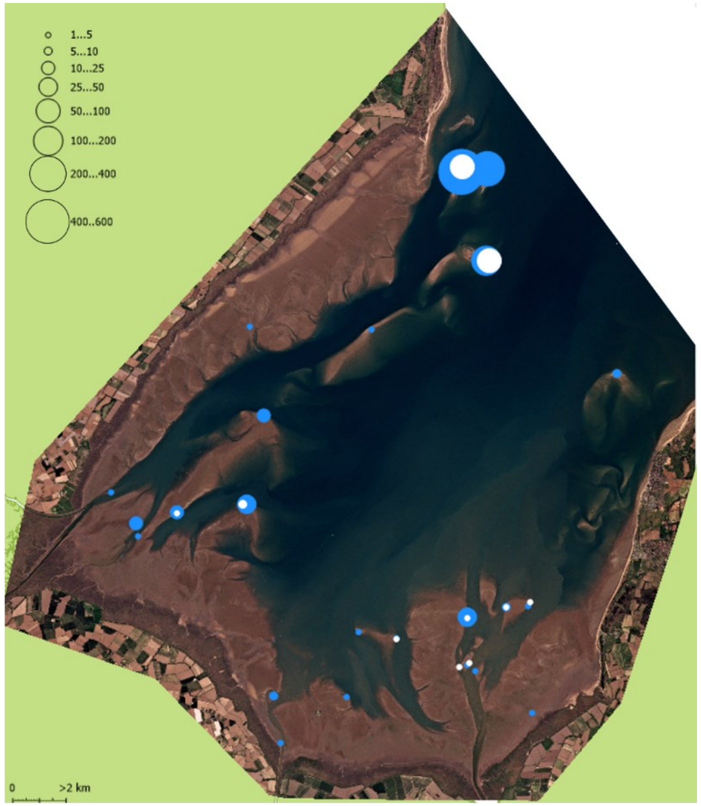

Figure 6. Distribution grey seals in The Wash on 1/7/2023 (blue) and on 4/7/2017 (white). Numbers of seals are represented by the areas of the circles on each site.

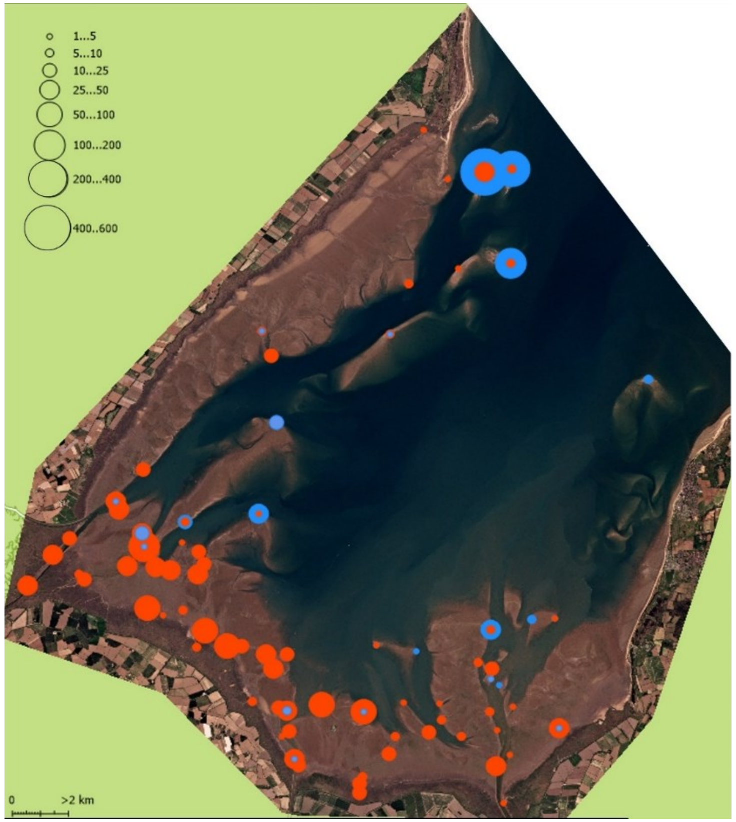

Figure 7. Distribution of harbour seal pups (red) and grey seals (blue) in The Wash on 1/7/2023. Numbers of seals are represented by the areas of the circles on each site.

Changes in grey seal pup survey system: implications for pup production estimates

Debbie JF Russell, Chris D Morris, Mia Goldman, Simon A Waitland, Callan C Duck, Alex Brown , Izzy Langley, Simon EW Moss, Patrick Pomeroy, Nick G Riddoch.

Sea Mammal Research Unit, The University of St Andrews, St Andrews, Fife, KY16 8LB

Abstract

Colonies encompassing the majority of UK grey seal pup production (~95%) are monitored by SMRU aerial surveys. Classed (whitecoat versus fully moulted) counts from 4 to 5 surveys across a season are combined with life history and observation parameters to estimate pup production. Image quality and conditions impact these observation parameters. Indeed, the change from film aerial surveys (up to 2010) to digital (Hasselblad; H4D) aerial surveys (2012-2022) led to a clear change in these parameters. The SMRU aerial survey programme now utilises a new digital Phase One (PAS) camera system. This system was used, for the first time, to survey the colonies of East Scotland, Northeast England and Southeast England SMUs between late October and mid-December 2023. To facilitate comparison of the H4D and PAS systems, during one of the survey rounds two planes were used to survey colonies with both systems concurrently.

The aim of this study was to assess the evidence for different observation parameters between the two methods. This would facilitate interpretation of the PAS-based pup production estimates and inform the potential range of these parameters for use in the current redevelopment of the pup production model. This was realized through two objectives: (1) colony-level comparisons of the classed counts between the two systems, and (2) estimation of the feasible values for the observation parameters for each system using pup-level comparison between counts from each system and assumed truth (drone and/or ground surveys).

The pup production model is currently being redeveloped, partly to allow incorporation of a more complex observation process. This study provided prior information, for both the H4D and PAS, systems which will be utilised in the redeveloped model.

Currently pup production is estimated using the observation process, and parameters, used for the digital survey time-series (H4D and PAS). The outputs of the two objectives suggest that the change in system will likely be associated with only modest changes in the observation parameters, and that any bias (compared to H4D) in estimates from the current pup production model would likely to be slightly upwards. The updated time-series of pup production estimates which included both H4D and PAS-based estimates indicated that the PAS-based estimates were not at odds with recent trends.

Introduction

Colonies encompassing the majority of UK grey seal pup production (~ 95%) are monitored by SMRU aerial surveys. Classed (whitecoat versus fully moulted) counts from 4 to 5 surveys across a season are combined with life history and observation parameters (reviewed in SCOS BP 15/03) to estimate pup production (Russell *et al.* 2019). Up to 2010, key Scottish colonies were surveyed every year using a large format film camera system (Linhof Aero Technika 45). Subsequent surveys (2012 onwards) were biennial (later triennial) and conducted using a digital system consisting of two Hasselblad H4D-40 cameras (hereafter H4D). The change in methodology led to an apparent step change (increase) in estimated pup production. It wasn't possible to carry out concurrent 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 (SCOS BP 24/03). This is discussed in SCOS-BP 25/03 where trend analyses for Seal

Monitoring Units (SMU) and Special Areas of Conservation (SAC) are presented accounting for the different methods used. The trends also account for a change in methods in eastern England. In eastern England, ground-based estimates were used (conducted by National Trust, Lincolnshire Wildlife Trust, and Friends of Horsey seals) until 2018; since then, they have been monitored by SMRU aerial survey.

Observation parameters are used within the pup production model. Based on the improved quality of the H4D images compared to the film, the observation parameters were updated for the H4D surveys. In brief, PCountWhite and PCountMoult denote the probabilities of counting (given it is expected to be there; see Discussion) a whitecoat and fully moulted pup, respectively, which are both set to 0.95. In addition, PCorrectMoult (set at 0.91) denotes the probability of correctly classifying a moulted pup as such (rather than as a whitecoat). Moulted pups have a pale underside, and thus when lying on their back can be misclassified as a whitecoat. It should be noted that the whitecoat class includes both fully white (pup developmental stages 1-3) and moulting pups (stage 4).

Although not considered in the current models, there is some additional information on the observation process associated with H4D surveys. In 2018, to provide such information, a ground survey was conducted on a subset of the Isle of May (East Scotland) by experienced seal researchers during an aerial survey using the H4D system. In addition, for North Rona (Western Isles), there were co-incident field observations (via telescope from a hide) and aerial surveys in 2012. For both the Isle of May and North Rona, individual pups were matched across the two methods (ground vs fixed-wing survey). This preliminary investigation presented and discussed at SCOS 2019, indicated that the observation process used in the current pup production model was not able to accommodate all the key types of observation error; whitecoats could be misclassified as moulted pups, but those misclassified were almost exclusively moulting pups (stage 4). As such, the results indicated that an update to the process model (explicit consideration of stage 4 pups) as well as a change to the observation model was required to increase the robustness of pup production estimates. Specifically, as well as the above observation parameters, an additional parameter, PCorrectS4 should be considered; the probability of a moulting pup being correctly classified (as a whitecoat) versus a moulted pup. The expectation is that the probability of classifying a pup that is not yet moulting (i.e. a stage 1-3) as a whitecoat (rather than a moulted pup) is close to 1 (PCorrectS1-3). To facilitate future work, the probability of detecting a dead pup (PCountDead) should also be considered. The redevelopment of the pup production model to allow incorporation of these processes is the focus of a current PhD project.

After dealing with multiple camera and associated computer issues, in 2021 and 2022, a NERC capital grant enabled the purchase of a new digital camera system in 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 (hereafter PAS). The georeferenced images can be processed to create detailed orthomosaics of each colony surveyed. This system was used, for the first time, to survey the colonies of East Scotland, Northeast England and Southeast England SMUs between late October and mid-December 2023. The pup production estimates from these surveys, using the same observation parameters as used for the H4D system, are presented in SCOS BP 25/02. To facilitate comparison of the systems, during one survey round predicted to be associated with a considerable proportion of both whitecoat and moulted pups, two planes were used to survey colonies with both H4D and PAS systems concurrently.

Robust parameterisation of this model will require information about the observation parameters for both H4D and PAS systems. The aim of this study was to assess the evidence for different observation parameters between the two methods. This would facilitate interpretation of the PAS-based pup production estimates and inform the potential range of these parameters for use in a redevelopment of the pup production model. This was realized through two objectives: (1) colony-level comparisons of the classed counts between the two systems, and (2) estimation of the feasible values for the observation parameters for each system using pup-level comparison between counts from each system and assumed truth (drone and/or ground surveys). Here we also formally report the results of the previous Isle of May and North Rona comparisons. Critically, the preliminary study indicated markedly higher probabilities of detections and correct classifications associated with the most experienced aerial image analyst. Here we only consider the counts of the analyst who has counted the vast majority of surveys in the H4D system (see Discussion).

Methods

Fixed-wing surveys were conducted at an approximate height of 335 m above sea level (ASL) producing a ground sampling distance (GSD) of approximately 2.5 and 1.8 cm/pixel for H4D and PAS images, respectively. Images were stitched using Microsoft Image Composite Editor (H4D) and SimActive's Correlator3D software (PAS). Pups were marked as whitecoat, fully moulted, or dead (white).

It should be noted that the PAS survey over the outer Farne Islands was conducted following the other methods (drone and H4D), in conditions which would normally be deemed too poor to survey (heavy rain).

Objective 1: Colony-level comparisons

The counts from the images conducted on the same days in 2023 (Table 1) were compared between the two methods to assess the evidence for any directional bias.

Objective 2: Pup-level comparisons

For subareas of three colonies, North Rona (Western Isles SMU), Isle of May (East Scotland SMU) and the Brownsman and Staple Islands (Farne Islands; Northeast England SMU), individual pups were matched between fixed-wing surveys and at least one other method. Ground-surveys were conducted on subareas of North Rona (2012) and the Isle of May (2018 and 2023); an experienced seal researcher staged pups (stage 1-3 whitecoat, stage 4 moulting, and stage 5 moulted), flagging if they were dead. On the Isle of May, the comparison in 2018, as for North Rona in 2012, was between H4D and a ground survey, whereas on the Isle of May in 2023, PAS and drone images were also considered. For the Farne Islands (2023 only), the comparison was between images taken by H4D, PAS, and a drone flown at two different heights. For the 2023 data, to allow pup-level comparisons to be made, all stitched H4D images were georeferenced to the PAS imagery using QGIS 3.36 software. Although both drone and PAS images were already georeferenced, the orthomosaics were not perfectly aligned geographically. Thus, the drone imagery was adjusted to closely match the PAS imagery. As such the PAS was the base layer on which all locations were considered.

Figure 11. A group of pups on Staple Island, Farnes shown for each survey method. Clockwise from top-left: drone low, drone high, H4D, PAS. The top right of the images shows four dead pups; and the bottom a mix of whitecoat and fully moulted pups; and top left includes a fully moulted pup. However, it is difficult to see that pup on all but the low drone image. It should be noted that the PAS survey was conducted under poor survey conditions (heavy rain; see text).

North Rona

The ground data from North Rona was collected for another purpose and used opportunistically in this study. An experienced seal researcher conducted ground surveys of a portion of the breeding colony on North Rona at three points in the 2012 season. Pups were staged, recorded on a hand-drawn map of the colony, and later matched to the counts of the aerial survey images. Due to the opportunistic nature of the comparison, the timings of the ground and aerial surveys were not synchronised but did occur on the same day. Comparison data were available for the first three aerial surveys of the season: 7th, 15th and 23rd of October 2012, but only the third included moulted pups in the ground study area and thus was the only one considered here.

Isle of May

In both 2018 and 2023, the locations of the pups ground-surveyed in the southern part of the island were marked on a geo-referenced aerial survey image. To facilitate matching ground-survey data with the aerial surveys conducted on the same day, panorama images were also taken of the ground surveyed areas using a hand-held camera.

On 28th November 2023, a DJI Mavic 3E was used by an experienced drone operator at a flight height of 40 m above ground level (AGL) achieving a ground sampling distance (GSD) of around 1.1 cm/pixel. The H4D aircraft flew the first survey just after 11am in approx. 6 min, directly followed by the PAS aircraft which completed the survey in around 10 min. The drone survey started as soon as the second aircraft had left and took around 25 min. All aerial (colour) imagery was collected within around 40 min. The ground observations started as soon as the aerial surveys began and lasted for over three hours. The fixed-wing surveys covered the entire island, whereas the drone (and ground) surveys were focussed on the southern end of the island. Comparison between the drone and ground counts indicated that drone classification (i.e. whitecoat vs moulted) could not be used as the truth. As such, the drone imagery was, for the most part, used to aid matching between the ground and fixed-wing surveys and also used, along with the panoramas, to facilitate identification of false positives (i.e. non-pups classed as pups on either fixed-wing survey).

Farne Islands: Brownsman and Staple

On 28th November, drone surveys, commissioned by the National Trust, were conducted by Skeye ASI Ltd using a DJI Matrice 300 RTK. The drone surveys were flown at two different altitudes. Both islands were fully covered at an altitude of 80 m AGL achieving a GSD of around 1.0 cm/pixel (hereafter 'high drone'), and subareas of both islands were flown at 40 m AGL, achieving a GSD of 0.5 cm/pixel (hereafter 'low drone'). Assessment of the low drone images indicated that the excellent image resolution would allow for similarly accurate staging of pups compared to a ground-survey, and thus were deemed appropriate for ground truthing (see Discussion).

The H4D aircraft covered the islands at 12pm (starting 1.25 h after the drone surveys had started and finishing just before the drone), followed by the PAS aircraft around 15-20 min later. When matching pups between survey imagery of Brownsman (see below), it became apparent that, for one of two low drone subareas, the orthomosaic provided by Skeye was a composite of three different surveys (the first two covering less ground) and thus counts and matching was hampered by movement of pups between surveys (resulting in numerous missing or duplicate pups). All aerial imagery of Brownsman was collected within approx. 1.5 h. For Staple Island, all aerial imagery was collected within 40 min, with much less pup movement between surveys.

Pups found within the subareas covered by the low drone were matched to pups found on all other images (high drone, H4D and PAS). Initial matches (i.e. pup pairings across two different georeferenced orthomosaics) were automatically generated using nearest neighbour distances. If the distance between two paired pups was less than 0.5 m and they had both been assigned the same class by the counter, the pairing was assumed to be a correct match. These matches were only visually checked if one of the paired pups was within 1 m of another pup on the same orthomosaic. All other pairings were visually checked and either confirmed as correct matches or edited (i.e. matched to a different pup further away, or marked as 'unpaired'). The areas covered by the low drone were scrutinised multiple times when matching pups; these methods combined with the image quality allowed us to conclude that no available pups were missed in the final drone counts. The low drone classifications were considered to be the truth (see Results and Discussion); for the low drone, pups classed as whitecoats were further divided into stage 1-3 and stage 4, to allow estimation of PCorrectS1-3 and PCorrectS4.

Results and Discussion

Objective 1: Colony-level comparisons (Table 1)

With the exception of the Outer Farne Islands (which were surveyed by PAS in poor conditions), in terms of total pup counts, the PAS values were higher than the H4D values. For the most part, this pattern was even more marked for the whitecoat counts. On the other hand, the moulted and dead PAS counts were generally lower than the H4D. It should be noted that living pups may inadvertently be classed as dead, and thus disparity between dead counts does not necessarily reflect differences in the proportion of dead pups detected.

The habitat differs across these colonies, and to lesser extent within the colonies. Broadly the island colonies (Inchkeith, Isle of May, Farne Islands) are similar, encompassing mud, scrub or grass in the middle of the islands with rock dominating the outer areas. For Inchkeith, there is a relatively high proportion of shingle beaches. The Fast Castle colony stretches across 11 km of shingle and boulder beaches that are backed by high cliffs, often resulting in relatively dark images. Finally, the Southeast England colonies (Donna Nook, Blakeney and Horsey) are predominantly sandy beaches. There are additional habitats including sand dunes (Horsey), marsh areas (Donna Nook) and tussock grass (particularly in Blakeney). In general, there is likely a higher probability of detecting a whitecoat, compared to a moulted pup, on rocks, whereas the opposite is the case for sand. Light conditions, more so than habitat, are likely to impact the probability of correctly classifying a pup once detected.

Table 1. Classed counts for each colonies/group (for which the total count > 200) for Phase One and Hasselblad surveys which occurred on the same day - 28th (29th for Blakeney and Horsey) November 2023.

SMU	Colony/group	Hasselblad (H4D) Total			Phase One (PAS) Total			Difference Total		
		White	Moulted	Dead	White	Moulted	Dead	White	Moulted	Dead
East Scotland	Fast Castle[1]		3563			3698			3.8 (135)	
		2060	1389	114	2221	1399	78	7.8 (161)	0.7 (10)	-31.6 (-36)
	Inchkeith		675			722			7 (47)	
		375	278	22	452	248	22	20.5 (77)	-10.8 (-30)	0 (0)
	Isle of May		1420			1460			2.8 (40)	
		553	798	69	686	705	69	24.1 (133)	-11.7 (-93)	0 (0)
	Total (including Craigleith)		5700			5925			3.9 (225)	
		3000	2494	206	3380	2374	171	12.7 (380)	-4.8 (-120)	-17 (-35)
Northeast England Farne Islands	Farnes Inner Group		936			963			2.9 (27)	
		726	165	45	764	160	39	5.2 (38)	-3 (-5)	-13.3 (-6)
	Farnes Outer Group – Brownsman[2]		1181			1152			-2.5 (-29)	
		652	424	105	613	443	96	-6 (-39)	4.5 (19)	-8.6 (-9)
	Farnes Outer Group - Staple Island[2]		526			506			-3.8 (-20)	
		299	180	47	288	194	24	-3.7 (-11)	7.8 (14)	-48.9 (-23)
	Farnes Outer Group – rest[2]		360			333			-7.5 (-27)	
		243	96	21	249	71	13	2.5 (6)	-26 (-25)	-38.1 (-8)
	Farne Islands total[2]		3003			2954		-1.6 (-49)		
		1920	865	218	1914	868	172	-0.3 (-6)	0.3 (3)	-21.1 (-46)
Southeast England	Blakeney		5779			5870			1.6 (91)	
		5380	298	101	5521	233	116	2.6 (141)	-21.8 (-65)	14.9 (15)
	Donna Nook		1929			1943			0.7 (14)	
		1648	222	59	1694	204	45	2.8 (46)	-8.1 (-18)	-23.7 (-14)
	Horsey		2914			2929			0.5 (15)	
		2844	43	27	2858	46	25	0.5 (14)	7 (3)	-7.4 (-2)
	Total		10622			10742			1.1 (120)	
		9872	563	187	10073	483	186	2 (201)	-14.2 (-80)	-0.5 (-1)

[1] For the Hasselblad survey, some pups (~15) missed in a small area due to aircraft roll
[2] Weather conditions (heavy rain) poorer than would usually survey

Objective 2: Pup-level comparisons (Table 2)

The key observation parameters were similar between camera systems for the colony for which Hasselblad and Phase One were used in similar conditions (Isle of May), though it should be noted sample sizes were small. Thus, although the drone could not be used as a proxy for ground surveys on the Isle of May, it provided useful information on PCount (using a much higher sample size than available for ground surveys alone). Both PCountWhite and PCountMoult were higher for PAS compared to H4D. The results also show that more pups were classed as whitecoats (rather than moulted pups) in the PAS compared to the H4D.

Here, we summarise the results, excluding (unless otherwise stated) the PAS surveys of the Farne Islands and the Isle of May comparison with drone surveys ([1] Table 2). Across all colonies and both camera systems, PCountWhite (≥ 0.97) was higher than PCountMoult. For PCountMoult, values were more variable (≥ 0.92) and were considerably lower for the PAS surveys of the Farnes (0.87/0.89). The PCountDead is shown for completeness; its variability is, in large part, due to the various stages of decomposition of pups included in the study. PCorrectWhite was 0.99-1.00, for all surveys except Brownsman though this may be a result of difficulties in matching between surveys. PCorrectS4 and PCorrectS5 were more variable, ranging from 0.70 and above.

Table 3. Estimated observation parameters for each method and island in comparison to the assumed truth.

Year	Sub/colony	Method	PCount			PCorrect		
			White	**Moult**	**Dead**	**S1-3**	**S4**	**Moult**
2012	North Rona	Hasselblad	1.00 (138)	0.96 (24)	**1.00 (5)**	1.00 (95)	0.70 (43)	0.70 (23)
2018	Isle of May	Hasselblad	0.98 (59)	0.94 (72)	0.90 (20)	1.00 (19)	0.76 (38)	0.85 (66)
2023	Isle of May	Hasselblad	0.98 (80)	0.98 (90)	0.67 (9)	1 (29)	0.92 (49)	0.97 (88)
		Hasselblad[1]	0.96 (378)	0.88 (396)	0.67 (30)	0.95 (194)	0.78 (167)	0.95 (350)
		Phase One	0.99 (80)	0.97 (90)	0.78 (9)	1 (29)	0.88 (50)	0.87 (87)
		Phase One[1]	0.99 (378)	0.90 (396)	0.90 (30)	0.98 (198)	0.87 (175)	0.89 (356)
	Staple	Hasselblad	0.97 (216)	0.92 (139)	0.83 (42)	0.99 (159)	0.8 (50)	0.8 (128)
		Phase One[2]	0.94 (216)	0.87 (139)	0.81 (42)	0.89 (159)	0.71 (45)	0.78 (121)
	Brownsman[3]	Hasselblad	0.97 (463)	0.92 (347)	0.88 (100)	0.95 (323)	0.9 (125)	0.76 (318)
		Phase One[2]	0.98 (469)	0.89 (347)	0.87 (100)	0.94 (332)	0.77 (126)	0.81 (309)

[1] Comparison with drone (ground if available). Drone not a reliable proxy of ground surveys.
[2] Weather conditions poorer than would usually survey (heavy rain)
[3] Timing of surveys resulted in difficulties matching pups between surveys

Interpretation of the observation parameters is complicated by the limited sample sizes per colony and survey-specific considerations. The North Rona parameters are based on ground observations conducted from a hide. Given the differences between classes assigned from ground-surveys and high quality drone images on the Isle of May, and that for many pups observed from the hide, only one side would be seen, there may be considerable error in the assignment of moulting vs moulted which would impact the parameters (with the likely exception of PCorrectS1-3).

The more reliable comparison of observation parameters between H4D and PAS was for the Isle of May in 2023. For Brownsman, the combination of repeat survey flights for the creation of the low drone orthomosaic, and the relatively large amount of time between the first and last images collected, caused issues in pup matching across the surveys which may have resulted in some biases (pups that looked to be same class potentially more likely to be matched). The PAS surveys of the Outer Farnes (including Staple and Brownsman) were conducted in weather conditions that would not normally be considered acceptable for surveying, and the calculated observation parameters could represent estimates at the lower end of the plausible range. It should be noted that for the Farne Islands, we were reliant on the classification from low drone rather than ground-staging. Although drone-based classifications were shown not to be robust for the Isle of May, the image resolution associated with the low drone surveys on the Farne Islands was much higher. However, the PCount parameters may be underestimates if pups were obscured in all four surveys, or in the case of deads, undetectable.

The application of these results to the pup production model currently in development is not straightforward. In the current model, the PCount observation parameters reflect the probability of detecting a pup given it SHOULD be there (according to the process model). The values from the comparison here comprised both availability and detectability, and their applicability of other colonies and timing in the season is not clear. There are two main reasons a live pup can be missed because it is unavailable in the final image mosaic: (1) it is obscured in (e.g. submerged in a pool) or by natural or human structures (e.g. a wall or overhanging cliff), and (2) it was removed due to stitching errors during the generation of composite images; such errors occurred in images from all survey platforms. The availability of dead pups to be detected is more nuanced; they may have left the colony or may be too decomposed to be detected. Detection of available pups will, to a large degree, depend on the quality of the image and light conditions.

Conclusions

The outputs of the two objectives suggest that PAS counts in good light conditions will be slightly higher than H4D counts due to a higher detection rate, particularly of whitecoats. As a result of PAS being associated with a higher proportion of both white and moulted pups being classified as white, the whitecoat counts will be disproportionately high (compared to the moulted). In good light conditions, both methods appeared to have similar False Discovery Rates (FDR): the probability of counting a non-pup (rock, juvenile etc.) as a pup was similar between both methods in good light conditions (~2%). FDR will likely vary, in a method-specific manner, across habitats and conditions. For example, in low light conditions, juveniles can look like moulted pups. There were no comparable observation parameter estimates for PAS and H4D in poor conditions (low light/heavy rain). Both the counts and observation parameter estimates for the Outer Farnes islands indicate that the poorer PAS survey conditions resulted in a lower PCount than for other colonies, especially for moulted pups. The probability of correctly classifying a pup was also impacted. Although surveys would not usually be conducted in these conditions, it provides a helpful indication of the likely lower bound for surveys flown in the poorer end of acceptable conditions or low light levels.

The exclusive use of one surveyor throughout these comparisons maximized comparability. However, previous work (Russell et al. unpublished) indicated marked differences between surveyors, with the most experienced (considered here) having the highest detection rates and accuracy. For this reason, comparisons of detection rates between surveyors should be explicitly considered going forward.

Acknowledgements

We are grateful to National Trust who commissioned the drone surveys of the Farnes and allowed us to use the resulting images. In addition, we thank Skeye for providing the images and answering our queries. Finally, thanks to Dr Richard Bevan, Newcastle University, for facilitating this work.

ANNEX I Terms of reference and SCOS membership

NERC SPECIAL COMMITTEE ON SEALS

Terms of Reference

a. To undertake, on behalf of NERC Council, the provision of scientific advice relating to the status of grey and harbour seals in United Kingdom waters and to their management, as required under the Conservation of Seals Act 1970, Marine Coastal and Access Act 2009 and the Marine (Scotland) Act 2010, and all subsequent amendments to those Acts. This advice will be provided to the Scottish Government, the Department for Environment Food & Rural Affairs (Defra), Natural Resource Wales (NRW) and the Department of Agriculture, Environment and Rural Affairs Northern Ireland (DAERA).

b. To comment on the Sea Mammal Research Unit's (SMRU) core strategic research programme and other commissioned research, and to provide a wider perspective on scientific issues of importance, with respect to the provision of advice under Term of Reference 1(a).

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

Current membership

Dr Josh London (Chair)	Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle
Dr Carol Sparling	Sea Mammal Research Unit, University of St Andrews
Dr Kate Brookes	Marine Directorate, Scottish Government
Dr Kimberley Bennett	Abertay University, Dundee
Dr Cornelia den Heyer	Fisheries and Oceans Canada
Dr Luis Huckstadt	University of Exeter
Dr Line Cordes	Norwegian Institute for Nature Research
Dr Alan Walker	Centre for Environment Fisheries and Aquaculture Science, Lowestoft.
Dr Martin Biuw	Institute of Marine Research in Norway, Tromsø
Mr Chris Armsby (Secretary)	UKRI Natural Environment Research Council, Swindon.

ANNEX II Standing SCOS Questions

1. SCOS will provide the latest estimates and trends in the number of seals in the UK and by individual UK country.

2. SCOS will provide the latest available August counts/pup production estimates and trends for Special Areas of Conservation in Scotland and England.

3. SCOS will provide an update on the most current information regarding the population structure of grey and harbour seals in the UK as well as within England, Scotland, and Europe. SCOS will include any updated information on mortality, age and sex structure of both species, highlighting any changes that might impact their conservation.

4. SCOS will provide the most current estimates of Potential Biological Removal (PBR) for both harbour and grey seals. Estimates will be provided for each Seal Monitoring Unit (SMU) in the UK.

5. SCOS will provide the latest estimates of seal bycatch across both Scottish and UK fisheries. Where available estimates will be provided by gear type and will provide any available information on the location of bycatch. Where there is insufficient information to provide bycatch estimates, SCOS will identify the key knowledge gaps (e.g., monitoring effort). SCOS will also provide advice regarding the impact of bycatch on seal populations and current technologies and approaches for mitigation (e.g., Acoustic Deterrent Devices, Acoustic Startle Devices).

6. SCOS will provide updates on prevalence and impact of other seal and fisheries interactions across the UK within rivers, in sea fisheries and at aquaculture sites. SCOS will also provide current information regarding the use of deterrence devices and other efforts to exclude or mitigate seals from rivers, fisheries, and aquaculture facilities.

7. SCOS will provide current information on population health and disease concerns for harbour and grey seals in the UK. SCOS will describe current efforts to monitor seals for known or emerging health threats and provide updates on any recent outbreaks or emerging diseases (regionally and globally) that may impact the conservation and management of grey and harbour seals in the UK.

8. SCOS will provide current information on the impacts of climate change and extreme weather events on UK seal populations.

9. SCOS will provide a summary of the emerging techniques used globally to survey and count seal haulouts and breeding colonies, and comment on their potential utility in the UK population monitoring programme.

10. Based on previous advice, SCOS will synthesise any outstanding suggested areas for further seal research, and indicate which may be of highest priority.